Greenhouse gas reporting of the LULUCF sector in the Netherlands

Methodological background, update 2023

E.J.M.M. Arets, S.A. van Baren, C.M.J. Hendriks, H. Kramer, J.P. Lesschen & M.J. Schelhaas | WOt-technical report 238

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Abstract
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This report provides a complete methodological description and background information of the Dutch National System for Greenhouse gas reporting of the LULUCF sector. It provides detailed description of the methodologies, activity data and emission factors that were used. Each of the reporting categories Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land and Harvested Wood Products are described in a separate chapter.

Keywords: Greenhouse Gas Reporting, Land Use, Land-use Change, Forestry, LULUCF, National Inventory Report, National system greenhouse gases, the Netherlands, UNFCCC, Emissions and Removals of greenhouse gases

Dit rapport geeft de methodologische achtergrondinformatie die gebruikt wordt binnen het nationale systeem om de broeikasgasemissies voor de LULUCF (landgebruik en bosbouw) sector te berekenen zoals die aan de VN Klimaatconventie (UNFCCC) worden gerapporteerd. Het rapport geeft gedetailleerde beschrijvingen van de gehanteerde methodologie, gebruikte activiteitendata en emissie-factoren. De te rapporteren categorieën Bos (Forest Land), Bouwland (Cropland), Grasland (Grassland), Wetlands, Bebouwd gebied (Settlements), Ander land (Other Land), en Geoogste houtproducten (Harvested Wood Products) worden per hoofdstuk beschreven.

Trefwoorden: Broeikasgasrapportage, VN Klimaatconventie, Landgebruik, LULUCF, Nationaal Inventarisatie Rapport, Nationaal Systeem Broeikasgassen, Nederland, emissies en verwijderingen van broeikasgassen.

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Preface

This report provides a complete methodological description and background information on the Dutch National System for Greenhouse Gas Reporting of the LULUCF sector for the UN Framework Convention on Climate Change (UNFCCC) from 2023 onwards. As the final reporting under the Kyoto Protocol (KP) was done in the 2022 inventory submissions, the chapters with specific methodologies relating to KP reporting which appeared in the previous background reports have been removed from this report.

IPCC Guidelines

The methodology largely follows the IPCC 2006 guidelines for Agriculture, Forestry and Other Land Uses (AFOLU) (IPCC 2006b). However, the methodology for calculating CH_4 emissions from drainage ditches in organic soils is based on the 2013 Wetland Supplement to the 2006 IPCC Guidelines: Wetlands. Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment (IPCC 2014b). The methodology for Harvested Wood Products (HWP) is based on the 2013 revised supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a). This background report reflects as much as possible the structure for national inventory reports as laid out in the appendix to Decision 24/CP.19.

Methodological changes

The contents are largely the same as in the previous methodological background report (Arets et al. 2022), which was prepared with the NIR 2022. For the 2023 inventory submission, three methodological changes were implemented:

1. Implementing a Tier 3 approach to calculating carbon stock changes in mineral soils for Cropland remaining Cropland and Grassland remaining Grassland under agricultural use.
2. Implementing a Tier 1 methodology with country specific emission factors for assessing CH_4 emissions from drainage ditches in Forest Land, Cropland and Grassland under agricultural use on organic soils.
3. A change in the method and use of input data for Harvested Wood Products (HWP).

Methodological change: carbon stock changes mineral soils

For Cropland remaining Cropland and Grassland remaining Grassland under agricultural use, changes in carbon stocks in mineral soils are now calculated dynamically with the RothC model. In previous submissions the Tier 1 assumption of dynamic equilibrium was applied, which implied that no net carbon stock changes were reported. The new Tier 3 model provides dynamic carbon stock changes that differ over time (see Section 11.2.2).

Methodological change: implementing CH_4 emissions from drainage ditches

A Tier 1 methodology with country specific emission factors for assessing CH_4 emissions from drainage ditches in Forest Land, Cropland and Grassland under agricultural use on organic soils was implemented (see Section 11.3.2). This change was implemented in response to previous recommendations from the UN expert review team.

Previously, the CH_4 emissions from drainage ditches were not considered, but emissions from drainage ditches were considered as part of the CO_2 emissions from drained cropland or grassland. The new method now assumes 5% of the land area with drained peat or peaty soils consists of drainage ditches (Tier 1 default value for the ditch fraction, based on the IPCC 2013 Wetlands Supplement (IPCC 2014b)). For this 5%, the emissions are no longer calculated as CO_2 emissions from drained organic soils, but as CH_4 emissions from drainage ditches.

Methodological change: input data for Harvested Wood Products

The calculation of carbon stock changes in HWP now includes carbon inflows for the years between 1960 and 1990 to take into consideration the legacy effect of historical inflows that contribute to carbon stock losses from HWP in subsequent years (following a first order decay function, see Chapter 10). In previous inventories, the starting point was the input of HWP from 1990 onwards. Other elements of the methodology remain the same.

Updated data
Additionally, based on data from the 7th National Forest Inventory (NFI-7), harvest rates of roundwood from forests were adjusted for the period from 2014 onwards (see Annex III). This has an effect on both carbon stock gains and carbon stock losses in living biomass in Forest Land (see Section 4.2.1), but this does not affect the net carbon stock change of living biomass. It also has an effect on the distribution of wood harvests over fuel wood (resulting in instantaneous oxidation) and industrial roundwood (input to HWP).

Error correction
Besides the methodological changes and use of updated data, the emission factors for organic (peat and peaty) soils were corrected in this inventory. New analyses assessing the effects of measures aimed at reducing emissions from peat meadow areas revealed an error in the calculation of the emission factor based on the 2014 soil map. According to the new calculations, the emission factors for drained peat and peaty soils remain constant over time, while the area of peat and peaty soils decreases as a result of the ongoing oxidation of organic matter.

Previous background documents
Previous background documents to the submissions under the UNFCCC and Kyoto Protocol dealing with similar topics were published as *WOt-technical report 1, 26, 52, 89, 95, 113, 146 168, 201 and 217* (Arets *et al*. 2013, 2014; 2015, 2017a, 2017b, 2018, 2019, 2020, 2021, 2022) and as Alterra reports, mostly but not exclusively in the 1035.x series (e.g. Nabuurs et al. 2003 2005; de Groot et al. 2005; Kuikman et al. 2003, 2005 and van den Wyngaert et al. (2006, 2008, 2009, 2011a, 2011b, 2012).

We would like to thank Natalie Bakker (RVO) and Anjo de Jong (Wageningen Environmental Research) for critically reviewing the report.

Eric Arets, Sven van Baren, Chantal Hendriks, Henk Kramer, Jan Peter Lesschen and Mart-Jan Schelhaas

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1 Overview of the LULUCF sector

1.1 Introduction

The Netherlands is a Party to the United Nations Framework Convention on Climate Change (UNFCCC) and has also ratified the Paris Agreement, committing itself to yearly reporting on its greenhouse gas emissions. Whereas the Convention on Climate Change lays the foundations for accurate monitoring of greenhouse gas emissions, the Paris Agreement focuses on reducing emissions and/or increasing removals. The climate actions to be taken by parties to the Paris Agreement are laid down in Nationally Determined Contributions (NDC). The EU Member States have communicated an EU-wide NDC for which further emission reduction targets and accounting rules are arranged through a body of legislation, including the EU Emission Trading System (EU-ETS), the Effort Sharing Regulation (EU 2018/842) (ESR) and the LULUCF Regulation (EU 2018/841), and which is governed through the Governance Regulation (EU 2018/1999). Both the UNFCCC and the EU regulations require countries to design and implement a system for annual reporting of greenhouse gases (GHG) (Article 5 of the UNFCCC and Article 26 of the Governance Regulation). For the LULUCF sector, accounting rules and further requirements for reporting are laid down in the EU LULUCF Regulation, which follows the UNFCCC system and its guidelines as much as possible, but at the same time enforces stricter minimum requirements compared to the reporting requirements under the UNFCCC.

For GHG reporting of the Land Use, Land-Use Change and Forests (LULUCF) sector (CRF Sector 4), the Netherlands has developed and an overall approach within the National System since 2003. Detailed background information on methods and assumptions have been documented in several publications, i.e. Nabuurs *et al.* (2003, 2005), De Groot *et al.* (2005), Kuikman *et al.* (2003, 2005) Van den Wyngaert *et al.* (2006, 2008, 2009, 2011a, 2011b and 2012), and Arets *et al.* (2013, 2014, 2015, 2017a,b, 2018, 2019, 2020 2021 and 2022).

The list of reports over the years reflects the continuous series of improvements and updates to the reporting of the LULUCF sector within the Dutch National System. This methodological background report describes the methodological choices and assumptions as applied from the NIR 2023 onwards.

The applied methodologies meet the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 2006b, hereafter referred to as the 2006 IPCC Guidelines) as implemented by Decision 24/CP.19. The methodology for calculating CH_4 emissions from drainage ditches in organic soils is based on the 2013 Wetlands Supplement to the 2006 IPCC Guidelines: Wetlands. Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment (IPCC 2014b). The methodology for Harvested Wood Products (HWP) is based on the 2013 revised supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC 2014a).

The Netherlands applies a spatially explicit wall-to-wall approach (Approach 3 following the 2006 IPCC guidelines) for reporting. This enables the combining of different geographically explicit data sources to determine activity data and link them to emission factors. This also allows the generation of results for different spatial aggregation levels.

An overview of the LULUCF sector is provided further in this Chapter 1. The definitions of land use categories are explained in Chapter 2. Information on approaches used for representing land areas, including land-use change matrices is provided in Chapter 3. The calculation methods for emissions and removals from living biomass and dead organic matter for the different CRF categories are elaborated in Chapters 4-10.

Methods for emissions from soils are similar among the different categories. Therefore the methodology for soil emissions is separately presented in more detail in Chapter 11. Category-specific issues are presented in the category chapters. In Chapter 12 the methodology to estimate GHG emissions from biomass burning is provided.

The uncertainty of the reported emissions was assessed using a Monte-Carlo approach as described in Chapter 13.

1.2 National system of GHG reporting for the LULUCF sector

As required by Decision 24/CP.19 The Netherlands follows the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006b; further referred to as 2006 IPCC Guidelines) for reporting under the UNFCCC. Category 4 'Land Use, Land-Use Change and Forestry' (LULUCF) consists of six land-use categories:

- 4A Forest Land (FL)
- 4B Cropland (CL)
- 4C Grassland (GL)
- 4D Wetlands (WL)
- 4E Settlements (Sett)
- 4F Other Land (OL)

and the additional pool:

- 4G Harvested Wood Products (HWP)

This methodological background report concerns emissions and removals in the aforementioned six land-use categories subdivided in the following two categories:

- 4.A.1 - 4.F.1: Land use remaining as such (e.g. 4.A.1 – Forest Land remaining Forest Land)
- 4.A.2 - 4.F.2: Land converted to another specific land use under 4A to 4F (e.g. 4.A.2 Land converted to Forest Land).

The Dutch methodology includes and reports on the entire terrestrial surface area of the Netherlands in a so-called wall-to-wall approach. The national system is based on activity data from land use and land-use change matrices for the periods 1970-1990, 1990-2004, 2004-2009, 2009-2013, 2013-2017 and 2017-2021. These matrices are based on topographic maps (see De Groot *et al.* (2005) for a motivation of using topographic maps as basis for our land-use calculations). The maps dated at 1 January 1970, 1990, 2004, 2009, 2013, 2017 and 2021 are gridded in a harmonised way and an overlay produced all land-use transitions within these periods (Kramer et al. 2009; van den Wyngaert et al. 2012). An overlay between the land-use maps with two organic soil maps (1977 and 2014) (Chapter 3.5) is used to calculate carbon stock changes in mineral soils and to calculate emissions from organic soils for all land-use classes. New land-use maps are compiled on a regular basis (every 4 years) and are used to derive new land-use matrices. In the meantime land-use changes from the latest land-use matrix are extrapolated until the current reporting year.

This report contains the definitions of land-use categories and the allocation of land areas to land-use categories (and changes between land-use categories) based on the land-use database for 1970, 1990, 2004, 2009, 2013, 2017 and 2021. This report also contains information for calculating the emissions in CRF Tables 4(I)-4(V).

Using a bookkeeping model (Nabuurs *et al.*, 2005), the activity data, carbon stock changes and non-CO_2 emissions are combined and calculated over the whole time-series from 1970 until the last year covered in the GHG inventory.

The carbon balance for living and dead biomass in **Forest Land remaining Forest Land** (Chapter 4.2.1) is based on National Forest Inventory (NFI) data. NFI plot data are available from four inventories: the HOSP dataset (1988-1992, 3448 plots; Schoonderwoerd and Daamen 1999) the fifth National Forest Inventory dataset (NFI-5; 2001-2005; 3622 plots; Dirkse *et al*. 2007), the sixth

National Forest Inventory (NFI-6; 2012-2013; 3190 plots; Schelhaas *et al.* 2014) and the seventh National Forest Inventory (NFI-7; 2017-2021; 3174 plots; Schelhaas et al. 2022b). The accumulation of carbon in dead wood is based on measured values in all four inventories, combined with some general parameters. Carbon stored in litter is estimated from a combination of national data sets (see Chapter 4).

The carbon balance for areas changing from **Forest Land to other land-use categories** (Chapter 4.2.3) is based on the mean national stocks in biomass and dead organic matter as calculated from the NFI data for biomass, dead wood and combined data sets for forest litter. On Forest Land converted to Trees Outside Forest (TOF) it is assumed that the woody cover is continued, but it does involve the complete loss of dead wood and litter (Chapter 6).

Cropland in the Netherlands mainly consists of annual crops. Therefore, consistent with the IPCC 2006 guidelines, no net accumulation of carbon in living biomass is estimated for **Cropland remaining Cropland** (Chapter 5).

For carbon stock changes in living biomass in **Grassland remaining Grassland** (Chapter 6.1.1) that is outside the TOF category, the Netherlands applies the Tier 1 method assuming there is no change in carbon stocks (IPCC 2006b) in grassland biomass. However, changes in the relative contribution of Orchards to the total Grassland area will change average carbon stocks on Grasslands outside TOF. Carbon stock changes in living biomass for the TOF category under Grassland will be the same as for Forests.

The carbon stock changes from changes in living biomass from **Land changing to and from Croplands and Grasslands** are based on Tier 1 methodology (see Chapters 5 and 6), except for changes to and from Trees outside Forest (Chapter 6).

This report also provides the methods for calculating carbon stock levels in soils for the various types of land-use (Chapter 11). These are used to calculate carbon stock changes between the different land-use under specific soil types.

For mineral soils under Cropland remaining Cropland and Grassland remaining Grassland in agricultural use, a Tier 3 approach has been implemented that considers the effects of agricultural soil management. Carbon fluxes are calculated using the soil carbon model RothC. This model takes (changes in) management practices, crop shares, input of organic fertilisers and use of cover crops into account. Further details are provided in Chapter 11.

Mineral soils in Other Land remaining in the same land category are considered to be in dynamic equilibrium and are reported using the notation key ‘NA’.

Carbon stock changes in mineral soils in land use conversion categories are calculated using a Tier 2 approach. Lesschen *et al*. (2012) provided the soil data from the national LSK soil survey, which were classified into new soil – land-use combinations. For each of the sample locations the land use at the time of sampling was known. The soil types for each of the sample points were reclassified to 11 main soil types, which represent the main variation in carbon stocks within the Netherlands. The carbon stock changes are calculated following the land-use changes and the 2006 IPCC Guidelines’ transition period of 20 years in which the carbon stock changes take place.

N_2O emissions from soil disturbance associated with land-use conversions are estimated and are reported in Table 4(III) for the whole time series (from 1990). More detailed information on calculating emissions from mineral soils is provided in Chapter 11.2.

The CO_2 emission from cultivation of organic soils is estimated using a Tier 2 approach for peat and peaty soils under agricultural use, forest land and settlements based on ground surface lowering and the characteristics of the peat layers (Kuikman *et al.*, 2005, de Vries et al. unpublished). Ground surface lowering was estimated from either ditch water level or mean lowest groundwater level (Kuikman *et al.*, 2005, de Vries et al. unpublished). For Cropland and Grassland the associated N_2O

emissions resulting from mineralisation of organic nitrogen are included under Agriculture (category 3D). Those N_2O emissions under Forest Land are estimated using assumptions on the area of drained forest land on organic soils and the default Tier 1 N_2O emission factor. Methane (CH4) emissions from drainage ditches in drained forest land, cropland and agricultural grasslands on organic soils are reported in CRF Table 4(II) using the Tier 1 approach described in Section 2.2.2.1 of the 2013 IPCC wetlands supplement (IPCC 2014b) in combination with a country specific emission factor.

CO_2 emissions from drainage of organic soils are reported for the respective land use categories in CRF Tables 4.A to 4.F. Associated emissions of N_2O are reported in CRF Table 4(II). CH_4 emissions from drainage ditches on organic soils are reported in CRF Table4(II).

More detailed information on calculation of emissions from organic soils is provided in Chapter 11.3.

Emissions of N_2O and CH_4 as a result of fertilisation in forests (CRF Table 4(I) and 4(II)) are reported 'not occurring' (NO) as these practices do generally not occur in Dutch forest ecosystems.

Because it is not possible to separate the N inputs applied to different land-use categories, the direct nitrous oxide (N_2O) emissions from nitrogen (N) inputs to all managed soils are reported in the agriculture sector.

Although forest fires seldomly occur in the Netherlands, CO_2, N_2O and CH_4 emissions resulting from forest fires are reported in Table 4(V) for the whole time series (from 1990, see Chapter 12). Also emissions from other wildfires (i.e. outside forests) are estimated. These emissions are calculated using Tier 1 methods in combination with historic information on annual areas burnt by wildfires in the Netherlands, average carbon stocks in forests for the particular calculation year and Tier 1 combustion and efficiency factors.

CH_4 emissions from wetlands are not estimated due to the lack of data.

The emissions and removals which are reported, are shown in Table 1.1 along with the Tier level of the used methodologies if applicable. Details on the methodology per land-use category can be found in Chapters 4-9. The methodology for assessing removals and emissions from Harvested Wood Products is provided in Chapter 10 and those for soils are given in Chapter 11.

Table 1.1 *Carbon stock changes reported per land-use (conversion) category. Pools for which carbon stock changes are reported are indicated in bold, with the corresponding tier level in brackets. 'NO' is used for pools for which there are no carbon stock changes. 'IE' indicates that carbon stock changes are included elsewhere. Pools for which carbon stock changes are not estimated are marked 'NE', with an indication of the significance of the respective source or sink ('s' = significant, 'n.s.' = not significant). The notation key NA is used in cases with a Tier 1 assumption of carbon stock equilibrium.*

From **To↓**	**FL**	**CL**	**GL**	**WL**	**Sett**	**OL**
FL	**BG** (T2) **BL** (T2) **DW** (T2) **Litt** (T2) **MS** (NA) **OS** (T2) **FF** (T1)	**BG** (T2) **BL** (T2) DW (NE[1]) Litt (NE[1]) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (NE[1]) Litt (NE[1]) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (NE[1]) Litt (NE[1]) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (NE[1]) Litt (NE[1]) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (NE[1]) Litt (NE[1]) **MS** (T2) **OS** (T2) FF (IE)
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Sett	BG (NE, n.s.) **BL** (T2) **DM** (T2) **MS** (T2) **OS** (T2) WF (NO)	BG (NE, n.s.) **BL** (T1) DM (NA) **MS** (T2) **OS** (T2) WF (NO)	BG (NE, n.s.) **BL** (T1, T2) DM (NA) **MS** (T2) **OS** (T2) WF (NO)	BG (NE, n.s.) **BL** (NO) DM (NA) **MS** (T2) **OS** (T2) WF (NO)	BG (NA, n.s.) BL (NA, n.s.) DM (NA,) **MS** (NA) **OS** (T2) WF (NO)	BG (NE, n.s.) **BL** (NO) DM (NA) **MS** (T2) **OS** (T2) WF (NO)
OL	BG (NO, n.s.) **BL** (T2) **DM** (T2) **MS** (T2) **OS** (NO) WF (NO)	BG (NO, n.s.) **BL** (T1) DM (NA) **MS** (T2) **OS** (T2) WF (NO)	BG (NO, n.s.) **BL** (T1, T2) DM (NA) **MS** (T2) **OS** (T2) WF (NO)	BG (NO, n.s.) **BL** (NO) DM (NA) **MS** (T2) **OS** (NO) WF (NO)	BG (NO, n.s.) **BL** (NO) DM (NA) **MS** (T2) **OS** (T2) WF (NO)	NA

Carbon stock changes included are: BG: Biomass Gain; BL: Biomass Loss; DW: Dead Wood; Litt: Litter; DM: Dead organic Matter; MS: Mineral Soils; OS: Organic Soils. Emissions included: FF: Forest fires; WF: other wildfires; Land-use types are: FL: Forest Land; CL: Cropland; GL: Grassland; TOF: Trees outside Forest; WL: Wetland; Sett: Settlement; OL: Other Land.

[1] Not a source; see chapter 4.2.

1.3 Workflow

The calculations of areas of land-use change, carbon stock changes in biomass and soil and for Harvested Wood Products is the result of combining a large number of databases and maps as input and intermediary calculations. Figure 1.1 gives the work flow of how the different input sources and intermediary calculations are combined to get to the required output data. The basis of this work flow is the same for each CRF table. The results are calculated for all relevant land-use change trajectories (Section 3.6) that can be aggregated differently in such way that the aggregation becomes relevant for the UNFCCC CRF classes. An overview of input data sources used is provided in Annex 1.

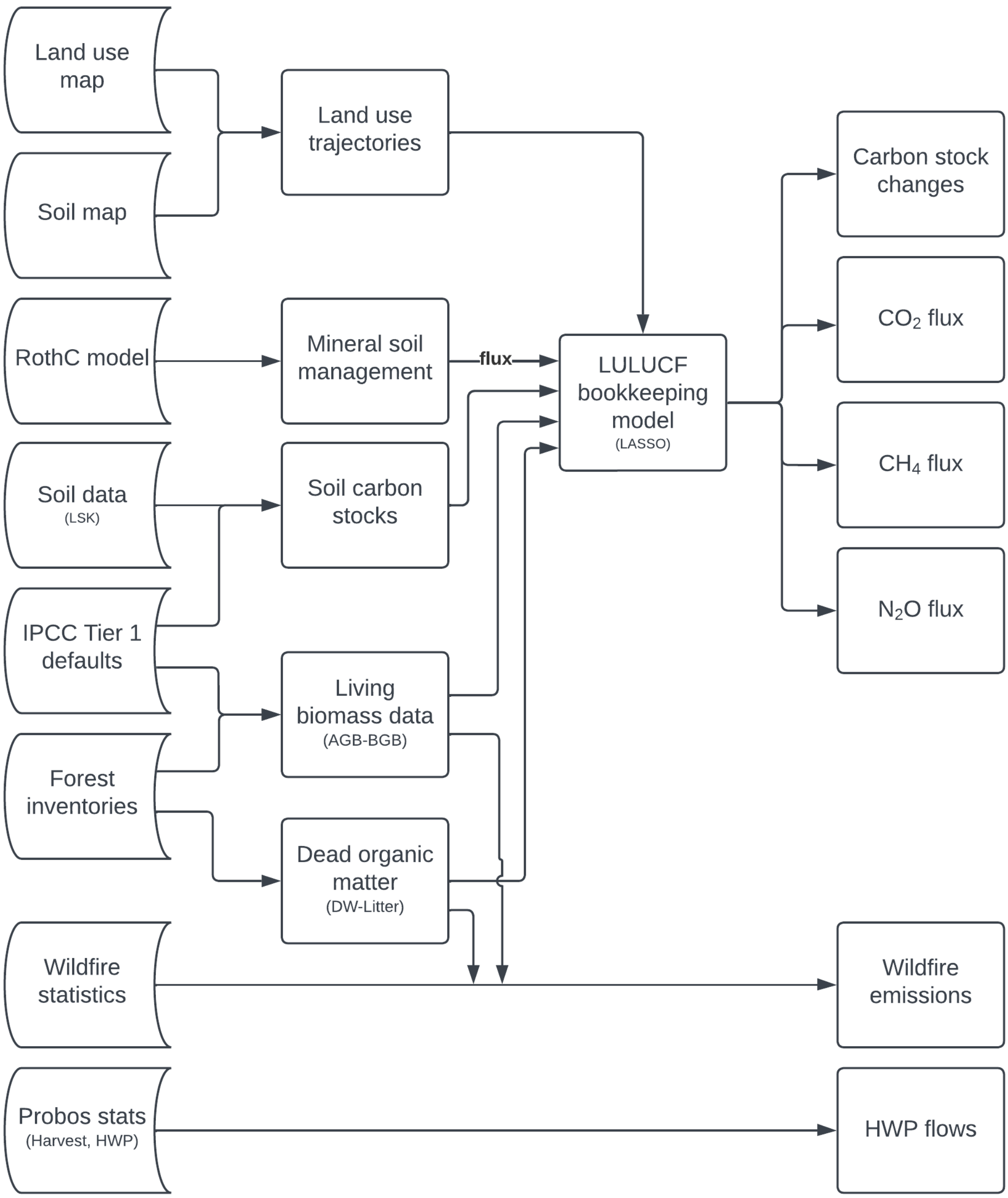

Figure 1.1 *High level overview of the work flow and aggregation of information for calculating the greenhouse gas emissions and removals from the input sources (left), intermediary calculations (middle, rounded squares) and the resulting outputs (right, squares). The LULUCF Bookkeeping model (LASSO) combines al land-use trajectories with the correct emission factors and keeps track of carbon stocks and fluxes for each of the trajectories over time.*

2 Definition of land-use categories

2.1 Background

The 2006 IPCC guidance (IPCC 2006b) distinguishes six main groups of land-use categories: Forest Land, Cropland, Grassland, Wetland, Settlements and Other Land. Countries are encouraged to stratify these main groups further e.g. by climate or ecological zones, or special circumstances (e.g. separate forest types in Forest Land) that affect emissions. In the Netherlands, stratification has been used for Grasslands remaining Grasslands (grassland vegetation, nature area, fruit orchards and trees outside forests) and Wetlands (reed swamps and open water).

The natural climax vegetation in the Netherlands is forest. Thus, except for natural water bodies and coastal sands, without human intervention all land would be covered by forests. Though different degrees of management may be applied in forests, all forests are relatively close to the natural climate vegetation. Extensive human intervention creates vegetation types that differ more from the natural climax vegetation like heathlands and natural grasslands. More intensive human intervention results in agricultural grasslands. In general, an increasing degree of human intervention is present for croplands and systems in the category Settlements are entirely created by humans. This logic is followed in the allocation of land to the land-use categories. In addition, lands are allocated to wetlands when they conform to neither of the former land-use categories and do conform to the 2006 IPCC guidelines' definition of wetlands. This includes open water bodies, which are typically not defined as wetlands in the scientific literature. The remaining lands in the Netherlands, belonging to neither of the former categories, are sandy areas with extremely little carbon in the soil. These were and are again included in Other Land.

2.2 Forest Land (4.A)

The land-use category '**Forest Land'** includes all land with woody vegetation consistent with thresholds used to define Forest Land in the national greenhouse gas inventory. It also includes systems with a vegetation structure that currently fall below, but in situ could potentially reach the threshold values used by a country to define the Forest Land category (Chapter 3.2 in IPCC 2006b).

The Netherlands has chosen to define the land-use category 'Forest Land' as all land with woody vegetation, now or expected in the near future (e.g. clear-cut areas to be replanted, young Afforestation areas). This is further defined as:
- forests are patches of land exceeding 0.5 ha with a minimum width of 30 m;
- with tree crown cover of at least 20% or, if this is not the case, likely to be achieved at the particular site, and;
- tree height at least 5 metres, or, if this is not the case, likely to be achieved at the particular site.

This definition conforms to the FAO reporting and was chosen within the ranges set by the Kyoto Protocol.

Forest Land may consist of either closed forest formations, where trees of various heights and undergrowth cover a high proportion of the ground, or open forest formations with vegetation cover in which tree crown cover exceeds 20%. Young natural stands and all forest plantations that have yet to reach a crown density of 20% or tree height of 5 metres are included under the term 'forest', as are areas normally forming part of the forest area, which are temporally unstocked as a result of human intervention or natural causes, but which are expected to revert to forest land.

Forest Land also includes:

- Forest nurseries and seed orchards, only in case these constitute an integral part of the forest.
- Forest roads, cleared tracts, firebreaks and other small open areas, which are smaller than 6 metres within the forest.
- Forest in national parks, nature reserves and other protected areas, such as those of special environmental, scientific, historical, cultural or spiritual interest, covering an area of over 0.5 ha and a width of over 30 metres.
- Windbreaks and shelterbelts of trees.

This excludes tree stands in agricultural production systems, for example in fruit plantations and agro-forestry systems. Units of land with trees that do otherwise meet the Forest definition except for the minimum area of 0.5 ha are not reported as Forest Land but as Trees outside Forest (TOF) as a subcategory under Grassland.

The topographic map classes (Chapter 3) that are reported under Forest Land are deciduous forest, coniferous forest, mixed forest, poplar plantations and willow coppice. Groups of trees are mapped as forest only if they have a minimum surface of 50 m^2, or of 1000 m^2 in built-up areas or parks. A patch of a certain forest class is allocated to Forest Land if it exceeds the minimum area requirements, i.e. larger than 0.5 ha and more than 30 m width, and to Trees outside Forest otherwise.

In the Netherlands, all forest land is considered to be managed. Consequently all emissions and removals are reported under managed land, and no further sub-division is used between managed and unmanaged forest land.

2.3 Cropland (4.B)

The land-use category '**Cropland**' includes arable and tillable land and agroforestry systems where the vegetation structure falls below the thresholds used for the Forest Land category, and is not expected to exceed those thresholds at a later time (Section 3.2 in IPCC 2006b).

The Netherlands has chosen to define croplands as arable lands and nurseries (including tree nurseries). For part of the agricultural land, rotation between arable land and grassland is frequent, but data on where exactly this is occurring are lacking. Currently, the situation on the topographic map is leading, with land under agricultural crops and classified as arable lands at the time of recording reported under Cropland and lands with grass vegetation at the time of recording classified and reported as Grassland.

Under Cropland the class 'arable land' as well as the class 'tree nurseries' of the used topographic maps are reported (Chapter 3). The latter does not conform to the forest definition, and the agricultural type of farming system justifies the inclusion in Cropland. Greenhouses are not included in Cropland, but instead they are considered as Settlements.

2.4 Grassland (4.C)

The land-use category '**Grassland**' includes different types of vegetation. At the level of the reporting two main sub-categories are identified: 1) Grassland and 2) 'Trees outside Forest' (TOF) (see Table 2.1). The subcategory Grassland will be identified with 'Grassland (non-TOF)' to prevent confusion with the main category Grassland.

The conversions of land use from and to Grassland (non-TOF) and Trees outside Forest are separately monitored and subsequent calculations of carbon stock changes differ (see Chapter 6)

Table 2.1 *Division of the main category Grassland in sub-categories that are reported in the NIR and CRF tables and the underlying subcategories for Grassland (non-TOF).*

Main category	Reported sub-categories	Underlying sub-categories
Grassland (4.C)	Grassland (non-TOF)	Grassland vegetation
		Nature
		Orchards
	Trees Outside Forest	-

Grassland (non-TOF)
The Grassland (non-TOF) category covers land that is dominated by a grassland vegetation, including rangelands and pasture land that are not considered Cropland. It covers all grassland from wild lands to recreational areas as well as agricultural and silvi-pastural systems, consistent with national definitions (Section 3.2 in IPCC 2006b). It also includes systems with woody vegetation and other non-grass vegetation such as herbs and brushes that fall below the threshold values of cover and tree height used in the Forest Land category.

This sub-category is further stratified in (also see Table 2.1):
- 'Grassland vegetation', i.e. all areas predominantly covered by grass vegetation (whether natural, recreational or cultivated).
- 'Nature', i.e. all natural areas not covered under the grassland vegetation. It mainly consists of heathland, peat moors and other nature areas. Many nature areas have an occasional tree as part of the typical vegetation structure.
- Orchards, i.e. areas with standard fruit trees, dwarf varieties or shrubs. They do not conform to the forest definition, and while agro-forestry systems are mentioned in the definition of Croplands, in the Netherlands the main undergrowth of orchards is grass. Therefore, these orchards are reported under grasslands.

The topographic map (Chapter 3) class heathland and peat moors, as stratified to Nature, includes all land that is covered (mostly) with heather vegetation or rough grass species. Most of these were created in the Netherlands as a consequence of ancient grazing and sod cutting on sandy soils. As these practices are not part of the current agricultural system anymore, conservation management is applied to halt the succession to forest and conserve the landscape and the high biodiversity values associated with it.

In background calculations of the land-use matrix, this ‘nature’ category is seen as a separate (spatially explicit) land-use class, and all land-use transitions to and from this class are treated in the same way as transitions to and from other classes. However, in the reporting ‘nature’ is seen as a subcategory of grasslands and transitions between ‘nature’ and grassland vegetation are therefore treated as Grassland (non-TOF) remaining Grassland (non-TOF). When land use on a unit of land changes, the soil carbon stock will gradually change from the current value to the new equilibrium value, assuming a transition period of 20 years. If land use on the same unit of land again changes before the 20 years transition is finished, a new 20 year transition period is started, using the same calculation method. Land is always reported under its last known transition. A piece of land that is converted from cropland to ‘nature’ and subsequently to grassland vegetation will therefore be reported first under Cropland converted to Grassland (non-TOF) until its conversion to grassland vegetation, and as Grassland (non-TOF) remaining Grassland (non-TOF) thereafter.

In the calculations orchards are not spatially explicitly included. Instead statistics on areas of fruit orchards as reported by Statistics Netherlands[1] are used. It includes the cultivation areas for apples, pears, stone fruits (plum, cherry), nuts and small fruit (blueberry, blackberry, raspberry, red currant, wine grape, black currant). The area of small fruit is excluded in the used area for orchards. Data are available from 1992 onwards and are updated annually with provisional figures for the previous year being published in April. Areas for 1990 and 1991 are backward estimated based on extrapolation of the trend 1992-1993.

[1] https://opendata.cbs.nl/statline/#/CBS/en/dataset/70671ENG/table?ts=1517913547111

Trees outside Forest
'Trees outside Forest' are wooded areas that comply with the forest definition (see Section 2.2) except for their surface, i.e. they are smaller than 0.5 ha or less than 30 m width. These represent fragmented forest plots as well as groups of trees in parks and nature terrains and most woody vegetation lining roads, fields, etc.

On the topographic map classes (Chapter 3) groups of trees are mapped as forest if they have a minimum surface of 50 m^2, or of 1000 m^2 in built-up areas or parks. If such patches of trees subsequently also meet the Forest definition minimum area requirement (>0.5 ha) these units of land are allocated to Forest Land, but if the patch remains smaller than 0.5 ha it will be allocated to Trees outside Forest.

2.5 Wetlands (4.D)

The land-use category '**Wetlands**' includes areas of former peat extraction and land that is covered or saturated by water for all or part of the year (e.g., peatlands) and that does not fall into the Forest Land, Cropland, Grassland or Settlements categories (Section 3.2 in IPCC 2006b).

The Netherlands is characterised by many wet areas, but because many of these areas are covered by a grassy vegetation those are included under grasslands. Some wetlands are covered by a more rough vegetation of wild grasses or shrubby vegetation, which is reported in the subcategory 'Nature' of Grassland. Forested wetlands like willow coppice are included in Forest Land.

In the Netherlands, only reed marshes and open water bodies are included in the Wetlands land-use category. Reed marshes are areas where the presence of Common Reed *(Phragmites australis)* is indicated separately on the topographic maps. These may vary from wet areas in natural grasslands to extensive marshes. The presence of reed is marked with individual symbols on the topographic maps. Because it is not included in any of the previous categories its was translated to separate areas in the extracted land-use maps (Kramer *et al.*, 2007, Chapter 3). In the Netherlands there is currently no peat extraction.

Open water bodies are all areas which are indicated as water on the topographic maps (water is only mapped if the surface exceeds 50 m^2). This includes natural (e.g. small parts of the North Sea along the west and north coast) or artificial large open waters (e.g. rivers, artificial lakes), but also small open water bodies like ditches and channels. Additionally, it includes so called 'emerging surfaces', i.e. bare areas which are under water only part of the time as a result of tidal influences (Wadden Sea), and very wet areas without vegetation. It also includes 'wet' infrastructure for boats, i.e. waterways but also the water in harbours and docks.

2.6 Settlements (4.E)

The land-use category '**Settlements**' includes all developed land, including transportation infrastructure and human settlements of any size, unless they are already included under other categories (Section 3.2 in IPCC 2006b).

In the Netherlands, the main land-use classes included under Settlements are urban areas, transportation infrastructure, and built-up areas. Built-up areas include any constructed item, independent of the type of construction material, which is (expected to be) permanent, fixed to the soil surface (i.e. to distinguish from caravans) and serves as place for residence, trade, traffic and/or labour. Thus it includes houses, blocks of houses and apartments, office buildings, shops and warehouses but also fuel stations and greenhouses.

Urban areas and transportation infrastructure including all roads, whether paved or not, are included in the land-use category Settlements with exception of forest roads less than 6 m wide, which are included in the official forest definition. It also includes train tracks, (paved) open spaces in urban areas, parking lots and graveyards. Though some of the last classes are often actually covered by grass, the distinction cannot be made based on the topographic maps.

2.7 Other Land (4.F)

The land-use category '**Other Land**' was included to allow the total of identified land to match the national area where data are available. It includes bare soil, rock, ice and all unmanaged land area that do not fall in any of the other five categories (Section 3.2 in IPCC 2006b).

In general, 'Other Land' does not have a substantial amount of carbon. The Netherlands uses this land-use category to report the surfaces of bare soil which are not included in any other category. It does not include bare areas that emerge from shrinking and expanding water surfaces (these 'emerging surfaces' are included in Wetlands).

It includes all terrains which do not have vegetation on them by nature. The last part of the phrase 'by nature' is used to distinguish this class from settlements and fallow croplands. It includes coastal dunes and beaches with little to no vegetation. It also includes inland dunes and shifting sands, i.e. areas where the vegetation has been removed to create spaces for early succession species (and which are being kept open by wind). Inland bare sand dunes developed in the Netherlands as a result of heavy overgrazing and were combated by planting forests for a long time. These areas were, however, the habitat to some species which have become extremely rare nowadays. Inland sand dunes can be created as vegetation and top soil is again removed as a conservation measure in certain nature areas.

3 Representation of land and land-use change matrix

3.1 Introduction

The Netherlands has a full and spatially explicit land-use mapping that allows for geographical stratification at 25 m x 25 m (0.0625 ha) pixel resolution (Kramer *et al*. 2009; *van den Wyngaert et al.* 2012). This corresponds with the wall-to-wall approach used for reporting under the Convention (approach 3 in Chapter 3 of IPCC 2006b)

This approach was chosen after an extensive inventory of available land-use datasets in the Netherlands (Nabuurs *et al*. 2003). Information on the area of the different land-use categories and conversions between categories was based on a wall-to-wall map overlay, resulting in a national scale land use and land-use change matrix (Nabuurs *et al*. 2005). The current submission for the LULUCF sector is based on land-use change matrices that are derived from five maps representing the land use on 1 January 1970, 1990, 2004, 2009, 2013, 2017 and 2021. These maps thus represent land-use changes from 1 January 1970 until 1 January 2021.

In Kramer *et al.* (2009, 2015) all steps involved in the calculation of the land use and land-use change matrix used are described in detail. In this chapter a short summary of the methodology is given and the land-use change matrices derived from map overlays are presented. In addition, a number of corrections to afforestation and deforestation that were necessary in the 2017 and 2021 maps are described in Chapter 3.2, below.

3.2 Source maps

The land-use maps used for 1970 and 1990 are based on the maps on historic land use in the Netherlands (‘Historisch grondgebruik Nederland, HGN)[2], while the later maps were based on the Nature Base maps that were originally used for monitoring nature development in the Netherlands; in Dutch 'Basiskaart Natuur' (BN). After 2009 these maps were not used anymore for monitoring nature development, but in order to guarantee consistency in the land-use change matrix for LULUCF reporting they are still developed on request as a basis for the LULUCF land-use change monitoring.

These maps are based on different topographic maps of the Dutch Kadaster (Land Registry Office). The source material for the HGN1970[3] and HGN1990 maps (Kramer and van Dorland 2009) consists of the topographic map 1:25,000 (Top25) and in the case of HGN1990 combined with the digital topographic map 1:10,000 (Top10Vector, see Table 3.1 for more details) for some parts. The paper TOP25 maps were converted to a digital high resolution raster map following the approach described in Kramer and van Dorland (2009). The source material for BN2004 (Kramer *et al.* 2007) consists of the digital topographic map 1:10,000 (Top10Vector).

The source materials for BN2009 (Kramer and Clement 2016), BN2013 (Kramer and Clement 2015), BN2017 (Kramer 2019) and BN2021 (Kramer and Los 2022) are based on the Top10NL digital topographic maps 1:10,000, which is the successor of the Top10Vector map. The Top10NL maps differ in some aspects from the Top10Vector maps. While analysing the land-use changes between 2004 and 2009, several counterintuitive land-use changes were observed. A further exploration of the

[2] https://www.wur.nl/nl/show/Kaarten-Historisch-Grondgebruik-Nederland-HGN.htm
[3] For this map no publication with background descriptions is available. However, the methodology to generate the map was the same as for the 1990 land use-map, which is described in Kramer and van Dorland (2009).

topographic maps from 2004 and 2009 in combination with the corresponding aerial photos showed that there is a difference in the way topographic elements are recorded for Top10Vector and Top10NL. For instance roads on the 2009 map are represented in more detail and higher resolution, resulting in more narrow representations on the map. Other examples where this happens are airfields and industrial sites that on the 2004 topographic map were classified as other land use, but now has the runways, buildings and roads and surrounding grasslands classified separately. Since these represent only a relatively small area there was no correction applied. On the 2013 map the representations of these elements were similar to the 2009 map as both are based on the TOP10NL source.

For all years the most recent version of the topographic map on 1 January of that year was used (i.e. based in the most recent aerial source photographs at that time, see Table 3.1). The BN maps were initially created to monitor changes in nature areas, but because of its national coverage and inclusion of other land-use types it is also very suitable as land-use data set for the reporting of the LULUCF sector (see Annex 2 for the land-use statistics and land-use maps for the different years). The latest BN maps, therefore, paid attention to the requirements for UNFCCC reporting.

The Top10Vector file, digitised Top25 maps and TOP10NL maps were (re)classified to match the requirements set for both the monitoring changes in nature areas and UNFCCC reporting. In this process additional data sets were used. Simultaneously, harmonisation between the different source materials was applied to allow a sufficiently reliable overlay (see Kramer *et al.*, 2009 for details). The final step in the creation of the land-use maps was the aggregation to 25 m × 25 m raster maps. For the 1990 map, which had a large part of the information derived from paper maps, an additional validation step was applied to check on the digitising and classifying processes.

All individual maps contained a few missing pixels (0.05% of total land use) when comparing them to other years. When the land-use for a certain pixel changed through time and the land use was missing for a single year the land use of the first map in the future was applied.

Table 3.1 *Characteristics of the maps BN1990, BN2004, BN2009 BN2013, BN2017 and BN2021.*

	HGN1970	HGN1990	BN2004	BN2009	BN 2013	BN 2017	BN 2021
Name	Historical Land use Netherlands 1970	Historical Land use Netherlands 1990	Base map Nature 2004	Base map Nature 2009	Base map Nature 2013	Base map Nature 2017	Base map Nature 2021
Aim	Historical land use map		Base map for monitoring nature development		Consistent monitoring of land use and land-use change for LULUCF		
Resolution	25 m						
Coverage	The Netherlands						
Base year source data	1966-1975	1986-1994	1999-2003	2004-2008	2009-2012	2015	2019-2020
Source data	Hard copy topographic maps at 1:25,000 scale		Digital topographic maps at 1:10,000 and additional sources to distinguish specific nature types				
		+ partly digital topographic maps 1:10,000					
Distinguished classes	Grassland, Arable land, Heath land/peat moor, Forest, Buildings, Water, Reed marsh, Sand, Built-up area, Greenhouses		Grassland, Nature grassland, Arable land, Heath land, Forest, Built-up area and infrastructure, Water, Reed marsh, Drifting sands, Dunes and beaches				

Corrections on the 1970 land-use map

The 1970 land-use map was only based on the (digitised) hard copy topographic maps at 1:25,000 scale (Top25) and no additional information of maps at 1: 10,000 scale is available. As a consequence, the quality is considered lower than the maps of later years. This map is used to generate the land-use change matrix 1970-1990 that is required to report the land-use change categories since 1990 correctly. The following corrections were applied to the 1970 land-use:

- Any pixels with unknown land use in the 1970 map, but with known land use in the 1990 map, were assigned the land use of 1990.
- The 1970 land use was reclassified to the 1990 land use for the areas that showed a changed land use from 1970 to 1990 that represented land-use change trajectories[4] covering less than 10 ha of land. These would be very rare land-use change trajectories and results in very long run-times with the LULUCF bookkeeping model. Using this approach maintains the overall land-use transition trend for the period 1970-1990 and keeps model run-times manageable. This procedure concerned 1.9% of the total land area.

Correction of forest area on the 2017 land-use map
A comparison of the 2013 and 2017 map showed a net loss of forest area. Further investigation revealed the following causes for this reduction:

1. Deforestation continued in more or less the same pace as before, mainly due to conversion of forest to settlements, for nature development and because temporary poplar forests that were planted 25-30 years ago under a set aside regulation for agricultural land, were harvested and converted back to agriculture in line with the conditions in the regulation.
2. Afforestation declined considerably. While in principle deforestation needs to be compensated with afforestation of an equal area elsewhere, exception to these rules is when conversion to priority nature takes place on the basis of ecological arguments, like on the basis of Natura 2000 management plans. In such cases forest conversion can take place without compensation.
3. Some areas were mapped in greater detail than before, particularly build-up areas with a lot of trees. Part of these areas were earlier incorrectly classified as forest and now on the 2017 map corrected to settlement.
4. In recent years several forest owners increased their harvest activity in the forest, with in many cases an explicit orientation to facilitate regeneration or to introduce different species. These practices need larger clear cut areas. Subsequently these areas on the 2017 map were often incorrectly classified as heathland or grassland, while in fact these areas are only temporary unstocked and therefore according to the forest definition should have been classified as forest land.

Points 1 and 2 above, are considered valid explanations of the observed development. Point 3, however, leads to a (small) overestimation of the forest area on earlier maps which is now corrected. Because correcting and reclassifying earlier maps was considered to be an excessive effort, this "deforestation" was accepted as a conservative estimate.

The misclassifications as indicated under point 4 above, were corrected using the following procedure.

- All polygons that were classified as deforestation of 1 ha and larger were checked visually using aerial images.
- Each polygon was assigned a code: accept deforestation, reject deforestation or uncertain. In most cases, the difference between a nature development project or a regeneration felling was clearly visible. Nature development projects were often irregular in shape, connected open areas in the landscape and/or were adjacent to existing open areas. Regeneration areas were usually of a more regular size, not too large, well within the forest boundaries and often already showed signs of a new regeneration of trees. In a few cases no decision could be made and the polygon was classified as uncertain.
- In order to decrease future uncertainty around afforestation and deforestation, we also checked all polygons equal to or larger than 1 ha that were converted to forest.
- These were also classified as accept, reject or uncertain based on the visual interpretation of the aerial images.
- These maps were combined into a BN2017 correction layer which was used to create a corrected BN2017 map.
  - For all pixels located in polygons classified as "accept" the land use in 2017 was accepted.
  - For all pixels located in polygons classified as "reject", the land use from the 2013 map was restored.

[4] Land-use change trajectories are a collection of pixels that show the same timing of subsequent changes in land use over time.

- The same procedure was applied to pixels located in a polygon classified as “uncertain”. In this way, these pixels will not be deforested now and afforested again in the next map if incorrectly classified, and will still be classified as deforested if the next map and aerial pictures provide evidence of deforestation. The same applies to the pixels labelled as uncertain afforestation.

Table 3.2 *Result of the check of deforestation and afforestation polygons derived from the BN2013 and 2017 maps. All deforestation and afforestation polygons ≥ 1 ha were checked.*

Result	Afforestation (ha)	Deforestation (ha)
accept	2319.0	5233.6
reject	135.7	688.9
uncertain (reject)	300.1	431.9
not checked (< 1 ha)	6627.1	13878.0
total	9381.9	20232.4

The correction was limited to polygons of 1 ha and more because of the huge number of separate polygons classified as afforestation or deforestation, and because the misclassifications due to regeneration areas are most likely to be in this size category. Out of the more than 144 thousand polygons classified as deforested, the majority (~75%) was of the size of a single pixel (25 m x 25 m). For deforestation, 2046 polygons were checked, equal to 6354.4 ha out of the total 20,232 ha classified as deforestation (Table 3.2). For afforestation, 1134 polygons were checked, equal to 2754.8 ha out of the 9381.9 ha classified as afforestation (Table 3.2).

Correction of forest area on the 2021 land-use map
Regarding forest land, the same checks and correction procedure as described for the 2017 land-use map were also applied to the 2021 land-use map. As before, polygons with area <1 ha were left out of the analysis, with again the majority being single pixels (Table 3.3).

Table 3.3 *Result of the check of deforestation and afforestation polygons derived from the BN2017 and BN2021 maps. All deforestation and afforestation polygons ≥ 1 ha were checked.*

Result	Afforestation (ha)	Deforestation (ha)
accept	2583.9	2769.7
reject	377.4	1556.8
uncertain (reject)	92.2	58.5
not checked (< 1 ha)	4647.0	6397.5
total	7700.5	10782.6

Corrections of the extent of land area
It was observed that the older land-use maps did not cover the whole wall-to-wall extent of the 2021 map. The missing parts were the same amongst most land-use maps covering 1,186 ha of the total 4,153,009 ha area of the Netherlands. To correct this, the missing areas of all earlier land-use maps were filled up with the data for that location from the original BN land-use maps. After the missing parts were added to the maps, they were all cut according to the official border of 2021 as set by the Dutch land registry.

After these corrections the total area covered in the reporting was 4,154,195 ha. Cropland and grassland were the most dominant land uses in the units of land that were added after filling the missing parts and making corrections along the Dutch border (Table 3.4).

Table 3.4 *Area added to each land-use per year relative to the 1,186 ha added to each map. Positive numbers indicate added area and negative numbers indicate reduced area.*

	Year					
Forest Land	75.6%	12.6%	13.1%	13.9%	14.2%	12.6%
Cropland	107.8%	27.8%	22.6%	22.2%	21.7%	21.0%
Grassland (non-TOF)	-74.7%	23.6%	24.3%	22.6%	23.3%	23.1%
Trees outside forest	21.1%	-0.4%	-0.1%	-0.5%	-0.3%	1.3%
Wetlands	1.4%	24.1%	23.9%	24.7%	12.2%	24.8%
Settlements	-30.8%	12.2%	16.2%	17.0%	20.1%	17.2%
Other Land	-0.3%	0.1%	0.1%	0.0%	8.7%	0.0%
Total	100%	100%	100%	100%	100%	100%

3.3 Overview of land-use allocation

The basis of allocation for IPCC land-use (sub)categories are the land-use/cover classifications of the national topographic maps (Section 3.2), TOP25, TOP10Vector and TOP10NL. For most of the topographic classes, there was only one IPCC land-use (sub)category where it could be unambiguously included. For other topographic classes, there would be some reasons to include it in one, and other reasons to include it in another IPCC land-use (sub)category. In these cases, we allocated it to the land-use category where (in sequential order):

- the majority of systems (based on surface) in the topographic class would fit best based on the degree of human impact on the system, or
- if this did not give an unambiguous solution, we allocated it where the different types of carbon emission considered/reported represented the situation in the topographic class best.

The resulting classification is summarised in Table 3.5.

Table 3.5 *Overview of allocation of topographic classes to IPCC land-use (sub)categories (based on Kramer et al. 2007).*

Topographic class	**Dutch name**	**IPCC classes**
Deciduous forest	Loofbos	Forest Land
Coniferous forest	Naaldbos	Forest Land
Mixed forest	Gemengd bos	Forest Land
Poplar plantation	Populierenopstand	Forest Land
Willow coppice	Griend	Forest Land
Arable land	Bouwland	Cropland
Tree nurseries	Boomkwekerij	Cropland
Grasslands	Weiland	Grassland
Orchard (high standards)	Boomgaard	Grassland
Orchard (low standards and shrubs)	Fruitkwekerij	Grassland
Heathland and peat moors	Heide en hoogveen	Grassland
Reed marsh	Rietmoeras	Wetland
Water (large open water bodies)	Water (grote oppervlakte)	Wetland
Water (small open water bodies)	Oeverlijn / Water (kleine oppervlakte)	Wetland
Emerging surfaces	Laagwaterlijn / droogvallende gronden	Wetland
'Wet' infrastructure	Dok	Wetland
Urban areas and transportation infrastructure	Stedelijk gebied en infrastructuur	Settlement
Built-up areas	Bebouwd gebied	Settlement
Greenhouses	Kassen	Settlement
Coastal dunes and beaches	Strand en duinen	Other Land
Inland dunes and shifting sands	Inlandse duinen	Other Land

3.4 Land-use change matrix

Overlays of all land-use maps (1970, 1990 2004, 2009, 2013, 2017 and 2021), using 25 m × 25 m grid cells, resulted in six land-use change matrices between 1970 and 1990, 1990 and 2004, 2004 and 2009, 2009 and 2013, 2013 and 2017 and between 2017 and 2021. The full extent of the 2017 land-use map was used as the basis for all overlays to be able to include the total area of the land that was reclaimed from the sea as an extension of the harbour in Rotterdam (Maasvlakte 2), which is ongoing since 2008 (see the 2017 map, Figure A2.5, Annex 2). The total extent of this area is about 2000 ha. About 500 ha of this area was already included as sea (open water) since the 1970 map.

The overlay of the land-use maps of 1970 and 1990 resulted in a land-use and land-use change matrix over twenty years (1-1-1970 to 1-1-1990; Table 3.6). The overlay of the land-use maps of 1990 and 2004 resulted in a land-use and land-use change matrix over fourteen years (1-1-1990 to 1-1-2004; Table 3.7). The overlay of the land-use maps of 2004 and 2009 results in a land-use change matrix over five years (1-1-2004 to 1-1-2009; Table 3.8), while the overlays of the 2009, 2013 and 2017 maps results in a land-use change matrices over 4 years (1-1-2009 to 1-1-2013; Table 3.9, and 1-1-2013 to 1-1- 2017; Table 3.10 and 1-1-2017 to 1-1- 2021; Table 3.11).

These matrices show the changes for nine land-use categories. For the purpose of the CRF and NIR, the nine land-use categories are aggregated into the six land-use classes that are defined in the LULUCF guidelines with Grassland further subdivided in Grassland non-TOF and Trees outside Forest (TOF) (Tables 3.6, to 3.11, and annual changes in Tables 3.12 to 3.17). The definitions of the UNFCCC land-use categories are given in Chapter 2.

Table 3.6 *Land-use and Land-use Change Matrix for 1970-1990 aggregated to the six UNFCCC land-use categories (in ha) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

	HGN 1990							
HGN 1970	**FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	***Total***
Forest Land	300,044	4,313	15,753	1,274	1,079	6,144	726	*329,333*
Cropland	22,133	687,295	182,415	2,094	11,176	50,894	195	*956,202*
Grassland (non-TOF)	28,182	297,694	1,243,850	4,896	21,533	86,068	1,174	*1,683,396*
Trees outside forest	1,697	1,249	4,039	10,361	175	2,207	107	*19,836*
Wetlands	1,350	4,762	15,077	156	753,597	4,527	3,648	*783,118*
Settlements	7,734	24,237	44,055	1,943	3,659	259,450	485	*341,564*
Other Land	1,109	132	2,774	77	3,117	312	33,227	*40,747*
Total	*362,249*	*1,019,682*	*1,507,962*	*20,801*	*794,336*	*409,602*	*39,563*	*4,154,195*

Table 3.7 *Land-use and Land-use Change Matrix for 1990-2004 aggregated to the six UNFCCC land-use categories (in ha) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

	BN 2004							
HGN 1990	FL	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	**Total**
Forest Land	334,348	1,220	14,592	2,852	1,503	7,035	699	362,249
Cropland	12,527	739,425	176,854	2,039	6,823	81,813	201	1,019,682
Grassland (non-TOF)	18,075	196,624	1,190,957	4,474	18,642	78,283	907	1,507,962
Trees outside forest	2,350	386	3,314	11,335	318	2,988	110	20,801
Wetlands	888	596	9,094	328	777,801	2,837	2,791	794,336
Settlements	1,456	1,626	10,993	1,078	1,391	392,936	122	409,602
Other Land	552	8	2,547	98	2,583	630	33,144	39,563
Total	*370,196*	*939,885*	*1,408,352*	*22,206*	*809,061*	*566,522*	*37,974*	*4,154,195*

Table 3.8 *Land-use and Land-use Change Matrix for 2004-2009 aggregated to the six UNFCCC land-use categories (in ha) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

BN 2004	**BN 2009** **FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	***Total***
Forest Land	357,622	352	5,223	1,514	703	4,575	208	*370,196*
Cropland	2,012	813,514	108,507	296	1,796	13,732	27	*939,885*
Grassland (non-TOF)	7,129	106,576	1,243,564	1,706	10,615	37,714	1,047	*1,408,352*
Trees outside forest	1,701	137	1,198	16,892	126	2,122	30	*22,206*
Wetlands	374	177	9,633	92	796,581	1,441	762	*809,061*
Settlements	4,598	4,368	23,125	1,556	3,035	529,603	237	*566,522*
Other Land	209	2	506	29	890	137	36,201	*37,974*
Total	*373,645*	*925,126*	*1,391,756*	*22,086*	*813,746*	*589,323*	*38,512*	*4,154,195*

Table 3.9 *Land-use and Land-use Change Matrix for 2009-2013 aggregated to the six UNFCCC land-use categories (in ha) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

BN 2009	**BN 2013** **FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	***Total***
Forest Land	360,356	1,319	6,257	1,483	699	3,327	204	*373,645*
Cropland	2,484	794,119	116,032	311	1,410	10,743	28	*925,126*
Grassland (non-TOF)	8,095	145,435	1,194,348	1,590	10,850	30,922	516	*1,391,756*
Trees outside forest	1,346	219	1,532	17,212	164	1,582	31	*22,086*
Wetlands	651	305	6,183	112	803,194	1,353	1,948	*813,746*
Settlements	2,535	3,199	20,664	815	4,477	557,496	135	*589,323*
Other Land	444	1	970	49	1,825	328	34,897	*38,512*
Total	*375,912*	*944,597*	*1,345,986*	*21,572*	*822,619*	*605,751*	*37,759*	*4,154,195*

Table 3.10 *Land-use and Land-use Change Matrix for 2013-2017 aggregated to the six UNFCCC land-use categories (in ha) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

BN 2013	**BN 2017** **FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	***Total***
Forest Land	356,773	1,665	9,353	2,022	804	4,890	404	*375,912*
Cropland	903	762,661	170,219	246	1,676	8,868	24	*944,597*
Grassland (non-TOF)	4,822	103,147	1,197,260	1,504	9,191	28,670	1,394	*1,345,986*
Trees outside forest	1,141	205	1,658	16,548	146	1,834	41	*21,572*
Wetlands	837	291	6,717	192	807,543	4,340	2,700	*822,619*
Settlements	1,036	2,583	21,378	711	1,571	578,275	196	*605,751*
Other Land	215	7	735	34	1,415	484	34,869	*37,759*
Total	*365,726*	*870,559*	*1,407,320*	*21,256*	*822,346*	*627,360*	*39,628*	*4,154,195*

Table 3.11 *Land-use and Land-use Change Matrix for 2017-2021 aggregated to the six UNFCCC land-use categories (in ha) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

BN 2017	BN 2021 FL	CL	GL (non-TOF)	TOF	WL	Sett	OL	*Total*
Forest Land	356,579	675	5,115	1,157	263	1,578	359	*365,726*
Cropland	762	707,797	154,279	130	1,023	6,541	27	*870,559*
Grassland (non-TOF)	4,398	125,580	1,251,360	870	5,473	18,691	948	*1,407,320*
Trees outside forest	693	218	1,502	17,928	82	739	96	*21,256*
Wetlands	301	332	4,394	65	812,759	1,471	3,024	*822,346*
Settlements	707	2,103	18,554	371	1,545	603,850	229	*627,360*
Other Land	361	5	2,967	42	2,258	166	33,828	*39,628*
Total	*363,801*	*836,710*	*1,438,171*	*20,563*	*823,403*	*633,037*	*38,511*	*4,154,195*

The total area of land-use change in the period 1970 to 1990 was about 866.4 kha, which is around 21% of the total area, in the period 1990 to 2004 674.2 kha (16%), in the period 2004 to 2009 360.2 kha (8.7%), in the period 2009-2013 392.6 kha (9.4%), in the period 2013-2017 400.3 kha (9.6%), and in the period 2017 to 2021 370.1 kha[2] (8.9%) changed. Note, however, that the time intervals differ among these periods, which results in accelerating dynamics of land-use change from 43.3 kha yr^{-1} over 1970-1990, 48.1 kha yr^{-1} over 1990-2004, 72.0 kha yr^{-1} over 2004-2009, 98.1 kha yr^{-1} over 2009-2013, 100.0 kha yr^{-1} over 2013-2017, to 92.5 kha yr^{-1} over 2017-2021. The largest changes in land use are seen in the conversion of cropland to grassland and vice versa. Other important land-use changes are the conversions of Cropland and Grassland to Settlements (urbanisation).

Table 3.12 *Annual changes in land us for the period 1970-1990 aggregated to the six UNFCCC land-use categories (in ha yr^{-1}) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

From:	To: FL	CL	GL (non-TOF)	TOF	WL	Sett	OL	Total
Forest Land		216	788	64	54	307	36	*1,464*
Cropland	1,107		9,121	105	559	2,545	10	*13,445*
Grassland (non-TOF)	1,409	14,885		245	1,077	4,303	59	*21,977*
Trees outside forest	85	62	202		9	110	5	*474*
Wetlands	68	238	754	8		226	182	*1,476*
Settlements	387	1,212	2,203	97	183		24	*4,106*
Other Land	55	7	139	4	156	16		*376*
Total	*3,110*	*16,619*	*13,206*	*522*	*2,037*	*7,508*	*317*	*43,319*

Table 3.13 *Annual changes in land us for the period 1990-2004 aggregated to the six UNFCCC land-use categories (in ha yr^{-1}) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

From:	To: FL	CL	GL (non-TOF)	TOF	WL	Sett	OL	Total
Forest Land		87	1,042	204	107	503	50	*1,993*
Cropland	895		12,632	146	487	5,844	14	*20,018*
Grassland (non-TOF)	1,291	14,045		320	1,332	5,592	65	*22,643*
Trees outside forest	168	28	237		23	213	8	*676*
Wetlands	63	43	650	23		203	199	*1,181*
Settlements	104	116	785	77	99		9	*1,190*
Other Land	39	1	182	7	185	45		*458*
Total	*2,561*	*14,319*	*15,528*	*776*	*2,233*	*12,399*	*345*	*48,161*

Table 3.14 *Annual changes in land us for the period 2004-2009 aggregated to the six UNFCCC land-use categories (in ha yr^{-1}) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

From:	**To:** **FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	**Total**
Forest Land		70	1,045	303	141	915	42	*2,515*
Cropland	402		21,701	59	359	2,746	5	*25,274*
Grassland (non-TOF)	1,426	21,315		341	2,123	7,543	209	*32,957*
Trees outside forest	340	27	240		25	424	6	*1,063*
Wetlands	75	35	1,927	18		288	152	*2,496*
Settlements	920	874	4,625	311	607		47	*7,384*
Other Land	42	0	101	6	178	27		*355*
Total	*3,205*	*22,322*	*29,638*	*1,039*	*3,433*	*11,944*	*462*	*72,043*

Table 3.15 *Annual changes in land us for the period 2009-2013 aggregated to the six UNFCCC land-use categories (in ha yr^{-1}) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

From:	**To:** **FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	**Total**
Forest Land		330	1,564	371	175	832	51	*3,322*
Cropland	621		29,008	78	353	2,686	7	*32,752*
Grassland (non-TOF)	2,024	36,359		398	2,713	7,731	129	*49,352*
Trees outside forest	337	55	383		41	396	8	*1,219*
Wetlands	163	76	1,546	28		338	487	*2,638*
Settlements	634	800	5,166	204	1,119		34	*7,956*
Other Land	111	0	243	12	456	82		*904*
Total	*3,889*	*37,620*	*37,910*	*1,090*	*4,856*	*12,064*	*716*	*98,143*

Table 3.16 *Annual changes in land us for the period 2013-2017 aggregated to the six UNFCCC land-use categories (in ha yr^{-1}) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

From:	**To:** **FL**	**CL**	**GL (non-TOF)**	**TOF**	**WL**	**Sett**	**OL**	***Total***
Forest Land		416	2,338	506	201	1,223	101	*4,785*
Cropland	226		42,555	62	419	2,217	6	*45,484*
Grassland (non-TOF)	1,206	25,787		376	2,298	7,168	349	*37,182*
Trees outside forest	285	51	415		37	459	10	*1,256*
Wetlands	209	73	1,679	48		1,085	675	*3,769*
Settlements	259	646	5,345	178	393		49	*6,869*
Other Land	54	2	184	9	354	121		*723*
Total	*2,239*	*26,975*	*52,515*	*1,177*	*3,701*	*12,272*	*1,190*	*100,067*

Table 3.17 *Annual changes in land us for the period 2017-2021 aggregated to the six UNFCCC land-use categories (in ha yr^{-1}) with Grassland (GL) divided in GL non-TOF and Trees outside Forest (TOF).*

From:	To: FL	CL	GL (non-TOF)	TOF	WL	Sett	OL	*Total*
Forest Land		169	1,279	289	66	395	90	*2,287*
Cropland	191		38,570	33	256	1,635	7	*40,691*
Grassland (non-TOF)	1,100	31,395		218	1,368	4,673	237	*38,990*
Trees outside forest	173	55	376		21	185	24	*833*
Wetlands	75	83	1,099	16		368	756	*2,397*
Settlements	177	526	4,639	93	386		57	*5,877*
Other Land	90	1	742	11	565	42		*1,450*
Total	*1,806*	*32,228*	*46,703*	*659*	*2,661*	*7,297*	*1,171*	*92,524*

3.5 Organic and mineral soils

The areas of organic and mineral soils have to be reported separately. Spatial distribution of mineral and organic soil types is taken from two different versions of the digital soil map of the Netherlands (see Annex A1.2) classifying 11 soil types of which 9 mineral soil types and two organic soil types. The original version is based on soil mapping that was carried out over the period 1960-1995 (de Vries et al. 2003) and on average is dated on 1 January 1977. De Vries et al. (2010) showed that the areas of organic soils (peat and peaty soils) are decreasing as a result of the oxidation of the organic soils, particularly in the drained agricultural areas on organic soils. Therefore, a new soil map was produced, dated 1 January 2014, with particular attention to peat and peaty soils (de Vries et al. 2014). To be able to assess the extent of organic soil oxidation after 2014, a forecast map of the extent of peat and peaty soils in 2040 is used (Erkens et al. 2021).

Mineral soils
For reporting of mineral soils 9 main soil types were distinguished (see Chapter 11.2). Since there is no reason to assume changes in main soil type within the mineral soil area the spatial classification of the specific mineral soil types was based on the 2014 update of the soil map. Nonetheless, as a result of oxidation some of the organic soils will change to mineral soils over time, resulting in increasing areas of mineral soils.

Organic soils
Two types of organic soils are recognised; peat soils ('veengronden' in Dutch) and peaty soils ('*moerige gronden*' in Dutch). These differ in the depth of the peat layer (see Chapter 11.3 for details). To assess changes in areas of peat soils and peaty soils the original digital soil map of 1977 and the 2014 updated soil map were combined. Between the original and the 2014 updated version of the soil map 56.8 kha (out of the original 337.5 kha) of peat soil were converted to peaty soils while 6.2 kha of peat soil were converted to mineral soils. At the same time 85.8 kha of peaty soil were converted to mineral soil. After 2014 the rate of loss of organic soils is linearly interpolated between the 2014 map and the 2040 forecast organic soil map and decreases with 972 ha per year between 2014 and 2040.

The 2014 soil map has a higher resolution (25 m) compared to the 2040 forecast map (100 m). Where the soil map of 2014 and the organic soil forecast map of 2040 did not match their starting soil type for 2014, the soil type from the 2014 map was considered leading. For example, when the organic soil forecast map stated that a particular pixel was peaty in 2014 and peaty in 2040, but the 2014 soil map stated that the soil type was peat in 2014, the soil type was set to peat in 2014 for the interpolation of changes between 2014 and 2040.

The loss of peat and peaty soil over the past decades is the result of oxidation in drained agricultural areas on organic soils and drainage for infrastructure and settlements. Commercial extraction of peat does not occur anymore since 1992[5], but at that time the last company had been phasing out the activities already for quite some time. While the quantity of peat extraction in 1990 and 1991 is unknown, it is believed that the affected area and resulting emissions are negligible. Until the 1950s peat was an important energy source in the Netherlands, but after that time other fossil fuels like coal and gas became more important energy sources. After that at a much smaller scale peat was extracted for application in potting soil. This extraction, however, largely ended by the early 1980s with the latest company stopping in 1992. Most of the peat for potting soils nowadays is imported from Germany and the Baltic states.

Peat and peaty soils each have their specific emission factor (see Chapter 11.3), but emissions are eventually lumped into one category of organic soils.

Organic and mineral soil area for Forest Land, Cropland, Grassland, and Other Land is presented in Table 3.13. This shows that 21% of the Grasslands, 10% of the Croplands, 6% of Forests and 5% of the other land uses are on organic soils, with 11% of the total area being organic soils. More information about the emission from organic soils can be found in Chapter 11.3.

Table 3.18 *Land use on organic and mineral soils on 1 January 1990, 2004, 2009, 2013, 2017 and 2021.*

Land use	Soil	1990	2004	2009	2013	2017	2021
Forest Land	organic soils area (ha)	20,482	21,990	21,885	21,453	20,396	19,780
	mineral soils area (ha)	341,619	348,052	351,595	354,291	345,183	344,020
	% organic	6%	6%	6%	6%	6%	5%
Cropland	organic soils area (ha)	108,979	85,117	80,816	75,967	66,842	63,866
	mineral soils area (ha)	910,373	854,500	844,046	868,373	803,468	772,843
	% organic	11%	9%	9%	8%	8%	8%
Grasslands (non-TOF)	organic soils area (ha)	322,053	292,709	282,252	276,031	278,616	268,680
	mineral soils area (ha)	1,185,629	1,115,356	1,109,236	1,069,678	1,128,425	1,118,387
	% organic	21%	21%	20%	21%	20%	19%
Trees outside forest	organic soils area (ha)	2,216	2,237	2,221	2,132	2,120	2,033
	mineral soils area (ha)	18,590	19,970	19,872	19,443	19,120	18,529
	% organic	11%	10%	10%	10%	10%	10%
Other Land uses	organic soils area (ha)	45,142	61,999	64,440	66,082	68,718	75,532
	mineral soils area (ha)	1,196,416	1,349,571	1,375,136	1,398,050	1,418,613	1,470,520
	% organic	4%	4%	4%	5%	5%	5%
Total	organic soils area (ha)	498,873	464,051	451,615	441,666	436,691	429,891
	mineral soils area (ha)	3,652,627	3,687,449	3,699,885	3,709,834	3,714,809	3,724,299
	% organic	12%	11%	11%	11%	11%	10%

3.6 From land-use change matrix to activity data

From overlays of the successive land-use and soil maps, the unique land use-soil sequences are derived. These sequences only provide information on the land use in the years for which maps are available. For each sequence, all possible intermediate land-use trajectories are calculated. It is assumed that only a single land-use change has occurred between map-dates. Each trajectory is then assigned an equal proportion of the area on which the corresponding sequence occurs.

Fluxes are calculated for each trajectory separately. Land-use change related biomass fluxes are calculated as the instantaneous flux of the difference between the biomass stocks of the two land-use categories. Land-use change related soil carbon fluxes are assumed to take place over a 20 years interval (for details see Chapter 11). With successive land-use changes, yearly soil carbon flux is

[5] https://www.nrc.nl/nieuws/1992/06/26/het-veen-is-op-nederlands-laatste-turfwinning-stopt-7147920-a517002

calculated as 1/20th of the difference between the accumulated soil carbon stock at the time of transition and the soil carbon stock of the new land use. This flux is then attributed to the last land-use change that has occurred.

When calculating beyond the last land-use map, the general relative trends in land-use change between the last two maps are extrapolated towards the desired end-year (i.e. the reporting year). Extrapolation is based on the rate of change from a certain land use to another land use in the last two land use maps, taking into account the soil type where the change occurred and whether or not a trajectory has been stable (no land uses change until the first reference year). This means that a ‘change’ rate is calculated for each specific land use, soil type and stable/unstable combination. These change rates are then applied to trajectories with the same combinations of land use, soil and stable/unstable to extrapolate towards the desired reporting year. The used end-point has an effect on the number of trajectories. The newly calculated endpoint is added to the sequences. In case the extrapolation resulted in a trajectory smaller than 0.0625 ha (1 pixel), the last observed land use was retained. As a result, the calculation will be less focussed on rare and frequently changing land-use sequences.

4 Forest Land [4.A]

4.1 Description

The definition for the land-use category Forest Land is provided in Section 2.2. This category includes emissions and removals of CO_2 caused by changes in forests. All forests in the Netherlands are classified as temperate, 20 per cent of which are coniferous, 45 per cent broadleaved and the remaining area a mixture of the two. The share of mixed and broadleaved forests has grown in recent decades (Schelhaas *et al.*, 2014[6], 2022b).

The land-use category Forest Land is defined as all land with woody vegetation consistent with thresholds used to define forest land in the national GHG inventory (see Section 2.2 for the definition). In the Netherlands, with its very high population density and strong pressure on land, all forests are managed. Consequently no further sub-division is used between managed and unmanaged forest land. Where such sub-divisions are asked for in the CRF, the notation key 'NO' will be used in the tables for unmanaged forests.

Within the category 4A, Forest Land, two subcategories are distinguished:

1. 4.A1 Forest Land remaining Forest Land (FF)
   Areas of land that have been Forest Land for at least 20 years. 'The greenhouse gas inventory for the land-use category Forest Land remaining Forest Land (FF)" involves estimating the changes in carbon stock from five carbon pools (i.e. above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter), as well as emissions of non-CO_2 gases.' (see Page 4.11 in IPCC 2006b).

2. 4.A2 Land converted to Forest Land (LF)
   This concerns changes in the carbon stocks for areas that have been forested for less than 20 years, and are the result of conversion from other land-use categories. 'Managed land is converted to forest land by Afforestation and Reforestation, either by natural or artificial regeneration (including plantations)'. These activities are covered under categories 4.A2.1 through 4.A2.5 of the 2006 IPCC Guidelines. The conversion involves a change in land use.' (see Page 4.29 in IPCC 2006b).

   Land that is converted to forest land remains in this category for 20 years. After this it is reported under the category Forest Land remaining Forest Land.

Besides the Forest Land category, information on carbon stocks in Forest Land is needed for the following categories:

3. *4.B2 - 4.F2: Forest Land converted to another land-use category*, i.e. Deforestation. This concerns changes in the carbon stocks of areas that were forest land and are converted to any other land-use category.

Expanding forest lands accumulate carbon. This accumulation can change as a result of changes in three components (carbon pools), i.e. (see Page in 1.9 in IPCC 2006b):
1. Living biomass, further specified in:
   - above-ground biomass (trunk and branches)
   - below-ground biomass (roots)

[6] Report on the 6th Forest Inventory with results only in Dutch. For English summary of the results and an English summary flyer "State of the Forests in The Netherlands", see: http://www.wageningenur.nl/en/Expertise-Services/Research-Institutes/alterra/Projects/Dutch-Forest-Inventory/Results.htm

2. Dead organic matter (DOM), further specified in:
   - dead wood
   - litter
3. Soil organic matter (SOM)

Emissions are reported for variables from Forest Land and for land-use change to other categories as shown in Table 1.1 in Chapter 1.

4.2 Methodological issues

4.2.1 Forest Land remaining Forest Land (4.A1)

The basic approach to assess carbon emissions and removals from forest biomass follows the 2006 IPCC Guidelines where a stock-difference approach is suggested. The net change in carbon stocks for Forest Land remaining Forest Land is calculated as the difference in carbon contained in the forest between two points in time. Our approach combines activity data from land-use maps (see Chapter 3) and emission factors from National Forest Inventories (Figure 4.1). Carbon in the forest is derived from the growing stock volume, making use of other forest traits routinely determined in forest inventories. For the period of interest, i.e. 1990 and onwards, data from four National Forest Inventories were available for the Netherlands: the HOSP inventory (1988-1992), NFI-5 (2001-2005) NFI-6 (2012-2013) and the NFI-7 (2017-2021). With these four repeated inventories, changes in biomass and biomass carbon stocks were assessed for the periods 1990-2003, 2003-2012 and 2012-2021. The annual changes for the years between the inventories are determined using linear interpolation. Starting from the NFI-7 onwards the forest inventories are implemented as a continuous inventory with a 5-year cycle. This means that each permanent sample plot will be visited and measured once every five years, enabling an annual update of forest data and calculation of carbon stock changes from 2021 onwards.

National Forest Inventories

The HOSP (Hout Oogst Statistiek en Prognose oogstbaar hout) inventory was designed in 1984 and conducted between 1988 and 1992 and 1992-1997 (Schoonderwoerd and Daamen 1999). For the LULUCF calculations only the data from the time period 1988-1992 were used, as these best represent the situation in the base year 1990. The HOSP was not a full inventory and its methodology was also different from earlier and later forest inventories. It was primarily designed to get insight in the amount of harvestable wood, but it still provides valuable information on standing stocks and increment of forest biomass. In total 3448 plots were characterised by age, tree species, growing stock volume, increment, height, tree number and dead wood. Each plot represented a certain area of forest ('representative area') of between 0.4 ha and 728.3 ha. Together they represent an area of 310,736.3 ha, the estimated surface of forest where harvesting was relevant in 1988.

The fifth National Forest Inventory (NFI-5; also referred to as Meetnet Functie Vervulling Bos, MFV) was designed as a randomised continuous forest inventory. In total 3622 plot recordings with forest cover were available for the years 2001, 2002, 2004 and 2005 (2003 was not inventoried because of a contagious cattle disease). Apart from the live and dead wood characteristics, in 2004 and 2005 litter layer thickness was measured in stands on poor sand and loss (Daamen and Dirkse 2005).

The sixth National Forest Inventory (NFI-6; Zesde Nederlandse Bosinventarisatie, NBI-6) was conducted between September 2012 and September 2013 (Schelhaas *et al.* 2014). To facilitate the direct calculation of carbon stock changes between the NFI-5 and NFI-6, the methodology of the NFI-6 closely followed the methodology of the NFI-5 (see Schelhaas *et al.* 2014). Measurements were done on 3190 sample plots, of which 1235 were re-measurements of NFI-5 sample plots. During the Seventh National Forest Inventory (NFI-7; Zevende Nederlandse Bosinventarisatie, NBI-7) between June 2017 and July 2021 (Schelhaas et al. 2022b) all permanent sample plots from NFI-6 were remeasured, except plots that according the 2017 LULUCF map had changed to other land uses in the meantime or that were not accessible (in total 1387 remeasured plots). Additionally, 1787 new plots were established and measured, resulting in a total of 3174 measured plots. The new plots were installed as permanent sample plots and will be remeasured according the continuous 5-year NFI cycle. The measurements largely followed the sampling and measurement methodologies of the earlier inventories, and to guarantee consistent calculations of carbon stock changes over time at least also included the same relevant measurements for assessing carbon stocks as done in the previous NFI's.

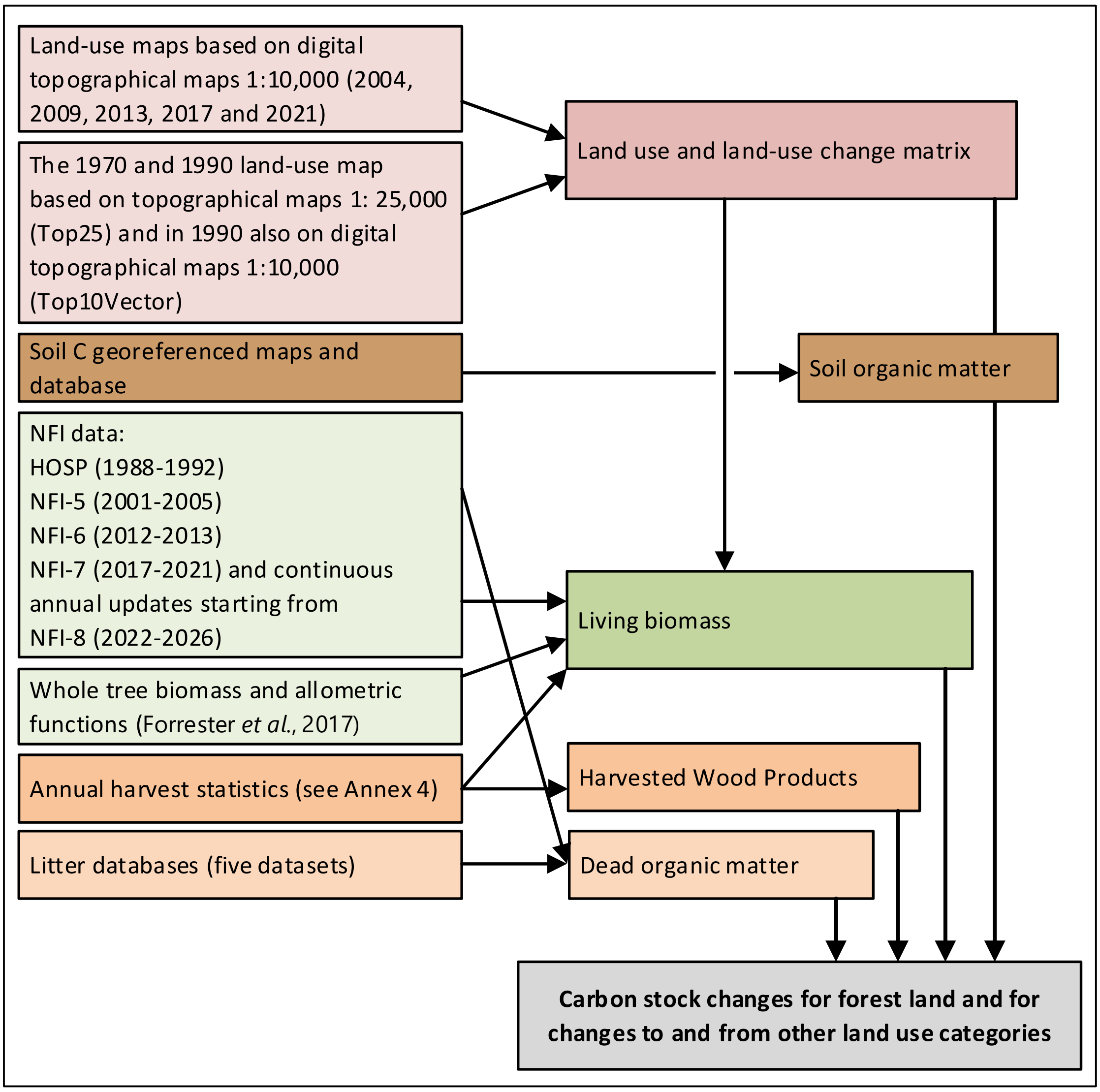

Figure 4.1 *Sources for the allocation of Forest Land and the calculations of carbon stock changes from Forest Land.*

EFISCEN extrapolation of forest information for 2022

Due to a delay in the start of the NFI-8, which is now a continuous forest inventory and was initially scheduled to provide updated information for 2022, the EFISCEN Space model (Schelhaas et al. 2022a) was used to project NFI forest information to 2022. The model projects the developments of the forests at plot level, in which the living biomass and dead wood pools are considered in relation to each other, depending on increment, mortality and harvesting functions elaborated from NFI data.

In a National Forest Inventory the whole of the forest is represented by a certain number of inventory plots. Each plot is considered to be representative for a specific forest area, typically in the range of 100–2000 ha, depending on the density of inventory plots. Similarly, in EFISCEN Space the future development of the forest is modelled through the development of the same set of inventory plots. The state of the forest at each of the inventory plots at a certain point in time is depicted as the number of trees per 25 mm diameter class, recorded as 20 individual species or species groups. Detailed information on the set-up, initialisation and validation of the EFISCEN Space model is provided in Schelhaas et al. (2022a).

Carbon stock changes in living biomass
All estimates of carbon stocks and carbon stock changes are derived from measurements done in the sequence of the Dutch National Forest Inventories. In the NFI sample plots both characteristics of the stand as a whole (main species, even-aged or uneven-aged, occurrence of natural disturbances, etc.), as of individual trees in a plot with a radius of 5-20 m are measured (see Schelhaas et al. 2022b). For each individual tree the diameter at breast height (dbh; i.e. a height of 1.30 m) is recorded, as well as the species and its status (alive, dead standing, dead lying). In addition, for each species present on the sample plot, for one tree the height is measured. Using specific volume models, for these tally trees the individual tree volume is estimated. Based on this set, direct conversion functions are developed to be able to estimate individual tree volume directly from the dbh. These functions are then applied to all trees on the plot to estimate the volume per ha.

Based on this information the biomass is estimated directly for each tree that is measured through the following calculation steps:

1. Using the species-specific wood density, based on IPCC default values, the stem volume is converted to stem biomass. The other biomass compartments (foliage, branches and roots) are estimated using the allometric equations that include only dbh as independent variable provided in a study by Forrester et al. (2017), which is based on an European-wide dataset of biomass observations. Total tree biomass is calculated as the sum of all compartments, and totals per ha are calculated from the individual biomasses and the plot size. For the HOSP dataset (1990; Annex A1.1 for details), individual tree observations are not available. A species-specific BCEF at the plot level was derived from the NFI-5 data (average year 2003), using the reported main species, and applied to the plot-level volume estimations for the HOSP.
2. Average growing stocks (m^3 ha^{-1}), average biomass conversion and expansion factors (BCEF) (tonnes biomass m^{-3}) and average root-to-shoot ratios are calculated (Table 4.1). These inventory specific BCEFs reflect the shifts in species composition seen over the years.
3. On the basis of the distribution of total biomass per hectare between coniferous and broadleaved trees, the relative share of coniferous and broadleaved forest is determined (Table 4.1).
4. The average growing stock, average BCEFs, average root-to-shoot ratios and shares of coniferous and broadleaved forests are linearly interpolated between the NFIs to estimate those parameters for the intermediate years.
5. Combining for each year average growing stock, the average BCEF and root-to-shoot ratios the average aboveground and belowground biomasses (tonnes dry matter ha^{-1}) are estimated for each year.
6. Using the relative share of coniferous and broadleaved forests and the differentiated carbon fractions (Table 4.3 of IPCC 2006b) of 0.51 tonnes C per tonne dry matter for conifers and 0.48 tonnes C per tonne dry matter for broad-leaved species, above- and belowground biomass are converted to carbon.
7. Losses from wood harvesting are already included in the differences in carbons stocks between the three forest inventories, HOSP, NFI-5 NFI-6 and NFI-7 (see below on approach to determine carbon stock losses and gains using harvest data). Hence the calculation steps above give the net carbon stock changes in an average forest plot in Dutch forests.

Table 4.1 *Per NFI inventory, its reference year, average Growing stock (GS; m^3 ha^{-1}), aboveground biomass (AGB; tonnes ha^{-1}), BCEF (tonne d.m. per m^3 stemwood volume), belowground biomass (BGB; tonnes ha^{-1}), root to shoot ratio (R), share of conifer biomass in the total forest biomass, mass (tonnes ha^{-1}) of standing deadwood (DWs) and lying deadwood (DWl). In the HOSP inventory all dead wood was recorded as one value without differentiating between standing and lying dead wood.*

NFI	Year	GS	AGB	BCEF	BGB	R	Share	DW Biomass	
							Conifers	DWs	DWl
HOSP	1990	158	112.7	0.713	24.3	0.22	0.51	0.84	
NFI-5	2003	199	143.2	0.721	30.6	0.21	0.50	1.35	1.49
NFI-6	2012	217	161.9	0.744	33.8	0.21	0.45	1.93	1.89
NFI-7	2021	229	176.6	0.773	36.3	0.21	0.41	2.99	2.66
EFISCEN Space	2022	230	178.1	0.772	37.4	0.21	0.43	3.05	2.70

Effects of wood harvests on biomass gains and losses

Information on annual volume of roundwood harvesting is only available at the national level and is based on a combination of information from the forest inventories and FAO harvest statistics (see Annex 3). Wood production is given as production roundwood in m^3 under bark. The total annual volume removed from the forest includes bark as well as losses that occur during harvesting. This volume removed is calculated from roundwood under bark harvest statistics as follows:

$$H_{NL} = H_{NLub} \cdot f_{\frac{ob}{ub}} \cdot f_{\frac{tw}{rw}}$$

With:

H_{NL}	Annually extracted total volume over bark from forests in NL (m^3 $year^{-1}$)
H_{NLub}	Annually extracted volume roundwood under bark from forests in NL (m^3 $year^{-1}$)
$f_{\frac{ob}{ub}}$	Conversion from under bark to over bark (1.136 m^3 over bark / m^3 under bark)
$f_{\frac{tw}{rw}}$	Conversion from roundwood to total wood (1.06 m^3 wood / m^3 roundwood $year^{-1}$)

For each year, the total volume of roundwood harvests (roundwood removals) is considered to be taken from Forest Land remaining Forest Land. This assumption is consistent with the way the total roundwood harvest is calculated, i.e. based on information on harvesting from permanent sample plots in the NFIs. The amount of wood harvested from deforestation is added to the reported harvest to get total harvest. The fraction of harvest from Forest Management from the total harvest is later used in the calculations for the Harvested Wood Products (see Section 10.2).

The differences in carbon stocks of the remaining forest biomass between the different NFIs (Figure 4.2) already includes the effect of wood harvesting. As a result the calculated carbon stock differences between the NFIs will provide the net carbon stock changes in living biomass. In the CRF both underlying gains and losses in carbon stocks in living biomass needs to be provided. Gains in carbon stocks are the result of the annual increment in biomass, while losses are the result of mortality and wood harvesting. For carbon stock gains the net effect of increment and mortality is provided by adding the carbon in the biomass of the harvested wood in that year (Figure 4.3) to the carbon stock changes in living biomass in that year as derived from the NFIs (Figure 4.4). At the same time this amount of harvested carbon was reported under carbon stock losses from living biomass. As a consequence, the net stock change is gradual (i.e. based on the carbon stock difference between NFIs), but the gains and losses are more erratic (i.e. following annual harvest statistics).

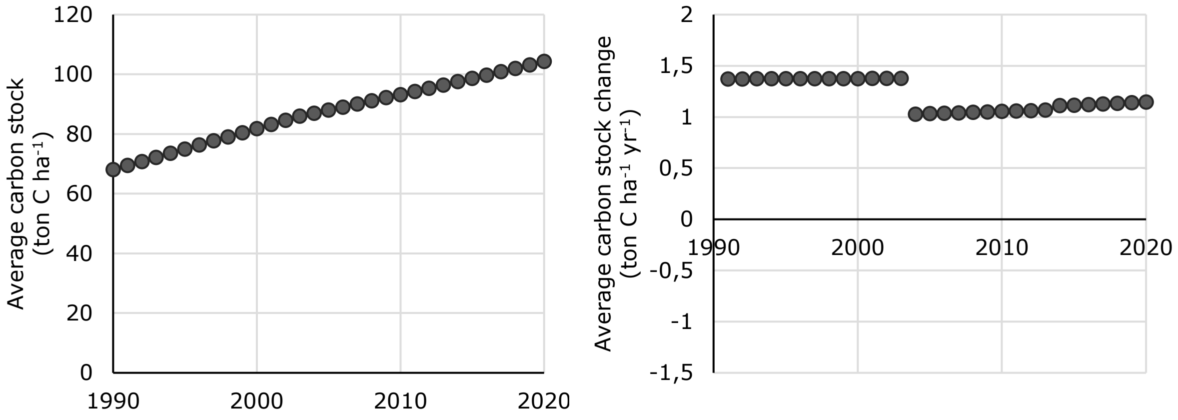

Figure 4.2 *Average carbon stocks and net carbon stock changes in biomass in forest land remaining forest land based on the stock differences in the NFI data.*

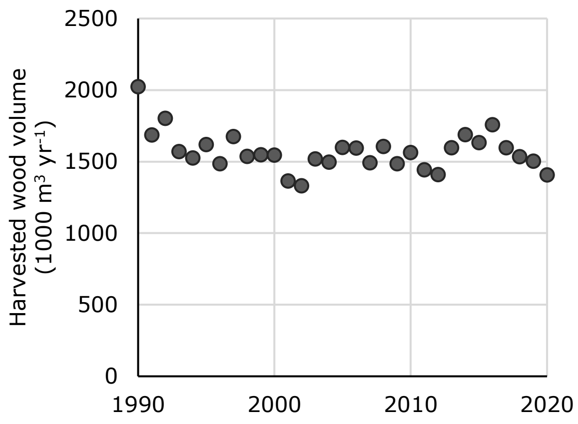

Figure 4.3 *Harvested roundwood volume (1000 m³ yr-1) since 1990. Projected years will be updated once new harvest statistics become available.*

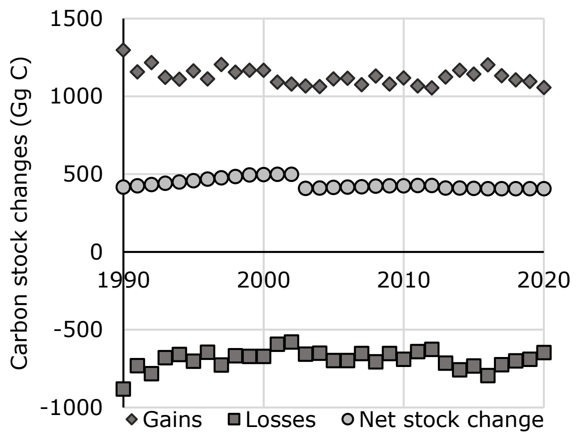

Figure 4.4 *Carbon stock gains and losses combining net carbon stock changes from the NFI data with the (stock change, cf. Figure 4.2) with the harvest statistics (Figure 4.3).*

Growth rates versus increase in growing stock

In several review reports the ERT referred to the apparent high growth rates of biomass in Dutch forests, indicating that it is among the highest in Annex I countries. This is considered a misinterpretation of the results. Although the increase in growing stock in Dutch forests indeed appears to be higher than in other countries, the volume growth rates are not. It is due to the overall very low harvest intensities in the Netherlands, with only about 55% of the increment being harvested (see Schelhaas et al. 2018), that the growing stock strongly increases over time.

Since the 1970s the purpose of forest management has changed from forests with a predominant wood production function to multifunctional forests that serve multiple purposes (e.g. nature conservation, recreation and wood production) (see Annex 4 for more details on Dutch forests and forest management). Moreover, forest policy in the Netherlands has been integrated into the nature policy over the past decades, which reflects the change towards multi-purpose forests in which more functions are combined. Subsidies (SNL) are an important source of income for forest owners. Forest owners covering in total 91% of the Dutch forest area receive a SNL subsidy (Schelhaas et al. 2022b). Of this subsidised forest area, 53% falls under the scheme for forests with production function, i.e. forest with explicitly integrated nature conservation and timber production objectives. Harvesting in these forests therefore is usually limited to thinnings and small group fellings (<0.5 ha).

In the other 47%, that is subsidised as natural forests, harvests are limited to 20% of the increment. These harvests are generally aimed at removing exotic species or improving forest structure. Forests with a production function usually integrate wood production with other functions like nature conservation and recreation.

In multifunctional forest, harvesting rates are on average 5.7 m^3 per ha per year, while in natural forests on average 2.9 m^3 is harvested per hectare per year (Schelhaas et al. 2018). The growing stocks on average increase annually by 2.0 m^3 per hectare in multifunctional forests to 2.9 m^3 per hectare for natural forests (Schelhaas et al. 2018).

Harvested Wood Products
The carbon stocks present in the wood harvested from Forest Land remaining Forest Land enter the Harvested Wood Products (HWP) carbon pool, which is a separate Category [4.G] and is explained in more detail in Chapter 10.

Carbon stock changes in dead wood
Dead wood volume was available from the three forest inventory datasets. The calculation of carbon stock changes in dead organic matter in forests follows the approach for calculation of carbon emissions from living biomass and is done for lying and standing dead wood (Table 4.2, above).

Carbon stock changes in litter
The carbon stock change in the litter layer was estimated using a stock difference method at national level. Data for litter layer thickness and carbon in litter were available from five different datasets (van den Burg 1999; de Vries and Leeters 2001, Schulp 2009 and unpublished data from Schulp and co-workers; Forest Classification database; NFI-5 litter inventory). The data from van den Burg (1999) were collected between 1950 and 1990 and were used only to estimate bulk density based on organic matter content. The data from de Vries and Leeters (2001) were collected in 1990 and their median was used until now as a generic national estimate. They also provide species specific values of (mostly) conifer species. However, they sampled sandy soils only. The Forest Classification dataset was designed to provide abiotic attributes for a forest classification in 1990, not to sample the mean litter in forests. However, it is the only database that has samples outside sandy areas. Schulp and co-workers intensively sampled selected forest stands in 2006 and 2007 on poor and rich sands with the explicit purpose to provide conversion factors or functions (Schulp 2009). They based their selection of species and soils on the NFI-5 forest inventory. During the last two years of the NFI-5 sampling (2004 and 2005) the litter layer thickness was measured for plots located on poor sands and loss (Daamen and Dirkse 2005). For 1440 plots values were filled, but only 960 (951 on sands) plots had any non-zero values. As it could not be made likely that all-zero value plots were really measured, only plots with at least one of the litter layers present were selected.

None of these datasets could be used exclusively. Therefore, a stepwise approach was used to estimate the national litter carbon stock and change therein in a consistent way.

First the datasets were compared for (if available) bulk density and carbon or organic matter content of litter separately as well as these combined into conversion factors or functions between litter thickness and carbon stock. Based on appropriate conversion factors, litter carbon stock was calculated for the Forest Classification database and the NFI-5 inventory. These were compared to each other and the available data from de Vries and Leeters (2001). From these, a hierarchy was developed to accord mean litter stock values to any of the sampled plots of the HOSP (1988-1992) and NFI-5 (2001-2005) inventories.

The followed hierarchy was:
1. For non-sandy soils the only source of information was the Forest Classification database. Though sampled around 1990, it was used for 1990 and 20003 alike. As such it is considered a conservative estimate for any changes occurring. The use of the same dataset in 1990 and 2004 means that changes in total litter stock on non-sandy soils only occur through changes in forest area and tree species composition. Peaty soils were kept outside the analysis.

2. For sandy soils with measured litter layer thickness (i.e. only from the NFI-5 in the years 2004 and 2005), regressions for rich and poor sands based on data from (Schulp 2009) were used to

convert them into litter carbon stock estimates. For sand rich in calcium (five plots) the regression equation of rich sand was used.

3. For sandy soils in the NFI-5 without measured litter layer thickness, but with all other information, a regression was developed from the 951 plots with measured litter layers to estimate the carbon stock from plot location and stand characteristics. However, as this estimate was completely based on data from the NFI-5 alone, we did not use it for the HOSP plots.

4. For sandy soils with missing data for the regression equation mentioned in point 3 of this hierarchy, or for the sandy soils in the HOSP inventory, the following procedure was used:
   a. For reasons of consistency with the non-sandy soils, if a mean estimate was available for the tree species from the Forest Classification database that was accorded to the plots.
   b. If no such estimate was available, the species specific estimate from the study of de Vries and Leeters (2001) was accorded. In this study, only median values were given and the mean value was taken as midway between the 5% and the 95% percentile.
   c. If no such estimate was available, the mean specific value for sandy soils from the Forest Classification database was accorded and considered to be a conservative estimate, i.e. underestimating rather than overestimating change. As the changes pointed to an increase of carbon in litter at the national level, an underestimate of change was considered to be conservative for the reporting of emissions. This value was always available.

5. For plots with missing soil information, the total area was summed and the total carbon litter stock in mineral soils was scaled up on an area basis.

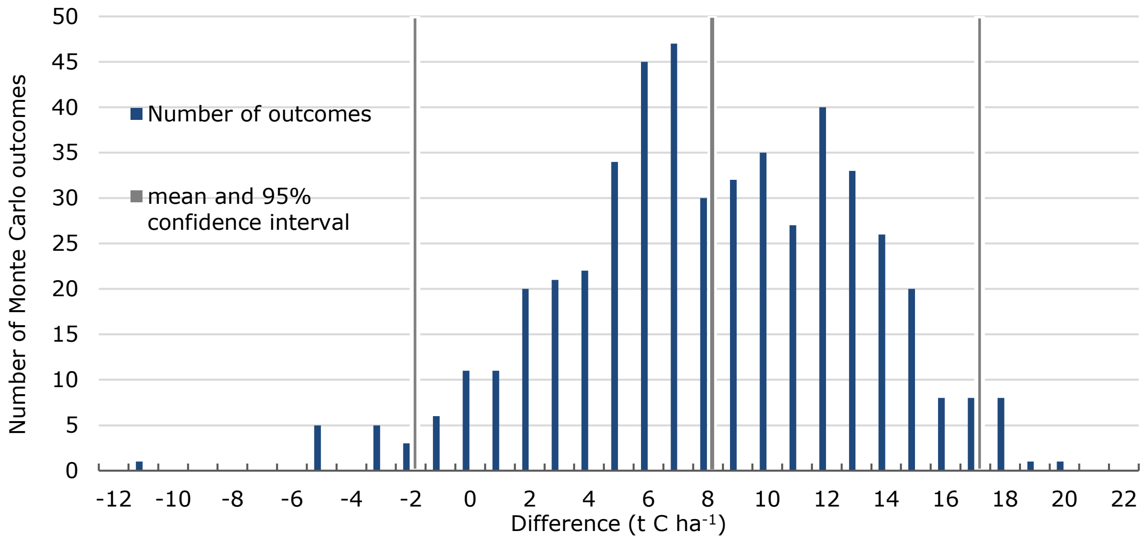

Figure 4.5 *Distribution of differences in carbon stock between HOSP and NFI-5 datasets based on a Monte Carlo analysis (positive values indicate a sink).*

The difference between 2003 (NFI-5 litter layer thickness measurements) and 1990 (Forest Classification database; de Vries and Leeters 2001) was estimated and a mean annual rate of carbon accumulation was calculated. To calculate the difference in carbon stocks between the two NFI's, a Monte Carlo uncertainty analysis was carried out with random litter carbon stocks taken from the distribution of stocks in plots measured in the HOSP and NFI-5, rather than comparing the mean values. The results of the Monte Carlo analysis consistently showed a carbon sink in litter; however the magnitude was very uncertain (Figure 4.5). Therefore, the more conservative estimate was used to set the accumulation of carbon in litter in Forest Land remaining Forest Land to zero. The uncertainty was attributed largely to the fact that no litter information was collected in the HOSP inventory which was used for 1990. Consequently under the KP accounting the litter carbon pool under Forest Management is considered to be not a source.

Nevertheless, 20 years after establishment, when Land converted to Forest Land transitions to Forest Land remaining Forest Land a litter layer will have formed. Therefore, these carbon stock gains that are a result of litter built up on units of Forest Land that newly enter the category Forest Land remaining Forest Land in the reporting year are reported under Forest Land remaining Forest Land. Hence, these reported carbon stock increases are not an effect of increasing carbon stocks in litter in Forest Land remaining Forest Land, which, as assessed above are an uncertain sink that is conservatively estimated to be zero.

Carbon stock changes in soils
See Chapter 11 for the calculation methods for carbon stock changes in soils for the different soil types.

4.2.2 Land converted to Forest Land (4.A2)

Carbon stock gains in living biomass
Piecewise regression analyses of the information on young forests from the National Forest Inventories show that it takes approximately 30 years before the forest biomass is similar to the biomass in the average forest reported as Forest Land remaining Forest Land in the Netherlands. Based on this insight, an approach was implemented in which below and above ground biomass in newly established forest areas are assumed to grow from zero just after establishment to the biomass in average forests after 30 years (Figure 4.6). After 20 years these newly established units of forest land will be reported under Forest Land remaining Forest Land, but carbon stock changes in biomass follow those of newly established forests until 30 years after conversion to forest land.

Conversions from the Grassland subcategory Trees outside Forest to Forest Land may occur if surrounding area is converted to forest, resulting in the areas previously reported under Trees outside Forest also meeting the minimum area requirement for Forest Land, i.e. more than 0.5 ha and more than 30 m width. Hence the change in category (from TOF to FL) on these units of land is not the result of changes on these units of land, but is the result of changes in surrounding units of land. In such cases the growth of the biomass is assumed to continue from the previous years.

Carbon stock losses
Carbon stock losses resulting from converting cropland or grassland to forest land are calculated as the complete loss of carbon stock in biomass associated with those land-use categories (see Chapters 5 and 6). Exception on this is the conversion from Trees outside Forest under Grassland. For such conversion no changes in carbon stock in biomass are assumed. In subsequent years the biomass in Trees outside Forest is assumed to follow the growth of biomass of Forest Land.

Carbon stock changes in dead wood and litter
Conversions of land towards Forest Land should yield an increase in both dead wood and litter, as no other land categories are assumed to have significant amounts of those carbon stocks. However, the current data do not permit an estimate of the amount of built-up in the first 20 years after conversion (see also van den Wyngaert et al. 2011b, justification for not reporting carbon stock change in dead wood and litter for land under Re/Afforestation). Therefore, it was considered the most conservative approach not to report carbon stock built-up in dead organic matter for lands converted to Forest Land. However, when Land converted to Forest Land transitions to Forest Land remaining Forest Land a litter layer will have formed. Therefore, under Forest Land remaining Forest Land, for each unit of land that transitions from Land converted to Forest Land to Forest Land remaining Forest Land the average carbon stock in litter will be included as a carbon stock gain.

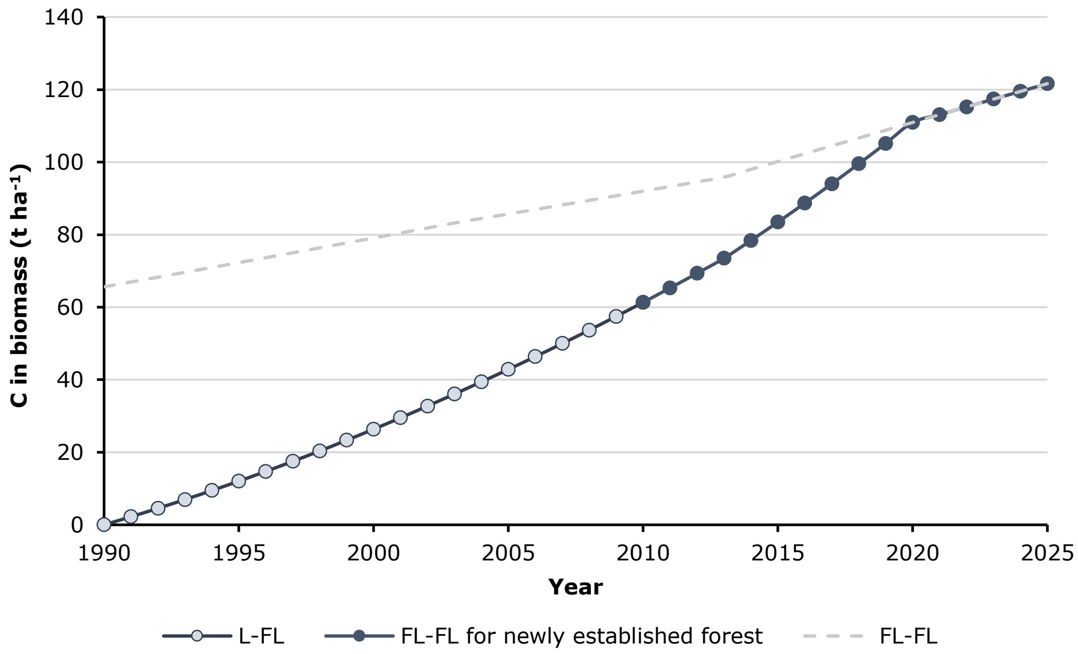

Figure 4.6 *Example of the development of carbon stocks (t ha^{-1}) on units of Forest Land newly established in 1990 (important: the graph follows the same 1 ha over time from 1990 to 2025). Within 30 years the carbon stock grows from 0 at the time of establishment (1990 in this example) to the average carbon stock of Forest Land remaining Forest Land (FL-FL). For the first 20 years after establishment these units of land are reported under Land converted to Forest Land (L-FL). After 20 years these units of land are reported under Forest Land remaining Forest Land (line FL-FL for newly established forest).*

4.2.3 Forest Land converted to other land-use classes

The total emissions from the tree component after Deforestation is calculated by multiplying the total area deforested with the average carbon stock in living biomass, above as well as below ground (Nabuurs *et al.*, 2005) and the average carbon stock in dead organic matter. Thus it is assumed that with Deforestation, all carbon stored in above and below ground biomass as well as in dead wood and litter is lost. National averages are used as there is no record of the spatial occurrence of specific forest types. An exception is conversion from Forest to Trees outside Forest under Grassland. Conversion from Forest to TOF may occur if connected surrounding units of Forest Land are converted to other land uses and the remaining area does not comply any longer to the forest definition. Such units of land are considered to remain with tree cover but losses of carbon in dead wood and litter will occur (see also Chapter 6).

Carbon stock changes in living biomass
The carbon stock losses in living biomass as a result of deforestation are determined based on the accumulated carbon in living biomass until the year of deforestation as calculated according the methodology for living biomass provided in Section 4.2.1 or Section 4.2.2.

Carbon stock changes in dead wood and litter
When Forest Land is converted to other land-use categories it is assumed that dead wood and litter are removed within one year of conversion. The average carbon stock in dead organic matter is the sum of two pools: dead wood and the litter layer (L+F+H).

- The average carbon in dead wood lost when deforestation of Forest Land remaining Forest Land occurs is based on the accumulated carbon in dead wood until the year of deforestation as calculated according the methodology for dead wood in Section 4.2.1. For deforestation of forest in the Land converted Forest Land category no loss of carbon in dead wood is assumed because no carbon was assumed to be accumulated yet (see Section 4.2.2).

- The average carbon in litter is based on a national estimate using best available data for the Netherlands as described in Section 4.2.1. Emission factors for litter between 1990 and 2013 are based on the calculated litter values based on the HOSP (1990) NFI-5 (2003) and NFI-6 (2013) using the approach described in Section 4.2.1. From 2013 onwards, the changes in carbon stocks from litter are linearly extrapolated from the changes in the years before.

The assessment of the carbon stocks and changes thereof in litter in Dutch forests have been based on extensive datasets on litter thickness and carbon content in litter (Section 4.2.1). On land subject to deforestation, the reported carbon stock changes per ha for the litter pool are much higher than those reported by other Parties. However, as a result of a characteristic combination of geomorphological and climate conditions, a large share of the forest area in the Netherlands is on poor Pleistocene soils that are characterised by a relatively thick litter layer, which explains the differences with other countries. Additional information on geomorphological aspects is provided in de Waal et al. (2012) and Schulp *et al.* (2008).

Carbon stock changes in soils

See Chapter 11 for the calculation methods for carbon stock changes in soils for the different soil types.

5 Cropland [4.B]

5.1 Description

The definition for the land-use category Cropland is provided in Section 2.3. Within the category 4B, Cropland, two subcategories are distinguished:

1. *4.B1 Cropland remaining Cropland*
   In annual cropland over time no net accumulation of biomass carbon stocks will occur. In a single year the increase in biomass stocks is assumed to be equal to the biomass losses from harvest and mortality in the same year (IPCC 2006b). The IPCC 2006 guidelines therefore indicate that change in biomass is only estimated for woody perennial crops. Because cropland in the Netherlands mainly consists of annual cropland, carbon stock changes in living biomass are not estimated for Cropland remaining Cropland. Net carbon stock changes in managed mineral soils under Cropland remaining Cropland are calculated based on the Tier 3 approach provided in Section 11.2.

   Emissions from lowering the groundwater table in organic soils under Cropland, however, are explicitly calculated for areas of Cropland remaining Cropland using the Tier 2 approach provided in Section 11.3.

2. *4.B2 Land converted to Cropland*
   Emissions of CO_2 from carbon stock changes in living biomass for Land converted to Cropland is calculated using a Tier 1 approach (see Section 5.2 below). This value is also used for determining emissions for Cropland converted to other land-use categories (4.A2, 4.C2-4.F2). Net carbon stock changes in both mineral and organic soils for land-use changes involving Cropland are calculated based on the Tier 2 approaches provided in Chapter 11.

5.2 Methodological issues

Carbon stock changes in biomass
Carbon stock changes due to changes in biomass in land-use conversions to and from Croplands were calculated based on Tier 1 default carbon stocks (Table 5.1) for total biomass. For the root-to-shoot ratio, no T1 value is available in the 2006 IPCC guidelines. For cropland we assumed this ratio to be 1. Annual land-use change rates were multiplied with the negative carbon stocks to calculate the loss in case of Croplands converted to other land-use categories. Annual land-use change rates were multiplied with the positive carbon stocks to calculate the gains in case of lands converted to Croplands.

Table 5.1 *Tier 1 carbon stocks for annual croplands used to calculate carbon stock changes due to changes in biomass associated with land-use conversions.*

Land use	C stock in biomass	Error	Reference
Croplands	5 tonnes C ha^{-1}	75%	2006 IPCC Guidelines, table 5.9 (IPCC 2006b), value for land converted to annual croplands.

Additional methodology to calculate carbon stock changes in biomass for Forest Land converted to Cropland is provided in Section 4.2.3.

Carbon stock changes in soils
See Chapter 11 for the calculation methods for carbon stock changes in soils for the different soil types.

6 Grassland [4.C]

6.1 Description

The definition for the land-use category Grassland is provided in Section 2.4. Within the category 4C, Grassland, two main categories are distinguished, 4.C1 Grassland remaining Grassland and 4.C2 Land converted to Grassland. In each main category Grassland is subdivided in Grasslands (non-TOF) and Trees outside Forest (TOF) (see Section 2.4).

6.1.1 4.C1 Grassland remaining Grassland

Grassland (non-TOF)
This category is further differentiated in (also see Section 2.4):
- 'Grassland vegetation', i.e. all areas predominantly covered by grass vegetation (whether natural, recreational or cultivated).
- 'Nature', i.e. all natural areas excluding grassland (natural grasslands and grasslands used for recreation purposes). Depending on the year, nature areas cover about 3-5% of the total Grassland area.
- Orchards of mainly fruit trees, which in the Netherlands predominantly have an undergrowth of grass.

The annual production of biomass in grassland vegetation can be large, but due to rapid turnover changes of standing biomass will be limited in permanent grasslands (IPCC 2006b). For carbon stock changes in living biomass in grassland vegetation and nature remaining in those categories a Tier 1 method is applied, assuming there is no change in carbon stocks (IPCC 2006b). Also for changes between grassland vegetation and nature which is also reported under Grassland (non-TOF) remaining Grassland (non-TOF) (see Section 2.4), no changes in carbon stocks in biomass are considered.

In fruit orchards an increase in carbon stocks can be expected with ageing of the trees. Carbon stocks in living biomass in orchards are based on an average age of trees in orchards and a Tier 1 biomass accumulation rate of 2.1 tonne C ha^{-1} yr^{-1}. This estimate is based on statistics providing the areas of apple and pear orchards in age classes (0-5, 5-10, 10-15, 15-25 and >25 years) in the Netherlands for 1997, 2002, 2007, 2012 and 2017[7]. Average age is based on the area corrected age distribution assuming that age class midpoint is representative for the age class and for >25 years 30 years was used. The average age of fruit orchards changed over time from 10.4 years in 1997 to 13 years in 2017. Between the measurement years the age developments were interpolated and before and after linearly extrapolated based on the two adjacent measured ages. Subsequently, the average ages of fruit orchard trees are multiplied by the Tier 1 biomass accumulation of 2.1 tonnes ha^{-1} yr^{-1} to calculate the average carbon stock in orchard biomass.

Net carbon stock changes in mineral soils under grasslands that are in agricultural use are calculated based on the Tier 3 approach provided in Section 11.2. For mineral soils under other grassland vegetation, nature and fruit orchards no carbon stock changes in mineral soils are expected as these usually are left largely undisturbed. However, since transitions between 'nature' and grassland vegetation are treated as Grassland (non-TOF) remaining Grassland (non-TOF) and land is always reported under its last known transition (see Section 2.4), a unit of land that is converted from another land use to 'nature' (or grassland vegetation) and subsequently to grassland vegetation (or nature) will therefore be reported first under land converted to Grassland (non-TOF) until its conversion to grassland vegetation, and as Grassland (non-TOF) remaining Grassland (non-TOF) thereafter. However, the soil carbon stock is still in its transition phase, causing a change in the

[7] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81735NED/table?ts=1517993072950

mineral soil carbon stock in the Grassland (non-TOF) remaining Grassland (non-TOF) category even if soil carbon under grassland is assumed to be stable.

No spatially explicit distinction is made between agricultural intensively and extensively managed Grasslands. Nevertheless, emissions from lowering the groundwater table in organic soils under Grassland vegetation and orchards are calculated under Grassland (non-TOF) remaining Grassland (non-TOF) (see Section 11.3). In the organic soil area under nature lowering of the groundwater table is not common and therefore such emissions from organic soils are considered negligible.

Trees outside Forest
For Trees outside Forest, no specific data on growth or increment are available. It is assumed that Trees outside Forest grow with the same growth rate as Forests. The only difference between them is the size of the stand (< 0.5 ha for Trees outside Forest), so this seems a reasonable assumption. It is assumed that no building up of dead wood or litter occurs. It is also assumed that no harvesting takes place. Even if this assumption would not completely be met, the error would be negligible, as the harvested wood would be counted in the national harvest statistics and therefore would be counted under Forests land.

Conversions between Grassland (non-TOF) and Trees outside Forest
Whereas conversions between Grassland (non-TOF) and Trees outside Forest are reported under Grassland remaining Grassland, the two subcategories in the calculations are considered as separate categories.

Conversions from Grassland (non-TOF) to TOF will result in the loss of the Grassland (non-TOF) biomass in the year of conversion and subsequent growth of biomass in TOF. The conversion from TOF to Grassland (non-TOF) will involve the loss of the carbon stocks in biomass from TOF and increase in carbon stocks from Grassland (non-TOF), similar to conversions from other land-use categories (see Section 6.1.2 below).

6.1.2 4.C2 Land converted to Grassland

Grassland (non-TOF)
Emissions of CO_2 from carbon stock changes in living biomass for Land converted to Grassland is calculated using a Tier 1 approach (see Section 6.2 below). Carbon stocks in Grassland (non-TOF) depend on carbon stocks per unit of area of grassland vegetation, nature and orchards and the relative contribution of these categories to the Grassland (non-TOF) area. This value is also used for determining emissions for Grassland converted to other land-use categories (4.A2, 4.B2, 4.D2-4.F2). Net carbon stock changes in both mineral and organic soils for land-use changes involving Grassland (non-TOF) are calculated based on the methodology provided in Chapter 11.

Trees outside Forest
For land-use conversion to Trees outside Forest the same biomass increase and associated changes in carbon stocks is assumed as for land converted to Forest Land. Similarly to Forest Land, no dead wood nor litter layer built up is assumed (see Section 4.2.2). Conversion from Forest to TOF may occur if connected surrounding units of Forest Land are converted to other land uses and the remaining area does not comply any longer to the forest definition. Such units of land are considered to remain with tree cover but losses of carbon in dead wood and litter will occur. Net carbon stock changes in both mineral and organic soils for land-use changes involving Trees outside Forest are calculated based on the methodology provided in Chapter 11 for which Trees outside Forest are treated similar as Forest Land.

6.2 Methodological issues

Carbon stock changes in biomass for Grassland (non-TOF)

Carbon stock change due to changes in biomass in land-use conversions to and from Grasslands (non-TOF) are calculated based on Tier 1 default carbon stocks. For the whole Grasslands (non-TOF), including grassland vegetation, nature and orchards an average carbon stock per unit of land is assessed based on the carbon stocks per unit area (see below) for grassland vegetation, nature and orchards weighted for their relative area contribution to the Grassland (non-TOF) category. As a result the average carbon stocks for Grassland (non-TOF) will vary over time as a result of varying relative contributions of the different vegetation types to the total Grassland (non-TOF) area. Below the average carbon stocks per Grassland (non-TOF) vegetation type are provided. The yearly updated areas for the different types and resulting average carbon stocks for Grassland (non-TOF) are provided in the NIR.

To assess the carbon stock changes resulting from conversions to and from Grassland (non-TOF), the annual land-use change rates are multiplied with the negative carbon stocks to calculate the loss in case of Grasslands (non-TOF) converted to other land-use categories. Annual land-use change rates were multiplied with the positive carbon stocks to calculate the gains in case of lands converted to Grasslands (non-TOF).

Grassland vegetation and nature

For grassland vegetation and nature the same Tier 1 default carbon stocks (Table 6.1) for total biomass are applied. These are combined with default root-to-shoot ratios (Table 6.2) to allocate total carbon stock to above- and belowground compartments.

Table 6.1 *Tier 1 carbon stocks for Grassland used to calculate carbon stock changes due to changes in biomass associated with land-use conversions.*

Land use	C stock in biomass	Error	Reference
Grassland	13.6 tonnes dry matter ha^{-1} (~ 6.4 tonnes C ha^{-1})	75%	2006 IPCC Guidelines Table 6.4 (value for cold temperate-wet) and the generic T1 value for the CF for biomass of 0.47 tonnes C per tonne dry matter

Table 6.2 *Tier 1 Root-to-Shoot values Grassland used to calculate carbon stock changes due to changes in biomass associated with land-use conversions.*

Land use	R:S ratio	Error	Reference
Grassland	4.0	150%	2006 IPCC Guidelines Table 6.1 (value for cold temperate – wet grassland)

Orchards

Carbon stocks in biomass in orchards were based on the average age of trees in orchards from Statistics Netherlands (information for 1997, 2002, 2007 and 2012) and a Tier 1 biomass accumulation rate of 2.1 tonne C ha^{-1} yr^{-1} (IPCC 2003).

Carbon stock changes in soils

See Chapter 11 for the calculation methods for carbon stock changes in soils for the different soil types.

7 Wetlands [4.D]

7.1 Description

The definition for the land-use category Wetlands is provided in Section 2.4.1. Only reed marshes and open water bodies are included in the Wetlands land-use category. Other wetlands and peatland areas covered by grasses or shrubby vegetation or forested wetlands are reported under the categories Grassland or Forest Land. Within the category 4D, Wetlands, two subcategories are distinguished:

1. *4.D1 Wetlands remaining Wetlands*
   Because the Wetlands category mainly includes open water and flooded land no carbon stock changes in living biomass, dead organic matter and soil are considered for Wetlands remaining Wetlands, which is also in line with the guidance for Flooded land in the 2006 IPCC Guidelines. All Wetlands in the Netherlands are reported under 4.D1.3 Other Wetlands remaining other Wetlands. Within this category a differentiation is made for reed swamps and open water.

2. *4.D2 Land converted to Wetlands*
   Carbons stocks in living biomass and dead organic matter for flooded land and open water are considered to be zero. For conversion from other land uses to Wetlands, the Netherlands applies a stock difference method assuming that all the carbon in biomass and organic matter that existed before conversion is emitted (IPCC 2006b).

7.2 Methodological issues

Carbon stock changes in biomass
Methodology to calculate carbon stock changes in biomass for Forest Land converted to Wetlands is provided in Section 4.2.3. Sections 5.2 (Cropland) and 6.2 (Grassland) provide the methodology to calculate carbon stock changes in biomass for conversions from Cropland and Grassland to Wetlands. Land-use conversions from Settlements or Other Land to Wetlands will not result in differences in carbon stocks.

Carbon stock changes in soils
See Chapter 11 for the calculation methods for carbon stock changes in soils for the different soil types for land-use conversions to Wetlands.

8 Settlements [4.E]

8.1 Description

The definition for the land-use category Settlements is provided in Section 2.5. In the Netherlands Settlements are urban areas and transportation infrastructure, as well as built-up areas. Within the category 4.E, Settlements, two subcategories are distinguished:

1. *4.E1 Settlements remaining Settlements*
   Although Settlements also include areas with grass and trees, biomass gains and losses are expected to be in balance. Moreover, land within urban areas that meets the criteria for Forest Land or Grassland will be reported under those land-use categories and is not reported under Settlements. Since no additional data are available on carbon stocks in biomass and dead organic matter in Settlements, the Netherlands applies the Tier 1 method, assuming no change in carbon stocks in biomass in Settlements remaining Settlements. Similarly it is assumed that no carbon stock changes occur in mineral soils under Settlements remaining Settlements.

   Emissions from lowering the groundwater table in organic soils under Settlements are explicitly calculated for areas of Settlements remaining Settlements (see Section 11.2.1).

2. *4.E2 Land converted to Settlements*
   Because no information is available on carbon stocks in biomass in the land-use category Settlements, this is conservatively estimated at zero. For conversion from other land uses to Settlements, the Netherlands applies a stock difference method assuming that all the carbon in living biomass and organic matter that existed before conversion is emitted at once.

8.2 Methodological issues

Carbon stock changes in biomass
Methodology to calculate carbon stock changes in biomass for Forest Land converted to Settlements is provided in Section 4.2.3. Sections 5.2 (Cropland) and 6.2 (Grassland) provide the methodology to calculate carbon stock changes in biomass for conversions from Cropland and Grassland to Settlement. Land-use conversions from Wetlands or Other Land to Settlements will result in no differences in carbon stocks.

Carbon stock changes in soils
See Chapter 11 for the calculation methods for carbon stock changes in soils for the different soil types for land-use conversions to Settlements.

9 Other Land [4.F]

9.1 Description

The definition for the land-use category Other Land is provided in Section 2.6. Within the category 4.F, Other Land, two subcategories are distinguished:

1. *4.F1 Other Land remaining Settlement*

2. *4.F2 Land converted to Other Land*

The land-use category 'Other Land' was included to allow the total of identified land to match the national area, where data are available. It includes bare soil, rock, ice and all unmanaged land areas that do not fall into any of the other five categories. (IPCC 2006b).

In general, Other Land does not have a substantial amount of carbon. The Netherlands uses this land-use category to report the surfaces of bare soils that are not included in any other category.

The land cover category 'Sand' is completely included in this category. It includes all terrains that do not have vegetation growing on them by nature. The last part of the phrase, 'by nature', is used to distinguish this class from Settlements and fallow Croplands. 'Sand' includes e.g. beaches and coastal dunes with little or no vegetation. It also includes inland dunes where the vegetation has been removed to create spaces for early succession species (and which are being kept open by the wind). Bare inland sand dunes were developed in the Netherlands as a result of heavy overgrazing and were combated (for a long time) by planting forests. These areas were, however, the habitat of certain species which have become extremely rare nowadays. Inland sand dunes can be created as vegetation and top soil is again removed as a conservation measure in certain nature areas.

It does not include bare areas that emerge from shrinking and expanding water surfaces (these 'emerging surfaces' are included in Wetlands).

9.2 Methodological issues

See Chapter 11 for the calculation method for the different soil types.

10 Harvested Wood Products [4.G]

10.1 Description

The Netherlands estimates changes in the Harvested Wood Products (HWP) pools based on the methodological guidance as suggested in the 2013 IPCC KP guidance (IPCC 2014a). This approach was initially chosen for greater transparency in comparison with the reporting under the Kyoto Protocol. Although the reporting under the Kyoto Protocol is finished, the methodology was kept the same. Following footnote 12 in the Convention CRF Table 4.G s1 this approach can be included in UNFCCC reporting and is considered to be conform Approach B for HWP reporting.

10.2 Methodological issues

The approach taken to calculate the HWP pools and fluxes follows the guidance in Section 2.8 of the 2013 IPCC KP guidance. Carbon from harvests allocated to Deforestation is reported using instantaneous oxidation (Tier 1) as the method for calculations. The fraction of harvest from Deforestation is based on the land-use change calculations under Forest Land (Chapter 4). The remainder of the harvests is allocated to Forest Land remaining Forest Land and subsequently is added to the respective HWP pools. As no country specific methodologies or half-life constants exist, the calculations for the HWP-pools follows the Tier-2 approach outlined in the 2013 IPCC KP guidance by applying equations 2.8.1 to 2.8.6.

Four categories of HWP are taken into account: sawn wood, wood-based panels, other industrial roundwood, and paper and paperboard. Domestically produced fuel wood is accounted using instantaneous oxidation and therefore does not contribute to the carbon stock changes reported in the HWP pool. Emissions from harvested wood products in solid waste deposit sites (SWDS) are not separately accounted.

The distribution of material inflow in the different HWP pools is based on the data reported from 1961 onwards to FAO-stat as import, production and export for the different wood product categories, including those for industrial roundwood and wood pulp as a whole (equations 2.8.1 – 2.8.4. in the 2013 IPCC KP guidance). Equation 2.8.4 from 2013 IPCC KP guidance is used to obtain the annual fractions of HWP from domestic harvests and to exclude imported HWP.

The statistics on production, import and export of industrial roundwood in 1990 appeared to be not correct in the FAO forestry statistics database. The data for the base year 1990 are adjusted on the basis of the statistics reported by PROBOS, the Dutch national correspondent to the Joint forest sector questionnaire (JFSQ), reporting national forestry statistics to FAO and other international organisations (Table 10.1). Since 2020 the updated data on production, import and export of industrial roundwood for the next reporting year are taken directly from the national publication of the JFSQ data by PROBOS (https://www.bosenhoutcijfers.nl/). In case the final data for the reporting year are not yet published, PROBOS will provide preliminary estimates which then are updated in the following submission.

To assess carbon amounts in the different HWP categories, the default carbon conversion factors for the aggregated HWP categories sawn wood, wood-based panels, and paper and paperboard were used from tables 2.8.1 and 2.8.2 of the 2013 IPCC KP guidance (see Table 10.2). For the category other industrial roundwood, the values for sawn wood were used. This category includes a variety of roundwood use, like the use of whole stems as piles in building fundaments, and in road and waterworks, and their use as fences and poles. These are considered applications with a long to very long life-time for which the 35 years half-life is considered appropriate.

Table 10.1 *Updated quantities of produced, exported and imported industrial roundwood (in m³) in the Netherlands in 1990 for which the FAO stat data are incorrect.*

Industrial roundwood in 1990	Quantity according FAO-stat (m^3)	Quantity according PROBOS (m^3)
Production	1,275,000	1,115,000
Export	142,377	480,559
Import	119,567	752,972

Table 10.2 *Tier 1 default carbon conversion factors and half-lives factors for the HWP categories as provided by the IPCC KP Guidance (IPCC 2014a).*

HWP category	C conversion factor (Mg C per m^3 air dry volume)	Half-lives (years)
Sawn wood	0.229	35
Wood based panels	0.269	25
Other	0.229	35
Paper and paperboard	0.386	2

The dynamics of the HWP pools is then calculated by applying equations 2.8.5 and 2.8.6 and the half-life constants reported in table 2.8.2 of the 2013 IPCC KP guidance (see Table 10.2).

11 Carbon stock changes in mineral and organic soils

11.1 Introduction

The Netherlands developed a Tier 2 approach for calculating carbon stock changes in mineral soils. The approach is based on the overlay of the land-use maps with the Dutch soil map, combined with soil carbon stocks that were quantified for each land-use soil type combination (see Section 11.2.1). Fluxes resulting from cropland and grassland management of mineral soils are calculated for Cropland remaining Cropland and Grassland remaining Grassland with a Tier 3 approach using the soil carbon model RothC (see Section 11.2.2). Emissions resulting from drainage of organic soils are calculated using a Tier 2 approach. This procedure is based on an overlay of a map with water level regimes and the soil map indicating the area with peat and peaty soils, combined with assumptions typically valid for agricultural peat and peaty soils in the Netherlands (see Section 11.3). The methodologies for assessing carbon stock changes in mineral and organic soil are based on spatially explicit input data.

11.2 Mineral soils

11.2.1 Carbon stock changes due to land use change

The methodology for carbon stock changes in mineral soils is based on Lesschen *et al.* (2012), who made a new soil carbon stock map for the Netherlands based on data derived from the LSK, a national sample survey of soil map units (Finke et al. 2001; Visschers et al. 2007). The LSK database contains quantified soil properties, including soil organic matter, for about 1400 locations at five different depths. Based on these samples soil carbon stocks for the upper 30 cm were determined (De Groot *et al.*, 2005 de Groot et al. 2005). The LSK was stratified to groundwater classes and soil type. However, land use was not included as separate variable.

Lesschen *et al.* (2012) used the base data from the LSK survey, but classified them differently into new soil – land-use combinations. For each of the LSK sample locations the land use at the time of sampling was known. The soil types for each of the sample points were reclassified to 11 main soil types used in the soil mapping that was carried out over the period 1960-1995 (de Vries et al. 2003) (Table 11.1 and Figure 11.1, also see Chapter 3.5). These represent the main variation in soil carbon stocks within the Netherlands. The number of observations for each soil type is still sufficient to calculate representative average soil carbon stocks for the main land uses. In Figure 11.2 the calculated average carbon stocks for Grassland (non-TOF), Cropland and Forest are shown.

Table 11.1 *Main soil types in the Netherlands and number of observations in the LSK database. Peat and peaty soils are organic soils.*

Soil Type	Soil type Dutch name	Area (km^2)	No. Observation
Brick soil	Brikgrond	272	32
Earth soil	Eerdgrond	2084	58
Old clay soil	Oude kleigrond	387	19
Loamy soil	Leemgrond	258	26
Sandy soil without lime	Kalkloze zandgrond	3793	249
Peaty soil	Moerige grond	1914	61
Podzol soil	Podzolgrond	7393	246
River clay soil	Rivierkleigrond	2652	111
Peat soil	Veengrond	3369	208

Soil Type	Soil type Dutch name	Area (km²)	No. Observation
Marine clay soil	Zeekleigrond	7751	299
Sandy soil with lime	Kalkhoudende zandgrond	958	75

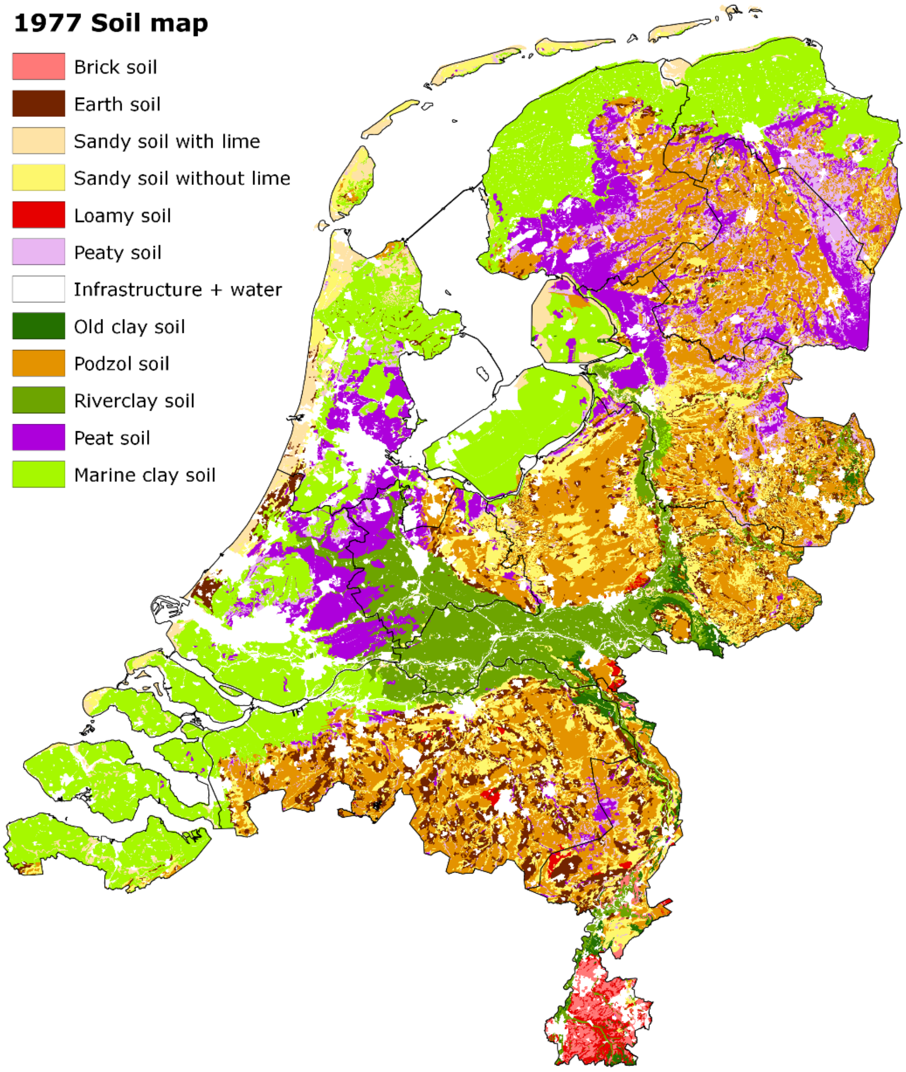

Figure 11.1 *Distribution of the main soil types in the Netherlands (Lesschen et al., 2012).*

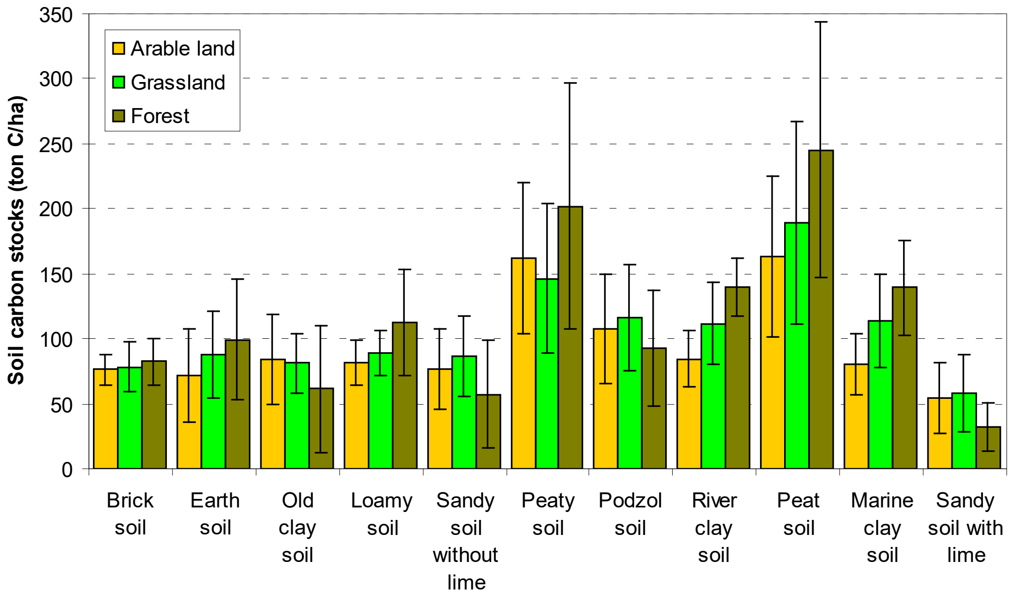

Figure 11.2 *Average soil carbon stocks per land use soil type combination. The error bars indicate the standard deviation (Lesschen et al., 2012). Grassland refers to the Grassland (non-TOF) subcategory. For soil Trees outside Forest are treated similar to Forest.*

The LSK data set only contains data on soil carbon stocks for the land uses Grassland (non-TOF), Cropland and Forest. For the other land-use categories (i.e. Settlements, Wetlands and Other Land) no data about soil carbon is available in the LSK database or other studies. Therefore, estimates had to be made. Especially for settlements it is important to estimate carbon stocks, since conversion to settlements is one of the main land-use changes. In the IPCC 2006 guidelines some guidance is provided for soil carbon stocks for land converted to settlement, see the text box below. Considering the high resolution of the land-use change maps in the Netherlands (25 x 25 m grid cells) it can be assumed that in reality a large portion of that grid cell is indeed paved. Using the following assumptions an average soil carbon stock under Settlements that is 0.9 times the carbon stock of the previous land use is assumed:

- 50% of the area classified as Settlements is paved and has a soil carbon stock of 0.8 times the corresponding carbon stock of the previous land use (IPCC default value)
- The remainder 50% consists mainly of grassland and wooded land for which the reference soil carbon stock is assumed (IPCC default value of 1 for all three stock change factors).

For Wetlands the same soil carbon stock as Forest Land is assumed for the different soil types. For Other Land a soil carbon stock of zero is assumed for all soil types, as other land comprises dunes and drift sands, which hardly contain any soil carbon.

2006 IPCC guidelines
The 2006 IPCC guidelines (IPCC 2006b) state the following for land converted to Settlements for the soil carbon pool. Default stock change factors for land use after conversion (Settlements) are not needed for the Tier 1 method for Settlements Remaining Settlements because the default assumption is that inputs equal outputs and therefore no net change in soil carbon stocks occur once the settlement is established. Conversions, however, may entail net changes and it is good practice to use the following assumptions: 1. for the proportion of the Settlements area that is paved over, assume product of F_{LU}, F_{MG} and F_I is 0.8 times the corresponding product for the previous land use (i.e., 20% of the soil carbon relative to the previous land use will be lost as a result of disturbance, removal or relocation); 2. for the proportion of the Settlements area that is turfgrass, use the appropriate values for improved grassland from Table 6.2, Chapter 6; 3. for the proportion of the Settlements area that is cultivated soil (e.g., used for horticulture) use the no-till FMG values from Table 5.5 (Chapter 5) with F_I equal to 1; and 4. for the proportion of the Settlements area that is wooded assume all stock change factors equal 1.

The difference between land-use classes, divided by 20 years (IPCC default) is the estimated annual C flux associated with land-use changes. Thus, land-use change of cropland to forest for example has the same annual C flux per hectare as land-use change from forest to cropland, but with an opposite sign:

$$E_{\min} = \frac{C_{t=20} - C_{t=0}}{t} * A_{\min\_x,t=20} \quad (11.1)$$

in which:

$C_{t=20}$	the final carbon stock after 20 years
$C_{t=0}$	the initial carbon stock 20 years ago
t =	20 years
$A_{min\_x\_t=20}$	the area of mineral soil with land use x after 20 years

Considering a 20 years transition period for carbon stock changes in mineral soils means that land-use changes in 1970 will still have a small effect on carbon stock changes in mineral soils in 1990. Therefore also a 1970 land use map has been created to be able to account for the changes in land use before 1990, which can still affect mineral soil carbon stocks after 1990.

11.2.2 Carbon stock changes due to cropland and grassland management

To calculate the carbon fluxes from mineral soils for Cropland remaining Cropland and Grassland remaining Grassland a Tier 3 approach is implemented using the soil carbon model RothC. This approach accounts for soil management practices that are taken to enhance carbon sequestration.

A consistent time series of input data was created for the period 2005–2021. The year 2005 was chosen as this is aligned with the start of the reference period for managed cropland and managed grassland accounting under the EU LULUCF Regulation (EU 2018/841). Besides, no detailed data was available for the period before 2005. Additional research will be done into methods to extend the model simulations for the time period 1990–2004.

RothC model
The RothC model is a dynamic model for the conversion of organic carbon in mineral soils. The model uses monthly intervals to calculate changes in the organic carbon stock on a timescale from one year to several centuries. The model is widely used internationally and described in many scientific publications. The calculation rules, as described in Coleman and Jenkinson (2014), version 26.3 of the RothC model, were included in the MITERRA-NL model to assess carbon stock changes at national scale, as described by Lesschen et al. (2021).

In the RothC model, the carbon is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments/pools are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). Each of these compartments has its own specific decomposition coefficient (the decomposition is a fraction of the amount present), except for the IOM compartment in which organic matter is no longer broken down. The decomposition coefficient for each compartment is influenced by soil texture, temperature, moisture and soil cover. The decomposition is described as a first order reaction in most soil carbon models, including the RothC model. The decomposition constants have been determined on the basis of the long-term experiments conducted at Rothamsted Research (United Kingdom) and are not usually changed for the purpose of using the model. Climate conditions in the Netherlands are considered to be similar to those in the study site in the UK and therefore the model is considered to be also representative for the Dutch conditions.

RothC requires the following input data on a monthly basis: rainfall (mm), open pan evaporation (mm), average air temperature (°C), clay content of the soil (as a percentage), input of plant residues (tonne C ha^{-1}), input of manure (tonne C ha^{-1}), estimate of the decomposability of the incoming plant material (DPM/RPM ratio), soil cover (if the soil is bare or vegetated in a particular month) and soil depth (cm). Initial carbon content can be provided as an input or calculated according to long-term equilibrium (steady state).

Input data

The following input data sources were used:

- Climate data: monthly data for the period 1983–2021 are available per KNMI zone (14 zones) from the Dutch Meteorological Institute.
- Crop areas are based on *Basisregistratie landbouwpercelen* (BRP, base layer for the Land Parcel Information System (LPIS) in the Netherlands) and aggregated into 40 crop categories.
- Crop yield is based on harvest statistics from Statistics Netherlands (CBS), for main crops at provincial level and other crops at national level.
- Organic fertiliser supply is based on data from the Initiator model, which is also used in the National Emission Model for Agriculture (NEMA) for reporting on the Agriculture sector. A distinction is made between grazing and fertiliser application on grassland and arable land. Data is based on nitrogen applications and converted to carbon using average C/N ratios.
- Compost inputs are fixed and were determined based on data for 2017 and are equally distributed over arable land. This is only a small supply source of carbon compared to manure.
- Green manures and catch crops: for 2017 and 2021 detailed regional data from BRP are available, for 2018–2020 this is interpolated, and for 2005–2016 national data from NEMA on total areas of catch crop after maize and after other arable crops was used.
- Straw removal is based on national average data from the *Bedrijven Informatie Netwerk* (BIN, the Dutch data for the EU Farm Accountancy Data Network (FADN)) for wheat and barley straw. For other straw crops a fixed percentage was applied, as described in Lesschen et al. (2021).
- For the initial soil carbon stock a map of the soil organic carbon content was used, which is based on data from the Dutch Soil Sampling Programme from 2018 (Knotters et al. 2022; van Tol-Leenders et al. 2019). This map was created from digital soil mapping, in which the data from the Soil Sampling Programme was used and linked to a whole range of other data, such as land use and topography (Figure 11.3). A pH map of the Netherlands has previously been made using this same digital soil mapping method, see Helfenstein et al. (2022). The average C content of mineral soils under grassland and cropland has been calculated per 4-digit zip code area.

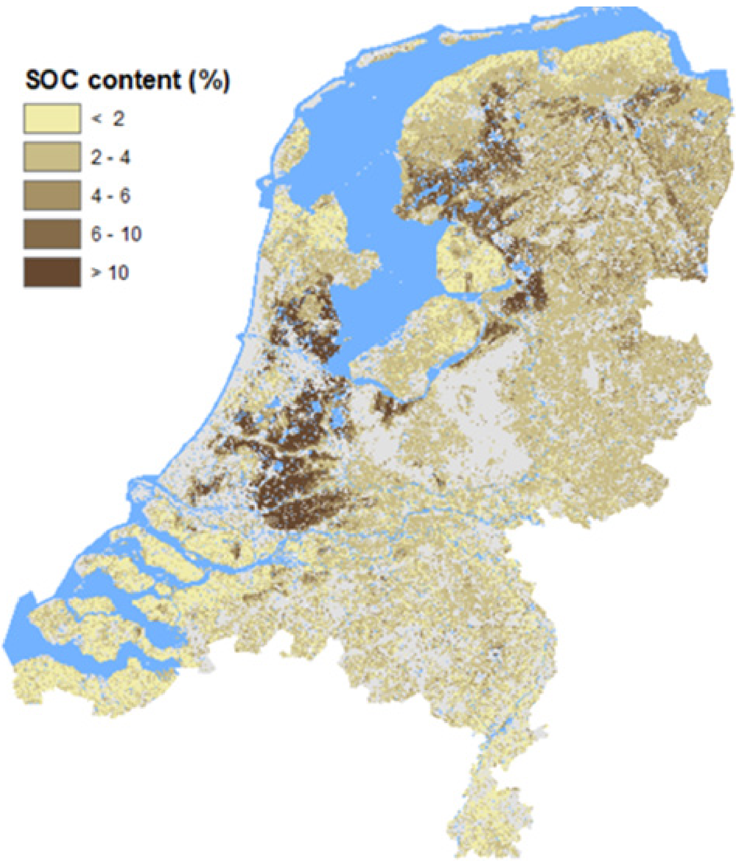

Figure 11.3 *Map of soil organic carbon content for cropland and grassland soils. Data are based on the Dutch Soil Sampling Programme from 2018 (van Tol-Leenders et al. 2019) and mapped following the procedure of Helfenstein et al. (2022).*

Calculations
Calculations in RothC are performed at 4-digit zip code level, which amounts to about 3400 units with agricultural land, and for all individual crops. The results of the model are aggregated per main soil type – sand, clay, loess and soils with human-induced organic rich topsoil (*eerdgrond*) – to obtain annual average carbon stock changes per ha cropland or grassland. The soil organic carbon balance calculations in RothC were made using the actual monthly climate data from the Dutch meteorological institute (KNMI). As the model is quite sensitive to the climate parameters, the annual variability of the national SOC balance was quite large (-0.41 to +0.25 tonne C/ha). Therefore, we opted to use the 5 year average SOC balance for C fluxes in the categories Cropland remaining Cropland and Grassland remaining Grassland. This 5 year period is in line with the 5 year accounting periods of the EU LULUCF Regulation and also with the National Forest Inventory, which is based on a 5 year cycle.

For the period before 2005 no detailed activity data on crop areas and soil management was available. To obtain a consistent time series, the average carbon stock change per soil type and land use type for the period 2005–2009 was applied to the period 1990–2004. To provide RothC simulations for the period 1990–2004 as well, the possibility of using additional data will be explored in the coming years.

Results
The main driver for the soil carbon balance is the carbon input. Figure 11.4 shows the annual carbon input for Cropland and Figure 11.5 for Grassland. In Cropland there is a clear trend of increasing carbon inputs. This is partly the result of higher manure inputs, as stricter manure policies increased the pressure on the manure market, which resulted in more manure being exported to arable regions further away from the livestock production areas, such as Zeeland and Groningen. In more recent years a clear increase in the carbon input from cover crops has been observed, which is the result of the EU greening measures which led many farmers to grow cover crops to comply with the ecological focus areas measure. The carbon input for the Grassland category shows a slight decline, mainly due

to lower carbon inputs from manure, probably as a result of stricter rules under the derogation for the maximum manure application rate.

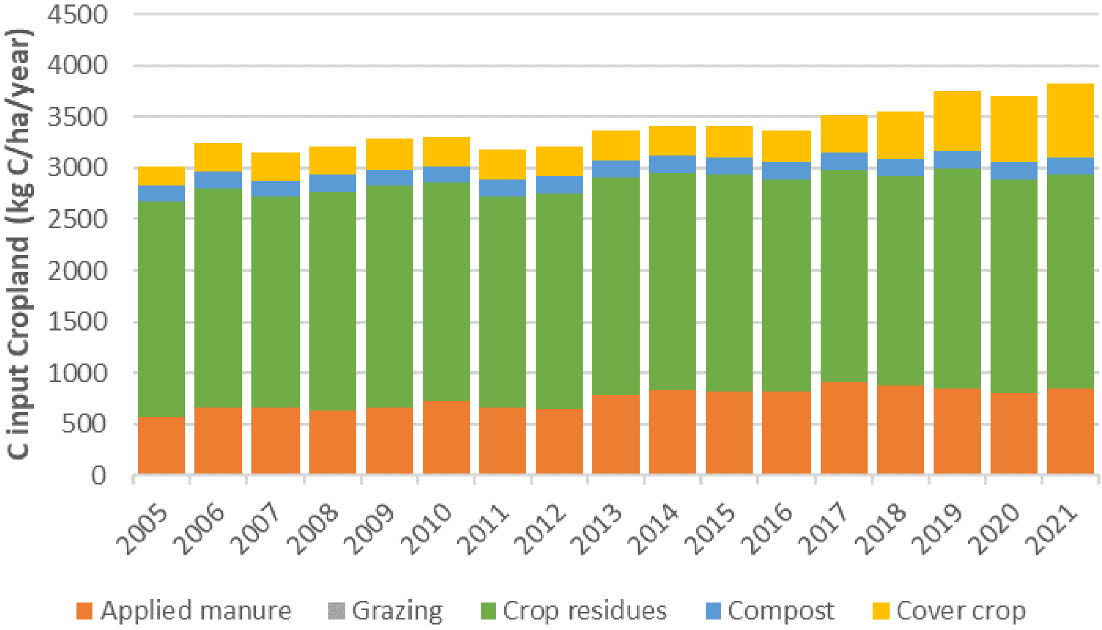

Figure 11.4 *Average annual carbon input to the soil for Cropland.*

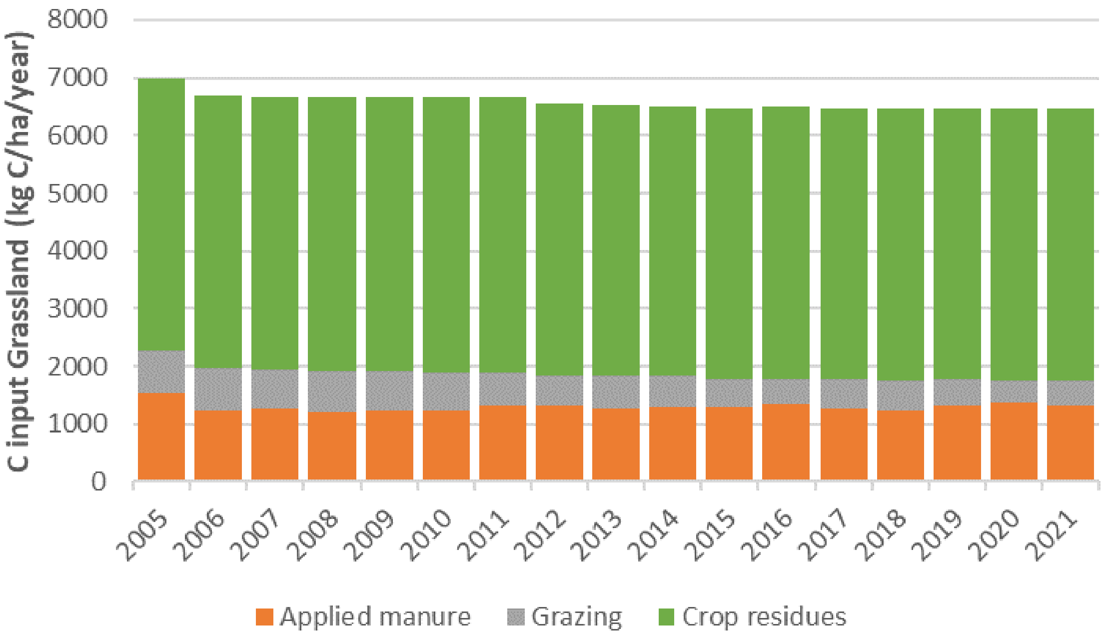

Figure 11.5 *Average annual carbon input to the soil for Grassland.*

The RothC model was used to calculate the soil organic carbon balance, based on the annual carbon inputs, annual climate data and other model inputs. The results are shown in Figure 11.6. On average the Cropland soils have a negative SOC balance, but with an upward trend, whereas the SOC balance for Grassland is positive. The trend is partly related to the carbon input, but the effect of using annual climate data is quite large and still visible in the five-year averaged results. The net SOC balance for agricultural soils shifted from slightly negative during the first period to slightly positive in the most recent years. The resulting SOC balance values were converted to net fluxes for each soil type for the categories Cropland remaining Cropland and Grassland remaining Grassland and used in the LULUCF calculations, where they are combined with the soil carbon stock changes due to land use change.

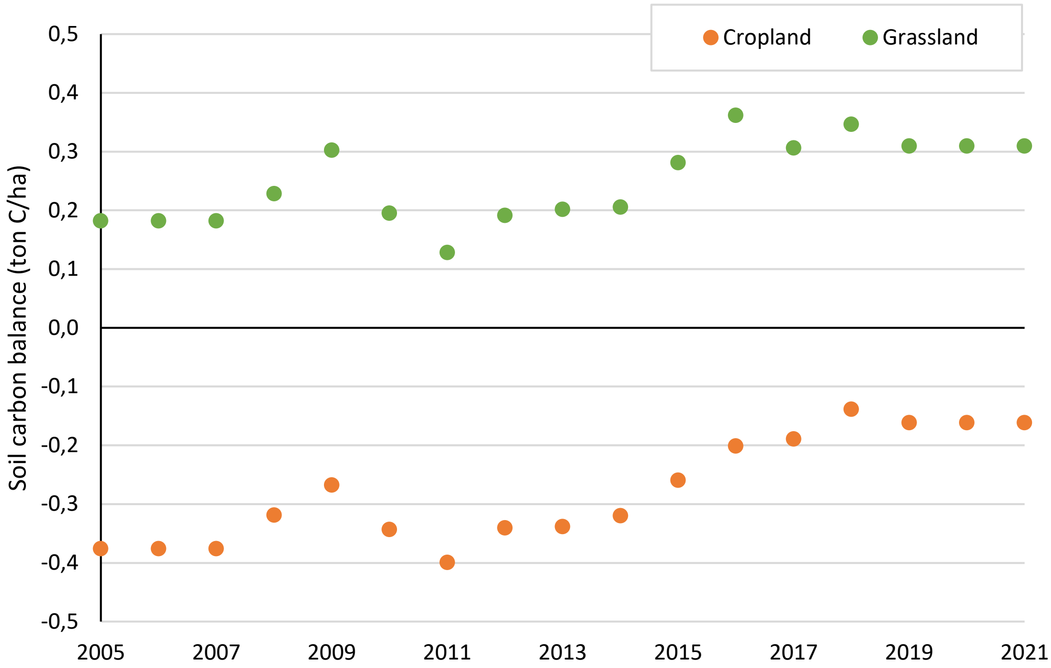

Figure 11.6 *Five-year average annual soil carbon balance for Cropland and Grassland based on RothC calculations.*

11.2.3 Nitrous oxide emissions from disturbance associated with land-use conversions

Nitrous oxide (N_2O) emissions from soils by disturbance associated with land-use conversions are calculated using a Tier 2 methodology, with Equation 11.8 of the 2006 IPCC guidelines for each aggregated soil type (also see emissions from carbon stock change in mineral soils in Section 11.2 of this report). The default EF1 of 0.01 kg N_2O-N/kg N was used. For three aggregated soil types, average C:N ratios, based on measurements, were available and used (17.3 for sandy soils with lime; 23.4 for sandy soils without lime; 25.6 for podzol soils). For all other aggregated soil types, we used the default C:N ratio of 15 (2006 IPCC guidelines p. 11.16). For aggregated soil types where conversion of land use led to a net gain of carbon, the nitrous oxide emission was set to zero.

11.3 Organic soils

As from the NIR 2015 two types of organic soils are identified, peat soils and peaty soils (i.e. shallow peat soils). The definition of organic soils in the 2006 IPCC guidelines is the following:

Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO 1998):

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.

2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and has either:
   - At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
   - At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60% or more clay; or
   - An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

Peat soils have a peat layer of at least 40 cm within the first 120 cm, while peaty soils, in Dutch called '*moerige gronden*', have a peat layer of 5-40 cm within the first 80 cm. Based on the available data sets, two different approaches for the emission factors have been developed for peat and peaty soils. For CO_2 emissions from cultivated organic soils[8] the methodology is described in Kuikman *et al.* (2005). This method is based on subsidence as a consequence of oxidation of organic matter. For the peaty soils, another approach was used, based on a large data set of soil profile descriptions over time (de Vries et al. unpublished). From this data set the average loss rate of peat, was derived from the change in thickness of the peat layer over time.

Peat soils
Oxidation typically is caused by a low groundwater table, which also causes two other types of subsidence: (irreversible) shrinking of the peat as a consequence of drying and compaction due to changes in hydrostatic pressure (consolidation). However, the last two processes are of importance only a few years after a sudden decrease in groundwater level. Based on many series of long-term measurements, a relation was established between subsidence and either ditch water level or mean lowest groundwater level (Kuikman *et al.* 2005). For all peat soils in the Netherlands, the estimated subsidence could thus be predicted. The occurrence of peat soils used in Kuikman *et al.* 2005 was based on an intermediary organic soils map for 2004 (de Vries et al. 2003; de Vries 2004) with a focus on peat soils. This resulted in 223,147 ha of peat soils under agricultural land use in the Netherlands, which was the best estimate when these calculations were performed.

The carbon emissions per ha are calculated from the mean ground surface lowering using the following general equation:

$$C_{em} = R_{GSL} \cdot \rho_{peat} \cdot f_{ox} \cdot [OM] \cdot [C_{OM}] \cdot f_{conv} \quad (11.2)$$

With

C_{em} Carbon emission from oxidation of peat (kg C ha^{-1} year^{-1})
R_{GSL} Rate of ground surface lowering (m year^{-1})
ρ_{peat} Bulk density of lowest peat layer (kg soil m^{-3})
f_{ox} Oxidation status of the peat (-)
$[OM]$ Organic matter content of peat (kg OM kg^{-1} soil)
$[C_{OM}]$ Carbon content of organic matter (0.55 kg C kg^{-1} OM)
f_{conv} Conversion from kg C m^{-2} year^{-1} to kg C ha^{-1} year^{-1} (10^4)

For deep peats (> 120 cm), the calculation is based on the properties of raw peat (bulk density of 140 kg soil m^{-3}, oxidation status of 1, and organic matter content of 0.80 kg OM kg^{-1} soil), which results in an emission of 616 kg C ha^{-1} year^{-1} for each mm of annual ground surface lowering.

For shallow peat soils (40 < depth < 120 cm), the (higher) bulk density of half ripened peat should be used. During the process of oxidation of the peat and further ground surface lowering, the decomposability of the remaining peat decreases, resulting in a decreasing rate of ground surface lowering, an increasing bulk density and a decreasing organic matter content. Up to a peat layer depth of about 80 cm all values in Equation 11.2 can be the same as for a deep peat soil, because the change in subsidence and bulk density of the raw peat below 60 cm depth is negligible. Also for peat soils thinner than 80 cm all values in Equation 11.2 were used. This estimation is done because there

[8] N_2O is reported under CRF Sector 3 Agriculture and not further considered here

is no data on subsidence of such shallow peat soils and because this would just cause a small error, because the vast majority of the Dutch peat soils are thicker than 80 cm. Besides, the underestimation of the bulk density will be compensated more or less by the overestimation of the subsidence.

The average ground surface lowering can be described as a function of the soil type of the upper soil layer and the drainage class. The following soil types were distinguished: peat, clay, sand and humus rich sand (‘*veenkoloniaal dek’*). For peat the ground surface lowering is higher than for the other soil types. Three drainage classes are distinguished based on the GLG (average lowest groundwater level): bad drainage (GLG < 80 cm); moderate drainage (GLG 80-120 cm) and good drainage (GLG > 120 cm). In Kuikman *et al.* (2005) the groundwater information from the soil map was used, which was mainly collected during the sixties and seventies. Since this information is outdated, since more land is now drained compared to the sixties, they assumed that 50% of the peat area in a certain groundwater class would now one class higher. In the updated calculation we used the updated groundwater data (GxG files), see de Gruijter et al. (2004) and van Kekem et al. (2005). This map was made based on geostatistics, groundwater level databases and some additional new measurements of groundwater levels. The resulting ground surface lowering for all peat soils in the Netherlands is shown in Figure 11.7.

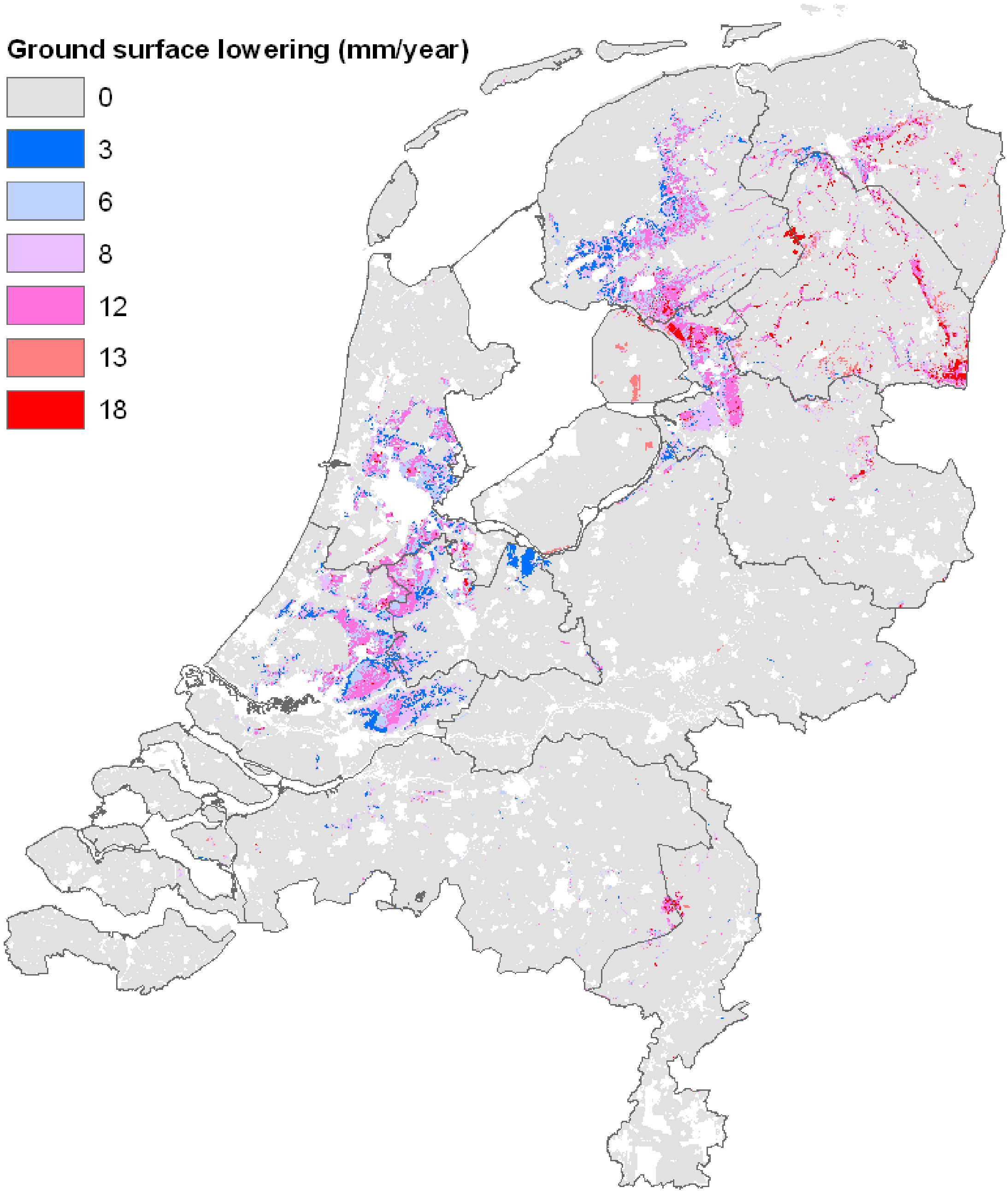

Figure 11.7 *Location of peat soils and their average ground surface lowering.*

In Table 11.3 the calculated ground surface lowering and the surface is shown for the different combinations of soil type of the upper soil layer, the peat type and drainage class. In the last column of the table the annual emission of carbon is reported. In this case, based on the land-use map of 2004, the total annual loss of carbon from organic soils under agricultural land use is 1.16 Mtonnes of C, which is an annual emission of 4.25 Mtonnes of CO_2. This has been converted to an annual emission factor of 19.0 tonnes CO_2 ha^{-1}. This emission factor is used for the entire time-series.

Table 11.2 *Carbon emissions as resulting from classification of peat soils in the Netherlands, estimated mean ground surface lowering (gsl) and surface (in ha), based on the 2004 land-use map.*

Soil type upper soil layer	**Peat type**	**Bad drainage**		**Reasonable drainage**		**Good drainage**		**Total**	**C-emission**
		gsl	**Surface (ha)**	**gsl**	**Surface (ha)**	**gsl**	**Surface (ha)**	**Surface (ha)**	**tonnes C yr^{-1}**
Clay	Eutrophic	3	16,149	8	17,250	13	531	33,929	119,100
	Mesotrophic	3	12,780	8	22,294	13	2863	37,935	156,403
	Oligotrophic	3	9,421	8	10,480	13	416	20,315	72,380
Peat	Eutrophic	6	16,668	12	16,846	18	206	33,719	188,415
	Mesotrophic	6	18,668	12	31,607	18	7169	57,443	382,118
	Oligotrophic	6	8,688	12	10,054	18	1168	19,911	119,381
Humus-rich sand	Mesotrophic	3	148	8	3,184	13	4771	8,102	54,167
	Oligotrophic	3	27	8	760	13	2256	3,041	21,856
Sand	Mesotrophic	3	1,365	8	3,370	13	1318	6,051	29,681
	Oligotrophic	3	415	8	1,450	13	836	2,700	14,604
Total			84,325		117,291		21531	223,147	1,158,105

In 2014 an updated soil map became available for the Netherlands[9]. In part of the Netherlands, especially in the north-eastern part, many of the peat and peaty soils have disappeared over the last decades. Due to its intensive use and drainage the organic soil material has oxidised and these soils now have become mineral soils or peaty soils. The area of organic soils has therefore decreased over the years. On average 1700 ha per year of peat soils (0.5%) have disappeared. This trend, based on the two soils maps, dated 1977 and 2014, has been interpolated between these years

In 2021 a new organic soil forecast map (Figure A2.10 in Annex 2) was developed for the Netherlands (Erkens et al., 2021). This map provides a spatially explicit projection of the extent of peat and peaty soils in 2040 . The starting situation was based on the 2014 soil map. The subsequent loss of the extent of peat and peaty soil was based on geohydrological modelling, where a scenario with limited subsidence was chosen, based on limited climate change in combination with surface water level fixation to mitigate subsidence (Erkens et al., 2021). This spatially explicit map is used to determine the area of organic soils per reporting year between 2014 and 2040 through linear interpolation. The organic soils show a decrease of 927 ha/year between 2014 and 2040 using this method.

Peaty soils

For peaty soils, soils with a thin (5-40 cm) peat layer, the subsidence approach from Kuikman *et al.* (2005), as used for peat soils, is not applicable. First of all, because the data on which this approach was based, is not available for peaty soils and second, the behaviour of such a thin layer of peat is different. Therefore a new approach was developed, as described in de Vries et al. (unpublished).

Resampling of soil units during the period of 2000-2002 revealed that large areas of peat and peaty soils were converted into other soil types, since (part of) the peat layer was lost due to continuing oxidation and disturbance. This led to large scale resampling of soil units with shallow peat soils and peaty soils during the period 2005-2013. The results of this Soil Information System (BIS) project lead to a large database with all soil profile descriptions and an updated soil map. This new 2014 soil map is also used since 2019 for the LULUCF reporting. From this database about 6150 soil profile descriptions were available on soil units that were previously classified as thin peat soils or peaty soils. For the new observations the measured thickness of the peat layer, if still present, was available. The historic thickness of the peat layer was not known, but was estimated using the average thickness for a peat layer in a peaty soil, which was still classified as a peaty soil. This average differed slightly among the three drainage classes, but was close to the arithmetic mean value, i.e. 22.5 cm, since a soil is classified as peaty soil if the peat layer is between 5 and 40 cm thick.

Because of the large number of observations, the average difference between the observed and historic thickness could be used to derive an average peat loss rate. This was differentiated for three

[9] https://www.wur.nl/nl/show/Bodemkaart-1-50-000.htm

drainage classes, similar as done for the peat soils. For each drainage class an average loss rate of the peat layer in the peaty soils was determined, which lead to an overall loss rate of 0.32 cm $year^{-1}$. Based on the bulk density and carbon content of the peaty soil types, an average C loss per cm of lost peat layer was calculated.

Based on the original organic soils map of 2004, this resulted in an average overall emission factor of 13.0 tonnes CO_2 ha^{-1} $year^{-1}$ for the peaty soils under agriculture, which has been used for the entire time-series. For settlements no data were available, but the same overall emission factor has been used.

Also the area of peaty soils has decreased over the years. On average 800 ha per year of peaty soils (0.4%) has disappeared. As for the peat soils, this trend has been interpolated between 1977 and 2014 years, and has been interpolated after 2014 using the organic soil forecast map of 2040. Emissions from peat and peaty soils are calculated separately, but in the CRF the sum of these emissions is reported in the relevant categories of organic soils.

Emissions from organic soils under forest land
Drainage of organic soils is usually not applied in forestry in the Netherlands. However, since afforestation often occurs on land with previously agricultural land use, it cannot be completely ruled out that the old drainage systems from the agricultural sites are still active. Therefore, to account for possible emissions, the area of forests and trees outside forests that are planted on organic soils that were in agricultural use before and where drainage systems may still be (partially) functioning was estimated, and associated emissions have been calculated using country specific emission factors.

The total area of forest on peat soils in the 2017 map was 11.3 kha. Out of this area, 2.7 kha (24.2% of the forest area on peat soils) was listed as being Cropland, Grassland or Settlements in at least one of the earlier maps. For each year we therefore assume that 24.2% of the forest area on peat soil is potentially drained and has an emission factor equal to that of agriculture on peat soil.

Similarly, the total area of forest on peaty soil in the 2017 map was 9.1 kha. Out of this area, 2 kha (22.0% of the forest area on peaty soils) was listed as being Cropland, Grassland or Settlements in at least one of the earlier land-use maps. For each year we assume that 22.0% of the forest area on peaty soil is potentially drained and has an emission factor equal to that of agriculture on peaty soils.

11.3.1 Nitrous oxide emissions from organic soils

Apart from CO_2 emissions from organic soils, also N_2O emissions occur, due to mineralisation of organic nitrogen. For cropland and grassland these emissions are included under Agriculture (category 3D). However, those emissions under forest land have to be reported under LULUCF. Based on an overlay of the soil map and land-use map, the share of nutrient rich (eutrophic organic soils) and nutrient poor (oligotrophic organic soils) was determined for organic soils under forest. On average 79% of the peat soils is nutrient rich and 21% is nutrient poor. All peaty soils have been classified as nutrient rich, as the average CN ratio is 17. The default IPCC tier1 N_2O emission factors (EF_2) of 0.6 kg N_2O-N/ha for nutrient rich and 0.1 N_2O-N/ha for nutrient poor organic soils have been applied.

11.3.2 Methane emissions from drainage ditches

Methane (CH_4) emissions from drainage ditches in drained forest land, cropland and agricultural grasslands on organic soils are reported in CRF Table 4(II) using the Tier 1 approach described in Section 2.2.2.1 of the 2013 IPCC wetlands supplement (IPCC 2014b) in combination with a country specific emission factor.

This calculation applies the default ditch fraction of 5%, meaning that 5% of the land areas determined as drained forest land, cropland or grasslands consists of drainage ditches. To these areas a country specific emission factor of 518 kg CH_4 ha^{-1} yr^{-1} is applied based on a case study for the Netherlands by Peacock et al. (2021). This value is similar to the default emission factor for drainage ditches in shallow drained temperate grassland (i.e. 527 kg CH_4 ha^{-1} yr^{-1}) in Table 2.4 of the 2013

IPCC wetlands supplement (IPCC 2014b). Individual data points on which the value is based is provided in the supplemental data of Peacock et al. (2021; https://iopscience.iop.org/article/10.1088/1748-9326/abeb36). The average CH_4 flux based on the references for the Netherlands was 51.8 g CH_4 m^2 yr^{-1} with a standard deviation of 20.9 g CH_4 m^2 yr^{-1}.

12 Greenhouse gas emissions from wildfires [4(V)]

12.1 Controlled biomass burning

The areas included under wildfires, partly include the occasional burning that is done under nature management. Controlled burning of harvest residues is not allowed in the Netherlands (article 10.2 of 'Wet Milieubeheer' - the Environment Law in the Netherlands). Therefore controlled biomass burning does not occur in the Netherlands, and therefore is reported as not occurring (NO).

12.2 Wildfires

In the Netherlands no country specific information on intensity of forest fires and emissions of Greenhouse gases from those fires is available. Therefore emissions of CO_2, CH_4 and N_2O from forest fires are reported using the Tier 1 method as described in Chapter 2 of the 2006 IPCC guidelines. Recent data on occurrence and extent of wild fires is lacking. Due to decreasing occurrence of wild fires the monitoring of these fires ceased in 1996. Between 1980 and 1992 besides the number of fires, also the area of forest fires was monitored (see Wijdeven *et al.*, 2006). The average area of forest that burns annually was based on the historical data series (1980 to 1992, Table 12.1). This was 37.8 ha (or 0.1 ‰ of the total forest land in the Netherlands) and this area was used from 1990 onwards as an estimate of area burnt.

Table 12.1 *Annual area of forest fires and area of other (outside forest) wild fires in the Netherlands (from Wijdeven et al., 2006)*

Year	Area forest fires (ha)	Area other wild fires (ha)
1980	153	303
1981	12	38
1982	40	645
1983	20	379
1984	65	147
1985	14	20
1986	15	265
1987	27	88
1988	26	54
1989	22	77
1990	40	184
1991	33	381
1992	24	153
Average 1980-1992	**37.8 ± 10.3 (s.e.)**	**210 ± 38.7 (s.e.)**

Forest fires

Equation 2.27 of the 2006 IPCC guidelines was used to calculate greenhouse gas emissions from forest fires. The mass of fuel available (tonnes ha^{-1}) for combustion was based on the annual carbon stock in living biomass, litter and dead wood in forests (calculation in Section 4.2), so these values change over time depending on forest growth and harvesting. The default combustion factor (fraction

of the biomass combusted) for "all other temperate forests" is used (0.45; 2006 IPCC guidelines Table 2.6). For each of the gases CO_2, CH_4 and N_2O default emissions factors for "Extra tropical forests" from Table 2.5 in the 2006 IPCC guidelines were used.
With the available data it is not possible to distinguish between forest fires in forests remaining forests and land converted to forest land. Therefore, the total emissions from forest fires are reported in CRF Table 4(V) under wild fires for forests remaining forests.

Other wild fires
Also CO_2, CH_4 and N_2O emissions from 'other' wildfires (mainly on grassland and heathland) are calculated and reported according the Tier 1 method as described in the 2016 IPPC Guidelines (Equation 2.27), with the mass of fuel based on the carbon stock in biomass in Grassland (non-TOF). For all years from 1990 onwards the area of other wildfires from the historic data was the basis for the area burned (Table 12.1). On average this is 210 ha yr^{-1} (Table 12.1).

In the Netherlands these other wildfires are predominantly fires in dunes and heathlands, that both are reported under Grassland (non-TOF). Emissions from these 'other' wild fires therefore are reported in CRF Table 4(V) under Grassland remaining Grassland.

12.3 Potential improvements

During the UNFCCC review process of the NIR 2019 the reviewer pointed to available geospatial techniques for the identification of forest fires, like the European Forest Fire Information System (EFFIS), as a possible data source to improve fire activity data after 1992.

In 2016, however, we already undertook an attempt to improve wild fire activity data by testing various remote sensing sensors and geospatial techniques (Roerink and Arets 2016). None of these approaches were very effective in detecting the relevant forest and wild fires. The alternative of combining information on wild fires from the media and subsequently analysing areas per vegetation type of wild fire (forest or non-forest) was effective (see Table 12.2 for results). Although this is only for two years, the average extent of forest (32 ha) and other wildfires (215) is similar to the areas in the historic situation (Table 12.1). The cost to for the monitoring and analyses, however, were considered to be disproportionate to the potential quality improvement for the greenhouse gas inventory.

Table 12.2 *Number and areas (ha) of wildfires in 2014 and 2015 (data from Roerink and Arets 2016)*

Year	Number of wildfires	Total area (ha)	Forest fires (ha)	Other wildfires (ha)
2014	5	410	54	357
2015	3	83	10	73

Additionally, we have looked into possible improvements in wild fire statistics in the Netherlands using the EFFIS data that are reported in its annual fire reports[10] since 2000. Until 2017 the Netherlands did not submit a report to EFFIS, but the EFFIS reports also include independent rapid damage assessment that aim to provide reliable and harmonised estimates of the areas affected by forest fires in collaborating countries. Although The Netherlands are included in these assessments, even with the recent improvements in the resolution of fire detection from 50 to 30 ha most fires in the Netherlands appear to remain undetected (Table 12.3).

Since 2018 the Netherlands also submits a country report to EFFIS, which is included in the 2018 annual EFFIS report (San-Miguel-Ayanz et al. 2019). The Netherlands Fire Service registered a total of 949 wildfires in 2018. These were concentrated in the summer months July and August. Fires mainly occurred on dry sandy soils in the Veluwe region (centre), Noord-Brabant and Limburg (southeast)

[10] https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports/

and in the sand dunes along the coast. The total number of fires in 2018 was roughly triple that of 2017, when 321 wildfires were registered.

Table 12.3 *Number and areas (ha) of wildfires reported under the rapid assessment chapter in the annual EFFIS reports since 2000[11].*

Year	Number of fires	Area forest/OWL	Area other natural	Area agriculture	Total area without Agriculture
2021					0*
2020	2	243	532	12	775
2019			21		21
2018	3	13	170	0	183
2017					0
2016					0
2015	1		23		22
2014	1	4	342	50	346
2013					0
2012					0
2011	1	55	93		147
2010					0
2009					0
2008					0
2007					0
2006	1	?	?		70
2005					0
2004					0
2003					0
2002					0
2001					0
2000					0

* The Netherlands were not included in the rapid assessment overview, possibly because the 2021 rapid assessment did not give wildfires for the Netherlands.

The wildfires registered by the Netherlands Fire Service include a large variation of wild fires, including small roadside fires. As a result the total number of fires registered by the Fire Service is very different from the numbers detected with the geospatial analysis in Roerink and Arets (2016) (Table 12.2) and the EFFIS rapid damage assessment (Table 12.3). Unfortunately the information collected by the Fire Service does not include information on the spatial extent of the registered fires. It does, however, include information on locations, estimated duration of the fires and the number of dispatched water tenders.

We will further explore possibilities to get improved wild fire activity data by combining geospatial analyses with the information registered by the Netherlands Fire Service. Given the currently small extent of wild fires in the Netherlands an important prerequisite will be that such approaches should be cost effective and proportionate to the expected emissions from wild fires

[11] https://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports

13 Uncertainty assessment

13.1 Introduction

To assess the uncertainty of the reported emissions from LULUCF an approach was developed and implemented using a Monte-Carlo approach (Approach 2 cf. Section 3.2.3.2 in IPCC 2006a).

Up to the NIR 2017, the uncertainty of LULUCF emissions was based on the old Tier 1 uncertainty assessment as presented in Olivier *et al.* (2009). That uncertainty assessment is, however, based on calculation methodology that is not used in recent submissions. Furthermore, it contained a strongly simplified implementation of the uncertainty in the land-use maps and not all parameters currently reported were included.

The documentation below presents
1. The background on the types of uncertainty addressed.
2. A description of the uncertainty range input parameters used.
3. A description of the MC simulation performed.
4. The resulting uncertainty ranges for the reported fluxes.
5. The temporal development of the uncertainty.
6. The attribution of these uncertainty ranges to different groups of input parameters.

Due to the demanding run times of the currently used Monte Carlo approach, it is not feasible to update this uncertainty assessment every year. Therefore, the assessment presented here does not include the most recent methodology changes yet. The information provided in this chapter is based on runs done in 2017 that included time series until 2014. This means that uncertainty of the new land-use map 2017, and the updated soil map have not been included in the results presented in this chapter. It is likely however that uncertainties remain in the same order of magnitude as presented here.

13.2 Types of uncertainty

The IPCC 2006 guidelines identify nine causes of uncertainty (Table 3.1 in IPCC 2006a). Of these nine causes, two are addressed with this uncertainty assessment: a) the statistical random sampling error and b) the random component in the measurement error. These types of uncertainty are readily assessed using appropriate statistical techniques. With this the precision of the calculated GHG emissions and removals is assessed given the bias in measurements, data and models.

Both type of causes of uncertainty addressed relate to uncertainty in the values of the input data of the calculation. Two approaches are suggested for the combination of these uncertainties. Because one source of uncertainty is in the mapping of land use, which is inherently correlated and analytically intractable, approach 2, the Monte Carlo simulation is applied.

In order to identify the main sources of uncertainty in the total emission estimation, partial uncertainties were derived from emission factors related to biomass, emission factors related to soil carbon and the activity data based on the land-use map. These partial uncertainties are derived as the uncertainty-range from those iterations in the Monte Carlo simulation that only include the focal source, divided by the uncertainty-range over all iterations.

13.3 Uncertainty ranges in input

Three main groups of input parameters are identified as uncertain and are evaluated;
1. uncertainties from emission factors related to biomass,
2. emission factors related to soil, and
3. activity data based on the land-use map

Where default Tier 1 emission factors and activity data are used from the IPCC 2006 guidelines also their Tier 1 uncertainty ranges are used as input to the Monte Carlos assessment. When measurement data were available, emission factor uncertainty was calculated as twice the standard-error of the mean (S.E.M.) calculated from these measurements (see Tables 14.1 to 14.5).

13.3.1 Biomass-related uncertainty

The biomass related uncertainty includes uncertainty in biomass stock (Table 13.1 and Table 13.2), the ratios between aboveground and belowground biomass, deadwood and litter estimates (Table 13.2) and parameters for the calculation of emission from wildfires (Table 13.3).

Table 13.1 *Uncertainty ranges for non-forest biomass*

Land use	Biomass stock (kton ha^{-1})	S.E.M.
Grassland vegetation & nature	0.0068	0.00255
Cropland	0.005	0.001875

Table 13.2 *Uncertainty ranges for forest biomass and dead wood (see Table 4.1)*

Parameter	Year	Units	Value	S.E.M.
Growing stock	1990	m^3/ha	157.98	1.93
Growing stock	2003	m^3/ha	194.61	1.91
Growing stock	2013	m^3/ha	216.52	2.26
BCEF	1990	kg/m^3	714	5.71
BCEF	2003	kg/m^3	736	6.06
BCEF	2013	kg/m^3	764	5.98
R	1990	-	0.18	0.000708
R	2003	-	0.18	0.000625
R	2013	-	0.18	0.000717
Standing dead wood mass	1990	tonne/ha	837.05	35.73
Standing dead wood mass	2003	tonne/ha	1333.32	53.12
Standing dead wood mass	2013	tonne/ha	1883.49	75.87
Lying dead wood mass	2003	tonne/ha	1527.01	74.35
Lying dead wood mass	2013	tonne/ha	1927.01	84.51

Table 13.3 Uncertainty ranges for wild fires

Parameter	Value	S.E.M.	Unit
Forest area burnt	37.77	10.38	Ha
NonForest area burnt	210	38.69	ha
Combustion efficiency Forest	0.45	0.16	-
Combustion efficiency NonForest	0.71	0.6	-
Gef_CO_2_Forest	1569	131	g /kg
Gef_CO_Forest	107	37	g /kg
Gef_CH4_Forest	4.7	1	g /kg
Gef_N2O_Forest	0.26	0.07	g /kg
Gef_NOX_Forest	3	1.4	g /kg
Gef_CO_2_NonForest	1613	95	g /kg
Gef_CO_NonForest	65	20	g /kg
Gef_CH4_NonForest	2.3	0.9	g /kg
Gef_N_2O_NonForest	0.21	0.1	g /kg
Gef_NOX_NonForest	3.9	2.4	g /kg

13.3.2 Soil-related uncertainty

The soil related uncertainties are the uncertainty in land use and soil type specific carbon stock and C-N ratio for mineral soils (Table 13.4), and carbon-fluxes for organic soils (Table 13.5).

Table 13.4 Uncertainty ranges for soil carbon stock and C-N ratio for mineral soils

Land use	Soil type	Cstock (tC/ha)	SEM (C-stock)	CN ratio (-)	SEM (CN ratio)
Grassland	Brikgrond	78.3	5.47	15	2.50
Grassland	Eerdgrond	87.84	6.47	15	2.50
Grassland	Kalkhoudende zandgrond	58.55	7.65	17.3	0.21
Grassland	Kalkloze zandgrond	86.56	2.76	23.4	1.34
Grassland	Leemgrond	88.91	5.32	15	2.50
Grassland	Onbepaald	105.64	1.65	15	2.50
Grassland	Oude kleigrond	81.12	6.36	15	2.50
Grassland	Podzolgrond	116.07	4.01	25.6	0.31
Grassland	Rivierkleigrond	111.32	3.36	15	2.50
Grassland	Zeekleigrond	113.66	2.77	15	2.50
Cropland	Brikgrond	76.37	2.8	15	2.50
Cropland	Eerdgrond	71.27	7.48	15	2.50
Cropland	Kalkhoudende zandgrond	54.11	5.41	17.3	0.21
Cropland	Kalkloze zandgrond	76.46	4.34	23.4	1.34
Cropland	Leemgrond	81.54	6.05	15	2.50
Cropland	Onbepaald	82.47	1.98	15	2.50
Cropland	Oude kleigrond	83.86	19.96	15	2.50
Cropland	Podzolgrond	107.56	6.94	25.6	0.31
Cropland	Rivierkleigrond	84.57	6.12	15	2.50
Cropland	Zeekleigrond	80.6	2.18	15	2.50
Forest Land	Brikgrond	82.47	12.77	15	2.50
Forest Land	Eerdgrond	99.53	17.39	15	2.50
Forest Land	Kalkhoudende zandgrond	32.16	5.78	17.3	0.21

Land use	Soil type	Cstock (tC/ha)	SEM (C-stock)	CN ratio (-)	SEM (CN ratio)
Forest Land	Kalkloze zandgrond	57.39	5.18	23.4	1.34
Forest Land	Leemgrond	112.18	15.41	15	2.50
Forest Land	Onbepaald	87.68	3.73	15	2.50
Forest Land	Oude kleigrond	61.39	34.37	15	2.50
Forest Land	Podzolgrond	92.23	4.68	25.6	0.31
Forest Land	Rivierkleigrond	139.95	7.45	15	2.50
Forest Land	Zeekleigrond	139.49	10.54	15	2.50
Wetland	Brikgrond	82.47	12.77	15	2.50
Wetland	Eerdgrond	99.53	17.39	15	2.50
Wetland	Kalkhoudende zandgrond	32.16	5.78	17.3	0.21
Wetland	Kalkloze zandgrond	57.39	5.18	23.4	1.34
Wetland	Leemgrond	112.18	15.41	15	2.50
Wetland	Onbepaald	87.68	3.73	15	2.50
Wetland	Oude kleigrond	61.39	34.37	15	2.50
Wetland	Podzolgrond	92.23	4.68	25.6	0.31
Wetland	Rivierkleigrond	139.95	7.45	15	2.50
Wetland	Zeekleigrond	139.49	10.54	15	2.50
Settlements	Brikgrond	74.22	11.49	15	2.50
Settlements	Eerdgrond	89.57	15.65	15	2.50
Settlements	Kalkhoudende zandgrond	28.94	5.2	17.3	0.21
Settlements	Kalkloze zandgrond	51.65	4.66	23.4	1.34
Settlements	Leemgrond	100.96	13.87	15	2.50
Settlements	Onbepaald	78.91	3.36	15	2.50
Settlements	Oude kleigrond	55.25	30.94	15	2.50
Settlements	Podzolgrond	83.01	4.21	25.6	0.31
Settlements	Rivierkleigrond	125.96	6.7	15	2.50
Settlements	Zeekleigrond	125.54	9.48	15	2.50
Grassland	Brikgrond	78.3	5.47	15	2.50
Grassland	Eerdgrond	87.84	6.47	15	2.50
Grassland	Kalkhoudende zandgrond	58.55	7.65	17.3	0.21
Grassland	Kalkloze zandgrond	86.56	2.76	23.4	1.34
Grassland	Leemgrond	88.91	5.32	15	2.50
Grassland	Onbepaald	105.64	1.65	15	2.50
Grassland	Oude kleigrond	81.12	6.36	15	2.50
Grassland	Podzolgrond	116.07	4.01	25.6	0.31
Grassland	Rivierkleigrond	111.32	3.36	15	2.50
Grassland	Zeekleigrond	113.66	2.77	15	2.50
Wetland	Brikgrond	82.47	12.77	15	2.50
Wetland	Eerdgrond	99.53	17.39	15	2.50
Wetland	Kalkhoudende zandgrond	32.16	5.78	17.3	0.21
Wetland	Kalkloze zandgrond	57.39	5.18	23.4	1.34
Wetland	Leemgrond	112.18	15.41	15	2.50
Wetland	Onbepaald	87.68	3.73	15	2.50
Wetland	Oude kleigrond	61.39	34.37	15	2.50
Wetland	Podzolgrond	92.23	4.68	25.6	0.31
Wetland	Rivierkleigrond	139.95	7.45	15	2.50
Wetland	Zeekleigrond	139.49	10.54	15	2.50

Table 13.5 *Uncertainty ranges for soil carbon fluxes from organic soils*

Land use	Soil type	Soil Flux	S.E.M.
Grassland / Cropland / Settlement	Peat soils	19.03	9.51
Grassland / Cropland / Settlement	Peaty soils	13.02	6.51

13.3.3 Land use related uncertainty

The land use related uncertainty is expressed as a confusion matrix, based on Kramer *et al.* 2015 Kramer and Clement (2015). This matrix provides the pdf of the land use in a pixel, given the classification of the pixel (Table 13.6, from Kramer and Clement 2015, table 2.12). Using these pdfs random alternative maps are generated for each iteration. Although the actual uncertainty in land-use mapping will involve both spatial and temporal auto-correlations, these are not taken into account here due to a lack of data. This confusion matrix is biased from Settlements and Other Land to mainly Grassland, Cropland and Forest. Due to this asymmetry in the confusion matrix, the land use related uncertainty is assessed as the range over iterations with only biomass and soil related uncertainty and iterations with biomass, soil and land use related uncertainty.

Table 13.6 *Confusion matrix for the land-use map (from Kramer and Clement 2015)*

PDF -> Classification	Other Land	Grassland	Cropland	Forest	Wetland	Settlements	Heath	Reed
Other Land	0.94	0.04	-	0.02	-	-	-	-
Grassland	0.00	0.98	0.02	0.00	-	0.00	-	-
Cropland	-	0.03	0.97	-	-	-	-	-
Forest	-	0.01	-	0.99	-	-	-	-
Wetland	-	-	-	-	1.00	-	-	-
Settlements	-	0.07	0.02	0.01	-	0.90	-	-
Heath	-	-	-	-	-	-	1.00	-
Reed	-	-	0.02	-	0.02	-	0.02	0.94

13.4 Monte Carlo simulation

In total 683 iterations are performed for the Monte Carlo analysis. Of these iterations, 1 was the nominal iteration without permutations in the input parameters. Of these iterations, 104 only addressed soil uncertainty, 103 only addressed biomass uncertainty and 104 addressed both soil and biomass uncertainty, making a total of 312 iterations without land-use map uncertainty. An additional 371 runs included land-use map uncertainty (with or without biomass and soil uncertainty)

The number of iterations used for the analysis were based on time constraints. No tests for convergence were performed.

13.5 Total uncertainty

The calculation of the GHG fluxes from LULUCF generate many detailed output. Here only the uncertainty ranges for the main categories in CRF Table 4 are presented for emissions in the year 2014 (Table 13.7).

In general we see that the uncertainty for the different categories varies. For some categories a highly asymmetric uncertainty range occurs. In general the uncertainty in the forest land sink is smaller than the uncertainty in the emissions from other land uses.

Zooming in on the details, it needs to be mentioned that the relative uncertainty is a function of the size of the total emissions or removals reported. Therefore, a large relative uncertainty on a small value can have a minor impact on the total uncertainty. When looking at the contribution of the different categories to the total emissions, we see that Grassland remaining Grassland accounts for 68% of the net emissions and cropland as a whole for 42% of the net emissions, while the Forest remaining Forest accounts for a sink of the size of 35% of the net emissions. The other categories contribute a maximum of 19% (Land converted to Settlements). The category with the largest uncertainty (Land converted to Grassland) only contributes 6% of the total net emissions.

Table 13.7 *Uncertainty range per category for 2014*[12]

Greenhouse gas source and sink categories	**Net CO_2 emissions/removals (min, max)**
4. Total LULUCF	**(-38%, + 64%)**
A. Forest Land	**(10%, + -12%)**
1. Forest Land remaining Forest Land	(11%, + -14%)
2. Land converted to Forest Land	(26%, + -21%)
B. Cropland	**(-39%, + 44%)**
1. Cropland remaining Cropland	(-61%, + 60%)
2. Land converted to Cropland	(-45%, + 61%)
C. Grassland	**(-62%, + 75%)**
1. Grassland remaining Grassland	(-60%, + 68%)
2. Land converted to Grassland	(-220%, + 340%)
D. Wetlands	**(-67%, + 76%)**
1. Wetlands remaining Wetlands	IE,NO
2. Land converted to Wetlands	(-67%, + 76%)
E. Settlements	**(-23%, + 69%)**
1. Settlements remaining Settlements	(-64%, + 53%)
2. Land converted to Settlements	(-17%, + 90%)
F. Other Land (4)	**(-3%, + 152%)**
1. Other Land remaining Other Land	NO
2. Land converted to Other Land	(-3%, + 152%)
G. Harvested Wood Products	(-8%, + 1%)
H. Other *(please specify)*	IE,NE,NO

13.6 Temporal variability in uncertainty

Table 13.7 gives the uncertainty over the numbers calculated for 2014. These uncertainty ranges are not stable over time, as different sources of data have different temporal resolution (Table 13.8). Here again the large uncertainty, and the volatility of this uncertainty, for land converted to grassland is apparent. Again the main cause for this is that the absolute value is small, and thus that a similar uncertainty in absolute values, results in an extreme relative uncertainty around 2010.

[12] A negative maximum implies that the category is a sink.

Table 13.8 *Temporal evolution of the uncertainty ranges by category*

Greenhouse gas source and sink categories	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
4. Total LULUCF	**(-51%, + 68%)**	**(-46%, + 60%)**	**(-46%, + 60%)**	**(-45%, + 59%)**	**(-45%, + 59%)**	**(-45%, + 60%)**	**(-45%, + 61%)**	**(-46%, + 61%)**	**(-46%, + 61%)**	**(-46%, + 62%)**	**(-46%, + 62%)**	**(-45%, + 61%)**	**(-45%, + 61%)**
A. Forest Land	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -14%)**	**(15%, + -13%)**	**(15%, + -13%)**	**(15%, + -13%)**	**(14%, + -13%)**
1. Forest Land remaining Forest Land	(15%, + -13%)	(15%, + -13%)	(14%, + -13%)	(14%, + -13%)	(14%, + -14%)	(14%, + -14%)	(14%, + -14%)	(14%, + - 14%)	(14%, + -14%)	(14%, + -15%)	(14%, + -15%)	(14%, + -15%)	(14%, + -16%)
2. Land converted to Forest Land	(-39%, + 63%)	(-45%, + 65%)	(-53%, + 70%)	(-76%, + 92%)	(-137%, + 153%)	(-939%, + 878%)	(213%, + -170%)	(108%, + -71%)	(81%, + -45%)	(69%, + -34%)	(61%, + -28%)	(56%, + -23%)	(54%, + -22%)
B. Cropland	**(-49%, + 58%)**	**(-48%, + 56%)**	**(-47%, + 55%)**	**(-46%, + 54%)**	**(-44%, + 54%)**	**(-43%, + 53%)**	**(-42%, + 53%)**	**(-41%, + 52%)**	**(-40%, + 52%)**	**(-40%, + 51%)**	**(-39%, + 50%)**	**(-38%, + 50%)**	**(-37%, + 49%)**
1. Cropland remaining Cropland	(-55%, + 68%)	(-55%, + 67%)	(-55%, + 66%)	(-55%, + 65%)	(-55%, + 65%)	(-56%, + 65%)	(-56%, + 65%)	(-57%, + 64%)	(-57%, + 64%)	(-57%, + 64%)	(-58%, + 64%)	(-58%, + 64%)	(-58%, + 64%)
2. Land converted to Cropland	(-152%, + 175%)	(-112%, + 135%)	(-88%, + 107%)	(-73%, + 94%)	(-62%, + 85%)	(-55%, + 77%)	(-49%, + 71%)	(-46%, + 67%)	(-41%, + 63%)	(-37%, + 59%)	(-35%, + 56%)	(-33%, + 54%)	(-32%, + 54%)
C. Grassland	**(-53%, + 69%)**	**(-53%, + 69%)**	**(-54%, + 69%)**	**(-54%, + 70%)**	**(-55%, + 70%)**	**(-55%, + 70%)**	**(-56%, + 70%)**	**(-56%, + 70%)**	**(-56%, + 70%)**	**(-57%, + 70%)**	**(-58%, + 70%)**	**(-58%, + 71%)**	**(-59%, + 71%)**
1. Grassland remaining Grassland	(-56%, + 68%)	(-56%, + 67%)	(-56%, + 67%)	(-56%, + 67%)	(-56%, + 67%)	(-56%, + 67%)	(-56%, + 66%)	(-57%, + 66%)	(-57%, + 66%)	(-57%, + 66%)	(-57%, + 67%)	(-57%, + 67%)	(-57%, + 67%)
2. Land converted to Grassland	(-111%, + 150%)	(-116%, + 154%)	(-123%, + 161%)	(-134%, + 168%)	(-140%, + 175%)	(-150%, + 184%)	(-162%, + 192%)	(-173%, + 204%)	(-186%, + 213%)	(-206%, + 228%)	(-218%, + 251%)	(-246%, + 277%)	(-266%, + 305%)
D. Wetlands	**(-24%, + 27%)**	**(-25%, + 29%)**	**(-27%, + 31%)**	**(-28%, + 33%)**	**(-30%, + 35%)**	**(-32%, + 37%)**	**(-35%, + 39%)**	**(-38%, + 41%)**	**(-41%, + 45%)**	**(-45%, + 50%)**	**(-52%, + 55%)**	**(-58%, + 64%)**	**(-65%, + 73%)**
1. Wetlands remaining Wetlands													
2. Land converted to Wetlands	(-24%, + 27%)	(-25%, + 29%)	(-27%, + 31%)	(-28%, + 33%)	(-30%, + 35%)	(-32%, + 37%)	(-35%, + 39%)	(-38%, + 41%)	(-41%, + 45%)	(-45%, + 50%)	(-52%, + 55%)	(-58%, + 64%)	(-65%, + 73%)
E. Settlements	**(-22%, + 33%)**	**(-22%, + 34%)**	**(-23%, + 34%)**	**(-23%, + 35%)**	**(-23%, + 37%)**	**(-23%, + 38%)**	**(-23%, + 38%)**	**(-23%, + 39%)**	**(-24%, + 39%)**	**(-24%, + 40%)**	**(-24%, + 40%)**	**(-25%, + 41%)**	**(-26%, + 41%)**
1. Settlements remaining Settlements	(-59%, + 58%)	(-59%, + 58%)	(-59%, + 58%)	(-59%, + 57%)	(-59%, + 56%)	(-59%, + 55%)	(-59%, + 55%)	(-59%, + 55%)	(-59%, + 55%)	(-59%, + 54%)	(-59%, + 54%)	(-60%, + 54%)	(-60%, + 54%)
2. Land converted to Settlements	(-20%, + 41%)	(-19%, + 40%)	(-18%, + 39%)	(-17%, + 39%)	(-18%, + 38%)	(-18%, + 40%)	(-19%, + 40%)	(-19%, + 40%)	(-19%, + 41%)	(-18%, + 43%)	(-19%, + 44%)	(-19%, + 45%)	(-20%, + 46%)
F. Other Land	**(-4%, + 119%)**	**(-3%, + 116%)**	**(-3%, + 115%)**	**(-3%, + 113%)**	**(-3%, + 112%)**	**(-3%, + 111%)**	**(-3%, + 111%)**	**(-3%, + 111%)**	**(-3%, + 110%)**	**(-3%, + 110%)**	**(-3%, + 109%)**	**(-3%, + 109%)**	**(-3%, + 109%)**
1. Other Land remaining Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Land converted to Other Land	(-4%, + 119%)	(-3%, + 116%)	(-3%, + 115%)	(-3%, + 113%)	(-3%, + 112%)	(-3%, + 111%)	(-3%, + 111%)	(-3%, + 111%)	(-3%, + 110%)	(-3%, + 110%)	(-3%, + 109%)	(-3%, + 109%)	(-3%, + 109%)
G. Harvested Wood Products	(0%, + - 8%)	(-5%, + 0%)	(-10%, + 0%)	(-8%, + 0%)	(-9%, + 0%)	(-7%, + 1%)	(-4%, + 1%)	(-4%, + 1%)	(-7%, + 1%)	(-2%, + 2%)	(-3%, + 20%)	(-7%, + 1%)	(-6%, + 1%)

Greenhouse gas source and sink categories	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
4. Total LULUCF	**(-44%, + 59%)**	**(-46%, + 62%)**	**(-47%, + 63%)**	**(-46%, + 63%)**	**(-46%, + 63%)**	**(-47%, + 65%)**	**(-45%, + 61%)**	**(-47%, + 64%)**	**(-46%, + 63%)**	**(-45%, + 61%)**	**(-39%, + 65%)**	**(-38%, + 64%)**
A. Forest Land	**(25%, + -20%)**	**(23%, + -21%)**	**(22%, + -20%)**	**(22%, + -20%)**	**(21%, + -21%)**	**(20%, + -20%)**	**(20%, + -20%)**	**(19%, + -18%)**	**(19%, + -18%)**	**(21%, + -19%)**	**(10%, + -12%)**	**(10%, + -12%)**
1. Forest Land remaining Forest Land	(25%, + -25%)	(25%, + -25%)	(25%, + -25%)	(25%, + -25%)	(25%, + -25%)	(25%, + -26%)	(25%, + -26%)	(23%, + -22%)	(23%, + -23%)	(23%, + -23%)	(11%, + -14%)	(11%, + -14%)
2. Land converted to Forest Land	(51%, + -18%)	(34%, + -17%)	(30%, + -16%)	(25%, + -16%)	(22%, + -17%)	(18%, + -17%)	(19%, + -19%)	(20%, + -19%)	(20%, + -19%)	(22%, + -24%)	(23%, + -23%)	(26%, + -21%)
B. Cropland	**(-36%, + 49%)**	**(-40%, + 49%)**	**(-39%, + 49%)**	**(-39%, + 49%)**	**(-38%, + 49%)**	**(-38%, + 49%)**	**(-43%, + 49%)**	**(-43%, + 49%)**	**(-42%, + 48%)**	**(-42%, + 48%)**	**(-40%, + 45%)**	**(-39%, + 44%)**
1. Cropland remaining Cropland	(-59%, + 64%)	(-59%, + 63%)	(-59%, + 62%)	(-60%, + 62%)	(-60%, + 62%)	(-60%, + 62%)	(-60%, + 62%)	(-60%, + 62%)	(-60%, + 61%)	(-60%, + 61%)	(-61%, + 61%)	(-61%, + 60%)
2. Land converted to Cropland	(-31%, + 54%)	(-47%, + 68%)	(-45%, + 66%)	(-44%, + 64%)	(-42%, + 63%)	(-41%, + 62%)	(-54%, + 71%)	(-54%, + 69%)	(-52%, + 67%)	(-51%, + 66%)	(-47%, + 63%)	(-45%, + 61%)
C. Grassland	**(-59%, + 71%)**	**(-67%, + 78%)**	**(-68%, + 78%)**	**(-68%, + 79%)**	**(-69%, + 79%)**	**(-69%, + 80%)**	**(-69%, + 77%)**	**(-69%, + 77%)**	**(-68%, + 76%)**	**(-68%, + 76%)**	**(-62%, + 75%)**	**(-62%, + 75%)**
1. Grassland remaining Grassland	(-57%, + 67%)	(-58%, + 67%)	(-58%, + 67%)	(-58%, + 67%)	(-58%, + 67%)	(-59%, + 67%)	(-59%, + 67%)	(-59%, + 67%)	(-59%, + 67%)	(-59%, + 67%)	(-60%, + 68%)	(-60%, + 68%)
2. Land converted to Grassland	(-288%, + 331%)	(369%, + -320%)	(394%, + -370%)	(424%, + -412%)	(444%, + -469%)	(483%, + -524%)	(1682%, + -1702%)	(-35719%, + 38682%)	(-1358%, + 1499%)	(-700%, + 794%)	(-246%, + 363%)	(-220%, + 340%)
D. Wetlands	**(-74%, + 85%)**	**(-72%, + 76%)**	**(-74%, + 80%)**	**(-76%, + 84%)**	**(-80%, + 86%)**	**(-87%, + 89%)**	**(-76%, + 81%)**	**(-77%, + 82%)**	**(-77%, + 81%)**	**(-78%, + 82%)**	**(-64%, + 73%)**	**(-67%, + 76%)**
1. Wetlands remaining Wetlands												
2. Land converted to Wetlands	(-74%, + 85%)	(-72%, + 76%)	(-74%, + 80%)	(-76%, + 84%)	(-80%, + 86%)	(-87%, + 89%)	(-76%, + 81%)	(-77%, + 82%)	(-77%, + 81%)	(-78%, + 82%)	(-64%, + 73%)	(-67%, + 76%)
E. Settlements	**(-26%, + 42%)**	**(-26%, + 45%)**	**(-25%, + 45%)**	**(-25%, + 46%)**	**(-24%, + 46%)**	**(-24%, + 47%)**	**(-25%, + 47%)**	**(-25%, + 47%)**	**(-24%, + 46%)**	**(-24%, + 46%)**	**(-23%, + 69%)**	**(-23%, + 69%)**
1. Settlements remaining Settlements	(-60%, + 54%)	(-61%, + 53%)	(-62%, + 53%)	(-62%, + 53%)	(-63%, + 53%)	(-64%, + 53%)	(-64%, + 53%)	(-63%, + 53%)	(-63%, + 53%)	(-63%, + 53%)	(-63%, + 53%)	(-64%, + 53%)
2. Land converted to Settlements	(-21%, + 46%)	(-19%, + 52%)	(-20%, + 53%)	(-20%, + 54%)	(-20%, + 55%)	(-21%, + 57%)	(-21%, + 58%)	(-21%, + 58%)	(-20%, + 58%)	(-19%, + 58%)	(-18%, + 89%)	(-17%, + 90%)
F. Other Land	**(-3%, + 109%)**	**(-4%, + 125%)**	**(-4%, + 122%)**	**(-4%, + 120%)**	**(-4%, + 118%)**	**(-4%, + 116%)**	**(-3%, + 107%)**	**(-3%, + 106%)**	**(-3%, + 104%)**	**(-3%, + 102%)**	**(-3%, + 151%)**	**(-3%, + 152%)**
1. Other Land remaining Other Land	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2. Land converted to Other Land	(-3%, + 109%)	(-4%, + 125%)	(-4%, + 122%)	(-4%, + 120%)	(-4%, + 118%)	(-4%, + 116%)	(-3%, + 107%)	(-3%, + 106%)	(-3%, + 104%)	(-3%, + 102%)	(-3%, + 151%)	(-3%, + 152%)
G. Harvested Wood Products	(-8%, + 1%)	(-10%, + 1%)	(-8%, + 1%)	(-10%, + 1%)	(-12%, + 0%)	(-9%, + 1%)	(-5%, + 1%)	(-4%, + 1%)	(-6%, + 1%)	(-6%, + 1%)	(-9%, + 1%)	(-8%, + 1%)

13.7 Partial uncertainties

To estimate the relative contribution of the different uncertainty sources to the total uncertainty estimate, calculations were performed with the specified uncertainties blocked. Partial uncertainties are discussed here for 2014 (Table 13.9). To understand the partial uncertainties, it must be said that they are calculated in two different ways. For the biomass and the soil based partial uncertainties, an uncertainty range is determined by a Monte Carlo simulation focussed on these uncertainties. The minimum and maximum values of the 95% interval of the results is then expressed relative to the minim and maximum values of the 95% interval of a Monte Carlo simulation with all uncertainties included. Thus, this minimum and maximum can be more than 100% if the partial uncertainty is higher than the total uncertainty (due to the effects of different uncertainties extinguishing each other). The partial uncertainty caused by the inclusion of the map uncertainty is calculated by extracting the uncertainty of a Monte Carlo simulation focussed on both the biomass and the soil uncertainty from the total uncertainty. The remaining uncertainty is interpreted as due to the uncertainty in the map.

Table 13.9 *Partial uncertainties per category as percentage of the total uncertainty*

Greenhouse gas source and sink categories	**Biomass 2014**	**Soil 2014**	**Map 2014**
4. Total LULUCF	**(8%, 15%)**	**(65%, 111%)**	**(17%, 0%)**
A. Forest Land	**(103%, 130%)**	**(16%, 21%)**	**(0%, 0%)**
1. Forest Land remaining Forest Land	(98%, 147%)	(0%, 0%)	(4%, 0%)
2. Land converted to Forest Land	(90%, 74%)	(77%, 66%)	(4%, 22%)
B. Cropland	**(73%, 105%)**	**(87%, 90%)**	**(1%, 0%)**
1. Cropland remaining Cropland	(0%, 0%)	(116%, 106%)	(0%, 4%)
2. Land converted to Cropland	(77%, 131%)	(43%, 55%)	(29%, 0%)
C. Grassland	**(30%, 30%)**	**(125%, 103%)**	**(0%, 0%)**
1. Grassland remaining Grassland	(0%, 0%)	(127%, 100%)	(0%, 8%)
2. Land converted to Grassland	(79%, 102%)	(49%, 65%)	(23%, 0%)
D. Wetlands	**(95%, 126%)**	**(67%, 81%)**	**(3%, 0%)**
1. Wetlands remaining Wetlands			
2. Land converted to Wetlands	(95%, 126%)	(67%, 81%)	(3%, 0%)
E. Settlements	**(14%, 45%)**	**(44%, 123%)**	**(58%, 0%)**
1. Settlements remaining Settlements	(0%, 0%)	(137%, 83%)	(0%, 9%)
2. Land converted to Settlements	(14%, 78%)	(26%, 139%)	(73%, 0%)
F. Other Land	**(1%, 76%)**	**(2%, 109%)**	**(98%, 0%)**
1. Other Land remaining Other Land			
2. Land converted to Other Land	(1%, 76%)	(2%, 109%)	(98%, 0%)
G. Harvested Wood Products	**(123%, 12%)**	**(0%, 0%)**	**(0%, 86%)**

In analysing these uncertainties we see that the partial uncertainty can be similar in size. But that the relative contribution of the partial uncertainty can be highly biased. Uncertainty in biomass is mainly responsible for the uncertainty in forest land, and the land converted to the other land uses. Although more on the maximum of the range than on the minimum of the range. This is due to the relatively large biomass on forested lands, and the effect that this biomass has on the emissions of land converted.

The uncertainty in soil parameters has a large impact on the total emissions. All of the maximum range can be accounted for by these uncertainties. While this is only a small contribution to the uncertainty related to forest land, it is the main source of uncertainty for the Cropland and Grassland category. As such it also has a major contribution to the land converted to other land uses. For Other Land and Settlements this contribution is mainly to the minimum range, rather than the maximum range.

The uncertainty that cannot be explained by the uncertainty in biomass and soil parameters is attributed to the uncertainty in the land-use maps. As the confusion matrix of the land-use maps is biased, the effect of this uncertainty on the total uncertainty is biased. Especially the Other Land and the Settlements category experience a skewed uncertainty with the minimum range mainly determined by the uncertainty in the land-use maps.

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This report provides the complete methodological description and gives background information on the Dutch National System for Greenhouse Gas Reporting of the LULUCF sector for the UN Framework Convention on Climate Change. It was prepared as part of the work for the Netherlands Release and Transfer Register. Methodologies are elaborated and applied within the LULUCF task group and are reviewed by the Release and Transfer Register. The methodologies follow the 2006 IPCC Guidelines, with additional use of the 2013 Wetlands Supplement to the 2006 IPCC Guidelines and the 2013 IPCC Supplementary Guidance for LULUCF reporting under the Kyoto Protocol.

The work was supported and supervised by Harry Vreuls and Natalie Bakker of the Netherlands Enterprise Agency (RVO) and Klaas de Vries and Stella Münninghoff of the Ministry of Agriculture, Nature and Food Quality.

This report was reviewed by Anjo de Jong of Wageningen Environmental Research and Natalie Bakker of the Netherlands Enterprise Agency.

Approved by External contact person

position: Policy Officer

name: Pauline Buffing

date: 9-3-2023

Approved by Internal contact person

name: Erwin van Boekel

date: 14-3-2023

Annex 1 Data files used

A1.1 National Forest Inventories

For calculating carbon stock changes in forest biomass data from four National Forest Inventories (NFI) are used, covering the period 1990-2021: HOSP, NFI-5, NFI-6 and NFI7.

HOSP
The HOSP (Hout Oogst Statistiek en Prognose oogstbaar hout) inventory was designed in 1984 and conducted between 1988 and 1992 and 1992-1997 (Schoonderwoerd and Daamen 1999). For the LULUCF calculations only the data from the time period 1988-1992 were used, as these best represent the situation in the base year 1990. The HOSP was not a full inventory and its methodology was also different from earlier and later forest inventories. It was primarily designed to get insight in the amount of harvestable wood, but it still provides valuable information on standing stocks and increment of forest biomass. In total 3,448 plots were characterised by age, tree species, growing stock volume, increment, height, tree number and dead wood. Each plot represented a certain area of forest ('representative area') of between 0.4 ha and 728.3 ha, and together they represented an area of 310,736 ha. From this total number of plots, 2,500 measurement plots representing 285.000 ha were selected for re-measurements in subsequent years. After 1997 only 2 annual re-measurements were carried out on about 40% of the original sample plots (Schoonderwoerd and Daamen 2000).

QA/QC
Instructions for the measurement in the HOSP were defined in a working paper (Anonymous 1988). According to Hinssen (2000) these instructions were very clear, leaving little room for alternative interpretations, which should guarantee consistent results over time. In every measurement year 2-3 days were included to randomly check measurements carried out during that year. Trees that were measured during a census were also always measured during subsequent censuses. The project coordinator regularly checked results from the database. Suspicious data and errors were checked in the field and results of these checks were discussed with the field staff and if needed the measurement instructions were improved (Daamen and Stolp 1997).

NFI-5, Meetnet Functievervulling bos (MFV)
The fifth National Forest Inventory (NFI-5) in Dutch is also known as 'Meetnet Functie Vervulling Bos' (MFV). It was designed as a randomized continuous forest inventory. In total 3622 plot recordings with forest cover were available for the years 2001, 2002, 2004 and 2005 (2003 was not inventoried because of a contagious cattle disease). Apart from the live and dead wood characteristics, in 2004 and 2005 litter layer thickness was measured in stands on poor sand and loss (Daamen and Dirkse, 2005).

QA/QC
The density of sample points in the monitoring network resulted in an estimated confidence level of plus or minus 10% in the most forest rich provinces (Dirkse *et al.* 2007). The confidence levels and quality of the methodology were tested in a pilot study by Dirkse and Daamen (2000). Further justification for the methodologies used during the collection of data for the NFI-5, and the subsequent analysis of the data is provided in an Annex to Dirkse *et al.* (2007).

NFI-6
Between September 2012 and September 2013 the sixth National Forest Inventory (NFI-6; Zesde Nederlandse Bosinventarisatie, NBI6) was conducted (Schelhaas *et al.* 2014). This inventory was implemented with the aim to also support reporting of carbon stock changes in forests to the UNFCCC and Kyoto Protocol. To facilitate the direct calculation of carbon stock changes between the NFI-5 and NFI-6, the methodology of the NFI-6 closely followed the methodology of the NFI-5 (see Schelhaas *et al.* 2014). The extent of forest land on the 2013 LULUCF map was used as a basis for defining the

sampling area. Sampling is done on a fixed 1 x 1 km raster (i.e. 1 sample point per 100 ha) with 3190 sample plots measured. This included 1235 permanent sample plots that were also measured during NFI-5.

QA/QC

The field measurements were carried out using a digital tree calliper that directly recorded the measurements in a database. The software then directly compared and validated the information with information from the NFI-5 inventory. In this way erroneous and impossible values would be signalled and could be checked and corrected while still in the field. After uploading of the data from the callipers into the inventory database the data were again checked for impossible combinations of values and missing values.

NFI-7

The seventh National Forest Inventory (NFI-7; Zevende Nederlandse Bosinventarisatie, NBI7) was carried out between June 2017 and July 2021 (Schelhaas et al. 2022b). Again, the methodology largely followed the methodology of the earlier inventories, and at least also included the same relevant measurements for assessing carbon stocks as done in the previous NFIs. This guarantees consistent calculations of carbon stock changes over time. In NFI-5 and NFI-6, half of the plots were permanent sample plots, while in NFI-7 all sample plots were made permanent sample plots. All NFI-6 permanent plots were re-measured during the NFI-7 campaign, except for those plots that according the 2017 LULUCF map had changed to other land uses in the meantime or were not accessible. New sample plots were added for newly established forest lands (according the 2017 map) that were on the 1x1 km sampling raster used for the NFI (see NFI-6 above). As a result, during the NFI-7 a total of 3174 sample plots were measured, of which 1387 were also measured during NFI-6.

QA/QC

The NFI design changed in 2017 from irregular intervals in NFI-5 and NFI-6 to a continuous 5-year cycle starting with NFI-7. One reason for this change is to guarantee the quality of the work, both in the field and in the design and data processing. Having a continuous flow of work allows to keep the same people involved, keep their knowledge up-to-date, and decreases the risk of knowledge loss if people leave in between the inventory cycles. Field workers in NFI-7 were partly the same as in NFI-6 (accounting for about 60% of the measurements), while the new people were trained by the ones involved in NFI-6. At the start of each measurement season a kick-off meeting was scheduled to make sure measurement methodologies were aligned among the field teams. The field measurements were carried out using a digital tree calliper that directly recorded the measurements. The calliper software then directly compared and validated the information with information from the previous NFI-6 inventory. In this way erroneous and impossible values would be signalled and could be checked and corrected while still in the field. After uploading of the data from the callipers into the central inventory database the data were again checked for impossible combinations of values and missing values. A random sub-sample of the measurement plots (about 4%) were re-measured by the QA/QC coordinator. The results of these checks were then used to further align the measurement procedures of the different field teams. In 2021 an external evaluation was held of the NFI-7 methods and procedures (Mohren et al. 2021), confirming the quality of the work and giving recommendations for further improvements, mostly on improving the documentation of the procedures.

A1.2 Soil information

Soil map

The soil map of the Netherlands with a scale of 1:50.000 provides detailed information on important characteristics of the soil profile up to a depth of 120 cm. The units applied in this soil map follow those provided in the Dutch system for soil classification (Systeem voor Bodemclassificatie, see de Bakker and Schelling 1989) complemented with a code for the groundwater table. The information used in the map is collected between 1960 and 1995 (de Vries et al. 2003) and was dated at 1977, the average year for all mapping units.

QA/QC
A validation of the peat areas by de Vries et al. (2010) showed that as a result of the oxidation of organic soils, particularly in the drained agriculture areas the extent of peat and peaty soils was decreasing. It appeared that areas with shallow peat layers and peaty soils are changing soil type. Peat soils change into peaty soils and peaty soil become more mineral soils. In response to this finding, in 2009 additional research started to assess and improve the reliability of the information for peat areas in the Netherlands for which the information was possibly outdated (de Vries et al. 2014). This work included a total area of 300,000 ha and focussed on all peaty soils and areas with shallow peat soils. Based on the results up to 2014 (in de Vries et al. 2014) the soil map was updated (see Chapter 3.5).

Soil information system
Soil information that is collected for the purpose of soil mapping is collected and saved in a soil information system (Bodemkundig Informatie Systeem, BIS) of Wageningen UR. BIS contains about 330.000 descriptions of soil profiles that provide for specific locations an overview of the development of layers in the profiles. A dataset with samples for national soil mapping (Landelijke Steekproef Kaarteenheden – LSK, Finke *et al.* 2001) is also part of the BIS system. Sampling locations were assigned using a stratified sampling scheme. The samples were taken during 1990 – 2001 and include groundwater table and soil chemical properties. With the assumption that 50% of organic matter contains of carbon, the soil carbon content can be inferred from information on soil organic matter, thickness of soil layers and bulk density functions (de Groot et al. 2005; Kuikman et al. 2003). The LSK data were used to assess the variability in the soil characteristics within the mapped units using the soil classification system.

Soil carbon map
The soil carbon map provides spatially explicit information on soil carbon content in the upper 30 cm of the soil. The soil carbon map is derived based on the sources mentioned in A1.2.1 the soil map, and A1.2.2 BIS and LSK and with additional information from additional monitoring of forest soils including chemical analyses of litter, humus profiles, mineral soil information and groundwater quality. Average soil carbon stocks were assessed for the top 30 cm soil layer. Because in organic soils oxidation can occur also in deeper soil layers (Kuikman *et al.* 2003), for soils containing more than 50% organic matter in the upper 80 cm, the carbon stock in the top 120 cm were calculated. The spatially explicit soil carbon map then was generated from the calculated carbon content per strata based on hydrological and soil characteristics applied to the 1:50,000 soil map (A1.2.1)

QA/QC
In de Groot et al. (2005) the results based on the LSK and LGN 1990 were compared against results based on the standard procedure in the IPCC guidelines. The results indicated that the methodology using the soil carbon map should be the preferred methodology. The system was reviewed in 2006 by external experts (van den Wyngaert et al. 2006), which resulted in different improvements that are described in van den Wyngaert et al. (2009).

Lesschen *et al.* (2012) provides more insight in quantifying potential changes in carbon stocks in Dutch soils. Based on a new stratification of the LSK information the carbon stock for the most important land use and soil types were assessed. The results showed that overall all emissions and removals are compensated among the most important land-use changes. The total net CO2 emissions from mineral soil therefore are around zero, which is the same as currently reported by the Netherlands. Since soil types and soil properties change over time as a result of soil and water management, regularly updated soil maps will be needed for accurate calculation of emissions from soils.

Annex 2 Land-use and soil maps

A2.1 Land-use statistics

Table A2.1 gives per land-use category the area (in ha) and coverage as percentage of the total land area of the Netherlands as identified on the land-use maps for 1970, 1990, 2004, 2009, 2013, 2017 and 2021.

Table A2.1 *Land-use statistics based on the 1970, 1990, 2004, 2009, 2013, 2017 and 2021 maps.*

Land use	1970		1990		2004	
	Area (ha)	% of total	Area (ha)	% of total	Area (ha)	% of total
Forest	329,333	7.9	362,249	8.7	370,196	8.9
Cropland	956,208	23.0	1,019,682	24.5	939,885	22.6
Grassland	1,629,331	39.2	1,458,389	35.1	1,360,428	32.7
Trees outside forest	19,835	0.5	20,801	0.5	22,206	0.5
Heath land	54,070	1.3	49,573	1.2	47,923	1.2
Wetland	775,212	18.7	773,494	18.6	781,935	18.8
Reed	7,907	0.2	20,843	0.5	27,126	0.7
Settlements	341,552	8.2	409,602	9.9	566,522	13.6
Other Land	40,747	1.0	39,562	1.0	37,974	0.9
Total	4,154,195	100	4,154,195	100	4,154,195	100

Land use	2009		2013		2017		2021	
	Area (ha)	% of total	Area (ha)	% of total	Area (ha)	% of total	Area (ha)	% of total
Forest	373,645	9.0	375,912	9.0	365,726	8.8	363,801	8.8
Cropland	925,126	22.3	944,597	22.7	870,559	21.0	836,710	20.1
Grassland	1,342,622	32.3	1,295,875	31.2	1,355,021	32.6	1,387,068	33.4
Trees outside forest	22,086	0.5	21,572	0.5	21,256	0.5	20,563	0.5
Heath land	49,134	1.2	50,110	1.2	52,299	1.3	51,103	1.2
Wetland	787,796	19.0	796,361	19.2	795,646	19.2	796,953	19.2
Reed	25,950	0.6	26,258	0.6	26,700	0.6	26,450	0.6
Settlements	589,323	14.2	605,751	14.6	627,360	15.1	633,036	15.2
Other Land	38,512	0.9	37,759	0.9	39,628	1.0	38,511	0.9
Total	4,154,195	100	4,154,195	100	4,154,195	100	4,154,195	100

A2.2 Land-use maps

The land-use maps 1990, 2004, 2009, 2013 and 2017 are presented on the next pages (Figures A2.1 to A2.6). More information on these maps is provided in Chapter 3 and in Kramer et al. (2007), Kramer and van Dorland (2009), Kramer et al. (2009), Kramer and Clement (2015), Kramer and Clement (2016), Kramer (2019) and Kramer and Los (2022).

Figure A2.1 *Land-use map of 1 January 1970*

Figure A2.2 *Land-use map of 1 January 1990*

Figure A2.3 *Land-use map of 1 January 2004*

Figure A2.4 *Land-use map of 1 January 2009.*

Figure A2.5 *Land-use map of 1 January 2013.*

Figure A2.6 *Land-use map of 1 January 2017. The grey arrow indicates the location of the newly reclaimed area (Maasvlakte 2) – compare with the 1990 map (Figure A2.1). On the 2013 map (Figure A2.4) the area is already partly changed from open water to Other Land and Settlements.*

Figure A2.7 *Land-use map of 1 January 2021.*

A2.3 Soil maps

Spatial distribution of mineral and organic soil types is taken from two different versions of the digital soil map of the Netherlands and one organic soil map. The original version is based on soil mapping that was carried out over the period 1960-1995 (Figure A2.8, based on de Vries et al. 2003) and on average is dated at 1 January 1977. De Vries et al. (2010) showed that the areas of organic soils (peat and peaty soils) are decreasing as a result of the oxidation of the organic soils, particularly in the drained agricultural areas on organic soils. Therefore, a new soil map was produced, dated 1 January 2014, with particular attention to peat and peaty soils (Figure A2.9, based on de Vries et al. 2003 and 2014). To be able to assess the extent of organic soil oxidation after 2014, a forecast map of the extent of peat and peaty soils in 2040 is used (Figure A2.10, based on Erkens et al. 2021).

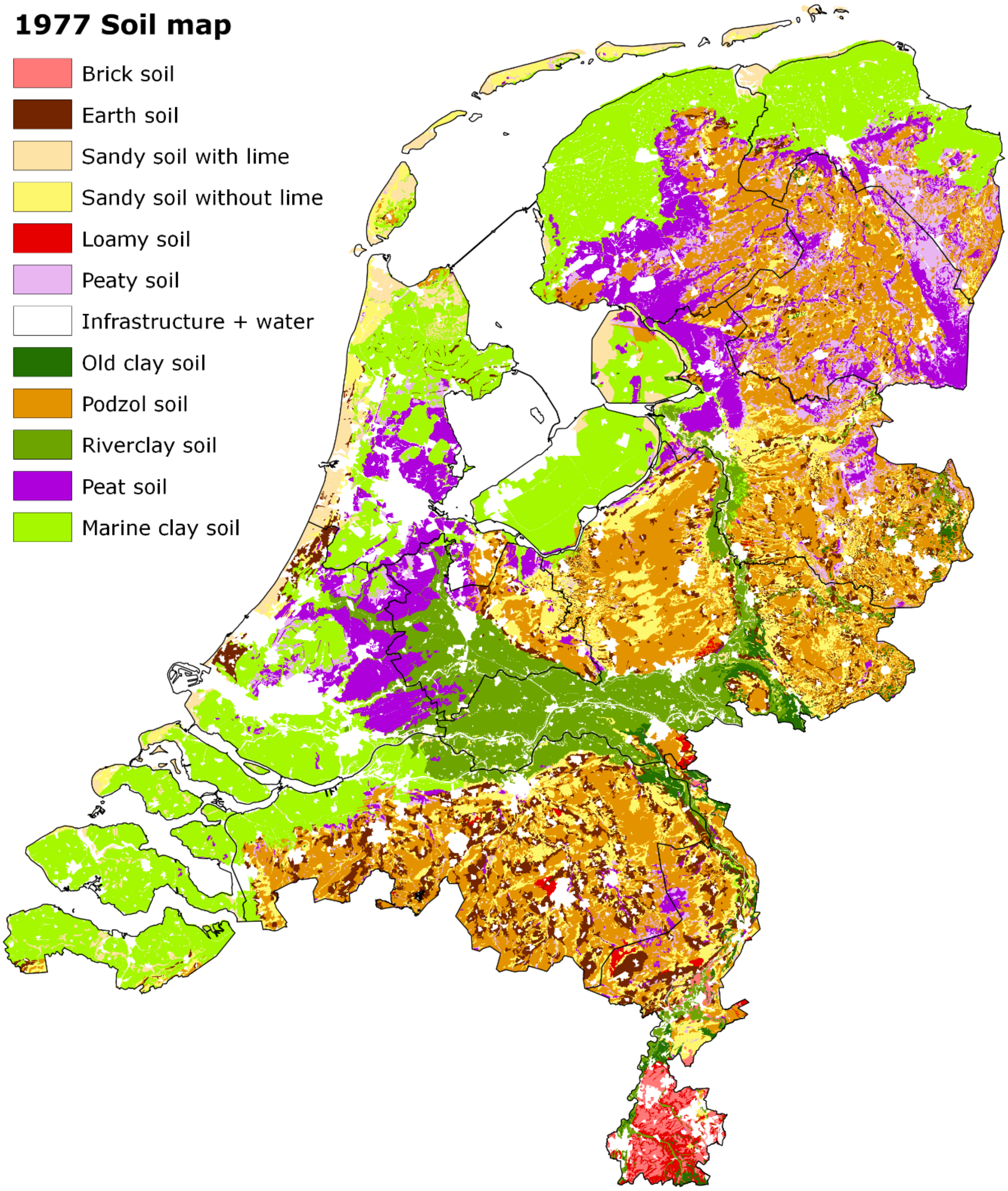

Figure A2.8 *Soil map of 1 January 1977.*

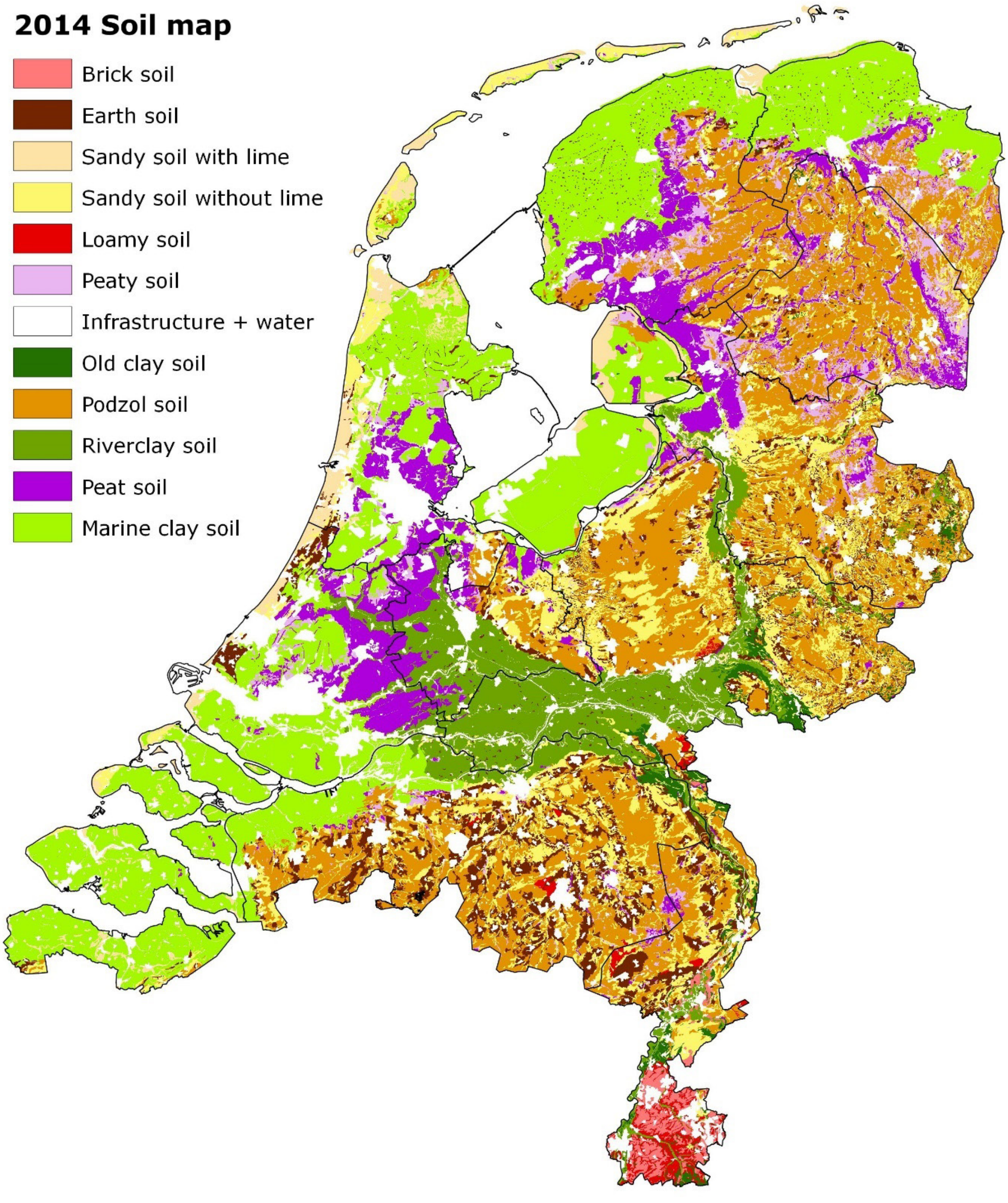

Figure A2.9 *Soil map of 1 January 2014.*

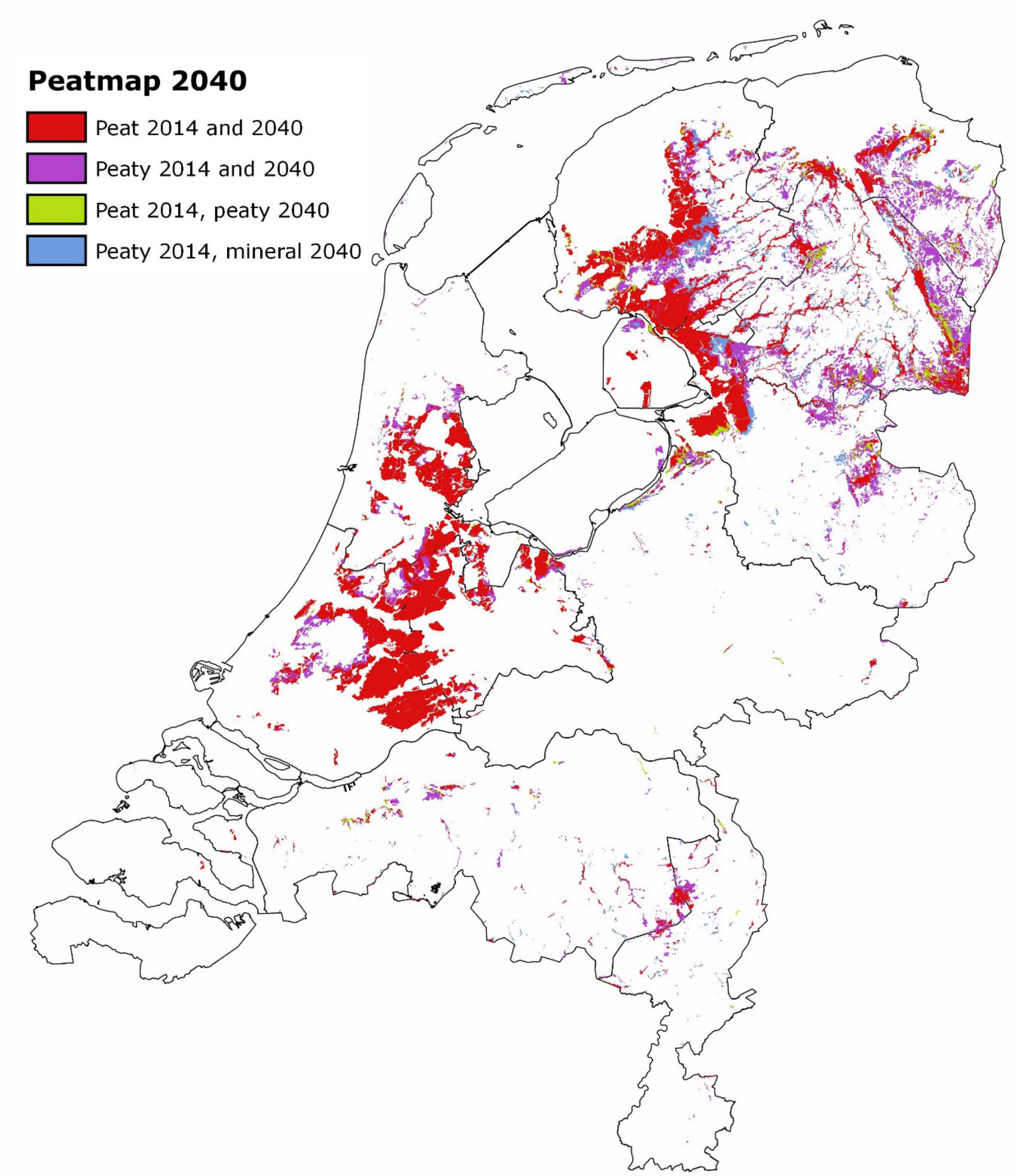

Figure A2.10 *Organic soil forecast map of 2040.*

Annex 3 Harvest statistics

A3.1 Introduction

Roundwood harvests from forests are calculated based on the wood balance inferred from National Forest Inventories in combination with information on roundwood harvests in FAO statistics.

The roundwood harvested from forests consists of two major components; roundwood harvested for industrial purposes, reported as Industrial Roundwood in the FAO statistics (item code 1865), and roundwood harvested for fuelwood, reported under Wood fuel (item code 1864). The quantity of industrial roundwood production in the FAO statistics is determined annually through a questionnaire to the major woodworking industries.

Until 2015 the category Wood fuel consisted mainly of fuelwood used by households. This amount is very difficult to estimate, not only due to the fact that it concerns many households with very variable consumption patterns, but also because wood fuel can originate not only from roundwood from the forest, but also from large branches and residues in the forest, as well as landscape and garden maintenance. Before 2003, the amount of Wood fuel originating from roundwood harvested in the forest was estimated annually by an expert. For the period 2003-2013 a fixed amount of 290,000 m^3 underbark was applied, also based on expert judgement. For 2014, this amount was estimated at 357,000 m^3, to account for increased use of wood fuel also in more industrial applications.

In 2016, while preparing the NIR over 2015 it was observed that total roundwood production in FAO statistics almost doubled (from 1.25 million m^3 in 2014 to 2.25 million m^3 in 2015, see Figure A3.1). A check with the organisation that prepares the Joint Forest Sector Questionnaire that is used for reporting forestry statistics to various UN statistics, including the FAO forest production statistics, learned that this was a result of a new method to assess the amount of wood fuel production in the Netherlands. While until 2015 the produced amount of wood fuel was based on an expert judgement, from 2015 onwards the results of a new household survey were included, with an estimated total amount of Wood fuel consumed of 1,397,000 m^3. This includes all sources in and outside forests, and no estimation is given how much of this quantity is roundwood harvested from the forest.

The information on industrial roundwood as generated through the Joint Forest Sector Questionnaire and reported in the FAO statistics is considered to be reliable and therefore will be used as such. However, given the uncertainties associated with fuel wood in the FAO statistics total volumes of roundwood harvests are estimated using information on the wood balance from National Forest Inventories. Subsequently the fuel wood harvests are calculated as the difference between the total roundwood harvests and industrial roundwood harvest.

A3.2 Analyses of roundwood production

With observations from permanent plots that were assessed in both the NFI-5 (measured 2001-2005) and NFI-6 (2013) national forest inventories, it was possible to generate a wood balance providing the total amount of roundwood that is annually felled in the forest. For the period 2003-2013 this was estimated at 1.267 million m^3 overbark per year (Schelhaas et al. 2014). Further investigation, however, indicated that this estimate was probably too low because it does not correct for the growth of the trees in the period between the initial measurement and felling. Trees felled in 2003 have not grown until harvest, but trees that were harvested in 2013 had an additional 10 years of growth before felling. Hence, on average the felled trees have grown 5 years before they were harvested. If this is included the annually felled volume is estimated at 1.528 million m^3 roundwood overbark (+20.6%). Of the felled roundwood 6% is left in the forest, and 12% of the overbark volume is bark (see Chapter 4.2.1). With these conversions the estimated volume of annually produced roundwood is 1.264 million m^3 underbark for the period 2003-2013. For this same period 2003-2013, the FAO reports an average annual production of 761,543 m^3 (underbark) of industrial roundwood. The difference with the total amount of roundwood then results in an average production of 502,400 m^3 (underbark) of wood fuel from forests.

We estimated the wood fuel produced from forests for the period 2014-2021 in the same way. The total wood felled in forests between NFI-6 and NFI-7 (2017-2021) is estimated at 1.31 million m^3 yr^{-1}, including the correction for growth between measurement and felling (Schelhaas et al. 2022). This is equal to 1.084 million m^3 yr^{-1} removals under bark. The reported industrial roundwood production for this period is 792,000 m^3 yr^{-1}, and thus leads to an estimated average wood fuel production from forests of 292,000 m^3 yr^{-1}.

Since the wood balance from the forest inventories can only give an average total production, the estimated average harvest for wood fuel is the same over the whole period between the NFIs. However, because the wood harvested as industrial roundwood adds to the HWP pool every year it would be important to maintain the annual variation in the reported FAO statistics for industrial roundwood. Therefore, for each year the average annual fuel wood production (i.e. 502,400 m^3 for the period 2003-2013 and 292,000 m^3 for the period 2014-2021) is added to the industrial roundwood production in that year as provided by the FAO statistics (Figure A3.1 and Table A3.1).

As long as no new information from forest inventories is available, the estimated average amount of wood fuel production is maintained from the period before.

Furthermore, we need to know the ratio between conifers and broadleaves in the harvested roundwood. Before 2016, this was derived directly from the FAO data. However, the fuelwood harvested from the forest as estimated above does not allow to distinguish the share of conifers and broadleaves. Therefore, we replaced the coniferous fraction as calculated using the FAO data by the fraction of conifers in the harvest as reported by the respective NFI's, i.e. 64.0% for the period 2003-2013 (Schelhaas et al. 2014) and 64.2% for the period 2014-2021 (Schelhaas et al. 2022).

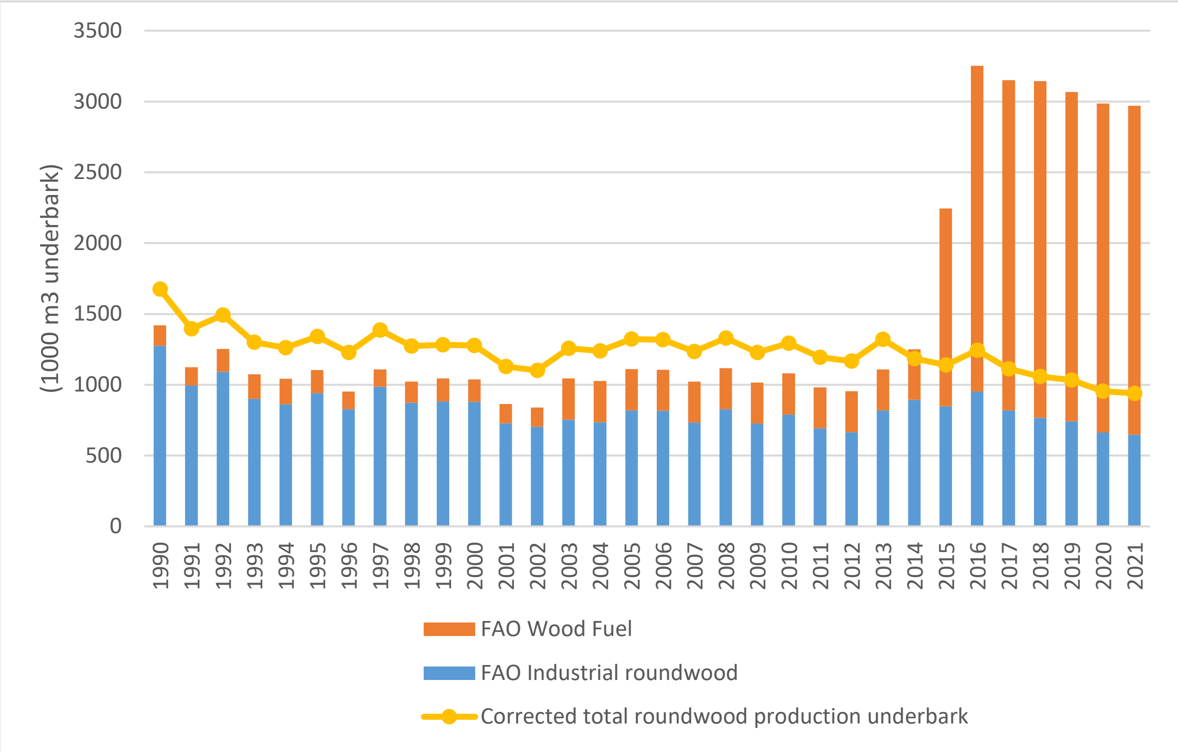

Figure A3.1 *Annual production of roundwood in the Netherlands. Dark bars represent production of industrial roundwood from FAO statistics, light coloured bars represent the amount of wood fuel from FAO statistics. The two together are the total volume of harvested roundwood from FAO statistics. The dots represent the total roundwood production with application of the approach using NFI data.*

Given the underestimate of Wood fuel harvested from the forest for the period 2003-2013, it seems likely that also the volume of harvested wood fuel for the period 1990-2002 is underestimated in the FAO statistics. We lack an inventory with permanent sample plots for this entire period. Before 2000, the HOSP system was in use to provide roundwood production estimates, based on permanent sample plots that were re-measured every 5 years. Reporting was rather irregular, and there is no good documentation available of procedures to arrive at these estimates, and definitions of the figures it produced. A concise overview is given by the "Compendium voor de Leefomgeving" (CLO 2007), with numbers for annual roundwood felling in the forest for the years 1990, 1995, 1996, 1997, 1998, 1999, 2002 and 2005. For each of these years we estimated the production of Wood fuel as described above. The value for 1990 yielded a negative amount of Wood fuel and was therefore discarded. Perhaps this is influenced by a large storm damage that occurred that year. We also omitted the year 2005 because that is already covered in the correction for the period 2003-2013. For the remaining years, we estimate an average amount of 399,000 m^3 Wood fuel (underbark) must have been produced, compared to a reported amount of 143,000 m^3.

Implementation in LULUCF reporting

For the period 1990-2002, the amount of Wood fuel produced as reported in the FAO statistics (149,000 m^3) will be replaced by the calibrated amount for the years where we have information (399,000 m3). For the period 2003-2013 we replace the amount of Wood fuel produced as reported in the FAO statistics (290,000 m^3) by the calibrated amount (520,000 m^3).

Table A3.1 *Volumes of industrial roundwood harvests in FAO statistics, estimated volumes of wood volumes based on the wood balance from the NFI's and the resulting total harvested roundwood volume (1000 m^3 underbark).*

Year	**FAO Industrial roundwood**	**Wood fuel based on wood balance from NFI's (1000 m^3 underbark)**	**Total roundwood**
1990	1275	399(1	1674
1991	996	399(1	1395
1992	1092	399(1	1491
1993	900	399(1	1299
1994	863	399(1	1262
1995	941	**399(1**	1340
1996	829	**399(1**	1228
1997	986	**399(1**	1385
1998	873	**399(1**	1272
1999	882	**399(1**	1281
2000	879	399(1	1278
2001	729	399(1	1128
2002	703	**399(1**	1102
2003	754	**502(2**	1256
2004	736	**502(2**	1238
2005	820	**502(2**	1322
2006	817	**502(2**	1319
2007	732	**502(2**	1234
2008	827	**502(2**	1330
2009	726	**502(2**	1229
2010	791	**502(2**	1293
2011	692	**502(2**	1194
2012	665	**502(2**	1167
2013	818	**502(2**	1321
2014	894	292	*1186*
2015	849	292(3	*1141*
2016	952	292(3	*1244*
2017	819	292(3	*1112*
2018	766	292(3	*1058*
2019	742	292(3	*1034*
2020	662	292(3	*954*
2021	647	292(3	*940*

1. Calibrated based on the calibrated average for 1995-1999 and 2002 from CLO (2007) data. The years on which the average is based are provided in bold.
2. Average based in the wood balance from the forest inventories for 2003-2013. In bold the years on which the average was based.
3. Average is based on the wood balance from the forest inventories from 2013-2021.

Annex 4 Overall description of the forests and forest management in the Netherlands and the adopted national policies

A4.1 Dutch forests

The forested area in the Netherlands in 2017 was 365.5 kha, which is 9% of total area included under LULUCF. Current forest stands are mostly planted mature stands. After almost all forests had been degraded or cut from the Middle Ages until the 19th century, from the end of the 19th century onward reforestation began, resulting in the forest area to date. The largest part of the forested area in the Netherlands was planted using regular spacing and just one or two species in even-aged stands, with wood production being the main purpose. A change towards multifunctional forests that serve multiple purposes (e.g. nature conservation, recreation and wood production) was started in the 1970s, and has had an impact on the management and appearance of these even aged stands.

Dutch forests are dominated by Scotch Pine (32%) that was introduced to reclaim heathland and inland driftsands in the 19th century and first half of the 20th century. The dominance of unmixed coniferous stands is gradually decreasing in favour of mixed and broadleaved stands. In the NFI-6 about 50% of the Dutch forests is categorised as mixed (i.e. dominant species makes up less than 80% of the stand) (Schelhaas et al. 2014). Natural regeneration plays an important role in the transformation process from the even-aged, pure stands into stands with more species and more age classes.

A4.2 Sustainable forest management

Most of the forest area in the Netherlands is considered to be managed according to sustainable forest management principles. In general, forest in the Netherlands is protected by a set of laws and (mostly spatial planning) regulations both on a national, provincial and municipal level. The whole forest area in the Netherlands is protected by the forest act which aims to prevent the forest area from decreasing. Only after thorough weighing of different public interests it can be decided to change the land-use destination from forest land to other land-uses like infrastructure or settlement. In such cases the deforestation needs to be compensated with afforestation of an equal area elsewhere. The exception to these rules is when conversion to priority nature takes place on the basis of ecological arguments, like on the basis of Natura 2000 management plans. In such cases forest conversion can take place without compensation.

Additionally sustainable forest management is one of the criteria in the nature subsidy scheme (below) that is in place in the Netherlands and from which most of the forest owners receive subsidies (FAO 2014). Apart from laws, regulations and subsidies, the maintenance and enhancement of forest resources is also fostered through for instance policy documents, education, communication and information, monitoring and research and development of knowledge (Hendriks 2016).

Third party independent forest certification shows an increasing trend in the Netherlands (FAO 2014). By the end of 2017 about 47% (171 kha)[13] of the Dutch forest area was certified. More than 98% of this certified forest area was FSC certified, and the remaining certified forest area had a PEFC certificate. In the Netherlands there is no obligation for either public or private forest owners to have a forest management plan. The availability of long term management plans is assumed for the total forest area owned and managed by public organisations and nature conservation organisations, and for about one third of the

[13] http://www.bosenhoutcijfers.nl/nederlands-bos/boscertificering/ (accessed on 22 November 2018)

private forest owners (FAO 2014). Since forest management plans are required by FSC and PEFC certification all certified forests will have one.

The national government also has adopted policies that directly or indirectly stimulate sustainable production and use of wood. For instance the national government commits to procure 100% sustainable timber through a set of clear criteria for procurement. The Dutch Timber Procurement Assessment Committee (TPAC) assesses whether timber certification systems meet these criteria and advises the responsible Dutch Ministry of Infrastructure and Environment (I&M) on the outcome. Three certification systems have been accepted at this moment: PEFC, FSC and MTCS (see Hendriks 2016). These rules apply both to domestically produced timber as well as to imported timber.

A4.3 Nature policy and subsidies

Over the past decades, forest policy in the Netherlands has been integrated into the nature policy, which reflects the change towards multi-purpose forests in which more functions are combined (e.g. nature, recreation). The development of a national nature network is a central theme of the nature (and forest) policy. Implementation of nature policy including the development and preservation of the national nature network has been decentralised from the central government to the provincial governments. The national nature network is a cohesive network of high-quality wetland and terrestrial nature reserves, including forests. Up to 1 January 2017 already 594 kha of the network was completed (based on IPO 2017). The aim is to extend the network to 640 kha by 2027.

Subsidies are an important instrument for provinces to realise these nature development goals. Through the currently prevailing subsidy scheme for nature and landscape (Subsidiestelsel Natuur en Landschap, SNL), the provinces grant subsidies for the conservation and development of nature reserves, including forests, that are part of the National Nature Network and for agricultural nature management.

These subsidies are also an important source of income for forest owners. Forest owners covering in total 80% of the Dutch forest area receive a SNL subsidy. Of this subsidised forest area, 60% falls under the scheme for forests with production function, i.e. forest with explicitly integrated nature conservation and timber production objectives. In the other 40% that is subsidised as natural forests, harvests are limited to 20% of the increment.

A4.4 Forest management and wood removals

The Dutch timber market is fairly homogeneous. Sawmills in the Netherlands can only handle stems of up to 60 cm diameter. As a result that is an important factor guiding forest management and maximum diameter of felled trees. Furthermore, forest managers have received very similar training, while there is only a limited number of contractors who take care of timber harvesting in Dutch forests.

Harvesting is mainly targeting stemwood, while some larger branches of broadleaved species may be removed as fuel wood. Due to concerns about soil fertility extraction of felling residues is limited. The majority (95%) of harvesting is done using harvesters and forwarders. In occasional cases, like the harvest of individual trees with large diameters, manual operations are performed.

For the forests that are subsidised under the SNL natural forest scheme, harvesting activities are limited to 20% of the increment. These are generally aimed at removing exotic species or improving forest structure. Forests with a production function usually integrate wood production with other functions like nature conservation and recreation. Harvesting in these forests therefore is usually limited to thinnings and small group fellings (<0.5 ha). Recently, however, also larger regeneration fellings (up to 5 ha) are applied in order to favour regeneration of species demanding more light.

In multifunctional forest, harvesting rates are on average 5.7 m^3 per ha per year, while in natural forests on average 2.9 m^3 is harvested per hectare per year (Schelhaas et al. 2018). The growing stocks on average increase annually by 2.0 m^3 per hectare in multifunction forests to 2.9 m^3 per hectare for natural forests (Schelhaas et al. 2018).

A4.5 New developments

The ongoing transition towards a more circular bio-economy will increase the demand for woody and non-woody biomass. In the Netherlands currently a number of policy developments and programmes are relevant. For instance, the National Biomass Vision 2030 (Ministerie van Economische Zaken 2015) states that an increase in the supply of biomass is needed for sustainable green growth. This would imply a need for an increase in forest productivity as well as increased imports (see Nabuurs et al. 2016). As part of the national programme for a national circular economy, transition agendas are being drawn up (Ministry of Infrastructure and the Environment and Ministry of Economic Affairs 2016). For forestry and wood the agendas for biomass & food and for construction are relevant. Furthermore, in the 2013 energy accord (SER 2013) between the Dutch Government and social and private partners an agreement was reached on the increased use of (woody) biomass for energy production. A stimulating policy to implement this is now under development. Woody biomass for large-scale energy production will however most probably be imported from abroad.

Climate agreement and climate law

On 28 June 2019 the Dutch Government agreed with other public, social and private parties on a National Climate Agreement (*Klimaatakkoord*)[14] containing actions to reduce emissions and increase removals of greenhouse gases in the Netherlands. Additionally, the Government has adopted a Climate Act[15] establishing a framework for the development of policies aimed at an irreversible and step-by-step reduction in Dutch greenhouse gas emissions in order to limit global warming and climate change. The Act entered into force on 1 September 2019 and required a Climate Plan to be prepared in which the Government outlines the main elements of its climate policies up to 2050 and more detailed plans for reaching an intermediary 2030 target. The target of the Climate Act and Climate Plan was initially to reduce greenhouse gas emissions in the Netherlands by at least 49% in 2030 compared to 1990. In the meantime the EU ambitions have been increased to reduce the emissions by at least 55%. In response, the Dutch Government has also increased the targets in its coalition agreement. In order to be climate neutral by 2050 at the latest, the Government is amending the climate legislation to raise the target for 2030 to a minimum of 55% reduction in greenhouse gas emissions. To ensure that this 55% target is achieved, the Government is aiming for 60% emission reductions by 2030 in its climate policy, so that even in the event of setbacks, the 55% target will not be at risk.[16]

The National Climate Agreement divides efforts and responsibilities among 5 economic sectors and the partners involved to meet its goals. The forest sector (including the wood supply chain), as part of the agriculture and land use sector, also will have to deliver its share to achieve the CO_2 reduction target. The measures aim to prevent deforestation, increase carbon removals in existing systems and expand the area of forest and increase the numbers of trees outside forests. Success will depends on the ability of the sector to mobilise forest owners to take effective measures and to arrange for the appropriate incentives with the provincial and national governments and other stakeholders. To this end the Government of the Netherlands is investing in developing and sharing the knowledge needed to further improve the climate mitigation function of landscapes and forests. For this purpose, since 2018 practical climate-smart forest management principles are being implemented and tested in a number of pilot projects. The results of these pilot projects are shared via an online toolbox[17] for climate-smart forest and nature management.

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[14] https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands (English translation)
[15] https://zoek.officielebekendmakingen.nl/stb-2019-253.html (in Dutch)
[16] Ontwerp beleidsprogramma klimaat. June 2022. https://open.overheid.nl/repository/ronl-53899d440127f31fa5f7382c72d031007894dd2e/1/pdf/Ontwerp_Beleidsprogramma_Klimaat.pdf
[17] https://www.vbne.nl/klimaatslimbosennatuurbeheer (in Dutch)

National Forest Strategy
As agreed in the Climate Agreement, in 2020 the Ministry of Agriculture, Nature and Food Quality and the 12 provinces launched a new National Forest Strategy to 2030. The aim is to increase the forest area in the Netherlands by 37,000 ha by 2030, which means about a 10% increase in forest area compared to the current area. The national government and the provinces have identified three routes for increasing the forest area:

1) more forest within the national ecological network (Natuurnetwerk Nederland, NNN),
2) forest outside the NNN and,
3) full compensation for conversion of forests to other nature areas.

Within the NNN, the provinces, together with land management organisations (such as the Staatsbosbeheer – the government forest and nature management agency, LandschappenNL and private landowners), are looking for locations for around 15,000 hectares of extra forest. Outside the NNN, the national government and the provinces are looking for opportunities for 19,000 hectares more forest near cities, villages and in transition zones between nature and agricultural areas. Forests that since 2017 have been – and are still being – converted to provide land for other types of prioritised nature types (such as heathland) will also be compensated. This compensation is expected to include 3,400 hectares of forest. In addition, the Government is looking for new opportunities to promote the creation of forests and the planting of trees outside these three routes.

Funding for the compensation plantings has been secured and the expansion of the forested area within the NNN is expected to be budget neutral within the funds already available for expansion of the NNN. Funding for the remaining 19,000 ha is still uncertain.

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