Greenhouse gas reporting of the LULUCF sector in the Netherlands

Methodological background, update 2025

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Methodological background, update 2025

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Abstract
Baren, S.A. van, E.J.M.M. Arets, G. Erkens, H. Kramer, J.P. Lesschen & M.J. Schelhaas (2025). *Greenhouse Gas Reporting of the LULUCF sector in the Netherlands; Methodological background, update 2025*. Statutory Research Tasks Unit for Nature & the Environment (WOT Natuur & Milieu), Wageningen. WOT-technical report 278.

This report provides background information and a complete methodological description for the Dutch National System for Greenhouse Gas Reporting of the LULUCF sector. It includes a detailed description of the methodologies, activity data, and emission factors used. Each reporting category Forest land, Cropland, Grassland, Wetlands, Settlements, Other Land and Harvested Wood Products is 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 Klimaat-conventie (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 background information and a complete methodological description for the Dutch National System for Greenhouse Gas Reporting of the LULUCF sector for the UN Framework Convention on Climate Change (UNFCCC) for 2025 onwards.

IPCC Guidelines
The methodology mainly adheres to the IPCC 2006 guidelines for Agriculture, Forestry and Other Land Uses (AFOLU) (IPCC 2006b). However, the methodology for calculating methane emissions from drainage ditches in organic soils follows the 2013 Wetland Supplement to the 2006 IPCC Guidelines(IPCC 2014b) and the methodology for methane emissions from Flooded land is based on the 2019 refinement to the 2006 IPCC Guidelines (IPCC 2019). 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). To the greatest extent possible, this background report reflects the structure of the National Inventory Document (NID) as laid out in Annex V of Decision -/CMA.3.

Methodological changes
The contents are largely similar to that of the previous methodological background report (van Baren et al. 2024) prepared with the NIR 2024. For the 2025 inventory submission, four methodological changes were implemented:
1. Updated emission factor for drained organic soils for all land uses.
2. Updated area of ditches on organic soils for the land uses Cropland, Grassland, Trees outside Forests and Forest land, from Tier 1 estimation to a country specific Tier 2 estimate.
3. Updated carbon stocks in mineral soils for all land uses and reduction of the number of aggregated soil types

Methodological change: emission factor update drained organic soils
The emission factor for drained organic soils for all land uses has been updated according to insights gained from the national research programme on emissions from drained organic soils "Netherlands Research Programme on Greenhouse Gas Dynamics in Peatlands and Organic Soils (NOBV)[1]". In 2020, this programme set up a measuring network for cultivated coastal peatlands consisting of automated transparent chambers and eddy covariance towers. To upscale the measurement outcomes, two process-based models were newly developed, calibrated and tested against measurements (section 11.3.1). These models were then used to develop new emission factors for Dutch coastal peatlands. The existing method was used for upland peatlands, (section 11.3.2). These two emission calculations were then combined to calculate a new implied emissions factor for all organic soils on all land uses in the Netherlands (section 11.3.3).

Methodological change: updated area of ditches on organic soils
The area of drainage ditches on organic soils was updated for the land uses Cropland, Grassland, Trees outside Forest and Forest land, from Tier 1 to country specific Tier 2 data (section 11.3.5).

Methodological change: updated carbon stocks in mineral soils for all land uses and reduction of the number of aggregated soil types
For mineral soil, for all land uses, soil carbon stocks were updated based on a national soil monitoring campaign from 2018. In addition, to decrease uncertainty in soil organic stocks, the number of aggregated soil types was reduced (section 11.2.1).

[1] https://www.nobveenweiden.nl/en/

Previous background documents

Previous background documents to the submissions under the UNFCCC and Kyoto Protocol dealing with similar topics were published as *WOt-technical reports 1, 26, 52, 89, 95, 113, 146 168, 201, 217, 238 and 255* (Arets *et al.* 2013, 2014; 2015, 2017a, 2017b, 2018, 2019, 2020, 2021, 2022, 2023 and van Baren *et al.* 2024) 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) for critically reviewing this report.

Sven van Baren, Eric Arets, Gilles Erkens, Henk Kramer, Jan Peter Lesschen and Mart-Jan Schelhaas

Contents

1 Overview of the LULUCF sector

1.1 Introduction

The Netherlands is a Party to the United Nations Framework Convention on Climate Change (UNFCCC). It has also ratified the Paris Agreement, committing itself to yearly reporting on greenhouse gas emissions. Whereas the Convention on Climate Change lays the foundations for accurately monitoring 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 (GHGs) (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 (CRT Sector 4), the Netherlands has developed 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), Arets *et al.* (2013, 2014, 2015, 2017a,b, 2018, 2019, 2020 2021, 2022 and 2023) and van Baren *et al*. (2024).

The list of reports over the years reflects the continuous improvements and updates to reporting the LULUCF sector within the Dutch National System. This methodological background report describes the methodological choices and assumptions applied from the NIR 2025 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 approach enables combining different geographically explicit data sources to determine activity data and link them to emission factors. Also, it allows the generation of results for different spatial aggregation levels.

An overview of the LULUCF sector is provided further in 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 CRT 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 into 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 the basis for our land-use calculations). The maps dated on 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 and two organic soil maps (1977 and 2014) (Chapter 3.5) is used to calculate carbon stock changes in mineral soils and 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 CRT 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), the seventh National Forest Inventory (NFI-7; 2017-2021; 3174 plots; Schelhaas *et al.* 2022) and the eight National Forest Inventory (NFI-8; ongoing started in 2022; Lerink *et al.* 2023). The accumulation of carbon in dead wood is based on a combination of measured values in all four inventories and 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) 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 uses 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. Knotters et al. 2022 provided the soil data from the national CC-NL soil survey, which were classified into new soil – land-use combinations. For each sample location, the land use at the time of sampling was known. The soil types for each of the sample points were reclassified into 6 main soil types and an unknown category, representing the main variation in carbon stocks within the Netherlands. These include 4 mineral soil types and 2 organic soil types. In the mineral soils 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 CRT 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 the ditch water level or the mean lowest groundwater level (Kuikman *et al.*, 2005, de Vries *et al.* unpublished). For Cropland and Grassland, the associated N_2O emissions resulting from the 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 CRT 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 CRT Tables 4.A to 4.F. Associated emissions of N_2O are reported in CRT Table 4(II). CH_4 emissions from drainage ditches on organic soils are reported in CRT Table 4(II).

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

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

Because it is impossible 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 seldom occur in the Netherlands, CO_2, N_2O and CH_4 emissions resulting from forest fires are reported in CRT Table 4(IV) 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 calculation year and Tier 1 combustion and efficiency factors.

CH_4 emissions from wetlands and in particular from the sub-category Flooded land are calculated using a Tier 1 approach from the 2019 refinements to the 2006 IPCC Guidelines.

The reported emissions and removals are shown in Table 1.1, along with the Tier level of the methodologies used, if applicable. Details on the methodology per land-use category can be found in Chapters 4-9. The method 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 with reported carbon stock changes 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 (T2) Litt (T2) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (T2) Litt (T2) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (T2) Litt (T2) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (T2) Litt (T2) **MS** (T2) **OS** (T2) FF (IE)	**BG** (T2) **BL** (T2) DW (T2) Litt (T2) **MS** (T2) **OS** (T2) FF (IE)
CL	**BG** (T1) **BL** (T2) **DM** (T2) **MS** (T2) **OS** (T2, T3) WF (IE)	BG (NA, n.s.) BL (NA, n.s.) DM (NA, n.s.) **MS** (T3) **OS** (T2, T3) WF (IE)	**BG** (T1) **BL** (T1) DM (NA, n.s.) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T1) **BL** (NO) DM (NA, n.s.) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T1) **BL** (NO) DM (NA, n.s.) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T1) **BL** (NO) DM (NA, n.s.) **MS** (T2) **OS** (T2, T3) WF (IE)
GL	**BG** (T1, T2) **BL** (T2) **DM** (T2) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T1, T2) **BL** (T1, T2) DM (NA) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T2) **BL** (T1, T2) **DM** (NO, NA, n.s) **MS** (T3) **OS** (T2, T3) **WF** (T1)	**BG** (T1, T2) **BL** (NO) DM (NA, n.s) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T1, T2) **BL** (NO) DM (NA, n.s) **MS** (T2) **OS** (T2, T3) WF (IE)	**BG** (T1, T2) **BL** (NO) DM (NA, n.s.) **MS** (T2) **OS** (T2, T3) WF (IE)
WL	BG (NE) **BL** (T2) **DM** (T2) **MS** (T2) **OS** (T2) WF (IE)	BG (NE, n.s. 6.7.1) **BL** (T1) DM (NE) **MS** (T2) **OS** (T2) WF (IE)	BG (NE, n.s.) **BL** (T1, T2) DM (NE) **MS** (T2) **OS** (T2) WF (IE)	BG (NE, n.s.) BL (NE, n.s.) DM (NE, n.s.) **MS** (NA) **OS** (NO) WF (IE)	BG (NE, n.s.) **BL** (NO) DM (NE, n.s) **MS** (T2) **OS** (NO) WF (IE)	BG (NE, n.s.) **BL** (NO) DM (NE, n.s) **MS** (T2) **OS** (NO) WF (IE)
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.

1.3 Workflow

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

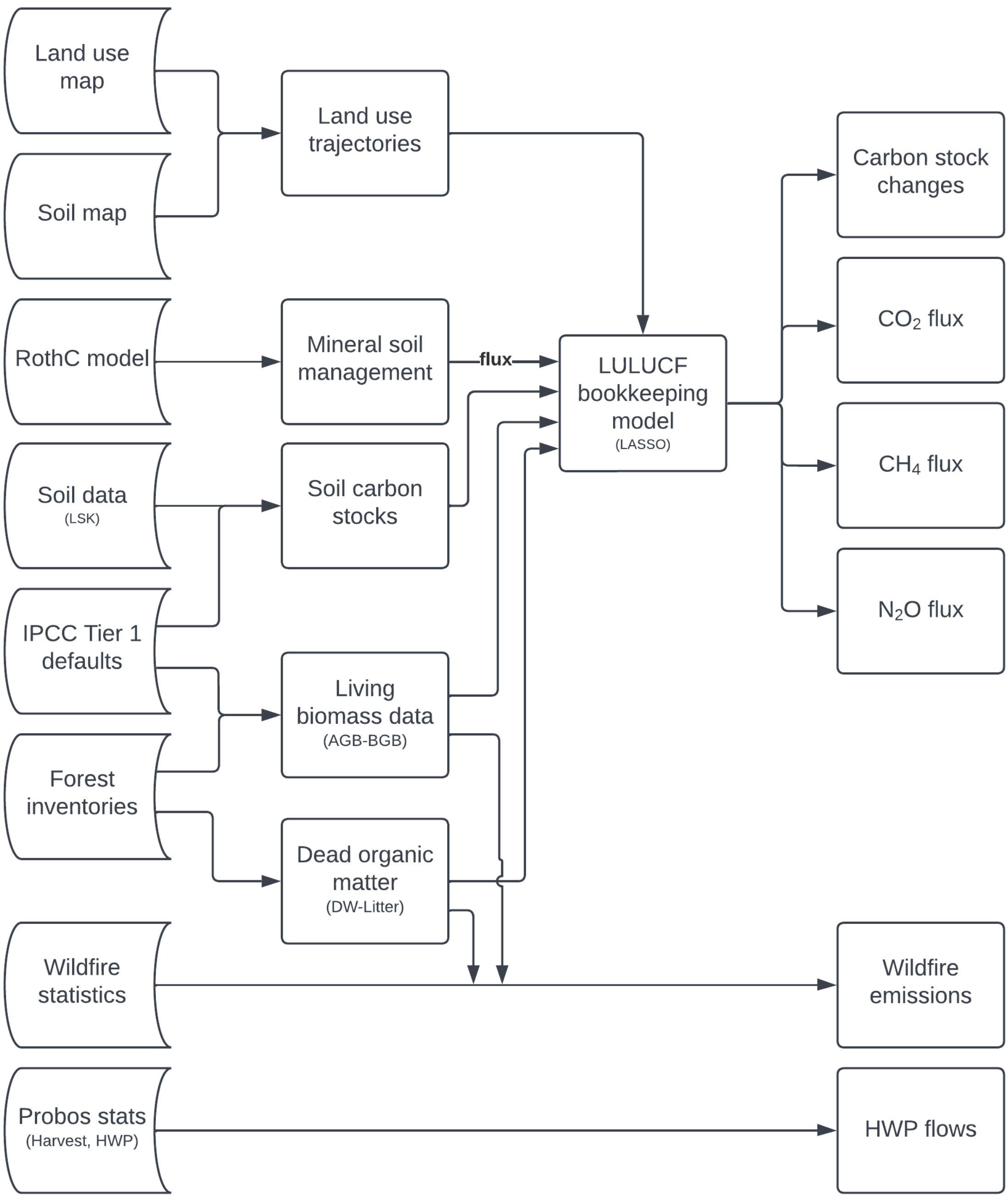

Figure 1.1 *High level overview of the work flow and aggregation of information for calculating the greenhouse gas emissions and removals from the input sources (left), intermediary calculations (middle, rounded squares) and the resulting outputs (right, squares). The LULUCF Bookkeeping model (LASSO) combines all land-use trajectories with the correct emission factors and keeps track of carbon stocks and fluxes for each trajectory 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, 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, all land would be covered by forests without human intervention. 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, which 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, 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 to define the Forest land category (Chapter 3.2 in IPCC 2006b).

The Netherlands has defined 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 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 definition excludes tree stands in agricultural production systems, such as 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 forests 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 otherwise to Trees outside Forest (under Grassland 4.C, see below).

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 defines 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.

The category Cropland includes both classes 'arable land' and 'tree nurseries' as defined on topographic maps used for geographically explicit representation of land (see 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 included as part of Settlements category, rather than as part of Cropland.

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 CRT 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 comprises land dominated by grassland vegetation, including rangelands and pastureland that are not considered Cropland. It covers all grassland from wildlands 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 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 no longer part of the current agricultural system, conservation management is applied to halt the succession to forest and conserve the landscape and its high biodiversity values.

In background calculations of the land-use matrix, this ‘nature’ category is considered 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 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 year 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[2], 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 from the used area for orchards. Data are available from 1992 onwards and updated annually, with provisional figures for the previous year published in April. Areas for 1990 and 1991 are backwards estimated based on extrapolation of the trend 1992-1993.

[2] 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. smaller than 0.5 ha or less than 30 m width. These represent fragmented forest plots, 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 grassy vegetation, those wet areas are included under grasslands. Some wetlands are covered by a rougher 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.

Wetlands are divided into two main types: Flooded land and Other wetlands. Flooded land is further divided in the sub-categories “Reservoirs” and “Other constructed waterbodies” (canals, ditches and freshwater ponds), while the category Other wetlands is divided into the sub-categories “Reed swamp” and “Open water” (Table 2.2).

Table 2.2 *Division of the main category Wetlands in sub-categories that are used and the underlying subcategories for Wetlands used for the calculations of emissions.*

Main category	Sub-categories	Underlying sub-categories
Wetlands (4.D)	Flooded land	Reservoirs
		Other constructed waterbodies
		- Canals and ditches
		- Freshwater ponds
	Other wetlands	Reed swamp
		Open water

Flooded land
Flooded land is defined in the 2006 IPCC guidelines as: “*water bodies where human activities have caused changes in the amount of surface area covered by water, typically through water level regulation.* In section 7.3 of the 2019 refinement to the 2006 IPCC guidelines also the following water bodies are considered*: i) water bodies where human activities have changed the hydrology of existing natural water bodies thereby altering water residence times and/or sedimentation rates, in turn causing changes to the natural flux of greenhouse gases; and ii) water bodies that have been created by excavation, such as canals, ditches and ponds.*“

In the Netherlands this definition mainly accounts for inland fresh waterbodies of which many are regulated in some way, for example through locks and sluices. Flooded land is further divided in the sub-categories Reservoirs and Other constructed waterbodies of which the latter is again sub-divided in Canals and ditches, and in Freshwater ponds:
- Reservoirs are big (>8 ha) inland freshwater bodies which were natural but now regulated by human influences. Reservoirs which are the result of hydropower dams do not exist in the Netherlands. There are hydropower plants present, but these are all installed on rivers or other flowing waterbodies in the form of watermills or sluices.

- Canals and ditches (>3 m) are linear constructed waterbodies. Smaller (drainage) ditches (<3 m) on organic soils are included in the respective land uses as these are too small to show up on the land use map grid (see section 11.3.2).
- Freshwater ponds (<8 ha) are mainly water bodies which have been constructed by excavation or are natural water bodies which are now regulated and do not fall within the reservoir category due to the area definition.

Other wetlands
Other wetlands are all wetlands which do not fall within the Flooded land category and is subdivided into the categories ''Reed swamp'' and ''Open water''.

Reed swamp
Reed marshes are areas where 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 previous categories, it 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
Open water bodies are all areas indicated as water on the topographic maps (mapped only if the surface exceeds 50 m^2) which are not classified as being Flooded land or Reed swamp. These water bodies may include 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 when these are not classified in the water type map; i.e. not part of Flooded land. Additionally, it includes so-called 'emerging surfaces', i.e. bare areas which are underwater only part of the time due to tidal influences (Wadden Sea) and very wet areas without vegetation. It also includes 'wet' infrastructure for boats, i.e. waterways and 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 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 a place for residence, trade, traffic and/or labour. Thus, it includes houses, blocks of houses and apartments, shops and warehouses, office buildings, fuel stations and greenhouses.

Urban areas and transportation infrastructure, including all roads, whether paved or not, are included in the land-use category Settlements, except for 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. Although some of the last classes are often covered by grass, a 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 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' distinguishes 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 due to heavy overgrazing, for a long time, were combated by planting forests. However, these areas were the habitat of some species which have become extremely rare nowadays. Inland sand dunes can be created as vegetation, and topsoil 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 complete 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 approach corresponds with the wall-to-wall approach used for reporting under the Convention (approach 3 in Chapter 3 of IPCC 2006b). It 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 derived from five maps representing the land use on 1 January 1970, 1990, 2004, 2009, 2013, 2017 and 2021. These maps depict land-use changes from 1 January 1970 until 1 January 2021.

In Kramer *et al.* (2009, 2015), all steps in calculating the land use and land-use change matrix are described in detail. This chapter gives a short summary of the methodology and presents the land-use change matrices derived from map overlays. In addition, several necessary corrections to afforestation and deforestation for 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 of historic land use in the Netherlands (‘Historisch grondgebruik Nederland, HGN)[3], 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 no longer used for monitoring nature development. However, 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[4] 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 and Clement 2022) 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. Several counterintuitive land-use changes were observed while analysing the land-use changes between 2004 and 2009. A further exploration of the topographic maps from 2004 and 2009 combined with the corresponding aerial photos showed a difference in the way topographic elements are recorded for Top10Vector and Top10NL.

[3] https://www.wur.nl/nl/show/Kaarten-Historisch-Grondgebruik-Nederland-HGN.htm

[4] 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).

For instance, roads on the 2009 map are represented in more detail and higher resolution, resulting in narrower representations. Other examples where this happens are airfields and industrial sites that, on the 2004 topographic map, were classified as other land use but now have the runways, buildings and roads and surrounding grasslands classified separately. Since these represent only a relatively small area, no correction was 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 on 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. However, because of its national coverage and inclusion of other land-use types, it is also very suitable as a land-use data set for reporting 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 for 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 creating the land-use maps was aggregating 25 m × 25 m raster maps. An additional validation step was applied to check on the digitising and classifying processes for the 1990 map, which had a large part of the information derived from paper maps.

When comparing them to other years, all individual maps contained a few missing pixels (0.05% of total land use). 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 based solely 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. Consequently, 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 correctly report the land-use change categories since 1990. 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 change in land use from 1970 to 1990 that represented land-use change trajectories[5] covering less than 10 ha of land. These would be very rare land-use change trajectories, resulting in very long runtimes 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 maps showed a net loss of forest area. Further investigation revealed the following causes for this reduction:

0. Deforestation continued at more or less the same pace as before, mainly due to the 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.
1. Afforestation declined considerably. While in principle, deforestation needs to be compensated with afforestation of an equal area elsewhere, an exception to these rules is when conversion to priority nature takes place based on ecological arguments, like based on Natura 2000 management plans. In such cases, forest conversion can take place without compensation.
2. Some areas were mapped in greater detail than before, particularly build-up areas with many trees. Some of these areas were incorrectly classified as forest and are now on the 2017 map corrected to settlements.
3. 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 temporarily unstocked and 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 (slight) overestimation of the forest area on earlier maps, which has now been corrected. Because correcting and reclassifying earlier maps was considered an excessive effort, so this "deforestation" was accepted as a conservative estimate.

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

- All polygons 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 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.
  - 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.
  - 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.

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

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 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 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 former total 4,153,009 ha 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 report was 4,154,195 ha. Cropland and grassland were the most dominant land uses in the units of land 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					
Land use	**1970**	**1990**	**2004**	**2009**	**2013**	**2017**
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%

Wetlands Flooded land classification
To classify the different Flooded land categories, the "Water type map" of Puijenbroek and Clement (2010) was used to reclassify the land-use source maps shown in table 3.2. All polygons in the Water type map were assigned a certain LULUCF wetland category by matching the definitions from the water type map and the definitions from section 2.5. The full table which was used to classify water types from the water type map into LULUCF wetland categories can be found in Annex A2.4. The polygons were converted into the same raster structure as the original LULUCF land-use map as defined in section 3.2. This gridded water type map was used to reclass the areas of open water into the different types of Flooded land categories. For Reservoirs and Freshwater ponds only the areas which were formed between 1900 and 1970 were included. For these areas it is certain they were human made. The year 1900 was chosen as it is the earliest year for which a digital land-use map is available that has been made in the same way the 1970 and 1990 map have been made (Knol *et al.* 2004). Also, all canals and ditches were included as these are human made.

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 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. Approximately 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 result 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 CRT 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 into 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 1970	**HGN 1990** **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).*

HGN 1990	**BN 2004** 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: 1970	**To: 1990** 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: 1990	**To: 2004** 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: 2004	**To: 2009** 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: 2009	To: 2013 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: 2013	To: 2017 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: 2017	To: 2021 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. The 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 6 soil types, of which 4 are mineral soil types and 2 are organic soil types. Also an 'unknown' soil type category is taken into account. The original version is based on soil mapping that was carried from 1960-1995 (de Vries *et al.* 2003) and, is dated 1 January 1977. De Vries *et al.* (2010) showed that the areas of organic soils (peat and peaty soils) are decreasing due to the oxidation of the organic soils, particularly in the drained agricultural areas on organic soils. Therefore, a new soil map, dated 1 January 2014, was produced, 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 mineral soils, 7 main soil types (6 plus 1 'unknown') were distinguished (see Chapter 11.2). Since there is no reason to assume changes in the 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 was converted to peaty soils, while 6.2 kha of peat soil was converted to mineral soils. At the same time, 85.8 kha of peaty soil was 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.

Over the past decades, peat and peaty soil loss resulted from oxidation in drained agricultural areas on organic soils and drainage for infrastructure and settlements. Since 1992, commercial peat extraction has not taken place[6]; notably, prior to that date, the previous company had been gradually discontinuing its operations for quite some time. While the quantity of peat extraction in 1990 and 1991 is unknown, the affected area and resulting emissions are believed to be 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. Nowadays, most of the peat for potting soils 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. The table 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.

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

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

The unique land-use-soil sequences are derived from successive land-use and soil map overlays. These sequences only provide information on the land use in the years 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 corresponding sequence's area.

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 occur over a 20-year interval (see Chapter 11). With successive land-use changes, yearly soil carbon flux is 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 previous two maps are extrapolated towards the desired end-year (i.e. the reporting year). Extrapolation is based on the rate of change from a particular 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 a trajectory has been stable (no land use 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 endpoint affects the number of trajectories. The newly calculated endpoint is added to the sequences. If 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 is a mixture of the two. The share of mixed and broadleaved forests has grown in recent decades (Schelhaas *et al.*, 2014[7], 2022).

The land-use category Forest land is defined as all land with woody vegetation consistent with thresholds used to determine 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 CRT, the notation key 'NO' will be used in the tables for unmanaged forests.

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

1. 4.A.1. 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.A.2. Land converted to Forest land (LF)
   This concerns changes in the carbon stocks for areas that have been forested for less than 20 year 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.A.2.a. through 4.A.2.e. 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.B.2.a. - 4.F.2.a.: 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 section 1.9 in IPCC 2006b):
1. Living biomass, further specified in:
   - above-ground biomass (trunk and branches)
   - below-ground biomass (roots)

[7] 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 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.A.1.)

The basic approach to assessing 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 five National Forest Inventories are available for the Netherlands: the HOSP inventory (1988-1992), NFI-5 (2001-2005), NFI-6 (2012-2013) and the NFI-7 (2017-2021) and NFI-8 (2022-2026). With these repeated inventories, changes in biomass and biomass carbon stocks were assessed for 1990-1992, 1992-2006, 2006-2014 and 2014-2022 and after 2022 each year an update with a 5 year window based on the last two NFI measurements. The annual changes for the years between the inventories are determined using linear interpolation. 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 1988-1992 was used, as these best represent the situation in 1992. 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 into the amount of harvestable wood, but it still provides valuable information on standing stocks and increments 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 forest area ('representative area') between 0.4 ha and 728.3 ha. Together, they represent an area of 310,736.3 ha, the estimated forest surface 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 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.* 2022) all permanent sample plots from NFI-6 were remeasured, except for plots that according to 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 to the continuous 5-year NFI cycle. The measurements largely followed the sampling and measurement methodologies of the earlier inventories, and the same relevant measurements for assessing carbon stocks as done in the previous NFI's were included to guarantee consistent calculations of carbon stock changes over time

The eighth National Forest Inventory (NFI-8; Achtste Nederlandse Bosinventarisatie) is being conducted from 2022-2026, continuing the NFI cycle from the NFI-7. Due to the new yearly updates of part of the plots, it is now possible to utilise the NFI statistics as input for the LULUCF bookkeeping calculations on a yearly basis, as opposed to updating the statistics only at the end of an NFI cycle. For example, the second data point for the NFI-8 (NFI-8-II) in Table 4.1 encompasses measurements taken from 2019-2023. In the second year of the NFI-8 (2023), plots were remeasured that during NFI-7 were measured in 2018. With this information a new average value for forest characteristics can be calculated based on the data 2019-2023, in which the NFI-7 data of 2018 are replaced by the data collected in 2023. In the following years, this calculation window will shift one year at a time as measurements from the previous NFI are replaced.

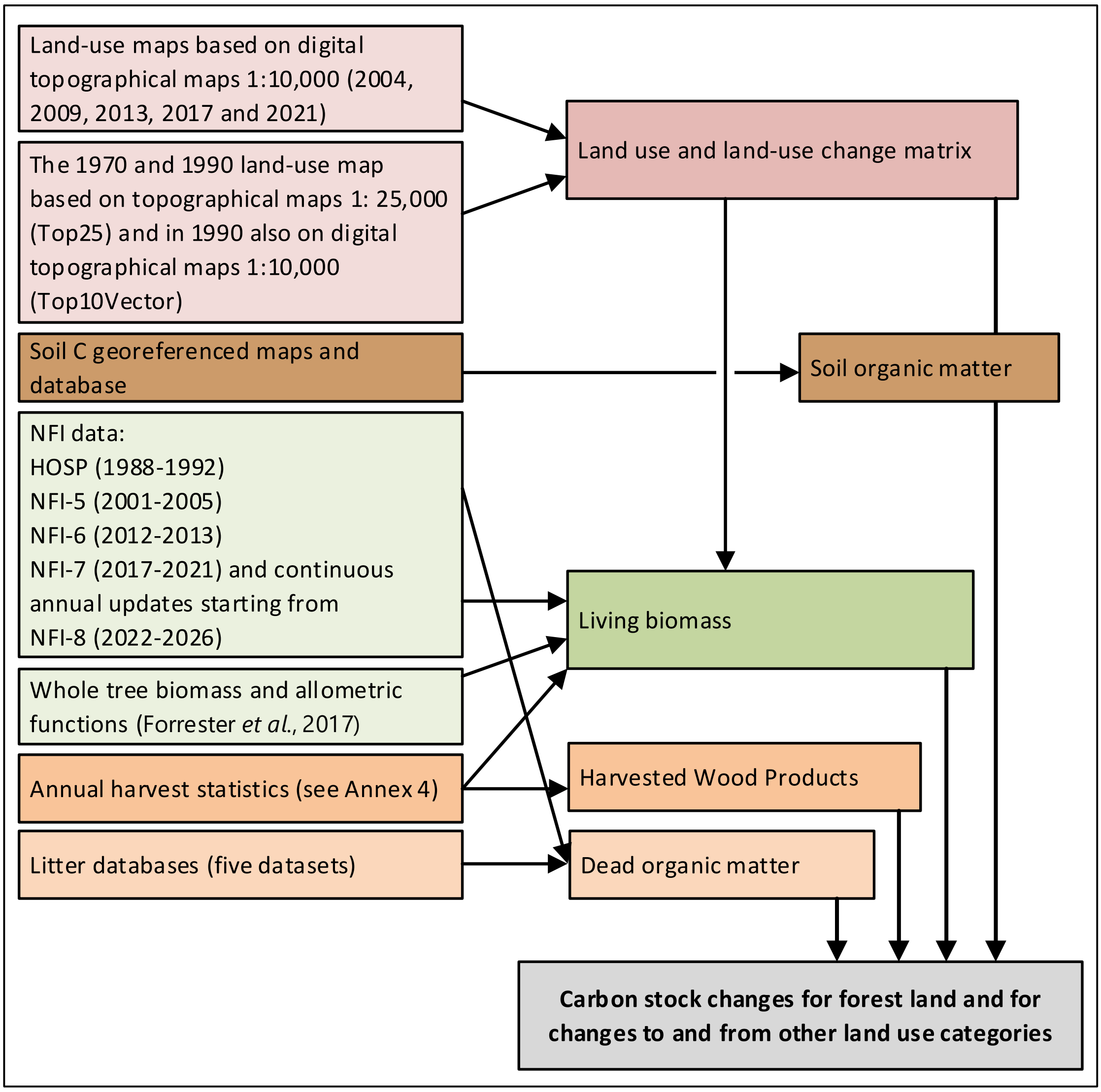

Figure 4.1 *Sources for the allocation of Forest land and the calculations of carbon stock changes from Forest land.*

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 are measured ,including the stand as a whole (main species, even-aged or uneven-aged, occurrence of natural disturbances, etc.), and as individual trees in a plot with a radius of 5-20 m (see Schelhaas *et al.* 2022). 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, the height is measured for one tree. For these tally trees, individual tree volume is estimated using specific volume models. Based on this set, direct conversion functions are developed 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 an independent variable provided in a study by Forrester *et al.* (2017), based on a 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. Information for base year 1990 was based on backward extrapolation of the trend between NFI-5 and HOSP (HOSPextra in Table 4.1).
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. The relative share of coniferous and broadleaved forest is determined based on the distribution of total biomass per hectare between coniferous and broadleaved trees (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. The average aboveground and belowground biomasses (tonnes dry matter ha^{-1}) are estimated for each year by combining the average growing stock, the average BCEF, and the root-to-shoot ratios.
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 is converted to carbon.
7. Losses from wood harvesting are already included in the differences in carbon stocks between the three forest inventories, HOSP, NFI-5, NFI-6 and NFI-7 (see below for an 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 (being the 1st of January after the last measurement 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 Conifers**	**DW Biomass DWs**	**DWl**
HOSPextra	1990	152	108.3	0.712	23.8	0.22	0.53	0.76	
HOSP	1992	158	112.7	0.713	24.3	0.22	0.51	0.84	
NFI-5	2006	199	143.2	0.721	30.6	0.21	0.41	1.35	1.49
NFI-6	2014	217	161.9	0.744	33.8	0.21	0.38	1.93	1.89
NFI-7	2022	229	176.6	0.773	36.3	0.21	0.34	2.99	2.66
NFI-8(II)	2024	2231	177.4	0.777	37.73	0.21	0.34	3.04	3.01

Effects of wood harvests on biomass gains and losses

Information on the annual volume of roundwood harvesting is only available at the national level. Itis based on a combination of information from the forest inventories and FAO harvest statistics (see Annex 4). Wood production is given as production roundwood in m^3 under bark. The total annual volume removed from the forest includes bark and 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 how 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 the 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 include 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 CRT, both underlying gains and losses in carbon stocks in living biomass must be provided. Gains in carbon stocks result from the annual increment in biomass, while losses result from 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. Consequently, 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).

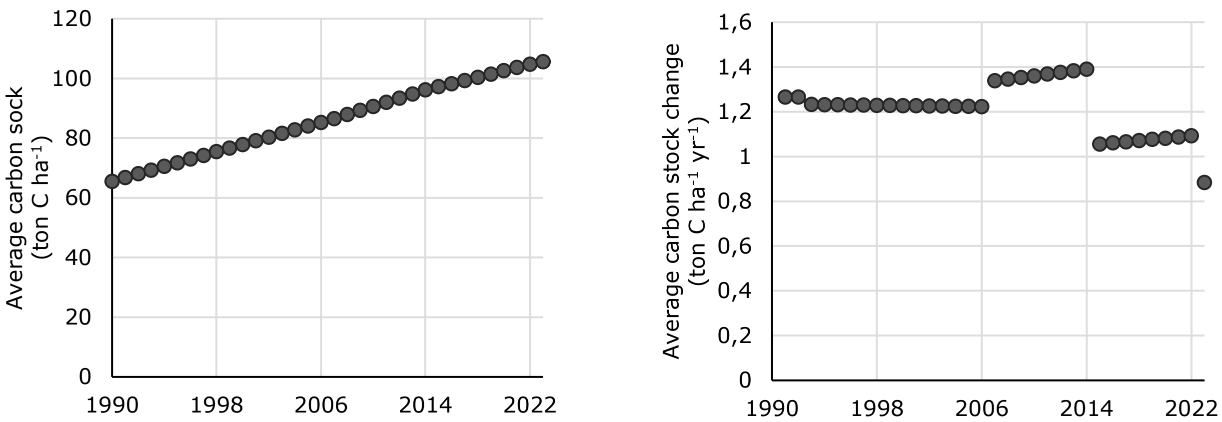

Figure 4.2 *Average carbon stocks and net carbon stock changes in biomass in forest land remaining forest land based on the stock differences in the NFI data.*

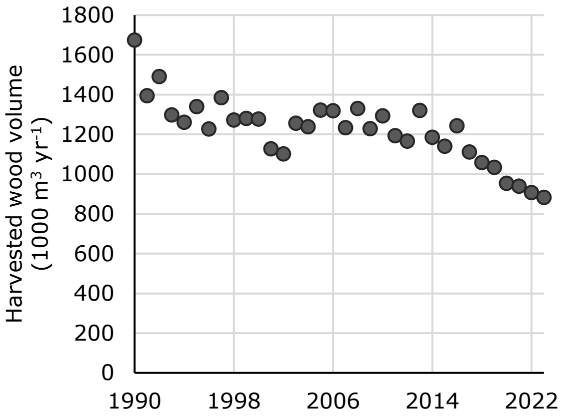

Figure 4.3 *Harvested roundwood volume (1000 m³ yr-1) since 1990. Projected years will be updated once new harvest statistics become available.*

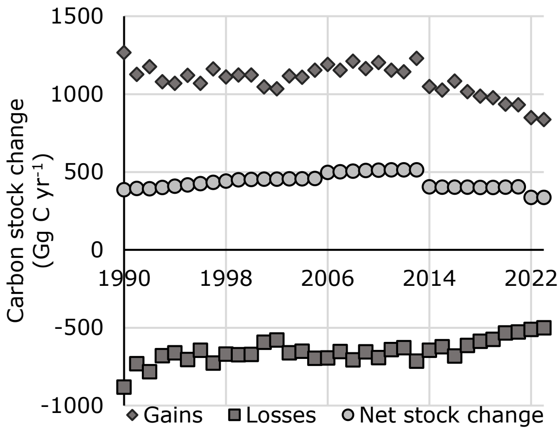

Figure 4.4 *Carbon stock gains and losses combining net carbon stock changes from the NFI data with the (stock change, cf. Figure 4.2) with the harvest statistics (Figure 4.3).*

Growth rates versus increase in growing stock

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

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 5 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 (SNLs) 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.* 2022). Of this subsidised forest area, 53% falls under the scheme for forests with production function, i.e. forests with explicitly integrated nature conservation and timber production objectives. Therefore, harvesting in these forests is usually limited to thinnings and small-group fellings (<0.5 ha).

In the other 47%, 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 forests, harvesting rates are, on average, 5.7 m³ per ha per year, while in natural forests, on average, 2.9 m³ is harvested per hectare per year (Schelhaas *et al.* 2018). The growing stocks increase, on average, annually by 2.0 m³ per hectare in multifunctional forests to 2.9 m³ 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]. More detail is explained in Chapter 10.

Carbon stock changes in dead wood

Dead wood volume was available from the forest inventory datasets. The calculation of carbon stock changes in dead organic matter in forests follows the approach for calculating carbon emissions from living biomass.

This is done for lying and standing dead wood (Table 4.1 above). For the carbon contents, 60% of the density compared to living biomass is assumed.

Carbon stock changes in litter

The carbon stock change in the litter layer was estimated using a stock difference method at the national level. Data for litter layer thickness and carbon in the litter were available from different datasets (van den Burg 1999; de Vries and Leeters 2001,; Forest Classification database; de Jong *et al.* (2021);litter thickness is measured in the NFI-5 litter inventory for plots measured in 2004 and 2005 and all plots in the subsequent NFI-6 and NFI-7. Vvan den Burg (1999) collected data between 1950 and 1990 and then used it only to estimate bulk density based on organic matter content. De Vries and Leeters (2001) collected data 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 forest classification in 1990, not to sample the mean litter in forests. However, it is the only database that has samples outside sandy areas. 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), while in the subsequent NFI's, measurements of litter thickness were included as a standard measurement for all plots.
Since none of these datasets could be used exclusively, a stepwise approach was used to estimate the national litter carbon stock and change therein consistently.

First, the datasets were compared for (if available) bulk density and carbon or organic matter content of litter separately and 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 NFIs. 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 NFIs.

The followed hierarchy was:

1. The only source of information for non-sandy soils was the Forest Classification database. Though sampled around 1990, it was used for 1990 and 2003 alike. As such, it is considered a conservative estimate for any changes that occur. Using the same dataset in 1990 and 2003 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 of the analysis.
2. For sandy soils with measured litter layer thickness (i.e. plots of NFI-5 measured in the years 2004 and 2005, and plots measured in the NFI-6 and -7), linear regressions, using data from de Jong *et al.* (2021), were used to convert them into litter carbon stock estimates (see Annex 3).
3. 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, it was assigned 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.
4. 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.

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).

The uncertainty was attributed largely to the fact that no litter information was collected in the HOSP inventory, which was used for 1990. Because currently no consistent timeseries based on changes in carbon stocks at the plot level could be assessed, for Forest land remaining Forest land the more conservative estimate was used to set the accumulation of carbon in litter in Forest land remaining Forest land to zero.

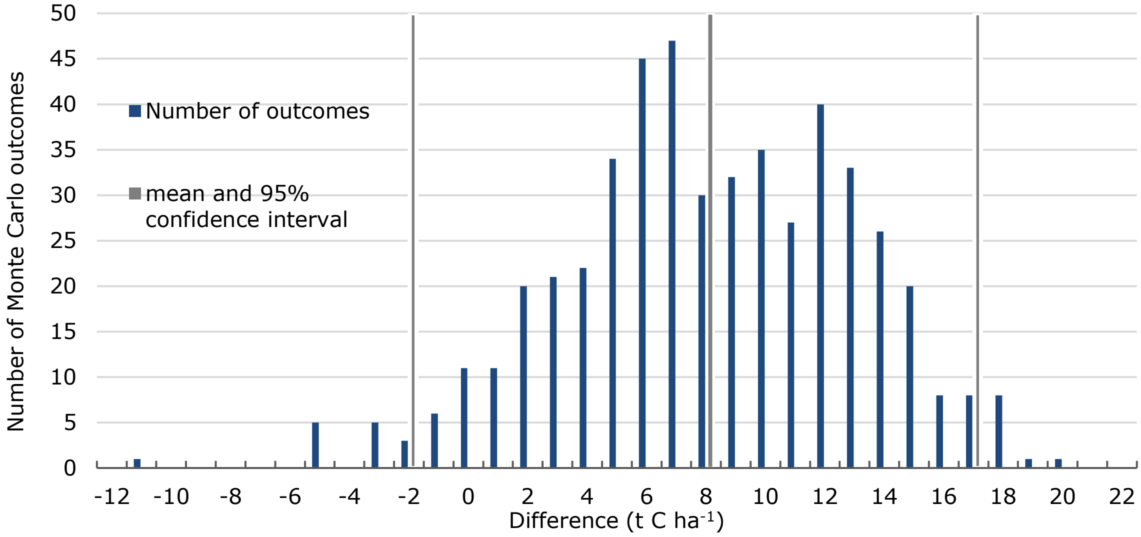

Figure 4.5 *Distribution of differences in carbon stock between HOSP and NFI-5 datasets based on a Monte Carlo analysis (positive values indicate a sink).*

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 resulting from 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. Similarly to net carbon stock changes in biomass, the time to build carbon stocks to the value of the average of Forest land remaining Forest land is considered to be 30 years (see section 4.2.2 below). Hence, reported carbon stock increases are not an effect of increasing carbon stocks in litter in Forest land remaining Forest land (which, as explained above is an uncertain sink that is conservatively estimated to be zero), but are rather the effect of gains from areas of land transitioning into the Forest land converted to Forest land category, which need 30 years to reach the average carbon stock in mature Forest land.

Carbon stock changes in soils
For methods on how to calculate changes in soil carbon stocks for various soil types, refer to Chapter 11.

4.2.2 Land converted to Forest land (4.A.2.)

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 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 the 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 biomass growth is assumed to continue from the previous years. In the bookkeeping models and also reported in the

CRT tables, a loss is reported in one land use while simultaneously being reported as again in the other. The amount of biomass gain therefore stays equal, but is assigned to a different land use category.

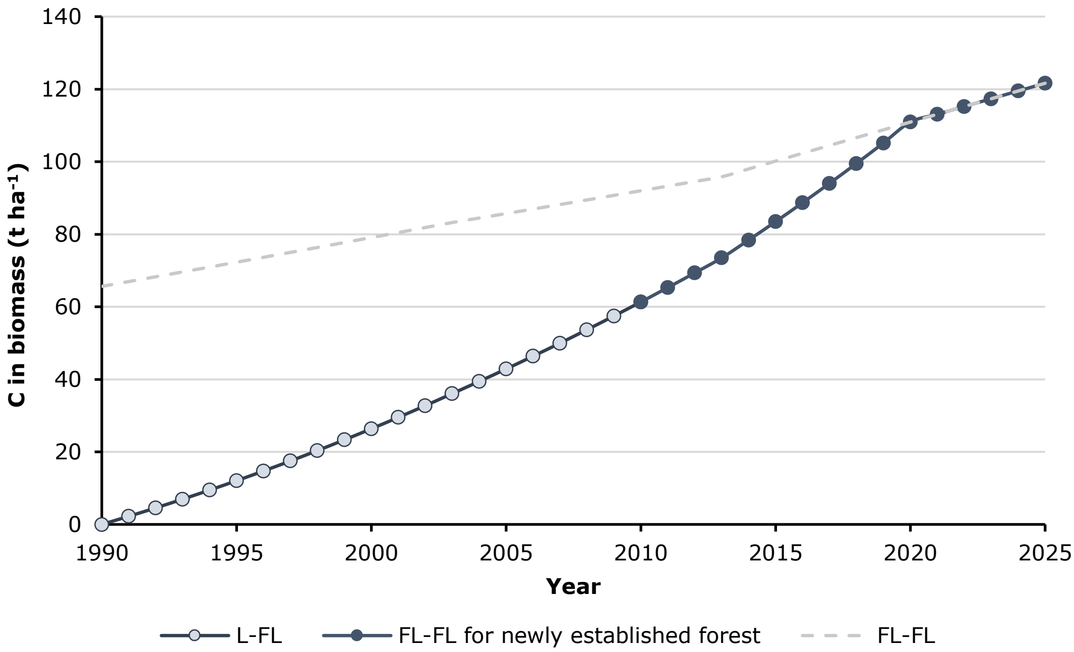

Figure 4.6 *Example of the development of carbon stocks (t ha^{-1}) on units of Forest land newly established in 1990 (important: the graph follows the same 1 ha over time from 1990 to 2025). Within 30 years, the carbon stock grows from 0 at the time of establishment (1990 in this example) to the average 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).*

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). An exception to 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 dead wood and litter, as no other land categories are assumed to have significant amounts of those carbon stocks. Similar to the net carbon stock gains in living biomass, gradual increases in carbon stock in forest litter and dead wood are considered. Starting from 0 in the year of conversion to Forest land, carbon stocks are considered to reach the average carbon stock in litter or dead wood in forest land remaining forest land after 30 years. I.e. 20 years in the converted to category and 10 years in the remaining category.

4.2.3 Forest land converted to other land-use classes

The total emissions from the tree component after Deforestation are calculated by multiplying the total area deforested with the average carbon stock in living biomass, above and 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, 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 a 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 no longer complies with 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 due to deforestation are determined based on the accumulated carbon in living biomass until the year of deforestation as calculated according to 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 to 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 the best available data for the Netherlands, as described in Section 4.2.1. Emission factors for litter are based on the calculated litter values based on the HOSP (1992), NFI-5 (2006), NFI-6 (2014) and NFI-7 (2022) using the approach described in Section 4.2.1.

The assessment of the carbon stocks and changes in litter in Dutch forests have been based on extensive datasets on litter thickness and carbon content in litter (Section 4.2.1). The reported carbon stock changes per ha for the litter pool on land subject to deforestation, are much higher than those reported by other Parties. However, due to a characteristic combination of geomorphological and climate conditions, a large share of the forest area in the Netherlands is on poor Pleistocene soils 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

For methods on how to calculate changes in soil carbon stocks for various soil types, refer to Chapter 11.

5 Cropland [4.B]

5.1 Description

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

1. *4.B.1. Cropland remaining Cropland*
   Over time, no net accumulation of biomass carbon stocks will occur in annual cropland. In a single year, the increase in biomass stocks is assumed to equal 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.

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

2. *4.B.2. Land converted to Cropland*
   Emissions of CO_2 from carbon stock changes in living biomass for Land converted to Cropland are calculated using a Tier 1 approach (see Section 5.2 below). This value is also used to determine Cropland emissions converted to other land-use categories (4.A.2., 4.C.2.-4.F.2.). Net carbon stock changes in 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 the 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 the 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
For methods on how to calculate changes in soil carbon stocks for various soil types, refer to Chapter 11.

6 Grassland [4.C]

6.1 Description

The definition for the land-use category Grassland is provided in Section 2.4. Two main categories are distinguished within the category 4.C, Grassland: 4.C.1. Grassland remaining Grassland and 4.C.2. Land converted to Grassland. In each main category, Grassland is subdivided into Grasslands (non-TOF) and Trees outside Forest (TOF) (see Section 2.4).

6.1.1 4.C.1. 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 in the Netherlands predominantly have grass undergrowth.

The annual biomass production in grassland vegetation can be large, but due to rapid turnover changes, 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 the ageing of trees. Carbon stocks in living biomass in orchards are based on the 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[8]. The average age is based on the area corrected age distribution, assuming that the age class midpoint represents 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 were 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 mainly left 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 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.

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

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 the groundwater table is not common, therefore, such emissions from organic soils are considered negligible.

Trees outside Forest
No specific data on growth or increment are available for Trees outside Forest,. It is assumed that Trees outside Forest grow with the same growth rate as Forests. The only difference between them is the stand size (< 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 was not completely 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 in TOF. The conversion from TOF to Grassland (non-TOF) will involve the loss of the carbon stocks in biomass from TOF and an 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.C.2. Land converted to Grassland

Grassland (non-TOF)
Emissions of CO_2 from carbon stock changes in living biomass for Land converted to Grassland are 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.A.2., 4.B.2., 4.D.2.-4.F.2.). 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 are assumed 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 no longer complies with 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 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 to 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 by 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 below-ground 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, 2012 and 2017)[9] and a Tier 1 biomass accumulation rate of 2.1 tonne C ha^{-1} yr^{-1} (IPCC 2003).

Carbon stock changes in soils
For methods on how to calculate changes in soil carbon stocks for various soil types, refer to Chapter 11.

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

7 Wetlands [4.D]

7.1 Description

The definition for the land-use category Wetlands is provided in Section 2.4.1. 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 4.D, Wetlands, two subcategories are distinguished:

1. *4.D.1. Wetlands remaining Wetlands*
   Because the Wetlands category 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.D.1.c. Other Wetlands remaining other Wetlands. Within this category a differentiation is made for reed swamps and open water. The Flooded land categories defined in Section 2.4.1 are at the moment all reported under open water in the CRT tables.

2. *4.D.2. Land converted to Wetlands*
   Carbon stocks in living biomass and dead organic matter for flooded land and open water are considered 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). The Flooded land categories defined in Section 2.4.1 are at the moment all reported under open water in the CRT tables.

7.2 Methodological issues

Carbon stock changes in biomass
The 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.

Methane and carbon dioxide emissions from Flooded Land
Methane and carbon dioxide emissions from all land uses converted to Flooded land and remaining Flooded land are calculated using a Tier 1 approach from the 2019 refinements to 2006 IPCC guidelines (IPCC 2019). For the climate zone definition Cool Temperate is used. Carbon dioxide emissions only occur on land converted to Reservoirs. Methane emissions from ditches and canals (>3m) on organic soils are calculated using a country specific emission factor from Peacock *et al.* (2021). All emissions factors are shown in Table 7.1.

Table 7.1 *Tier 1 emission factors per hectare (ha) per year (yr) used for land converted to and remaining Flooded land categories. Source refers to the table from the 2019 refinements to the 2006 IPCC guidelines (IPCC 2019). [1]CH_4 emissions from drainages ditches <3 m are reported under the land-use these drainage ditches are part of (Forest land, Cropland or Grassland).*

Wetlands category	Emission factor			Source
Reservoirs	Converted to	3.74	ton CO_2/ha/yr	Table 7.13, 2019 refinements
		0.0847	ton CH_4/ha/yr	Table 7.15, 2019 refinements
	Remaining	0.054	ton CH_4/ha/yr	Table 7.9, 2019 refinements
Freshwater ponds	Converted to and Remaining	0.183	ton CH_4/ha/yr	Table 7.12, 2019 refinements
Canals + Ditches (>3m)[1]	Converted to and Remaining (mineral)	0.416	ton CH_4/ha/yr	Table 7.12, 2019 refinements
Canals + Ditches (>3m)[1]	Converted to and Remaining (organic)	0.518	ton CH_4/ha/yr	Peacock *et al.* (2021)

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, transportation infrastructure, and built-up areas. Within the category 4.E, Settlements, two subcategories are distinguished:

1. *4.E.1. 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 not 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.E.2. Land converted to Settlements*
   Carbon stock changes are conservatively estimated at zero because no information is available on carbon stocks in biomass in the land-use category Settlements. 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
The 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.F.1 Other Land remaining Other Land*

2. *4.F.2 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 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', distinguishes 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 (which are 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 topsoil 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 suggested in the 2013 IPCC KP guidance (IPCC 2014a). This approach was initially chosen for greater transparency compared to the reporting under the Kyoto Protocol. Although the reporting under the Kyoto Protocol is finished, the methodology remained the same. Following footnote 12 in the Convention CRT Table 4.G s1, this approach can be included in UNFCCC reporting and is considered to conform to Approach B for HWP reporting.

10.2 Methodological issues

The approach to calculating the HWP pools and fluxes follows Section 2.8 of the 2013 IPCC KP guidance. Carbon from harvests allocated to Deforestation is reported using instantaneous oxidation (Tier 1) as the calculation method. The fraction of harvest from Deforestation is based on the land-use change calculations under Forest land (Chapter 4). The remaining harvests are allocated to Forest land remaining Forest land and added to the respective HWP pools. As no country-specific methodologies or half-life constants exist, the calculations for the HWP pools follow 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 considered: sawn wood, wood-based panels, other industrial roundwood, and paper and paperboard. Domestically produced fuel wood is accounted for 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 for.

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 the production, import and export of industrial roundwood in 1990 appeared to be incorrect in the FAO forestry statistics database. Because FAO sometimes updates country data without transparent justification, the data for the base year 1990 are adjusted based on 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 the 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/). If the final data for the reporting year still needs to be published, PROBOS will provide preliminary estimates, which 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). The values for sawn wood were used for the category other industrial roundwood. This category includes a variety of roundwood uses, 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 lifetime 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 has developed a Tier 2 approach for calculating carbon stock changes in mineral soils based on the overlay of the land-use maps with the Dutch soil map, combined with soil carbon stocks quantified for each land-use soil type combination (Section 11.2.1). Fluxes 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 RothC soil carbon model (Section 11.2.2). Emissions resulting from drainage of organic soils are calculated using a combination of a Tier 2 and Tier 3 approach. The Tier 2 approach 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 (Section 11.3.2). The Tier 3 approach is based on a model ensemble built on and validated by measurements in the Netherlands. 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 the 2018 national soil survey by Knotters *et al*. (2022) (CC-NL), an update of the previous soil carbon stock map for the Netherlands which in turn was based on data derived from the LSK, a national sample survey of soil map units (Finke *et al.* 2001; Visschers *et al.* 2007). The CC-NL database contains quantified soil properties including soil organic carbon, for 1152 locations at two different depths (0-30 cm and 30-100 cm). The CC-NL survey is more future-proof for SOC monitoring, as detailed coordinates of the sampling points are now available, a fixed soil depth of 30 cm was used, and soil organic carbon content was measured, whereas in the LSK only soil organic matter was available. SOC stocks in the upper 30 cm were determined based on the measured SOC content and soil bulk densities derived via a pedo-transfer function (Knotters et al., 2022).

The land use at the time of sampling was known for each CC-NL sample location. The soil types for each sample point were classified into either six main soil types or an unknown class, and three land use categories (cropland, grassland and forestland). In the original 1960-1995 soil mapping by de Vries *et al.* (2003), SOC stocks were linked to ten soil types, however the number of observations for some soil types were limited, increasing uncertainty. These soil types have therefore been further aggregated into six main types (peat soils, peaty soils, clay soils, earth soils, sandy soils, and loamy soils) which represent the SOC stocks and have lower standard deviations than the original classification. In addition, one 'unknown' class was added, which contains the average SOC stock of all soil types. This is used in areas where there is a lack of soil map information such as city infrastructures and water. Data on the (spatial) extent of the six soil types and the unknown class are provided in Table 11.1 and Figure 11.1, see also Chapter 3.5). Figure 11.2 shows the calculated average SOC stocks for Grassland (non-TOF), Cropland, and Forest.

Table 11.1 *Main soil types in the Netherlands and number of observations in the CC-NL database.*

Soil Type	Soil type Dutch name	Area (km²)	No. observation
Sandy earth soil	Zandige eerdgrond	2084	59
Loamy soil	Leemgrond	258	41
Other sandy soils	Overige zandgronden	12144	289
Peaty soil	Moerige grond	1914	45
Clay soil	Rivierkleigrond	11062	336
Peat soil	Veengrond	3369	165
Unknown	Onbekend	10043	-

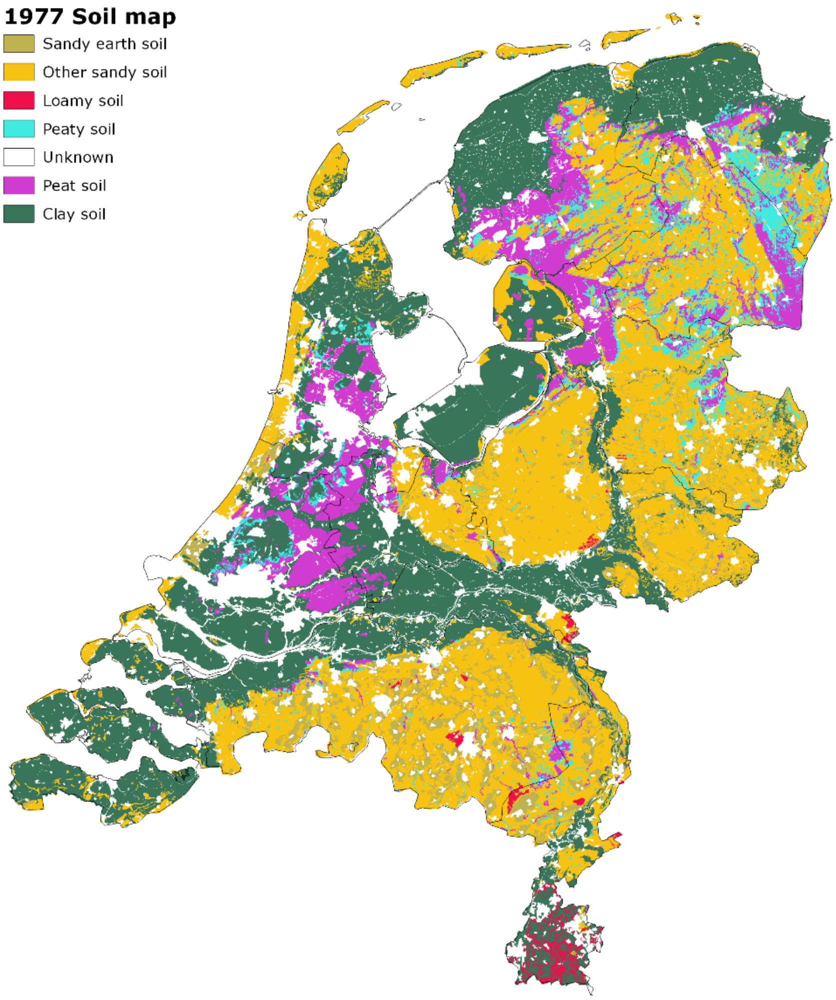

Figure 11.1 *Distribution of the main soil types in the Netherlands (Lesschen et al., 2012).*

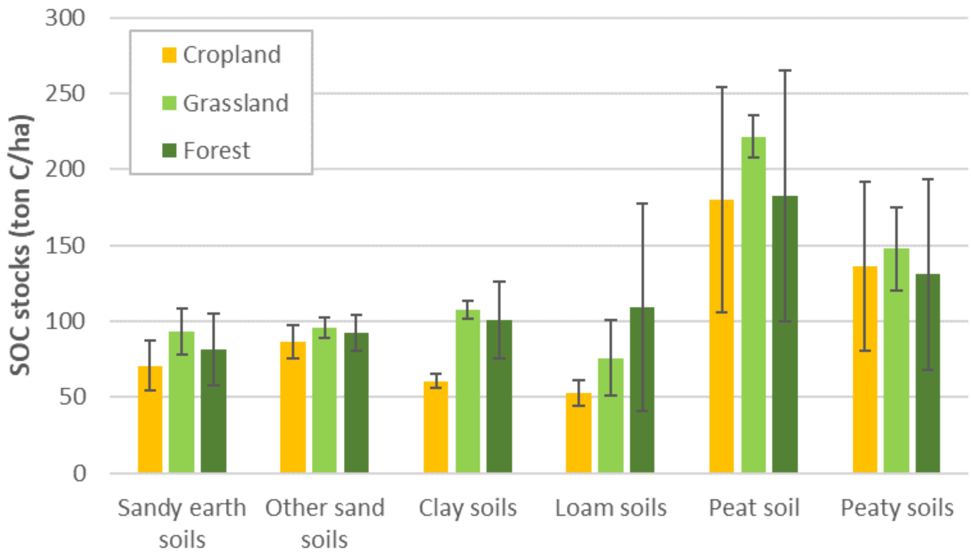

Figure 11.2 *Average soil organic carbon stocks per land use soil type combination for the 0-30 cm layer. The error bars indicate the standard error (based on Knotters et al., 2022). Grassland refers to the Grassland (non-TOF) subcategory. Trees outside Forest soils are treated similarly to Forest.*

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 CC-NL data set only contains data on soil carbon stocks for the land uses Grassland (non-TOF), Cropland and Forest. As no data on soil carbon are available in the LSK database or other studies for the other land-use categories (i.e. Settlements, Wetlands and Other Land), estimates had to be made. It was especially important to estimate soil carbon stocks for settlements, as conversion to settlements is one of the main land-use changes. The IPCC 2006 guidelines provide some direction for soil carbon stocks for land converted to settlement (text box) above. Given the high resolution of Dutch land-use change maps (25 x 25 m grid cells), it can be assumed that, in reality, a large portion of the assessed grid cell is paved. An average soil carbon stock under Settlements 0.9 times that of the previous land use is deemed valid using the following assumptions:

- 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 remaining 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 and Trees Outside Forest, 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 this category comprises dunes and drift sands, which hardly contain any soil carbon.

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 from 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:

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

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 year 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, an additional 1970 land use map has been created 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 enhance carbon sequestration. A consistent time series of input data was created for the period 1990–2023.

RothC model
RothC model is a dynamic model that simulates the turnover 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 the national scale, as described by Lesschen *et al.* (2021) and on the project web-page[10].

In the RothC model, 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 specific decomposition coefficient (the decomposition is a fraction of the amount present), except for the IOM compartment, where 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 RothC, as in most soil carbon models. The decomposition constants have been determined based on the long-term experiments conducted at Rothamsted Research (United Kingdom) and are usually kept the same 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 also considered to be representative of 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).

[10] https://slimlandgebruik.nl/sites/default/files/2023-07/Handleiding_BodemCoolstof_ENG.pdf

Input data

Below the input data sources for the RothC model are described. Although a full time-series (1990-2023) was created, the level of detail is not the same for the entire period. In those cases, data was extrapolated, or national instead of local data was used. This is indicated below where relevant.

- Climate data: monthly data for the period 1990–2023 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. Detailed data was available from 2005 onwards, while for the period 1990-2004, national data was downscaled based on the crop distribution data of 2005.
- Crop yield is based on harvest statistics from Statistics Netherlands (CBS), for the most common 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 cropland. This data was available from 2000 onwards (Initiator model: Kros *et al.* 2019), while for the period 1990-1999 national data from CBS was used (Mineralen balans landbouw)[11]. Both data sources are based on nitrogen applications and were converted to carbon using average C/N ratios. The following C/N ratios were used: 8.5 for manure applied on grassland (mostly cattle slurry), 4.6 for manure applied on cropland (combination of pig, poultry and cattle manure) and 9.5 for grazing manure (combination of manure from dairy cattle, horses and sheep)[12].
- Compost inputs are derived from the NIR data from Agriculture, which has data on the nitrogen inputs from compost. These data were converted to carbon inputs, using a C/N ratio of 14.5 for biowaste compost and 29.6 for green compost. Compost was only allocated to cropland and equally distributed over all crops. This is only a small supply source of carbon compared to manure.
- For cover crops (green manures and catch crops) detailed data from LPIS is available from 2017 onwards, while for the period before only national total areas are available, which were taken from NEMA. The NEMA data distinguishes two classes, cover crops after maize (a legal obligation since 2006) and other cover crops on cropland. These totals were distributed over the postal code regions, based on the 2017 LPIS data.
- 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. This information is available from 2005 onwards, while for the period 1990-2004 the average of the period 2005-2007 was used as this represents the period before 2005 best. For other straw crops a fixed percentage was applied, as described in Lesschen *et al.* (2021).
- A map of the soil organic carbon content was used for the initial soil carbon stock, 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.

[11] https://www.cbs.nl/nl-nl/cijfers/detail/83475NED?dl=69544
[12] https://nutrinorm.nl/meststoffen/de-samenstelling-van-organische-meststoffen/

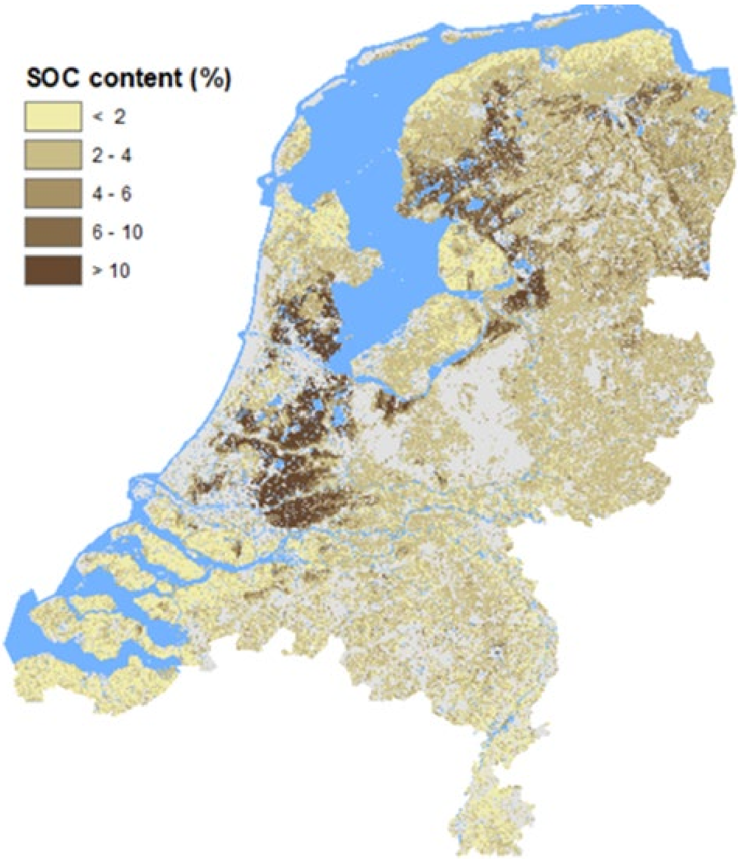

Figure 11.3 *Map of soil organic carbon content for cropland and grassland soils. Data are based on the Dutch Soil Sampling Programme from 2018 (van Tol-Leenders et al. 2019; Knotters et al., 2022) and mapped following the procedure of Helfenstein et al. (2022).*

Calculations

Calculations in RothC are performed at the 4-digit zip code level, which amounts to about 3400 units with agricultural land and 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 the NFI, which is based on a 5 year cycle. The 5 year average SOC balance is calculated using the actual year and the four preceding years, e.g. the value for 2023 is based on the average of the period 2019-2023.

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, respectively. In Cropland there was a decline in carbon inputs since 1990, mainly due to lower manure inputs as manure policies became more strict. However, during the last years there is a clear trend of increasing carbon inputs. This increase is partly the result of higher manure inputs, as stricter manure policies for livestock farms 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 resulting from the EU greening measures, which led many farmers to grow cover crops to comply with the ecological focus areas measure.

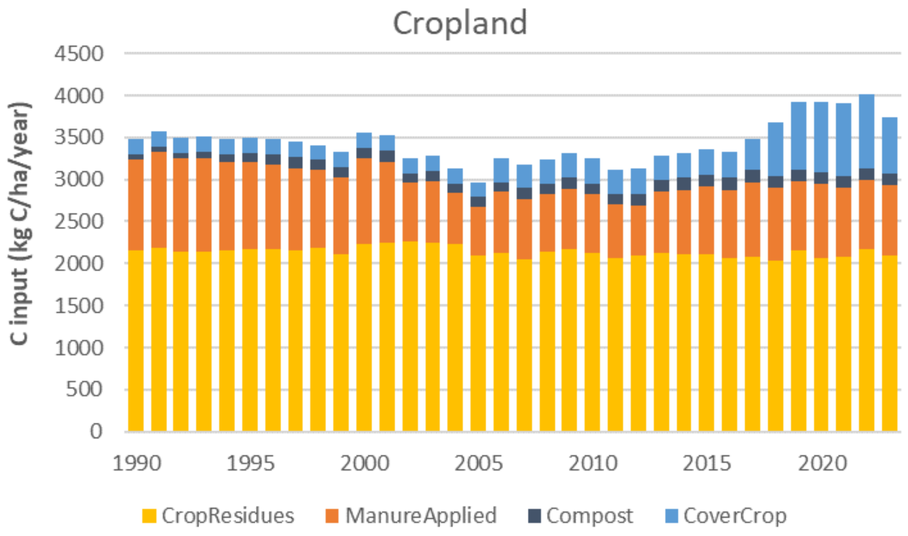

Figure 11.4 *Average annual carbon input to the soil for Cropland.*

The carbon input for the Grassland category shows quite a strong decline in the period 1990-2005, which is mainly due to lower carbon inputs from manure because of more stringent manure policies and a reduction of grazing on most dairy farms. Carbon inputs from grass residues are more or less constant over time, although slightly higher during the period 1990-2002 because of a lower share of temporary grasslands.

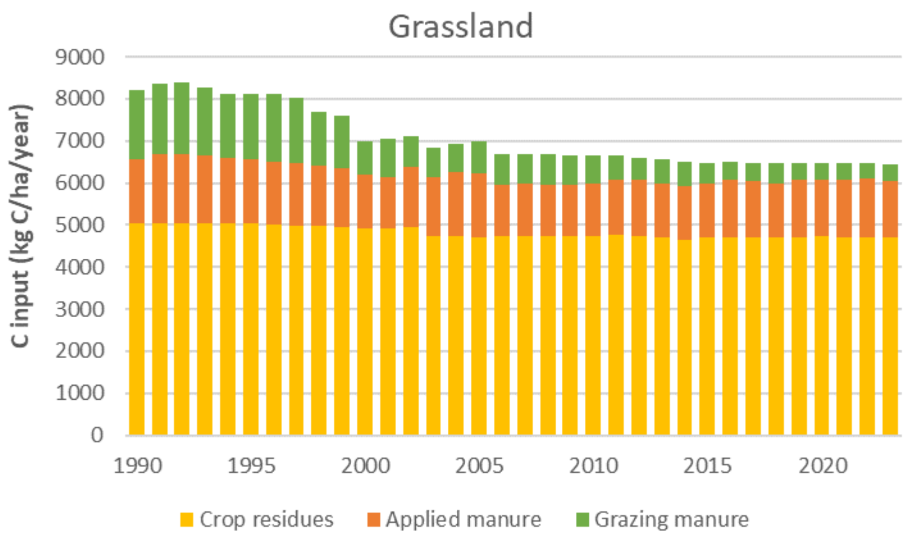

Figure 11.5 *Average annual carbon input to the soil for Grassland.*

The RothC model was used to calculate the soil's 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 during the last years, 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, Cropland and Grassland combined, shifted from positive during the nineties (high carbon input from manure), to negative during the period 2000-2015 to positive again in the most recent years (due to higher carbon input from cover crops).

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, combining them with the soil carbon stock changes due to land use change.

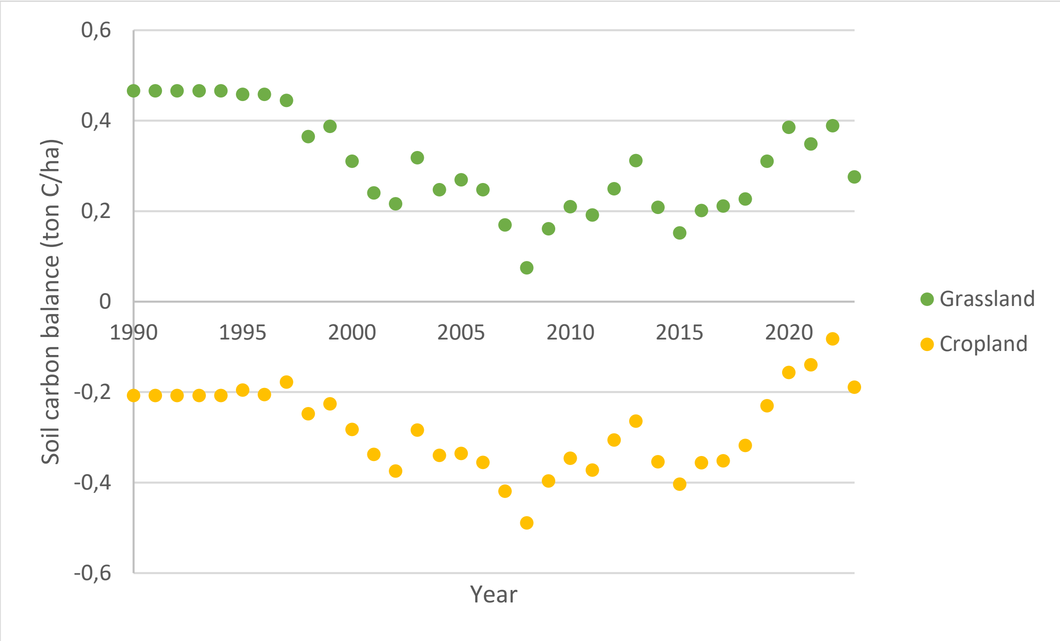

Figure 11.6 *Five-year average annual soil carbon balance for Cropland and Grassland based on RothC calculations.*

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 and 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

The soil map identifies two types of organic soils: peat soils and peaty soils (i.e. shallow peat soils). Organic soils are defined in the 2006 IPCC guidelines as follows:

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

1. The thickness of the organic horizon is greater than or equal to 10 cm. A horizon of less than 20 cm must have 12% 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% organic carbon by weight (i.e., about 35% organic matter).
3. Soils are subject to water saturation episodes and have either:
   a. At least 12% organic carbon by weight (i.e., about 20% organic matter) if the soil has no clay; or
   b. At least 18% organic carbon by weight (i.e., about 30% organic matter) if the soil has 60% or more clay; or
   c. An intermediate, proportional amount of organic carbon for intermediate amounts of clay.

Peat soils have a peat layer of at least 40 cm in the first 120 cm, while peaty soils, in Dutch, called '*moerige gronden*', have a peat layer of 5-40 cm in the first 80 cm. Based on the available data, two approaches for the emission factors have been developed, one for coastal peatlands and one for upland peatlands, each with different distinguishing characteristics.

Peatlands in the Netherlands are found in two different environments: the coastal zone and the uplands. Coastal peatlands contribute to around 72% of the total organic soil area and are mainly located in the coastal plain along the southwestern to northern edge of the country. This is the area that was (pre)historically prone to flooding from sea storm surges. All organic soils up to one meter above sea level are regarded as coastal peatlands (Erkens and Melman 2020). Upland peatlands cover the organic soils in the rest of the country and are found at elevations one meter above sea level. Upland peatlands are mainly found in the provinces of North Brabant and Drenthe, where they mainly occur in valley systems or on watersheds.

In 2014, an updated soil map became available for the Netherlands[13] showing that in recent decades, especially in the north-eastern part, many peat and peaty soils have disappeared. Due to intensive use and drainage, the organic soil material has oxidised, and these soils now have become mineral soils or peaty soils, thus the area of organic soils has decreased over time. On average, 1700 ha of peat soils per year (0.5%) have disappeared. Based on the 1977 and 2014 soil maps, this trend has been interpolated for this period.

In 2021, a new organic soil forecast map (Figure A2.10 in Annex 2) was developed for the Netherlands (Erkens *et al.*, 2021). It 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 is based on geohydrological modelling, where a scenario with limited subsidence was chosen based on limited climate change combined with surface water level fixation to mitigate subsidence (Erkens *et al.*, 2021). Through linear interpolation, this spatially explicit map is now being used to determine the area of organic soils per reporting year between 2014 and 2040.

11.3.1 Coastal peatlands

From 2020 onwards, CO_2 and CH_4 fluxes[14] in the Dutch coastal peatlands have been structurally measured using eddy covariance towers (e.g. Buzacott et al. 2024) and automated transparent closed chambers (e.g. Aben et al. 2024). These measurements form part of the Netherlands Research Programme on Greenhouse Gas dynamics in Peatlands and Organic Soils (NOBV[15]).

Measurement set-up
Measurements are available for ~50 measurement sites. Three types of sites are available, each with different instrumentation levels. The most extensively equipped sites have automated year-round continuous greenhouse gas flux measurements with additional environmental parameter monitoring. Concentration and flux measurements for CO_2 are taken at all sites, with CH_4 mostly at sites with high groundwater levels or those that are (semi-)permanently submerged, with N_2O measured at selected sites.

Currently, for the LULUCF reporting, only CO_2 site measurements with preferably three years of data are used as reference data. Environmental parameters include several groundwater measurement points, soil temperature and moisture, and redox probes at different depth intervals and spatially distributed locations. Surface movement and land subsidence is measured using extensometers (van Asselen et al. 2020), subsidence platens (Massop et al. 2024) and spirit levelling (Van Asselen et al., preprint).

On installation at the site, the subsurface build-up is characterised geologically and pedologically, and continuous cores are retrieved from the peat layer which are then analysed for biochemical characteristics, organic matter content, and carbon densities. In addition, the presence of microbial communities are analysed and samples for basal respiration experiments are collected. To support the analysis and interpretation of the flux measurements, filed meteorological and management (harvest events, fertiliser addition) data are collected. For a full overview of the site equipment and instrumentation, see, amongst others, Erkens et al. (2021), Van den Berg et al. (2021), Nijman et al. (2023), Aben et al. (2024), Buzacott et al. (2024).

[13] https://www.wur.nl/nl/show/Bodemkaart-1-50-000.htm
[14] N_2O is reported under CRF Sector 3 Agriculture and not further considered here.
[15] www.nobveenweiden.nl/en/

Measurement sites are distributed over the coastal peatlands in the Netherlands to cover the variability of peat types and the water and vegetation management. In some cases, measurements are paired. In these cases, one measurement plot is installed on a parcel where a measure is taken aiming at reducing greenhouse gas emission. At a second paired reference site (the same or a nearby parcel), the same equipment is installed however no measure is implemented. In other occasions, a single site is installed with the aim of measuring specific landscape conditions. The network covers grassland under intensive and extensive use, nature conservation locations with reed/sedge marshes, and sphagnum/reed land and cattail and sphagnum paludiculture sites. The sites also cover a range of water management and ground water dynamics common to the Dutch coastal plain.

Based on measured CO_2 concentrations by the closed chambers or EC towers, fluxes of CO_2 between the soil–vegetation system and the atmosphere were estimated. The Net Ecosystem exchange (NEE) is then determined from these flux estimates. NEE is separated into gross primary production (GPP) and ecosystem respiration (Reco) via relationships with solar radiation and soil temperature in order to fill any gaps in the data and to eventually be able to obtain annual budgets (see Aben et al., 2024 and Buzacott et al., 2024 for details on gap filling). Using harvest and fertilisation data, imports and exports of carbon to and from the field are quantified and used to calculate the net ecosystem carbon balance.

The annual NECB from the NOBV measurement network show a clear relation between CO_2 emission and the year average groundwater level for Dutch coastal peatlands, albeit with a considerable variability. The correlation increases if the amount of exposed carbon is taken into account. Every 10 cm annual average groundwater level increase lowers CO_2 emissions by ~3.1 ton per ha per year (Aben et al. 2024). Based on the automated closed chambers, the average CO_2 emission for the coastal peatlands for the five sites (12 annual budgets in total) at reference sites was 14.15 ton CO_2 per ha per year (Figure 7 in Aben et al. 2024).

Model implementation

To upscale the measurement outcomes to all peatland parcels in the Dutch coastal zone, two process-based models were developed: i) a hydrological model PP2D (PeatParcel 2D), and ii) a carbon model AAP (Aerobe Afbraak Potentie; 'Aerobic decomposition potential'). Both models have been calibrated and tested against the measurements described above and are coupled and part of the SOMERS multi-model ensemble (Subsurface Organic Matter Emission Registration System; Erkens et al. 2022). SOMERS is deployed to calculate greenhouse gas emissions (currently only CO_2) from organic soils at land parcel level. A specific model interface has been built to use SOMERS' output for the national greenhouse gas inventory.

The PP2D model (Erkens et al. 2022) is a MODFLOW-based (Langevin et al. 2017) groundwater model that calculates the phreatic groundwater level per 0.5 meter in a 2D profile across a parcel on a daily base. This is done for every parcel in the coastal zone that contains a minimum of 10% peat or peaty soil in area. The subsurface composition of these ~110,000 parcels is derived from the soil map and the GeoTOP geological model (Stafleu et al. 2012). The parcels' alignment is based on the topographic map of the Netherlands and on other land use, such as water (ditches, canals, lakes), buildings, urban public space, etc. For each parcel, the shortest distance between two ditches (being the parcel boundary) is calculated. The phreatic groundwater level is calculated using four types of parameters:

1. Parcel characteristics: the parcel width between two ditches, ditch depth, elevation, water management of the surface water in the ditches, and if applicable, any further water management measure characteristics.
2. Time-dynamic parameters: precipitation, evapotranspiration, seepage/infiltration head/flux. All weather parameters are from the weather year 2013 (northern Netherlands) and 2015 (western Netherlands) as these are representative of an average weather year for the period 2010-2019.
3. Soil parameters: soil and subsurface build-up and type, permeability, moisture characteristics and phreatic storage coefficient.
4. Model parameters: drainage pipe resistance in case of infiltration systems.

These parameters were calibrated using measurements from the NOBV measurement network. Overall performance of the PP2D model is acceptable, with a KGE-index of 0.70-0.80.

Based on the modelled phreatic ground water level, on a daily basis, the soil moisture and soil temperature per 5 cm depth interval is modelled for the unsaturated soil profile over the 2D cross-section. Input data include measured air temperature and rainfall/evapotranspiration.

In the AAP module, relations between the soil moisture and the microbiological activity and a relation between soil temperature and microbiological activity, both from Boonman et al. (2022) are used to derive relative microbial activity level per 5 cm. The maximum microbial activity is derived by CO_2 respiration measurements in the laboratory under standardized stable conditions for selected peat samples in the Netherlands. Using the relative activity level, the decomposition level, as fraction of the maximum decomposition, is calculated daily for each 5 cm unsaturated soil. This decomposition level is converted to C-loss and thereafter CO_2 emission using the basal respiration value database. Input for this calculation is the amount of carbon exposed in the 5-cm soil interval, which is derived from the organic matter density profiles and C:N ratios from NOBV measurements and from the soil map.

Overall outcomes accumulate to an annual emission per parcel in tons CO_2 per ha per year or in CO_2 tons per year for the parcel area. These outcomes are presented in Figure 11.9, which also shows the outcome for upland Netherlands. This value is summed for all 110 000 parcels and divided by the area of these parcels to derive an average emission factor for coastal peatland parcels.

The values derived by the SOMERS model ensemble (PP2D-AAP) are generally in line with those for the same location. In Figure 11.7, the modelled values are compared to the measured values. Although a direct comparison between a nation-wide model and a site-specific measurement has limited value and should be treated with caution, for the majority of sites the modelled values are within +/- 5 ton CO_2 per ha per year from the measured value (the dashed envelope). This is considered acceptable based on the uncertainty ranges of both the measurement values and the modelling outcomes. For sites with an over or underestimation of the measured values, the reason is often known and is not related to the model (e.g. extra-large uncertainties in measurements, indicated with the red values). Because the model is capable of reproducing the majority of the measurements within acceptable limits, no further tuning of the model has been applied.

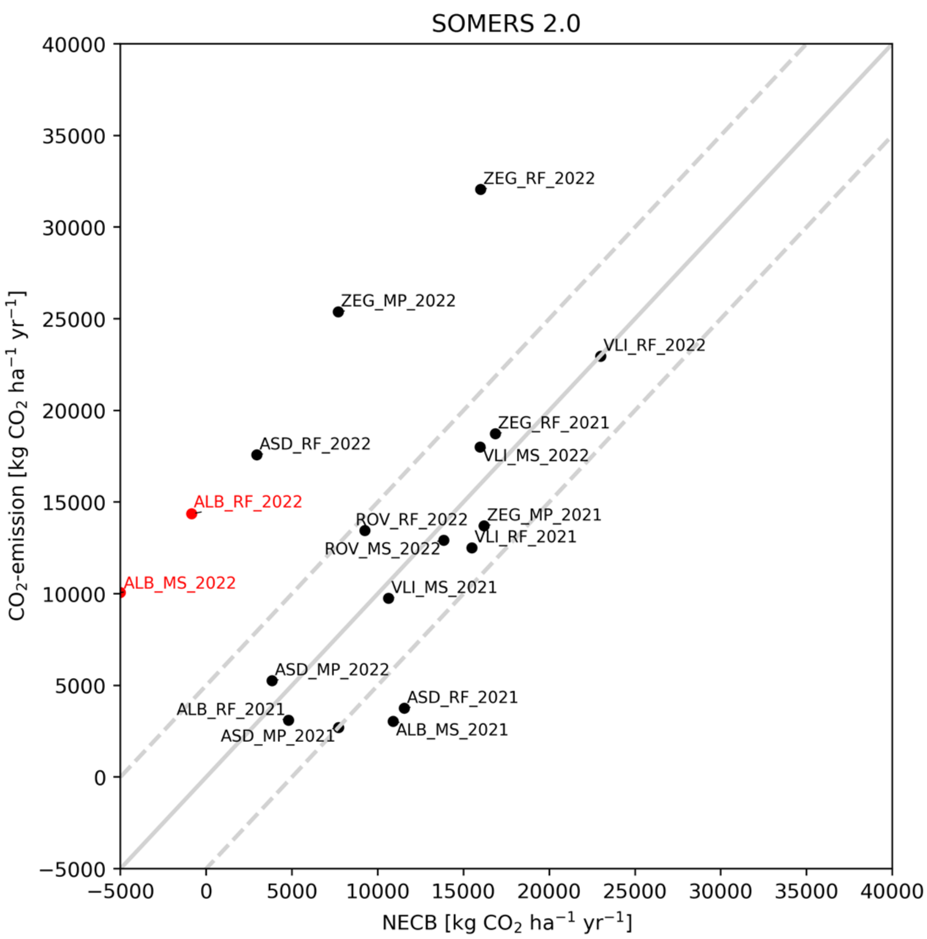

Figure 11.7 *Measured emissions (Y-axis, NECB: net ecosystem carbon balance) compared to modelled emissions (X-axis) in coastal peatlands. Every point represents a measurement location and year which has also been modelled using the SOMERS model framework. Dotted lines represents the 5 ton CO_2 per ha per year range. Model predictions on the solid line are in line with measurements. For the majority of sites the modelled values are within the +/- 5 ton CO_2 per ha per year range from the measured value (the dashed envelope). This is acceptable based on the uncertainty ranges of both the measurement values and the modelling outcomes. For the sites with an over or underestimation of the measured values by the model, the reason is often known and is not related to the model (e.g. extra-large uncertainties in measurements, indicated in red). As the model is capable of reproducing the majority of the measurements within acceptable limits, no further tuning of the model was applied.*

11.3.2 Upland peatlands

As described by Kuikman *et al.* (2005), a different approach was taken for peat and peaty soils in the uplands of the Netherlands. For peat, this method is based on subsidence due to oxidation of organic matter. Yet another approach was taken for peaty soils, 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 peat layer thickness over time.

Peat soils

Typically, oxidation 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 important 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). Thus, for all peat soils in the Netherlands, the estimated subsidence could 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:

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

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 is no data on the subsidence of such shallow peat soils and because this would cause just a small error because the majority of Dutch peat soils are thicker than 80 cm. Besides, the underestimation of the bulk density will be compensated more or less by overestimating 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 be 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 11.8.

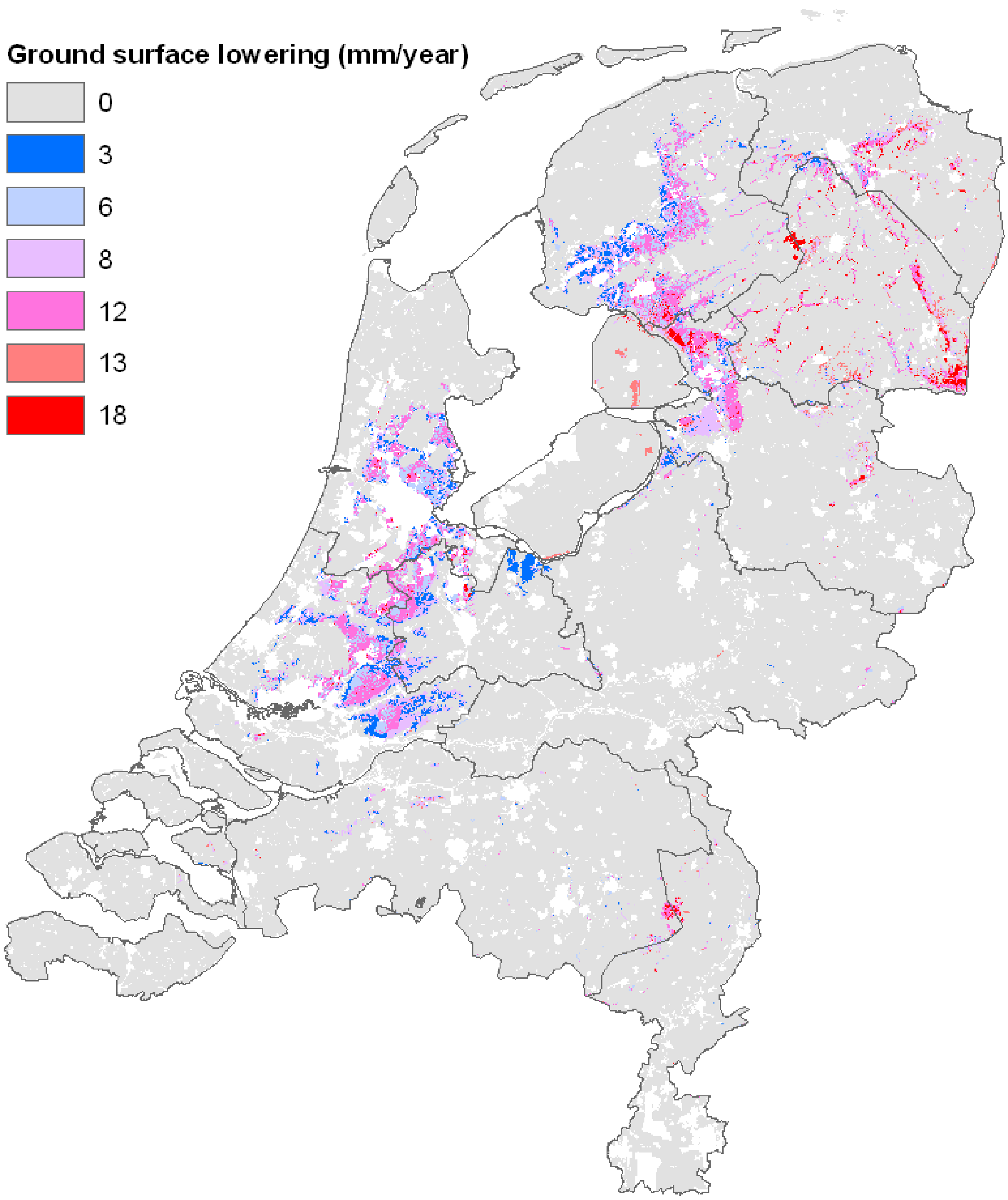

Figure 11.8 *Location of peat soils and their average ground surface lowering.*

In Table 11.2 the calculated ground surface lowering and the area are provided for the different combinations of soil types of the upper soil layer, the peat type and the drainage class. The last column of the table reports the annual carbon emission. In this case, based on the 2004 land-use map, the total annual loss of carbon from organic soils under agricultural land use is 1.16 Mtonnes of C, an annual emission of 4.25 Mtonnes of CO_2. This has been converted to an annual emission factor of 25.7 tonnes of CO_2 ha^{-1}. This emission factor is used for the entire time series for upland peatlands.

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	**Area (ha)**	**gsl**	**Area (ha)**	**gsl**	**Area (ha)**	**Area (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

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 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 disturbance 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 led to a large database with all soil profile descriptions and an updated soil map. This new 2014 soil map has also been 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 soil is classified as peaty soil if the peat layer is between 5 and 40 cm thick.

Due to 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 thickness was differentiated for three drainage classes, similar to what was done for the peat soils. For each drainage class, an average loss rate of the peat layer in the peaty soils was determined, which led 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 upland peaty soils under agriculture, which has been used for the entire timeseries. No data were available for Settlements, but the same overall emission factor has been used.

Also, the area of peaty soils has decreased over the years. On average 800 ha of peaty soils per year (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 CRT, the sum of these emissions is reported in the relevant categories of organic soils.

Emissions from organic soils under forest land on the upland peatlands
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 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 forest area 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 Cropland, Grassland or Settlements in at least one of the earlier maps. Therefore, we assume for each year 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 forest area 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.

11.3.3 National implied emission factor organic soils

To obtain a national emission factor covering all organic soils, the results for the coastal peatlands and upland peatlands (11.3.1 and 11.3.2.) were combined and are shown in Figure 11.9. The following steps were taken to derive a national implied emission factor:

- For meadow parcels with peat soils and for meadow parcels with peaty soils in the coastal zone (see above), a parcel-specific emission was calculated using the SOMERS models for the calendar year 2022 under average weather conditions for the period 2010-2019 and under current water management.
- The average of the total emission from the parcels was then converted to an emission factor for peat soils and peaty soils in the coastal zone using the representative meadow parcel area.
- The coastal zone emission factor for peat soils and peaty soils were applied to all organic soils under all land uses in the coastal zone except open water, using the LUSOS (LULUCF SOMERS Shell) model package.
- Based on Kuikman *et al.* (2005), a separate emission factor and total emission was calculated for peat soils and peaty soils in the upland peatlands.
- The total emission from organic soils in the coastal zone was combined with the total emission from upland organic soils to derive a total CO_2 emission under all land uses, except open water. This was calculated separately for peat and peaty soils.
- The total emissions for Dutch peat soils were divided by the area of peat soils for different LULUCF land use classes. This resulted in an implied emission factor for drained peat soils of 14.60 ton CO_2/ha/year.
- The total emissions for Dutch peaty soils were divided by the area of peaty soils for different LULUCF land use classes. This resulted in an implied emission factor for drained peaty soils of 13.77 ton CO_2/ha/year.
- For both peat and peaty soils, the 2022 values were extrapolated to 2023 and back to 1990 using a factor describing the trend in organic soil coverage.

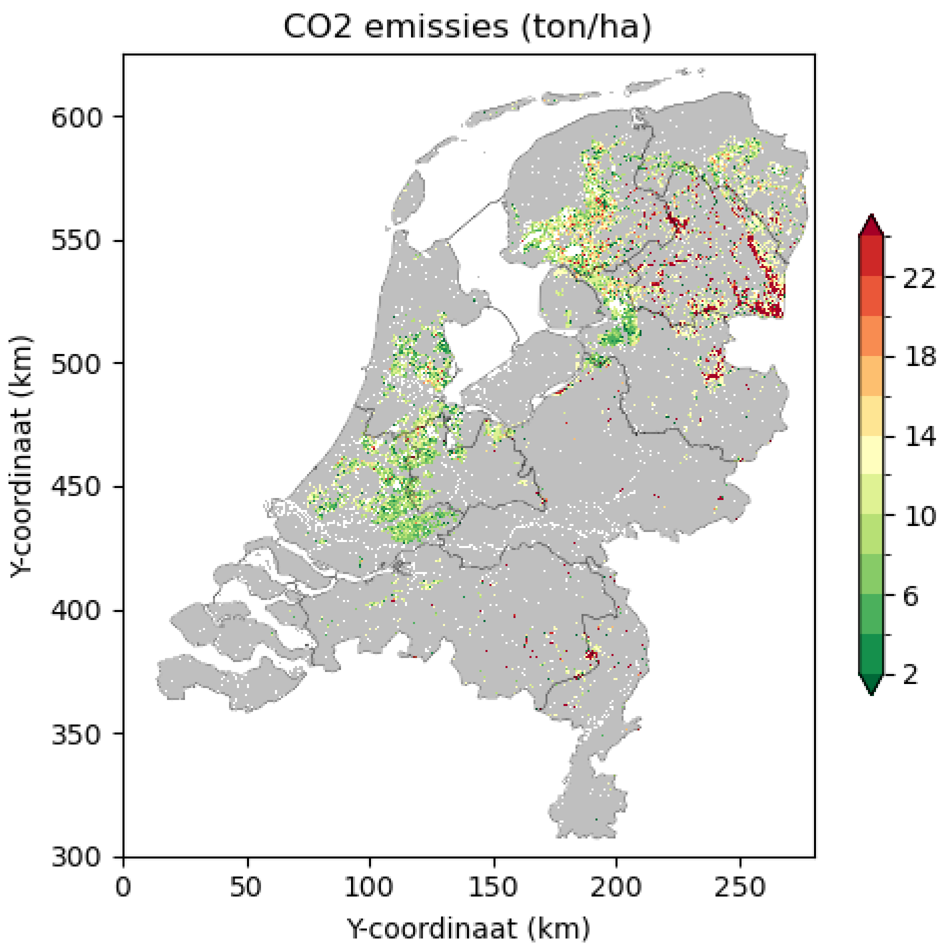

Figure 11.9 *CO_2 emissions from Dutch peat and peaty soils for the calendar year 2023 on a grid-cell level. This is the outcome from the Lusos model that combines the SOMERS outcomes for coastal peatlands with the calculated emissions for the upland peatlands.*

11.3.4 Nitrous oxide emissions from organic soils

Apart from CO_2 emissions from organic soils, N_2O emissions also occur due to the mineralisation of organic nitrogen. These emissions are included under Agriculture (category 3D) for cropland and grassland. However, those emissions under Forest land must 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 under forest are nutrient-rich and 21% are nutrient-poor. All peaty soils have been classified as nutrient rich, as the average CN ratio is 17. The default IPCC Tier 1 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.

11.3.5 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 CRT Table 4(II). This was calculated using a Tier 2 approach described in Section 2.2.2.1 of the 2013 IPCC wetlands supplement (IPCC 2014b) using a country-specific ditch fraction and emission factor.

Ditch fraction calculations are based on an extraction of ditches (< 3m) from the "Large-scale Topography Basic Registry (BGT)" (Dutch: *Basisregistratie Grootschalige Topografie (BGT)*[16]), a detailed digital map of all physical objects in the Netherlands overlayed with the land-use map and soil map. The percentage of ditch

[16] https://www.geobasisregistraties.nl/basisregistraties/grootschalige-topografie

area was calculated from this analysis for the land-uses Cropland, Grassland, Trees outside Forest, and Forest land (Table 11.3).

A country-specific emission factor of 518 kg CH_4 ha^{-1} yr^{-1} is applied to these areas based on case studies for the Netherlands by Peacock *et al.* (2021). Individual data points on which the value is based are provided in the supplemental data of Peacock *et al.* (2021). 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}. 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).

Table 11.3 *Percentage of area of drained organic soils per land-use assumed to be ditches smaller than 3 m.*

Land-use	**Percentage**
Cropland	1.4%
Grassland	5.8%
Trees outside forest	9.6%
Forest land	2.8%
Total	**4.9%**

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

12.1 Controlled biomass burning

The areas included under wildfires partly include the occasional burning 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 is reported as not occurring (NO).

12.2 Wildfires

In the Netherlands, no countryspecific information on the intensity of forest fires and emissions of Greenhouse gases from those fires is available. Therefore, CO_2, CH_4 and N_2O emissions from forest fires are reported using the Tier 1 method described in Chapter 2 of the 2006 IPCC guidelines. Recent data on the occurrence and extent of wildfires is lacking. Due to the decreasing occurrence of wildfires, monitoring ceased in 1996. Between 1980 and 1992, besides the number of fires, the area of forest fires was also 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 area was 37.8 ha (or 0.1 ‰ of the total forest land in the Netherlands), and was used from 1990 onwards as an estimate of the 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 CRT Table 4(IV) under wildfires for forests remaining forests.

Other wildfires
CO_2, CH_4 and N_2O emissions from ‘other’ wildfires (mainly on grassland and heathland) are calculated and reported according to 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). 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, and both are reported under Grassland (non-TOF). Emissions from these ‘other’ wildfires, 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 identifying 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 attempted to improve wildfire activity data by testing various remote sensing sensors and geospatial techniques (Roerink and Arets 2016). None of these approaches effectively detected the relevant forest and wild fires. The alternative of combining information on wildfires from the media and subsequently analysing areas per vegetation type of wildfire (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). However, the cost of monitoring and analysis was considered 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 wildfire statistics in the Netherlands using the EFFIS data reported in its annual fire reports[17] since 2000. Until 2017, the Netherlands did not submit a report to EFFIS, but the EFFIS reports also include independent rapid damage assessments 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 has also submitted 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

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

dry sandy soils in the Veluwe region (centre), Noord-Brabant and Limburg (southeast) and 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[18].*

Year	Number of fires	Area forest/OWL	Area other natural	Area agriculture	Total area without Agriculture
2023	2		53		53
2022	15	1	330		331
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 wildfires, including small roadside fires. As a result, the total number of fires recorded 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. However, it provides information on locations, the 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 wildfires in the Netherlands, an important prerequisite will be that such approaches should be cost effective and proportionate to the expected emissions from wildfires.

[18] 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 by Olivier *et al.* (2009). That uncertainty assessment is, however, based on a calculation methodology that has not been 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

0. The background on the types of uncertainty addressed.
1. A description of the uncertainty range input parameters used.
2. A description of the MC simulation performed.
3. The resulting uncertainty ranges for the reported fluxes.
4. The temporal development of the uncertainty.
5. 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 yet include the most recent methodology changes . 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. However, uncertainties are likely to 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). Two of these nine causes 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 types of causes of uncertainty 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;
0. uncertainties from emission factors related to biomass,
1. emission factors related to soil, and
2. activity data based on the land-use map

Where default Tier 1 emission factors and activity data are used from the IPCC 2006 guidelines, their Tier 1 uncertainty ranges are used as input to the Monte Carlo 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

Land use	Soil type	Cstock (tC/ha)	SEM (C-stock)	CN ratio (-)	SEM (CN ratio)
Forest land	Eerdgrond	99.53	17.39	15	2.50
Forest land	Kalkhoudende zandgrond	32.16	5.78	17.3	0.21
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

Land use	Soil type	Cstock (tC/ha)	SEM (C-stock)	CN ratio (-)	SEM (CN ratio)
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

Based on Kramer *et al.* 2015 and Kramer and Clement (2015), land use related uncertainty is expressed as a confusion matrix. 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 were 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, totalling 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 was based on time constraints. No tests for convergence were performed.

13.5 Total uncertainty

The calculation of the GHG fluxes from LULUCF generates many detailed outputs. Here, only the uncertainty ranges for the main categories in CRT 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[19].*

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

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

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 data sources have different temporal resolutions (Table 13.8). Here, the large uncertainty and the volatility of this uncertainty for land converted to grassland, is apparent. Again, the leading cause for this is that the absolute value is small, and thus, a similar uncertainty in absolute values results in an extreme relative uncertainty around 2010.

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 are then expressed relative to the minimum 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	Soil	Map
	2014	2014	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. However, 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 other land uses. However, there is more on the maximum range than the minimum 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. These uncertainties can account for all of the maximum range. 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 categories. 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. The Other Land and the Settlements category especially 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 a 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, the 2013 IPCC Supplementary Guidance for LULUCF reporting under the Kyoto Protocol and the 2019 refinements to the 2006 IPCC Guidelines.

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Annex 1 Data files used

A1.1 National Forest Inventories

For calculating carbon stock changes in forest biomass data from five National Forest Inventories (NFI) are used, covering the period 1990-2022: HOSP, NFI-5, NFI-6, NFI7 and NFI8.

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 differed from earlier and later forest inventories. It was primarily designed to get insight into the amount of harvestable wood, but it still provides valuable information on standing stocks and increments 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 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 the results of these checks were discussed with the field staff. 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 data collection for the NFI-5 and the subsequent data analysis 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 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.* 2022). Again, the methodology largely followed the methodology of the earlier inventories, and also included the same relevant measurements for assessing carbon stocks as done in the previous NFIs. This guarantees the consistent calculation 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.

NFI-8
Measurements for the eighth National Forest Inventory (NFI-8; Achtse Nederlandse Bosinventarisatie, NBI8) started in 2022 and will end in 2026. It is a continuation of the NFI cycle started by the NFI-7. A final report on the NFI-8 will follow after the last measurements in 2026, but in the meantime data relevant for the LULUCF GHG inventory are processed. With the dataset of the NBI-7 as a basis, each year the data for the plots measured in the NBI-8 are updated. The NFI-8 follows the methodology used in the earlier inventories including the relevant measurements for assessing carbon stocks as done in the previous NFIs (Lerink *et al.* 2023). This guarantees the consistent calculation of carbon stock changes over time. In 2022, 412 permanent sample plots were remeasured.

QA/QC
The same QA/QC measures as in the NFI-7 are implemented. It was carried out partly by the same field workers as in the NFI-7, while the new assessors were trained by the ones involved in NFI-7.

With the start of the NFI-8, a modernization has been made in the way in which the raw data is uploaded by the field workers and the processing of the data by WUR and the Probos Foundation. An online fieldwork portal has been set up, in which the field surveyors can upload their raw data. The employees of the Probos Foundation can then view the data in the portal and adjust it when errors are reported during the automatic check. In addition, the automatic check ensures that many of the errors that were previously made when entering the data are prevented.

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 CO_2 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, 2013,2017 and 2021 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 and Clement (2022) 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).

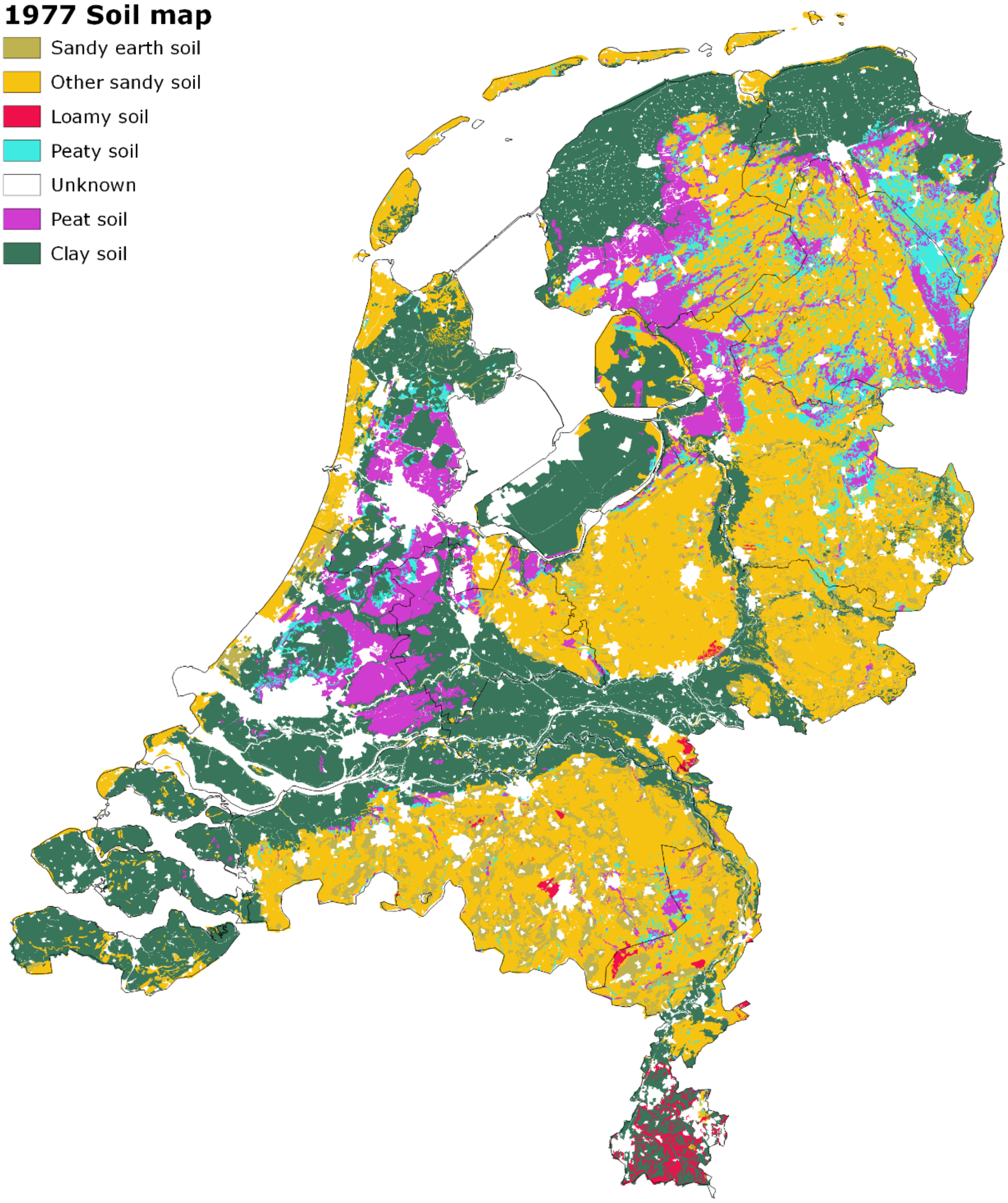

Figure A2.8 *Soil map of 1 January 1977.*

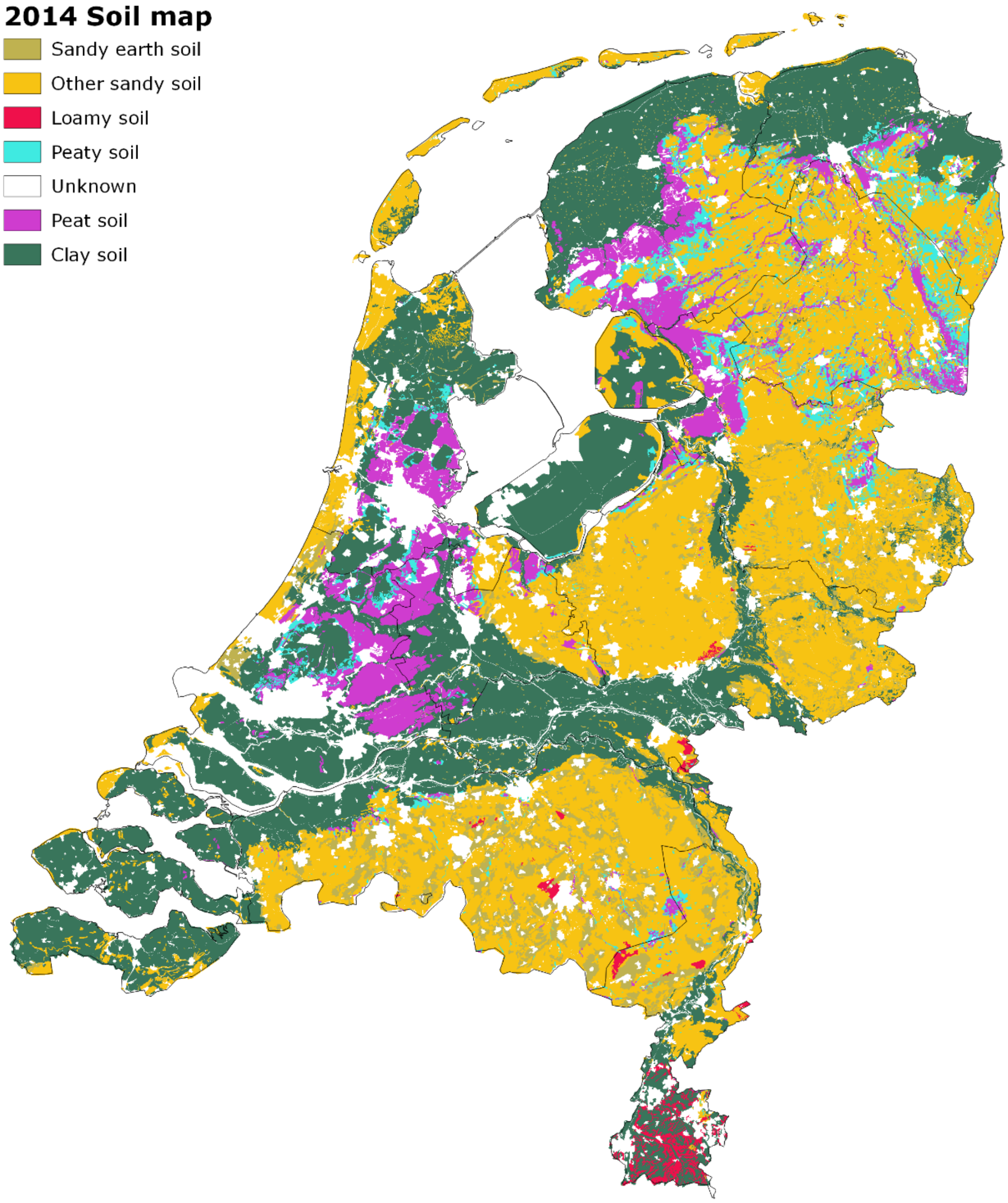

Figure A2.9 *Soil map of 1 January 2014.*

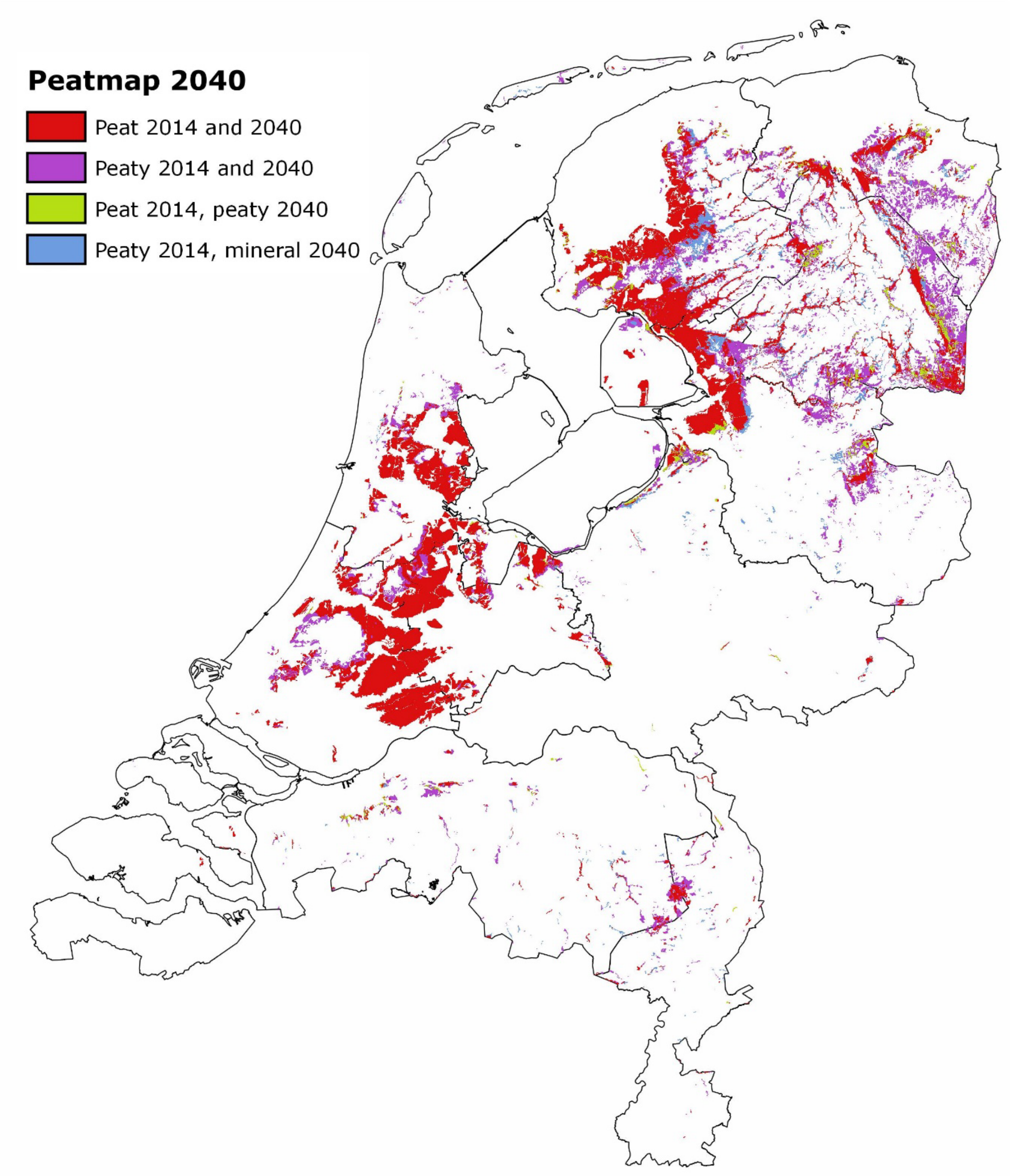

Figure A2.10 *Organic soil forecast map of 2040.*

A2.4. Water type map

Characterisation and spatial distribution of waterbodies is taken from the "Water type map" from Puijenbroek and Clement (2010) who developed this map for the Netherlands in accordance with the water typology from the European Water Framework Directive. It is also used in other policy areas to identify waterbodies and their types for the Dutch Water Framework Directive. In the Water type map 50 water types are identified, these definitions have been matched with the definitions used for the different Flooded land categories (see section 2.5). In table A2.2 the full list of matches is given.

Table A2.2 *Water types identified in the "Water type map" by Puijenbroek and Clement (2010) for the Netherlands, with the Water code, Water Framework Directive (NL: Kader Richtlijn Water (KRW) type) and the corresponding LULUCF Wetland category.*

Water code	KRW type	LULUCF Wetland category	Sub-category
ZEE: Noordzee	K1,K3	Open water	
KBS: Waddenzee, Oosterschelde	K2	Open water	
MBR: Brakke wateren	M30,M31,M32	Open water	
MGD: Grote meren	M21	Reservoirs	
MKA: Kanalen	M3,M4,M6,M7,M10	Other constructed waterbodies	canals
MKD: Kleine diepe plassen	M16,M17,M18,M24,M28	Reservoirs	
MKO: Kleine ondiepe plassen (zand, kalk)	M11,M22	Other constructed waterbodies	Freshwater ponds*
MKV: Kleine ondiepe veenplassen	M25	Other constructed waterbodies	Freshwater ponds*
MMD: Matig grote diepe meren	M20	Reservoirs	
MWR: Water in rivierengebied	M5,M19	Other constructed waterbodies	Freshwater ponds*
MMO: Matig grote ondiepe meren	M21	Reservoirs	
MSL: Sloten laag Nederland	M1,M2,M8,M9	Other constructed waterbodies	ditches
MSH: Sloten Hoog Nederland	M1,M2,M8,M9	Other constructed waterbodies	ditches
MVN: vennen	M12, M13, M29	Other constructed waterbodies	Freshwater ponds*
OTY: Eems-Dollard, Westerschelde	O2	Open water	
RBL: Langzaam stromende wateren	R3,R4,R5,R11,R12	Other constructed waterbodies	ditches
RBS: Snel stromende wateren	R13,R14,R15,R17,R18	Other constructed waterbodies	ditches
RMB: Middenloop of benedenloop	R6	Open water	
RRV: Rivier	R7,R8	Open water	
RRS: Snelstromende rivier	R16	Open water	
OVE: Overig		Open water	
ONB: Onbekend		Open water	
BUI: Buitenland		N.a.	

Annex 3 Carbon in forest litter

A3.1 Introduction

Carbon stocks in litter in the different forest inventories are determined by combining data on litter layer thickness (A3.2) from the national forest inventories with data on carbon content in litter from specific research studies (A3.3).

A3.2 Litter layer thickness measurements

In line with the 2006 IPCC Guidelines, litter was considered to include the entire dead organic top soil layer, including the L, F and H horizons (IPCC, 2006a). Thicknesses of litter layers L, F and H were measured during the national forest inventories. During the NFI-5 (2005), litter layers L, F and H were only measured during the second half of the inventory, which included 1473 plots to be included in the calculation of litter layer thickness from the NFI-5. During the NFI-6 and NFI-7, litter layers L, F and H were measured for all plots.

During the NFI-6, litter layer thickness was measured one time. In the upper soil horizon (up to a maximum depth of 40cm), the thickness of the following organic layers, which indicate increasing digestion were measured:
- freshly fallen leaf litter (L);
- partially digested litter (F);
- fully humified organic matter (H).

The litter layer thickness was measured by cutting a block of soil out of the ground with a breadknife. The thickness of the individual layers (L,F, and H) was measured on the cut-out bottom block or on the profiles in the resulting pit. The thickness of the humus layers is measured in mm. The humus measurement is not carried out in peat soils (Schelhaas *et al.* 2014).

In NFI-7, the litter layer measuring method remained identical to the method applied in the NFI-6. The only changes were that litter thickness was measured for three samples per plot instead of one, and the L and F layers were taken together (Schelhaas *et al.* 2022).

A3.3 Data on carbon in forest floor

During 2020, measurements were taken on 143 NFI plots to sample carbon in soil and litter. Litter layers were divided into L+F and H layers. A soil sample was taken with an "*edelmanboor*" (manual earth auger). Because the litter layer thickness differs over a shorter spatial distance than the horizons in the soil profile, three observations were made for the humus profile within a few meters of the borehole. At these three locations, a piece of the topsoil and the humus profile were extended with a humus chopper. The litter layer thickness was measured in mm. For the analysis, average thicknesses of the humus horizons were made to arrive at an average profile of each research site (de Jong *et al.* 2021).

The results from the research on carbon in forest floors are used to establish regression relationships that can be used to calculate carbon stocks in litter for each forest inventory. Within this dataset, a division was made between coniferous and deciduous trees. Soil type was found not to have a significant influence on the relation between litter layer thickness and associated carbon stocks. Therefore, soil type was not taken into account in establishing the relationships between litter layer thickness (mm) and carbon stock (t C ha^{-1}). Litter layer horizon (L+F and H), on the other hand, did influence the carbon content. Therefore, in establishing the relationships between litter layer thickness and carbon content, a distinction was made between coniferous tree species and broadleaf tree species, and between LF and H layers (see Table A3.1 and Figure A3.2).

Table A3.1 *Overview of the results of the regression analyses of carbon content per mm of litter layer thickness.*

	Carbon stock (to C ha^{-1}) per mm of litter layer thickness	
Main tree species	**L+F layer**	**H layer**
Coniferous	0.522	0.728
Broadleaf	0.514	0.654

A3.4 Calculation of litter carbon stocks

In order to calculate the litter carbon stock (t C ha^{-1}) for each of the forest inventories (NFI-5, NFI-6 and NFI-7), the regressions established with the research on carbon in forest floors (De Jong *et al.*, 2021) were linked to the litter thickness measurements from the national forest inventories. All plots with litter data available from the NFI-5, NFI-6 and NFI-7 surveys, along with information on the respective forest type, entered into calculation of litter carbon stocks. Plots where the litter layer thickness and soil type were not measured were not taken into account. Furthermore, for NFI-6 and NFI-7, all values with tree label KV, "kapvlakte" ("felling area") were assigned the main tree species of the specific plot from the previous forest inventory, assuming there was litter on these plots coming from the previous (felled) tree species. The values of the remaining sampling points for the NFI-5 (n = 1473), NFI-6 (n = 3164) and NFI-7 (n = 3170) enabled the calculation of carbon stocks separately for coniferous forest and deciduous forest, and for litter layers "LF" and "H".

During the NFI-5 only the second half of the plots were measured for litter thickness. This results in a non-representative sample selection of the Dutch forest for the NFI-5. To take this into account, the division of the forest in coniferous and deciduous trees during the period 2001-2005 was calculated based on (Dirkse *et al.* (2007; resulting in 55% coniferous forest and 45% deciduous forest). Sub-results of the carbon stocks in the litter layers in coniferous forests and deciduous forests were weighted accordingly, to result in a weighted total carbon stock for the total forest.

For the NFI-6 and NFI-7, there is no weighted average, as the NFI sample is already representative of the entire Dutch forest. For each plot, the respective regression is selected for the LF and H litter layers. This results in separate C stocks for the LF layer and for the H layer per plot. From all separate plots together, average C stocks for both the LF and H litter layers are calculated. After this, the average C stocks of the LF and H layers are added together, resulting in the total average C stock per ha of the entire NFI-6 and NFI-7. The mean carbon stocks in the samples were 29.5 t C ha^{-1} for 2005 (NFI-5), 32.9 t C ha^{-1} for NFI-6) and 31.6 t C ha^{-1} for NFI-7) (Table A3.2).

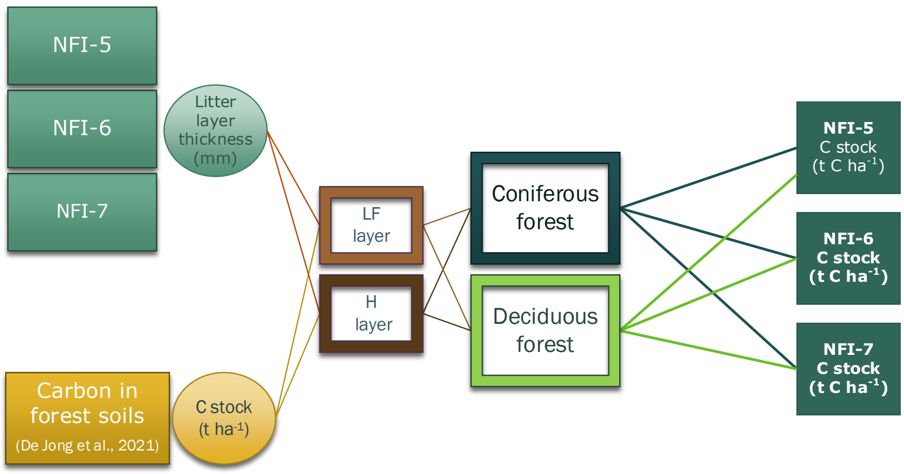

Figure A3.1 *Visualization of data behind calculation of carbon stocks in litter.*

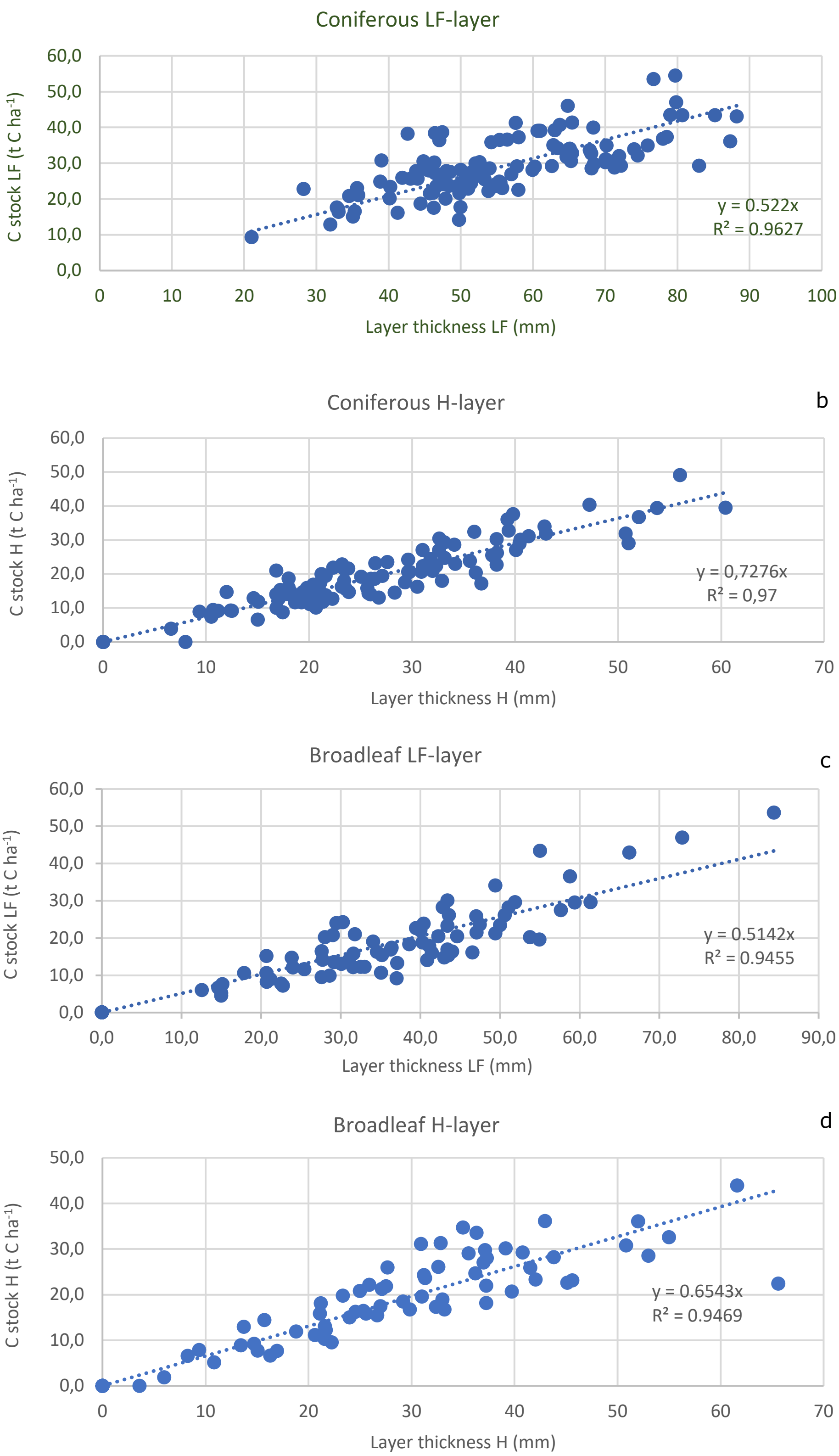

Figure A3.2 *Relations between litter layer thickness (mm) and carbon content (t C ha^{-1}) for: a) coniferous LF-layer, b) coniferous H-layer, c) broadleaf LF-layer, d) broadleaf H-layer (data from de Jong et al. 2021).*

Table A3.2 *Overview of average carbon stocks in litter per forest inventory.*

Forest inventory	**C stock LF ($t\ ha^{-1}$)**	**C stock H ($t\ ha^{-1}$)**	**C stock total ($t\ ha^{-1}$)**
NFI-5	20.6	8.9	**29.5**
NFI-6	22.8	10.1	**32.9**
NFI-7	22.5	9.2	**31.6**

Annex 4 Harvest statistics

A4.1 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 A4.1). 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.

A4.2 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 A4.1 and Table A4.1).

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).

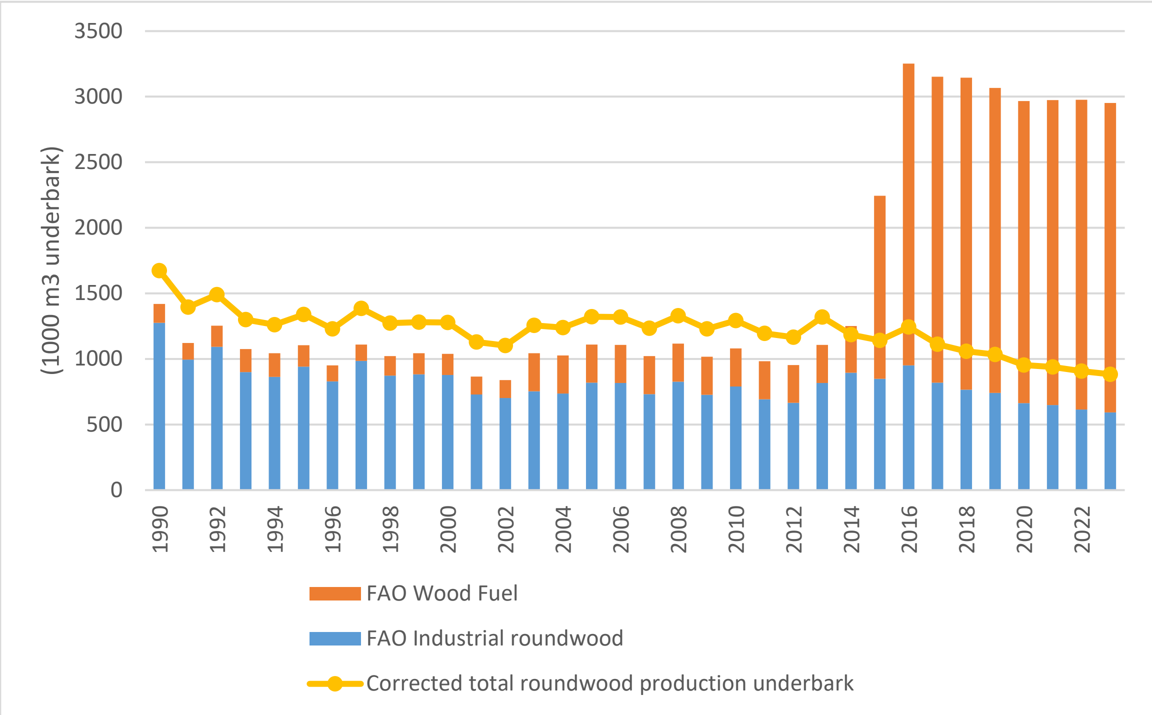

Figure A4.1 *Annual production of roundwood in the Netherlands. Dark bars represent production of industrial roundwood from FAO statistics, light coloured bars represent the amount of wood fuel from FAO statistics. The two together are the total volume of harvested roundwood from FAO statistics. The 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 A4.1 *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*
2022	615	292[3]	*907*
2023	592	292[3]	*883*

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

A5.1 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.

A5.2 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)[20] 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

[20] 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.

A5.3 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.

A5.4 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).

A5.5 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*)[21] containing actions to reduce emissions and increase removals of greenhouse gases in the Netherlands. Additionally, the Government has adopted a Climate Act[22] 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.[23]

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[24] for climate-smart forest and nature management.

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[21] https://www.klimaatakkoord.nl/documenten/publicaties/2019/06/28/national-climate-agreement-the-netherlands (English translation)

[22] https://zoek.officielebekendmakingen.nl/stb-2019-253.html (in Dutch)

[23] Ontwerp beleidsprogramma klimaat. June 2022. https://open.overheid.nl/repository/ronl-53899d440127f31fa5f7382c72d031007894dd2e/1/pdf/Ontwerp_Beleidsprogramma_Klimaat.pdf

[24] 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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