The SEEA EEA carbon account

for the Netherlands

Marjolein Lof

Sjoerd Schenau

Rixt de Jong

Roy Remme

Cor Graveland

Lars Hein

Natural capital accounting (ecosystem accounting) aims to systematically measure and monitor ecosystem services and ecosystem condition over time for decision making and planning. In 2016 Statistics Netherlands and Wageningen University started the project 'Natural capital accounting in the Netherlands', financed by the Ministries of Economic Affairs and Infrastructure and the Environment. The aim of this project is to develop detailed physical ecosystem accounts the Netherlands and to experiment with compiling the monetary ecosystem accounts, following the guidelines of the UN System of Environmental Economic Accounts – Experimental Ecosystem Accounting' (SEEA EEA). This document reports on the carbon account for the Netherlands, one of the thematic accounts of the SEEA EEA.

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Executive summary

The carbon account provides a comprehensive overview of all relevant carbon stocks and flows. The carbon account for the Netherlands was developed within the scope of the 'System of Environmental Economic Accounts – Experimental Ecosystem Accounting' (SEEA EEA) project for the Netherlands (Natuurlijk Kapitaalrekeningen Nederland: NKR_NL), which is currently carried out jointly by Statistics Netherlands and Wageningen University. Funding and support was provided by the Ministries of Economic Affairs and Infrastructure and the Environment. Within the NKR_NL project, a number of accounts are currently under development. The carbon account is described in detail in this report.

Scope and methods

The carbon account was developed to allow for a consistent and quantitative comparison of carbon stocks and flows in the reservoirs 'biocarbon' (organic carbon in soils and biomass), 'geocarbon' (carbon in the lithosphere), atmospheric carbon and carbon in the economy. Hence, the account provides a comprehensive overview of stocks of carbon in its many different forms and the ways in which carbon flows through these different reservoirs. The carbon account was based on the combination of datasets from numerous sources, combined with new modelling efforts to capture aspects of the carbon account that were not yet known. For biocarbon, the inputs to the account were modelled in a spatially explicit manner. For the development of these maps, existing models and data describing biocarbon (kindly provided by, among others, PBL and Wageningen Environmental Research) were combined with new data and with the Ecosystem Unit map for the Netherlands (EU_NL map, Statistics Netherlands, 2017). This resulted in an up-to-date overview of major stocks and flows of biocarbon for the ecosystem units recognized in this map (these ecosystem units are also the basic spatial unit throughout the NKR_NL project, to develop ecosystem accounts for the Netherlands). For geocarbon, data were derived from existing asset accounts for fossil fuels. These data were complemented with additional data on other types of geocarbon. Data on atmospheric carbon were derived from the national air emissions inventory and air emission accounts, whereas the information on carbon in the economy was primarily derived from the Energy accounts, the economy wide Material Flow accounts, the physical supply and use tables (Material Monitor) and the Waste accounts. Carbon in the oceans was not included in this carbon account due to a lack of data. For biocarbon and carbon in the atmosphere, a comparison with other reporting frameworks (e.g. LULUCF) was provided.

The purpose of the carbon account was to integrate existing information on carbon as reported through various mechanisms including the national air emissions inventory, the reports on forests and LULUCF to the UNFCCC, the air emission accounts, and to extend these data by adding spatially explicit data on emissions and sequestrations in the biosphere, including emissions from peat oxidation. The scope of the carbon account as described in this report thus builds upon, but goes beyond current carbon reporting systems. The structure of the account follows the SEEA EEA, leading to a fully comprehensive carbon account. Because all values are reported in units of C they can be compared quantitatively. Hence, the applications of the carbon account are broader in scope than other reporting efforts. However, to allow for an assessment of climate impacts of carbon emissions, a bridge table was compiled to calculate GHG equivalents from carbon values where relevant.

Results: Biocarbon (Chapter 2)

- Biocarbon stocks and flows were modelled in a spatially explicit manner, providing information from national down to local/regional scale.
- Values for all stocks and flows were calculated per province and for the national level, as well as per Ecosystem Unit (as used in the EU_NL map), allowing for a comparison of sequestration between different types of ecosystems.
- Biocarbon stocks assessed were stocks of C in aboveground vegetation (29 Mton C) and stocks of C in the top 30 cm of soils (353 Mton C, of which 73 Mton C in peat and peaty soils).
- In 2013, ecosystems (in particular forests) sequestered approximately 1.0 Mton C, or 3.6 Mton CO_2. Peat ecosystems emitted in total 1.9 Mton C, or 7.0 Mton CO_2. For comparison, the total Dutch CO_2 emissions in 2013 were 166 Mton CO_2 (IPCC definition) and the total greenhouse gas emissions in the NLs in the same year were 195 Mton CO_2 equivalent.
- Given that drainage of peatlands is general deeper in Drenthe and Friesland compared to the peat areas in the west of the Netherlands, the per hectare CO_2 emission is highest in these provinces, up to 12.5 ton C (45 ton CO_2) per hectare per year. In total, 44% of the Netherlands' peat CO_2 emissions originate in these two provinces.
- The biocarbon account is aligned with existing reporting methods, in particular the UNFCCC LULUCF reporting, but has a spatial approach which allows estimating emissions for administrative units such as provinces as well as analysing how emissions are spread over the landscape.

Results: Geocarbon (Chapter 3)

- The geocarbon account for the Netherlands includes stocks and flows for oil, gas, shale gas, coal and limestone (for limestone no total C stocks are known).
- The estimated stocks of geocarbon in 2013 in these materials amounts to 13.300 Mton C, of which the stock of coal is by far the largest (excluding the stock of C in limestone; no data available).
- The net carbon balance for geocarbon in 2013 was – 41 Mton C which is almost entirely related to the extraction of gas (-40 Mton C).

Results: Carbon in the economy (Chapter 4)

- Carbon in the economy reflects a wide range of materials that are either in stock or that flow through the economy.
- Some flows of carbon related to products (including imports and exports) are relatively well known and were derived from the physical supply and use tables (Material monitor), the economy wide Material Flow Accounts, and the energy, water and air emissions accounts.
- The stocks of carbon in the economy are often not well known, as well as the amount of carbon in fixed assets and the flow of carbon associated with fixed capital formation: carbon in e.g. building materials and in waste dumps, bitumen in roads, etc.

- Reductions of stock taken into account here include carbon emissions to the atmosphere and water and to soils (primarily manure).
- The net balance for carbon in the economy in 2013 was an increase in stock of 7.2 Mton C.
- The account for carbon in the economy also includes data on recycled products, which is valuable information with regard to the circular economy.

Results: Carbon in the atmosphere (Chapter 5)

- The account for carbon in the atmosphere shows the relations between emissions to the atmosphere (primarily from economic activities) and the natural sequestration of carbon in biomass, both in Mton C and in CO_2 equivalents.
- The net carbon balance developed here was compared to official reporting in the air emissions accounts and the UNFCCC reporting.
- The stock of C was defined as the cumulative carbon emissions since AD 1900.
- The balance for carbon in the atmosphere in 2013 amounted to an increase of nearly 55 Mton C, which is almost entirely attributable to 'emissions from economic activities'.
- Natural emissions in 2013 (1.8 Mton C/yr) exceeded sequestration in natural ecosystems (1 Mton C/yr), and therefore sequestration in natural vegetation at the current rate cannot be expected to compensate for emissions from economic activities.

Policy applications and indicators (Chapter 6)

For the Netherlands, this is the first time that a carbon account was developed following the SEEA EEA guidelines. The account provides several important policy applications related to facilitating the implementation of climate change policies and actions, and providing a monitoring and planning tool for moving towards a circular economy. Chapter 6 presents detailed indicators, with the main policy applications outlined below:

1. Because of its extended scope, the carbon account is an ideal format to be used for the more detailed requirements on carbon emissions reporting to the EU as of 2020 required as part of the Effort Sharing Regulation (ESR) (European Commission, 2016). This because the account includes both the carbon flows in the economy and the carbon flows in the ecosystems. Both are considered in an integrated way and double counting of carbon emissions or sequestration is avoided. The ESR is currently being designed as the EU response to the Paris Agreement, and is likely to involve compulsory emission reduction targets for member states plus the possibility to use a specific amount of carbon credits from the LULUCF sector to comply with the ESR.
2. The ecosystem part of the carbon account (i.e. biocarbon) is spatially explicit. Maps depict where carbon emissions take place and which areas are most important for carbon sequestration. This facilitates climate action by provincial and local stakeholders. For instance, provinces or water boards can identify which areas are most important for carbon emissions (e.g. drained peat areas with a low water table) and use the information to plan interventions in the landscape. The reliability of the accounts will be tested in the next project phase. It may well be that the accounts are sufficiently reliable to also support climate actions by local stakeholders such as an estate owner or municipality. For example, the carbon account shows where emissions from organic soils are currently highest. Such

areas could be targeted with priority with measures such as increasing ground water levels, or adapting land use practices. The carbon account can therefore also be used to support interventions by local stakeholders, and to monitor the effectiveness of their actions. Hence, the account would allow the government to transition from a climate change policy implemented at national scale to facilitate actions by local stakeholders by allowing them to plan and monitor their interventions. In addition, the carbon account allows analysing the national level impacts of the local interventions over time (which requires updating the carbon account around once every two years).

3. The carbon account is integrated in the SEEA environmental economic accounting approach. This natural capital accounting approach is also gaining traction in the EU where it is currently being tested. The carbon account is an integral and important element of the overall natural capital accounting approach of the SEEA, and allow a better monitoring and planning of natural capital use. This includes information required for a transition to circular economy, which requires closing the flows of matter and energy within the economy. Since the carbon account integrates biocarbon and carbon in the economy it provides a very detailed picture of progress towards closing the carbon cycle.

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1. Introduction

1.1 Overview

Ecosystem accounting is an approach to systematically measure and monitor ecosystem services and ecosystem condition over time for decision making and planning. Under the auspices of the United Nations the System of Environmental – Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA) has been developed to guide the implementation of ecosystem accounting (UN et al., 2014). One of the main objectives of the SEEA EEA is to measure ecosystem services in a way that is aligned with national accounting. The SEEA EEA prescribes the development of a series of core accounts, reflecting the extent and condition of ecosystems, and the supply and use of ecosystem services (physical and monetary). In addition to the core accounts for ecosystem accounting, the SEEA EEA promotes the development of four thematic accounts, centred around the themes carbon, biodiversity, water and land. Within the project 'Ecosystem Accounting for the Netherlands', carried out jointly by Statistics Netherlands and Wageningen University and funded by the Ministries of Economic Affairs and Infrastructure and the Environment, the choice was made to include carbon (current report) and biodiversity (forthcoming) as thematic accounts, in addition to the core accounts mentioned previously (work in progress).

In the current report we present the carbon account for the Netherlands. Carbon is an important central theme in the SEEA EEA because it is, in a number of ways, related to the core accounts of ecosystem accounting; it plays a role in the supply and use accounts of ecosystem services (e.g. supply of wood and other biomass, and carbon sequestration) and in the condition account (e.g. soil carbon content influences crop productivity). In addition, the carbon account takes into account the registered emissions of carbon to the atmosphere (air emission accounts of the SEEA-CF) and includes some of the carbon in materials, as reported in the physical supply and use tables and more specifically the economy wide material flow accounts (MFA in the SEEA-CF). Hence, the stocks and flows of carbon are an important theme in a number of the environmental accounts in general, and in the ecosystem accounts in particular. Moreover, carbon account presents a number of important additional policy applications compared to present monitoring systems, related to both the integrated approach where carbon in the economy and in the ecosystems are analysed in an integrated manner, and related to the mapping of carbon flows in the ecosystems, as further discussed in Chapter 6.

The SEEA EEA carbon account can be used to answer a range of questions such as; 1) where and how much carbon is currently 'in stock' in a country and in what form, 2) how large are natural and man-made emissions of carbon, 3) where and how strong are the natural sinks for carbon (i.e. carbon sequestration), 4) what is the impact of recycling on emissions of C, and 5) which economic sectors contribute most to emissions of these gasses? The carbon account is unique in that it provides a fully comprehensive and fully consistent overview of C in its different forms and uses. In section 6 of this report the various policy applications of the carbon account will be discussed in more detail.

Currently only few countries have experimented with the development of a carbon account in line with SEEA EEA recommendations. Australia is a pioneering country that has developed a carbon account including data on the reservoirs geocarbon and biocarbon. For biocarbon, estimates were provided for different types of ecosystems (Ajani and Comisari, 2014). Although no data for carbon in the economy were included, different methods on how data could be derived were discussed in their report. Similarly, the UK Office for National Statistics recently published a first experiment with the development of a carbon account, which also included data for geocarbon and biocarbon (ONS, 2016).

1.2 The SEEA EEA carbon account

The SEEA EEA carbon account records the flows and stock changes resulting from human activities and natural processes at any point along the chain: ranging from the changes occurring at their origin in the geosphere and biosphere to changes in the various anthropogenic stocks (i.e. carbon stored within the economy) and as residuals to the environment, including emissions to the atmosphere (SEEA EEA, 2014).

The structure of the carbon account is presented in Figure 1.2.1. It provides a complete and ecologically grounded articulation of carbon accounting based on the carbon cycle and, in particular, the differences in the nature of particular carbon reservoirs. Opening and closing stocks of carbon are recorded, with the various changes between the beginning and end of the accounting period recorded as either additions to, or reductions in, the stock.

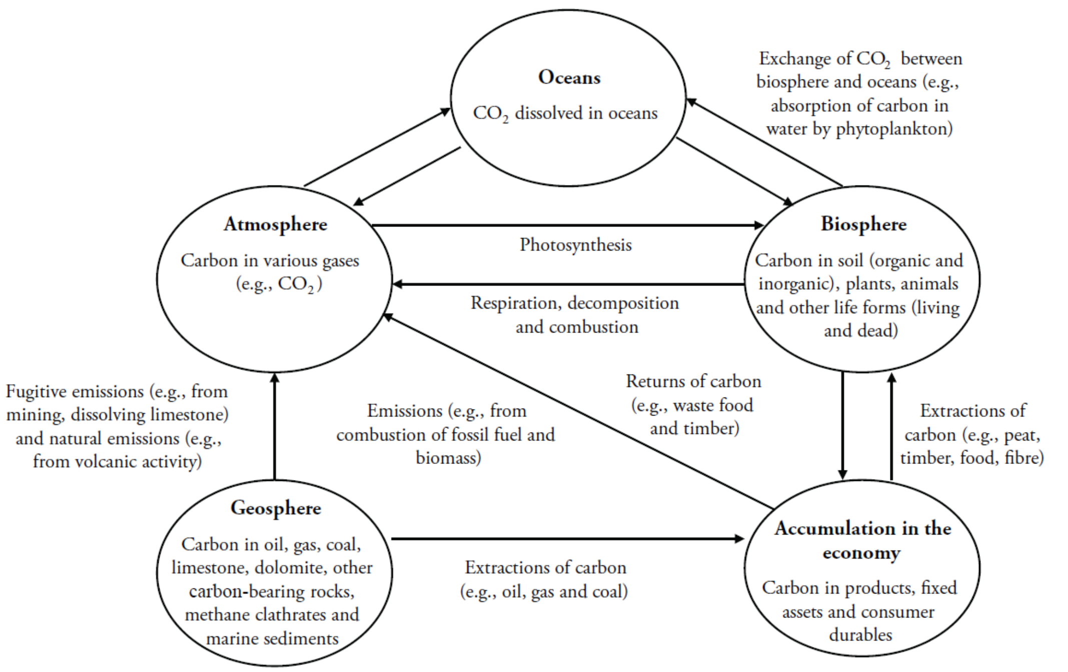


Figure 1.2.1 Main components of the carbon cycle, and the carbon flows between these components. Source: SEEA EEA.

The different carbon stocks are shown in the columns of the carbon account (Figure 1.2.2). These are disaggregated into: **geocarbon** (carbon stored in the geosphere), **biocarbon** (carbon stored in the biosphere; in living and dead biomass and in soils), **carbon accumulation in the economy, carbon in**

the oceans and **carbon stored in the atmosphere**. Geocarbon is further disaggregated into: oil, gas and coal resources (fossil fuels), rocks (primarily limestone), and sediments (e.g. methane clathrates and marine sediments). Biocarbon is classified by type of ecosystem and storage type. At the highest level, ecosystems are terrestrial, aquatic or marine.

	Geocarbon						Biocarbon			Carbon in the economy				Carbon in the seas	Carbon in the atmosphere	Total
	Oil	Gas	Coal	Limestone and marl	Other	Total geocarbon	Terrestrial ecosystems	Aquatic ecosystems	Total biocarbon	Inventories	fixed assets, cosumer durables	Waste	Total	Total	Total	
Opening stock																
Additions to stock																
Natural expansion																
Managed expansion																
Discoveries																
Upwards reappraisals																
Reclassifications																
Imports																
Reductions in stock																
Natural contraction																
Managed contraction																
Downwards reappraisals																
Reclassifications																
Exports																
Net carbon balance																
Closing stock																

Figure 1.2.2 The carbon stock account as presented in the SEEA EEA. Grey cells are null by definition.

The presentation of the row entries in the account follows the basic form of the asset account in the SEEA Central Framework. The entries are the opening stock, additions to stock, reductions in stock and closing stock.

There are six types of additions in the carbon stock account (SEEA EEA):

- **Natural expansion:** These additions reflect increases in the stock of carbon over an accounting period due to natural growth. Effectively, this will be recorded only for biocarbon and may arise from climatic variation, ecological factors such as reduction in grazing pressure, and indirect human impacts such as the CO_2 fertilization effect (where higher atmospheric CO_2 concentrations cause faster plant growth).
- **Managed expansion:** These additions reflect increases in the stock of carbon over an accounting period due to human-managed growth. This will be recorded for biocarbon in ecosystems and accumulations in the economy, in inventories, consumer durables, fixed

assets and waste stored in controlled landfill sites, and also includes greenhouse gases injected into the earth.

- **Discoveries of new stock**: These additions comprise the emergence of new resources added to a stock, which commonly arise through exploration and evaluation. This applies mainly—and perhaps exclusively—to geocarbon.
- **Upward reappraisals**: These additions reflect changes due to the use of updated information permitting a reassessment of the physical size of the stock. The use of updated information may require the revision of estimates for previous periods so as to ensure a continuity of time series.
- **Reclassifications:** Reclassifications of carbon assets will generally occur in situations where the carbon asset is used for a different purpose and thus is reallocated to a different stock category. For example, increases in carbon in semi-natural ecosystems following the establishment of a national park on an area previously used for agriculture would be offset by an equivalent decrease in agricultural ecosystems.
- **Imports:** These additions are recorded to enable accounting for imports of produced goods (e.g., petroleum products).

There are five types of reductions recorded in the carbon stock account:

- **Natural contractions:** These reductions reflect natural losses of stock during the course of an accounting period. They may be due to changing distribution of ecosystems (e.g., a contraction of natural ecosystems) or biocarbon losses that might reasonably be expected to occur based on past experience. Natural contraction includes losses from episodic events including drought, fires and floods, pests and diseases, and the category also includes losses due to volcanic eruptions, tidal waves and hurricanes.
- **Managed contractions:** These are reductions in stock due to human activities and include the removal or harvest of carbon through a process of production. This includes mining of fossil fuels and felling of timber. Extraction from ecosystems includes both those quantities that continue to flow through the economy as products (including waste products) and those quantities of stock that are immediately returned to the environment after extraction because they are unwanted—for example, felling residues. Managed contraction also includes losses as a result of a war, riots and other political events; and technological accidents such as major toxic releases.
- **Downward reappraisals:** These reductions reflect changes due to the use of updated information that permits a reassessment of the physical size of the stock. The reassessments may also relate to changes in the assessed quality or grade of the natural resource. The use of updated information may require the revision of estimates for previous periods to ensure a continuity of time series.
- **Reclassifications:** Reclassifications of carbon assets will generally occur in situations where carbon asset is used for a different purpose and thus is reallocated to a different stock category. For example, decreases in carbon in agricultural ecosystems following the establishment of a national park on an area used for agriculture would be offset by an increase in carbon in semi-natural ecosystems. In this case, it is only the particular land use that has changed; that is, reclassifications may have no impact on the total physical quantity of carbon during the period in which they occur.

- **Exports:** These reductions are recorded to enable accounting for exports of produced goods (e.g., petroleum products).

1.3 Study scope and aim

This study aims to compile a comprehensive carbon account for the Netherlands for one year (2013). All currently available information on carbon stocks and flows were combined in a consistent manner and new models for a number of carbon stocks and flows were developed for which no information was available. Where relevant and possible, data were made spatially explicit. The approach is consistent with the Ecosystem Accounting project for the Netherlands and reporting was carried out for the same ecosystem units as those defined in the Ecosystem Units map for the Netherlands (EU_NL 2013 map, Statistics Netherlands, 2017). The detailed Ecosystem Unit map was developed for 2013, and therefore this year forms the basis for the carbon account. The EU_NL 2013 map is the basis for the SEEA ecosystem accounting approach and is produced by Statistics Netherlands using a combination of different maps that are regularly prepared for its standard monitoring program (Statistics Netherlands, 2017).

The carbon account for the Netherlands is comprehensive in a sense that all important carbon reservoirs, i.e. geocarbon, biocarbon, carbon in the economy and carbon in the atmosphere are included. For the moment, we exclude marine and lacustrine carbon. Carbon exchange between the atmosphere and surface waters was not included due to a lack of sound data. The focus of this account is on the national level. Some elements will also be presented on the provincial level.

All values included in this study represent the equivalent carbon weight. For example, methane (CH_4) emissions from peatlands and peaty soils were expressed in kg of carbon, and not in CO_2 equivalents. Similarly, for recycled plastic, paper and other products the equivalent C content was determined per kg, using the average composition of these materials to determine the C content. This approach was chosen because for a number of stocks, the type of emission (as CH_4, CO_2 or other greenhouse gasses) depends on the specific circumstances and the specific composition of the product under consideration. For example, for peatlands, the emissions of methane and CO_2 and the ratio between these depend on a number of variables, such as temperature, depth of the water table and the species composition of the peat (e.g. Treat et al., 2014). Therefore, re-calculating the carbon content of peat or soils in CO_2 equivalents does not provide relevant or reliable data. For emissions to the atmosphere, a bridge table was compiled both in Mton C and in CO_2 equivalents (chapter 5).

For **biocarbon**, within this project a large effort was made to combine existing data with new, spatially explicit models to provide a detailed overview of carbon stocks and flows in the current vegetation and soils in the Netherlands. The biocarbon accounts are therefore available at the national and provincial scales. Biocarbon stock in soils and peat lands at a depth >30 cm was not included here due to data restrictions and a lower policy relevance. For biocarbon flow in peat lands depths >30 cm were included.

For **geocarbon**, detailed data on stocks, extractions and other developments are readily available and these were used here. The spatial aspect of the stocks was not deemed policy relevant: the location of stocks of gas, oil and coal are well known and cannot be changed. Carbon may also be released to the atmosphere from other geological sources than those mentioned here; for example methane emissions from solid methane hydrate deposits (present in e.g. sedimentary deposits on ocean floors) or carbon dioxide emissions from volcanic eruptions. These forms of emissions are, however, non-predictable and episodic, and are not included in the current carbon account.

For **carbon in the economy,** a spatial distribution at the level of Nuts 3 units (NL: COROP gebied) and hence provincial levels is probably feasible, although flows of carbon between these spatial units cannot be monitored. However, a more detailed spatial analysis of carbon in the economy was outside the scope of the current study and numbers for carbon in the economy were determined at the national level only. For **carbon in the atmosphere**, data on emissions are available from the air emissions accounts as well as from the LULUCF reporting.

Although a number of data gaps were observed, not all could be addressed within the time frame and scope of this project. Therefore, this project should be regarded as an exploratory study of carbon stocks and flows in the Netherlands. In the account different carbon accounts, a number of identified gaps are indicated explicitly (yellow marked cells), to allow for an easy recognition by the reader and to provide directions for future research.

2. Biocarbon in the Netherlands

2.1 Definition and scope of biocarbon

Biocarbon includes all carbon in the biosphere, i.e. carbon in living biomass (plants and animals) and soil organic matter (SEEA EEA, 2014)[1]. Following the concepts of the SNA, cultivated biological resources are, however, part of the economy. Consequently, biomass in crops, grass in meadows and livestock are part of ‘carbon in the economy’ and not of biocarbon. This only applies to the living biomass of crops and livestock; soil carbon underlying cropland and meadows and dead crop residues left on the field are part of biocarbon. Although forests in the Netherlands are to a large degree managed, it was decided to allocate carbon in forests to biocarbon and not to the economy.

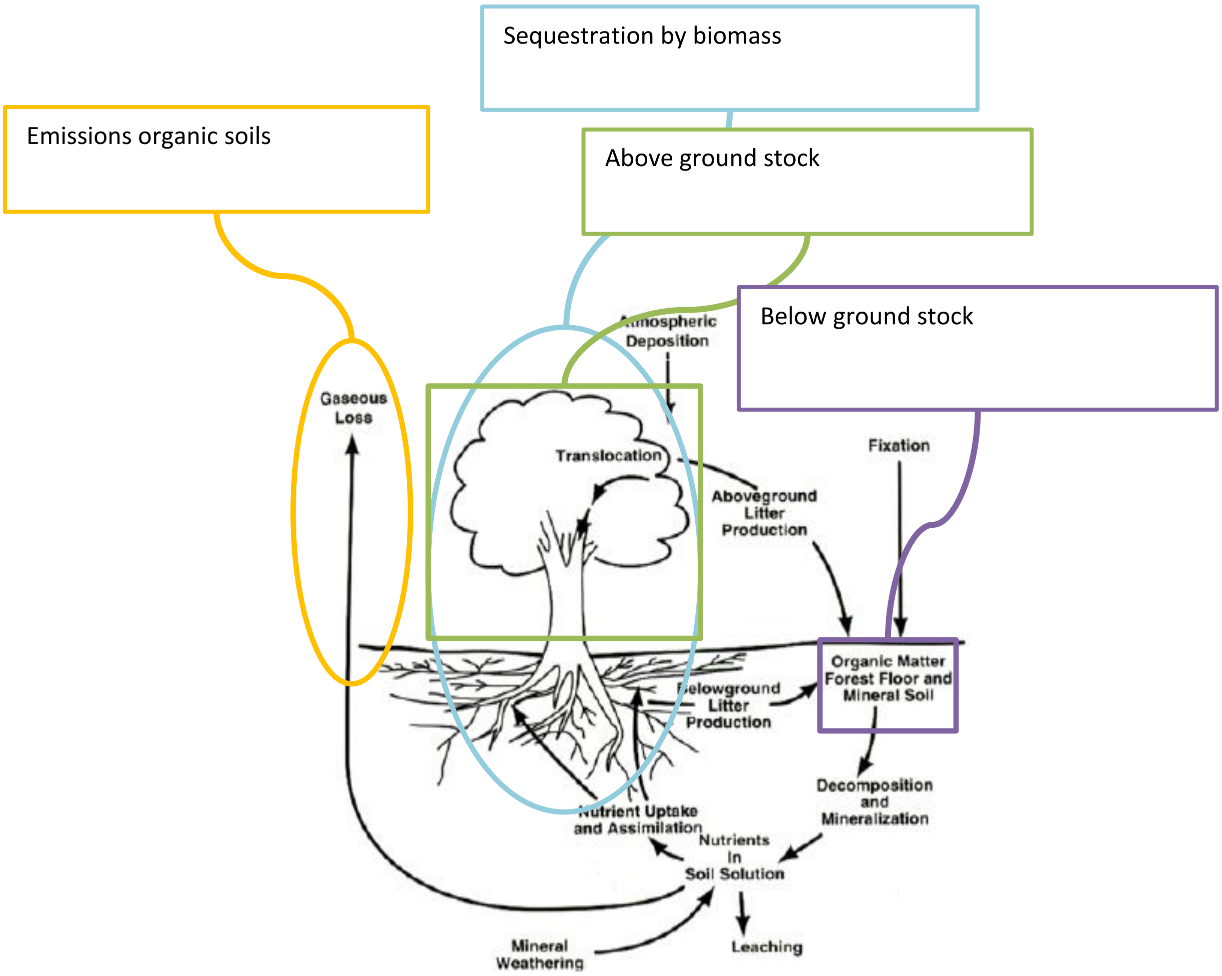


Figure 2.1.1 Processes in the biocarbon cycle.

[1] For biocarbon in soils, for practical reasons only the top 30 cm were included in this study. In particular for peat and peaty soils, this results in a strong underestimation of the total stock of biocarbon in soils. This shortcoming in the current models also potentially influences C flows in the case of water table changes exceeding this depth.

The carbon account records the total stocks for biocarbon and the changes in these stocks. In principle all relevant stock changes for biocarbon can be accounted for, i.e. net primary production, degradation of biomass, soil respiration, harvesting of biomass etc. Particularly relevant here are the different processes related to the formation and storage of carbon in the biocarbon cycle (Figure 2.1.1). The biocarbon cycle is known as a short carbon cycle because storage of the carbon is, in principle, relatively short lived; if trees or wood are burned, carbon is released again into the atmosphere. Similarly, surficial soil carbon can be released by e.g. ploughing or erosion, and carbon stored in peatlands may be released when water levels change, be it by natural or man-made causes. Therefore, the duration of carbon storage in the form of biocarbon is relatively instable in the long geological perspective. Nevertheless, biocarbon stocks can be substantial and are highly relevant because of their sensitivity to land use and hence to policy measures.

For this study total carbon sequestration (i.e. the net amount of carbon that is annually stored in vegetation and soils) was modelled in a spatially explicit manner. Carbon sequestration will be accounted for as an addition of stock by natural expansion. In addition, some biocarbon stocks acts as a net emission source. In the Netherlands, biocarbon is oxidised in peat lands as a result of lowering water tables, resulting in a net emission of CO_2 (and CH_4) to the atmosphere. These emission will be accounted for as a reduction in stock by managed contraction.

Finally, manure produced by livestock is -currently- considered to be a waste residual but is increasingly considered as a resource in the circular economy. Manure is as such part of the economy. It is assumed that all carbon contained in manure will on the short term be returned as CH_4 or CO_2 to the atmosphere[2]. Emissions from manure (CH_4, CO_2) are considered as direct flows from the economy to the atmosphere (section 4.2). This is in line with the recording by the IPCC guidelines and the SEEA air emission accounts.

2.2 Methodology and data sources

For biocarbon both the assets (in soils, peatlands and above and belowground vegetation) and flows (sequestration in living vegetation, emissions from soils and wetlands) were analysed in detail. In general, the methodology was based upon a qualitative look-up table (LUT) approach. This is the same methodology as was used by Remme et al. (2014). Qualitative LUT weigh different land-use or land-cover classes according to their capacity to provide ecosystem services. Separate LUTs were used for terrestrial carbon sequestration and for terrestrial carbon stock. These LUT were combined with the Ecosystem Units map that was developed for the Netherlands (EU_NL map, de Jong et al., 2015). Furthermore, multiple layer LUT were used to quantify emissions from organic soils, based on the location of peat soils and associated ground water tables. Data published by Lesschen et al. (2012) were used to quantify carbon stock in the upper 30 cm of the soil.

[2] In principle, some of the carbon in manure may be mixed into the soil and stored there (in which case it would become biocarbon). However, these amounts will probably be small and eventually also this carbon will be oxidized and returned to the atmosphere.

2.2.1 Carbon stocks

The organic carbon stock in the soil was mapped based on data from Lesschen et al. (2012), who determined the soil carbon stocks for the upper 30 cm. Organic carbon is abundant in the top one meter of the soil. The highest abundance is in the top 30 cm. Furthermore, the depth of 30 cm is consistent with the IPCC guidelines as adopted by the Netherlands. Nevertheless, it is possible to calculate soil stock for a thicker layer, when data becomes available we will take it into account. Lesschen et al. estimated the carbon stock in the top 30 cm of the soil based on soil types (De Groot et al., 2005) combined with the land use map of 2004 (Lesschen et al., 2012). Estimations were based on data of the "Landelijke Steekproef Kartering (LSK)" that was conducted between 1990 and 2000. The LSK was a stratified survey based on soil type and groundwater class. The data set contains information on soil organic matter (inorganic soil carbon was not included in these analyses). The LSK database contains data on approximately 1400 locations. For each location soil samples were taken at five depths. To calculate the carbon stock, De Groot et al. (2005) and Lesschen et al. (2012) assumed that the carbon content of soil organic matter is 50% (Kuikman et al., 2003). Soil bulk density values were derived through pedotransfer functions for the main soil types sand, clay and peat. Furthermore, land use occurring at the time of the sample was recorded and aggregated to grassland, arable land, forest and other nature. For other land uses (wetland, built-up area, other land) no data were available in the LSK. Therefore, carbon stock was estimated for these land uses; for wetlands the value for forest was used, for urban areas 0.9 times the carbon stock of the soil type was used and for other land uses (mostly sand and dunes) the carbon stock was set at 0 (for more information see Lesschen et al., 2012).

Based on a previous study for Limburg province (Remme et al., 2014) we used a look-up table approach for the carbon stock in the above ground biomass and extended it to the national scale. In a look-up table approach, each spatial unit (in our case each ecosystem type) in the map is attributed a specific value for a given process or property (in our case the carbon sequestration or stock). Hence, each ecosystem type (e.g. forest or heathland) is given a specific value for carbon stock or sequestration. In the case of carbon stock, these values are based on values used for greenhouse gas reporting of the LULUCF sector in the Netherlands (Arets et al, 2015) and scientific literature. The look-up table for carbon stock in above ground biomass is provided in Table A2.2 (Annex 2).

2.2.2 Carbon flow: sequestration

Terrestrial carbon sequestration is the storage of carbon in biomass and in soils. Carbon sequestration can be related to net ecosystem productivity (NEP), i.e. the difference between net primary productivity (NPP) and soil respiration. Similar to the above ground carbon stock, we used the lookup table approach for carbon sequestration as used by Remme et al. (2014) for Limburg province. We updated the look-up table with new data for carbon sequestration rates where relevant. It was mapped using published data on carbon sequestration in different land cover types (Table A2.1 in Annex 2).

2.2.3 Carbon flow: emission by organic soils

In their natural state, vegetation in peat lands capture carbon dioxide (CO_2) which is retained in the ecosystem because of a slow breakdown of organic matter. Natural peat lands, however, also emit methane (CH_4) as a result of the waterlogged (anaerobic) conditions that lead to methanogenesis. In natural peatlands, the total balance between CO_2 uptake and CH_4 release mostly results in net carbon sequestration. The rate and balance of sequestration versus emissions depends, among other factors, on moisture conditions and temperature. Whilst natural peat lands thus act as carbon sinks, agriculturally used peat lands commonly act as sources for carbon. This is related to drainage, which is required for agricultural activities. In the Netherlands, most peatlands (about 235,000 ha, 7% of the land surface) are subject to various sorts of agricultural practices associated with drainage, resulting in oxidation of peat and release of CO_2 to the atmosphere. Since the industrial period a large proportion of these peat soils were heavily drained and fertilized. As a result, peat subsidence rates in the Netherlands are up to 18 mm yr^{-1}. Between 1970 and 2003, 67,000 ha of peat soils oxidized and these areas are now classified as mineral soil (Kuikman et al., 2005).

Kuikman et al. (2005) used the definition of the IPCC Good Practise guidelines for Histosols to quantify carbon emission from organic soils. A Histosol is a profile with more than 40 cm organic soil in the top 80 cm of the soil (FAO, 1998). Peaty soils contain less than 40 cm organic soil and are therefore not included in this definition of organic soils by the IPCC. In 2014 the soil map was updated for peat and peaty soils in the Northern part of the Netherlands; and changes from peat to peaty and from peaty to mineral soils have been updated (de Vries et al., 2014). In this study, all soils that were classified as peat or peaty in the soil map of the Netherlands 2014 were included. Furthermore, we distinguished two types of peat soils: rainwater-fed bogs and eutrophic fens. Peat lands were classified as rainwater-fed bogs if, according to the soil map, the dominant vegetation was *Sphagnum* ('veenmos') and no soil layer was present on top of the peat deposits. This is the case in a minority of the peat soils (less than 0.5% of all organic soils). Rainwater-fed bogs mainly occur in Drenthe and Friesland. The *Sphagnum*, which constitutes this type of peat, has a very high rainwater retaining capacity, causing these bogs to behave fully independent of the groundwater and all the nutrients that come with it. All other peat soils were classified as eutrophic fens. Eutrophic fens are the dominant type of bog in the Netherlands (approximately 99.5 % of all organic soils), they are present mostly in western and northern parts of the Netherlands. They primarily depend on groundwater for nutrients and peat formation.

Van den Akker et al. (2010) calculated CO_2 emissions from subsidence of peat soils in the Netherlands. They found a relationship between subsidence, ground water levels and ditch water levels. Furthermore, they found that peat soils with a clay cover had lower subsidence rates. We used the reported relationship for subsidence; subsidence (in mm) = 15.5 * ditch water level (in m below soil surface) + constant. This constant is 2.7 without a clay layer and -3.5 with a clay layer. Furthermore, van den Akker et al. (2010) found an average CO_2 emission of 2.259 ton CO_2 ha^{-1} yr^{-1} per mm subsidence, or 0.706 ton C ha^{-1} yr^{-1} per mm subsidence. We used a map developed for PBL (2016) that depicted the ditch water levels in an area that is managed by seven water boards. For the remaining areas we used the ground water tables map of 2006 to estimate subsidence rates (Alterra, 2006).

In a modelling study for an extensively studied raised bog system in Southern Sweden, Belyea and Malmer (2004) estimated that carbon sequestration of the raised bog (i.e. rainwater fed bog) ranged between 14 and 72 g m^{-2} yr^{-1} in the past 5000 years. Birne et al. (2004) reports an apparent C accumulation rate of 27 g m^{-2} yr^{-1} (i.e. 0.27 ton C ha^{-1} yr^{-1}). Net carbon sequestration only occurs in healthy raised bogs that are fed by rainwater and, consequently, are not influenced by ground water level. We used the latter value as the carbon sequestration rate for *Spagnum* bogs in the Netherlands. Not all *Spagnum* bogs in the Netherlands will still function as rainwater fed bog. Because the total area is small (less than 0.5% of all organic soils), our first approach is to consider them all as healthy rainwater fed bogs. However, we might change this in the future, to include that a fraction of this area will depend on ground water levels. In those areas the carbon balance will turn to net emission.

2.3 Results

2.3.1 Carbon sequestration and carbon stocks in biomass

As indicated in section 2.1, stocks in biomass are in part considered as representing carbon in the biosphere (e.g. forests, heaths and dune areas), and in part as representing carbon in the economy (non-perennial and perennial plants, grasslands) following SEEA-CF. To model carbon stocks in biomass, the same methodology was, however, followed for all categories of biomass. Therefore, all results are presented in the current section. However, C in biomass that technically falls within C in the economy is not included in the national totals for C in the biosphere (in Tables 2.3.1 and 2.3.2), and is included as C in the economy in the full carbon account (Chapter 6).

Table 2.3.1 Carbon sequestration and carbon stock in biomass in the Netherlands; totals per Province. Data based on Figures 2.3.1 and 2.3.2.

	Total area (1000 ha)	Total carbon sequestration (10^3 ton C/yr)	Mean carbon sequestration (ton C/ha/yr)	Total carbon stock in biomass (10^6 ton C)	Mean carbon stock (ton C/ha)
Groningen	296	38	0.1	1.0	3.2
Friesland	575	90	0.2	1.8	3.1
Drenthe	268	81	0.3	3.1	11.6
Overijssel	342	100	0.3	3.5	10.0
Flevoland	241	36	0.2	1.5	6.4
Gelderland	514	216	0.4	8.3	1.6
Utrecht	145	47	0.3	1.6	1.1
Noord Holland	409	60	0.2	2.0	5.0
Zuid Holland	341	41	0.1	1.1	3.3
Zeeland	293	30	0.1	0.7	2.5
Noord Brabant	508	163	0.3	6.4	12.5
Limburg	221	73	0.3	2.9	13.0
Netherlands	4,153	975	0.2	29.1*	8.2

*Stock in annual plants, perennial plants and meadows are attributed to C in the economy (see text above and Table 2.3.2). To prevent double counting, these are not included in the totals for biocarbon stocks for the Netherlands.

Table 2.3.2 Summary table of biocarbon stocks (Mton C) and flows (kton C) in the Netherlands; totals per ecosystem unit. Data based on all maps presented in this section. Carbon stocks for ecosystem units that are attributed to C in the economy (see text) are indicated with an asterisk (*). These stock values are not included in the totals for biocarbon stock in the Netherlands.

	Area	**Biocarbon stocks (in Mton C)**				**Biocarbon flows (in kton C)**		
Ecosystem unit	**(1000 ha)**	**in biomass**	**mineral soils**	**peat(y) soils**	**totals**	**Sequestra tion**	**Emission from peat soils**	**Emission from peaty soils**
Non-perennial plants	781	1.6*	65.7	10.3	77.5	0	156	121
Perennial plants*	79	1.3*	6.9	0.8	9.0	30	15	6
Greenhouses	12	0.0	1.1	0.2	1.3	0	5	1
Meadow*	927	1.9*	74.6	36.9	113.4	167	737	173
Buffer strips	36	0.1	2.6	1.9	4.	6	38	8
Farmyards and barns	35	0.0	3.1	0.7	3.8	0	14	3
Dunes with perm. veg.	16	1.3	0.5	0.0	1.9	30	0	0
Active coastal dunes	34	0.0	0.4	0.0	0.4	0	0	1
Beaches	0	0.0	0.0	0.0	0.0	0	0	0
Deciduous forest	109	9.4	9.6	2.5	21.5	206	43	16
Coniferous forest	82	6.6	6.5	0.2	13.4	155	2	2
Mixed forest	119	10.0	9.9	0.5	20.3	224	6	4
Heath land	41	0.3	3.8	0.8	4.9	8	20	4
Inland dunes	2	0.0	0.0	0.0	0.0	0	0	0
Fresh water wetlands	34	0.0	3.3	1.6	4.9	8	31	7
Natural grassland	54	0.1	4.2	2.4	6.7	10	51	8
Public green space	68	0.4	6.0	0.9	7.3	18	23	4
Other unpaved terrain	295	0.6	25.4	5.3	31.3	53	108	34
River flood basin	73	0.2	6.8	0.0	7.1	15	1	0
Tidal salt marshes	11	0.1	1.0	0.0	1.2	45	0	1
Paved surfaces	540	0.0	45.5	6.1	51.6	0	133	36
Sea	382	0.0	0.0	0.0	0.0	0	0	0
Lakes and ponds	123	0.0	3.5	2.2	5.7	0	60	11
Rivers and streams	298	0.0	0.4	0.0	0.4	0	0	0
Total	4,151	29.1	281.1	73.4	388.3	975	1,443	440

Figures 2.3.1 and 2.3.2 represent the modelled C stocks and sequestration respectively, in biomass. Table 2.3.1 summarizes the total C stocks and sequestration rates in biomass for the Netherlands in 2013, calculated per province. Table 2.3.2 provides an overview of all biocarbon stocks and flows included in this study, represented per Ecosystem Unit.

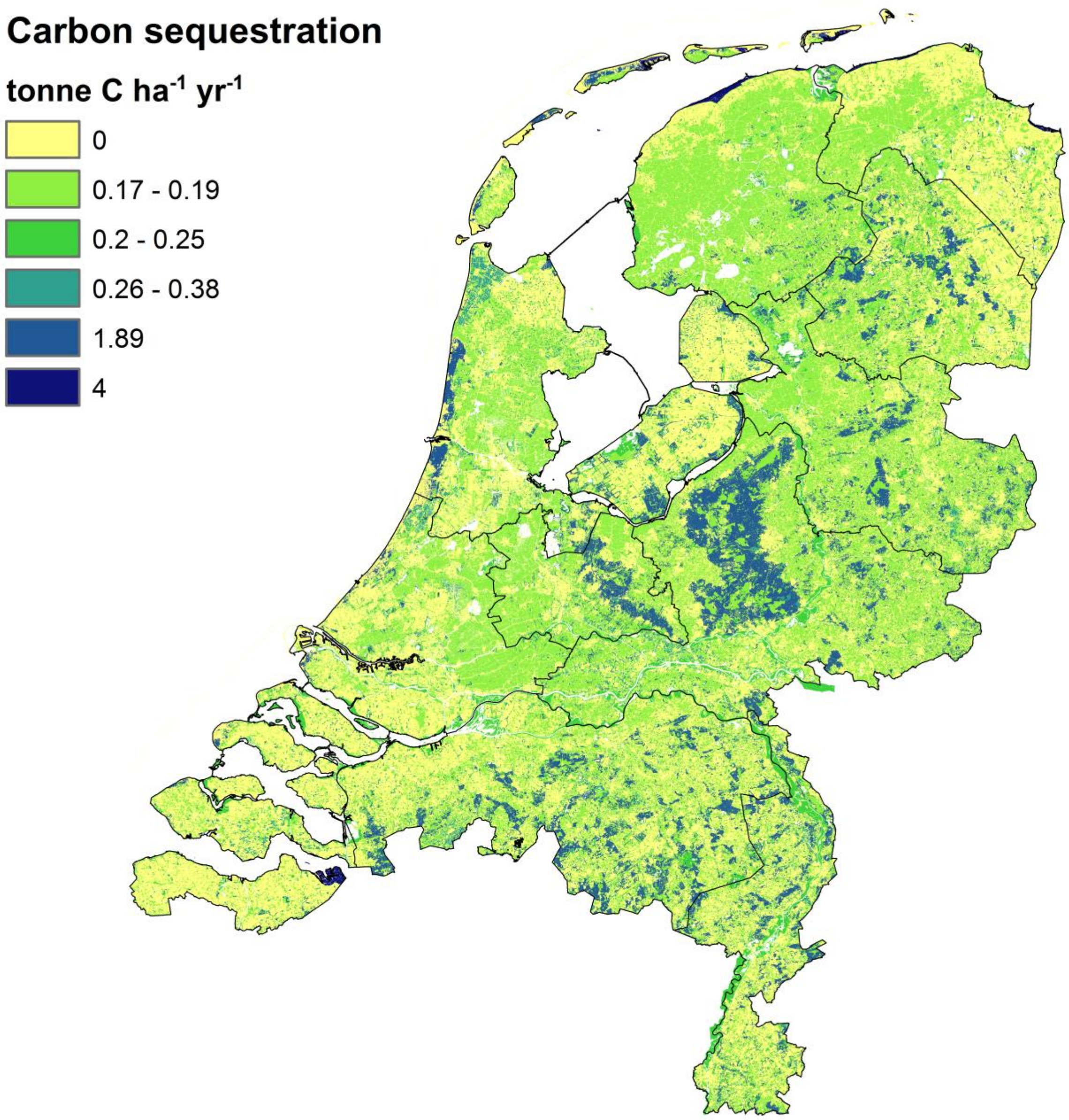


Figure 2.3.1 Carbon sequestration in above and below ground biomass. Based on EU_NL map and Table A2.1 (Annex 2). Note that this map summarises and thereby simplifies data available in specific environmental models. For example, Conijn and Lesschen (2015) present a more detailed model for the carbon balance of grasslands. In the next version of the carbon account, a more detailed spatial model for grassland sequestration can be included.

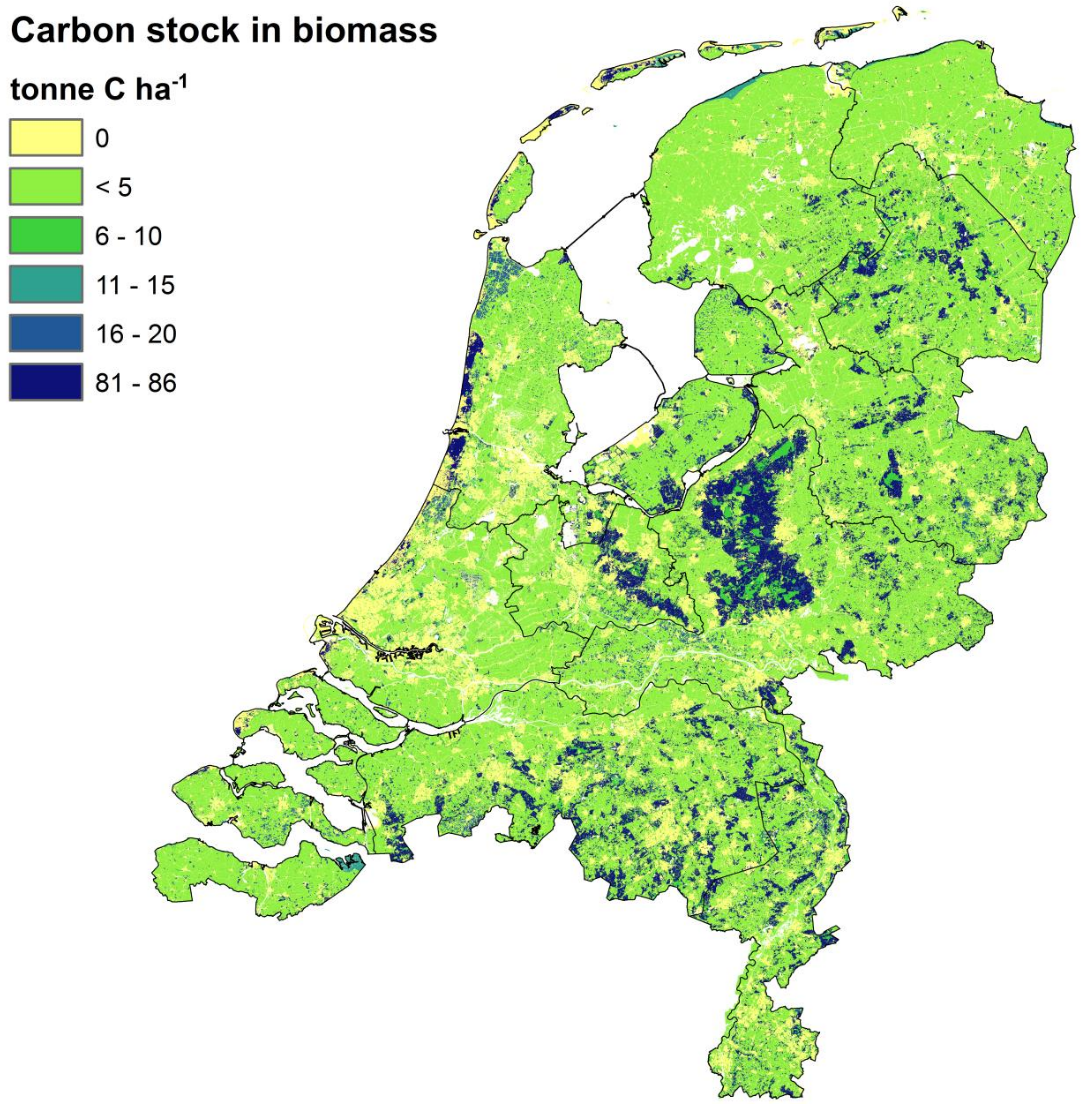


Figure 2.3.2 Carbon stock in above ground biomass. Based on EU_NL map and Table A2.2 (Annex 2).

Carbon sequestration was mostly concentrated in the forest areas in the Netherlands; Gelderland, Utrecht, Limburg, Noord Brabant, Drenthe and Overijssel have the highest mean sequestration rates and the highest mean carbon stock in the above ground biomass. In total 975 kton C yr^{-1} was sequestered in above ground vegetation, mostly in forests and meadows. Even though the total area is small, tidal salt marshes have a very high sequestration rate (Annex 2 and Figure 2.3.1); almost half of the total amount of carbon fixed in Zeeland is captured by salt marshes.

2.3.2 Carbon soil stocks

Figure 2.3.3 shows the carbon stocks in the top 30 cm of the soil for the Netherlands. The highest soil carbon stock is found in soils in the Northern and Western part of the Netherlands. Clearly, high values in the map reflect the area that is characterized by (thick) peat deposits. It should be noted (again) that the data presented here only represent soil carbon stocks in the upper 30 cm of the soil. This implies that the carbon stock in peat deposits > 30 cm thick (locally the peat deposits in the west of the Netherlands exceed 10m), as well as carbon in peat deposits that are covered by marine and fluvial clays are not included in this account. In addition, analyses were carried out separately for mineral soils and for peat and peaty soils (Table 2.3.2).

Mineral soils such as dunes and beaches relatively have the lowest mean soil carbon stock, while fresh water wetlands have the highest mean soil carbon stock (Table 2.3.2). Forests have the highest soil carbon stock of peat and peaty soils. The total soil carbon stock in the Netherlands in mineral and peat and peaty soils is 355 Mton.

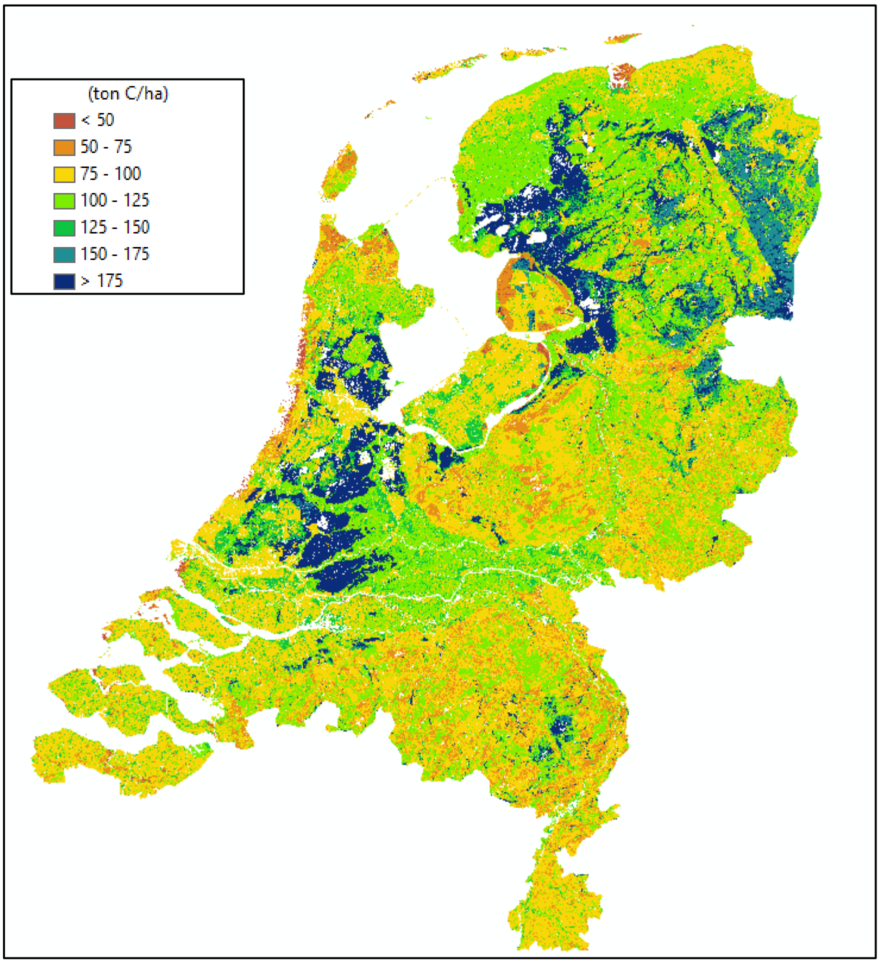
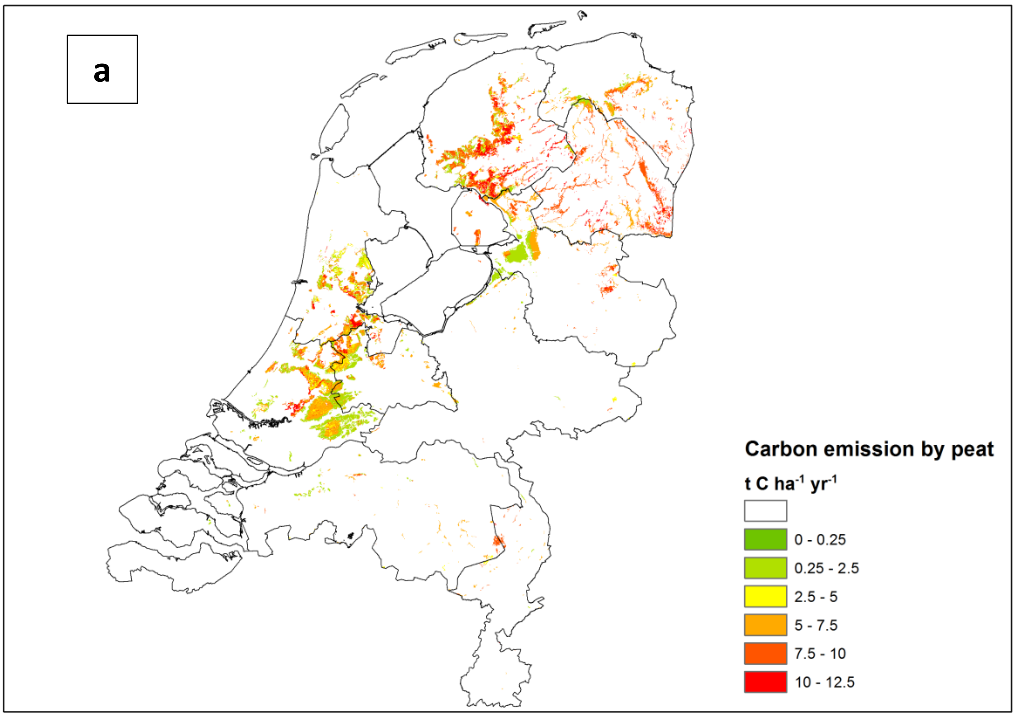


Figure 2.3.3 Map of soil carbon stock in upper 30 cm (Map: Alterra, 2012, Documentation: Lesschen et al., 2012). Values are based on average values for soil types sampled for the LSK database and land use data from 2004.

2.3.3 Carbon flows in soils

In this section the C flows from peat and peaty soils (emissions and sequestration) were modelled separately from emissions related to agricultural soils, because the latter are associated with C in the economy (Chapter 4). Hence, the maps shown here represent data of emissions and sequestration in peat and peaty soils, based on the assumption that soil organic carbon in peat lands may oxidise (and hence emit C) depending on the ground water level. Intact peat lands with natural vegetation and water levels close to the surface are able to sequester carbon. However intact rainwater-fed peatlands with *Spagnum* mosses have almost completely disappeared in the Netherlands. There are a few peat areas with *Spagnum* in the top layer; we assume that these rainwater-fed bogs sequester carbon (Belyea and Malmer (2004)). The influence of agricultural practices and the use of manure (and subsequent emissions of methane to the atmosphere) are thus not included in this section; these practices are associated with C flows in the economy and are estimated and included in Chapter 4. Maps and detailed data are provided in Annex 1.

Figures 2.3.4 a and b show the flows of C from peat and from peaty soils respectively. In the Netherlands, there is 255,700 hectare of low land peat soils (of which 102,200 hectare with a clay cover) and 158,100 hectare peaty soils (of which 15,300 hectare with a clay cover). Furthermore, there are about 2,200 hectares of peat soil with *Sphagnum* in the top layer (rainwater-fed bogs). However, not all areas with Spagnum in the top layer may actually represent active rainwater-fed bogs, however we are not able to further quantify this (the resulting effect on our calculations is very small given the small area covered by Spagnum peatlands). Managed and drained peat and peaty soils emit in total 1883 kton C yr^{-1} (6.9 Mton CO_2) of which 1443 kton C is emitted by peat soils and 440 kton C is emitted by peaty soils (Table 2.3.2). Rainwater-fed bogs have a very small, but positive, contribution to the total carbon balance of organic soils. Total sequestration of rainwater-fed bogs in the Netherlands is 0.6 kton C (596 ton C) per year. Meadows have the largest contribution to the total carbon emission by peat (737 kton C yr^{-1}), followed by annual crops (156 kton C yr^{-1}) and paved and unpaved surfaces (133 respectively 108 kton C yr^{-1}) (Table 2.3.2). Losses of C from peat and peaty soils are – by far- highest in Friesland, Drenthe and Zuid Holland (Table 2.3.3).



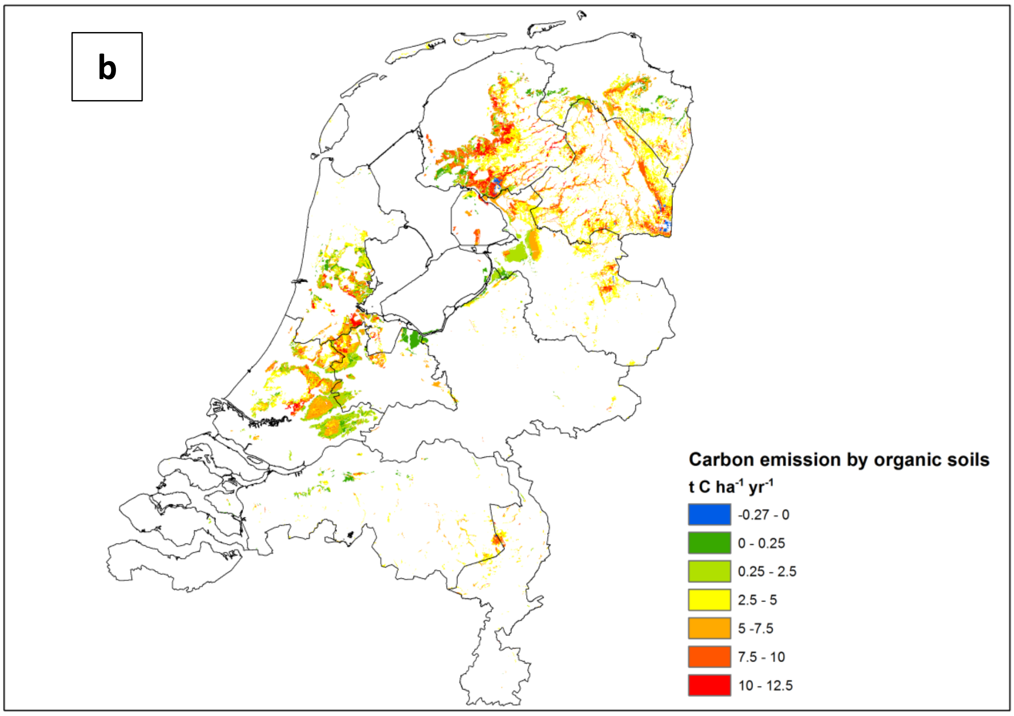


Figure 2.3.4 a and b Carbon emissions by a) peat soils only and b) by peat and peaty soils and raised bogs (negative emission indicates sequestration). Carbon emissions were calculated based on ditch level data (PBL, 2016) when available and otherwise on ground water table (Alterra, 2006), and presence of a clay layer (Alterra, 2014). A few areas in Noord Holland were classified as *Sphagnum* peat in the 1980's, but are not known as rainwater-fed bogs, therefore we assumed that they are peat soil and classified them according to the ditch level data.

Table 2.3.3 The first three columns report the carbon emission by peat soils resulting from peat oxidation (> 40 cm thick peat layer in soil) and peaty soils (5-40 cm thick peat layer in soil) in the Netherlands in kton C yr^{-1} per province. For reference, the final column shows the CO_2 equivalent values in kton CO_2 yr^{-1}.

	Peat soils (kton C yr^{-1})	Peaty soils (kton C yr^{-1})	Total carbon emission from org. soils (kton C yr^{-1})	Total CO_2 emission (kton CO_2eq yr^{-1})
Groningen	85	63	148	544
Friesland	375	76	451	1,655
Drenthe	270	139	409	1,501
Overijssel	127	64	192	702
Flevoland	20	4	23	85
Gelderland	14	7	20	75
Utrecht	109	8	116	426
Noord Holland	154	21	175	642
Zuid Holland	247	30	277	1,014
Zeeland	1	0	1	3
Noord Brabant	28	18	46	170
Limburg	16	11	27	98
Netherlands	1,445	441	1,886	6,915

2.4 Comparison with National Inventory Report (LULUCF)

The National Inventory Report (2016) reports changes in carbon stock and emissions due to land use and land use change (Coenen et al., 2016). They report, net emissions due to land use and land use change are reported of 6.19 Mton CO_2 equivalents yr^{-1}, or 1.69 Mton C yr^{-1}, including emission from mineral and organic soils. They report emissions from organic soils of 6.9 Mton CO_2-eq yr^{-1}(or 1.89 Mton C yr^{-1}). Our calculations of emissions of organic soils in the Netherlands result in the same number as what is reported in the National Inventory Report, in both cases emissions from peat are 6.9 Mton CO_2 per year(Table 2.3.4).

The reported carbon sequestration in biomass of 732 kton C per year (Table 2.3.8), in the LULUCF calculations of the National Inventory Report, is entirely attributable to increases in living biomass in forests; carbon change for the other land uses is assumed to be equal to zero. Based on scientific literature (Table A2.1, Annex 2), we assume that not only forest but also other ecosystems contribute to carbon sequestration; e.g. natural grasslands, heath, fresh water wetlands and tidal salt marshes. In this study, we estimated the total ecosystem contributions to carbon sequestration (based on extent of the ecosystems in the EU_NL map) at 975 kton C per year, of which 615 kton C per year was sequestered by forests. This is due to differences in assumed forest area, as discussed below.

Table 2.3.4 Carbon stock change in biomass in the Netherlands; comparison of total change calculated in current study (light grey columns) and total stock change calculated for LULUCF 2013 (Coenen et al., 2016) (dark grey columns).

LULUCF Category	Ecosystem Unit	Total area (1000 ha)	Total carbon change in biomass (kton C/yr)	Area continuing same land use (1000 ha)	Area converted to this land use (1000 ha)	Total area (1000 ha)	Carbon change in biomass (kton C/yr)	Change in carbon stock in biomass due to land use change[1] (kton C/yr)
Forest	Deciduous forest	326	615	339	59	398	732	0
	Coniferous forest							
	Mixed forest							
	Dunes with permanent vegetation							
Cropland	Non-perennial plants	860	30	618	331	949	0	-87
	Perennial plants							
Grassland	Meadow	1372	249	925	369	1293	0	-119
	Buffer strips							
	Heath land							
	Other unpaved terrain							
	River flood basin							
	Natural grasslands	54	10	41		41	0	
Wetlands	Lakes and ponds	803	0	757	52	809	0	-42
	Sea							
	Rivers and streams							
	Fresh water wetlands	34	8	14		14		
Settlement	Paved surfaces	655	18	400	210	610	0	-199
	Greenhouses							
	Public green space							
	Farmyards and barns							
Other land	Active coastal dunes	36	0	30	7	37	0	-8
	Beaches							
	Inland dunes							
	Tidal salt marshes	11	45					
Total		4151	975	3124	1028	4151	732	-454

[1] Negative carbon stock changes are solely a result of forest that is converted into other land uses. In this case, standing forest and dead wood is removed resulting in a lower carbon stock after conversion.

2.5 Recommendations for further improvement

To attune our study with relevant reporting on carbon, the carbon sequestration rate and carbon stock for forests used in the look-up table approach in this study were equal to values used in National Inventory Report (NIR) to the UNFCCC by the LULUCF sector. At present, there is a difference between the total area of forest in the ecosystem unit map for the Netherlands (EU_NL map) and the total area of forest that is reported for the LULUCF sector. The difference can be attributed to differences in the method how forest was defined. Both maps are based on TOP10NL map for 2013, a grid with 2.5 m x 2.5 m pixel resolution. Currently, only forest, tree rows and groves within main class forest are classified as forest in our EU_NL map, while tree rows and groves in other main classes are not classified as forest. For the NIR LULUCF land use and land use change maps, all forests, tree rows and groves are classified as forest, provided that their combined area in a 25 m x 25 m pixel covers more than half of the pixel. As a result, the total area of forest in the EU-NL map is lower than in the LULUCF-GHG inventory (Table 2.3.8). Further harmonisation of classification of forest at the development phase of the ecosystem unit map for the Netherlands could reduce the difference between the results from the current study with the CO_2 reporting of the LULUCF sector. In the next carbon account we intend to add carbon sequestration in tree groves and rows to strongly reduce the difference. As mentioned before, an advantage of the carbon account compared to the LULUCF report is to also have a detailed spatial information set on where carbon sequestration and emissions take place – the figures to be reported are similar (and we also consider carbon sequestration in other ecosystems than forests, which may be reported separately from the sequestration in forests).

Note that currently we use one value for carbon sequestration by grasslands. Conijn and Lesschen (2015) present a more detailed model for the carbon balance of grasslands. In the next version of the carbon account, a more detailed spatial model for grassland sequestration can be included. In addition, in the current study, reporting of soil carbon stock is restricted to the top 30 cm due to data availability. If more data becomes available, this will be included in the next version of the carbon account.

The NIR LULUCF calculations show that 454 kton C per year has been released due to conversion of forests into other land use types (Table 2.3.4). In the current study, we do not include land use change. However, when ecosystem accounts are periodically assessed this is an aspect that will be included.

3. Geocarbon

3.1 Definition and scope of geocarbon

Geocarbon includes all carbon stored in the lithosphere. It can be disaggregated into oil, gas, coal resources, rocks (primarily limestone), and minerals, e.g. carbonate rocks used in cement production, methane clathrates and marine sediments (UN et al., 2014). Basically, carbon that is part of the Earth's lithosphere is considered as geocarbon (or geological carbon: carbon present in the Earth's bedrock and sediments, primarily from marine sediment deposits: inorganic geocarbon), as well as carbon formed originally in the Earth's biosphere millions of years ago, that, after geological metamorphosis due to high pressure and temperatures in the Earth's crust, was turned into e.g. oil and gas (organic geocarbon)). Organic carbon in soils and in peat deposits is included in biocarbon[3].

Following this definition of geocarbon, all inorganic and organic carbon present in the lithosphere could be accounted for in the carbon account. Underlying the Netherlands are several kilometres of sedimentary rocks, including limestone, shale and sandstone, but also rocks containing oil, gas and coal resources. Most of these sedimentary rocks contain high amounts of carbon, however, only for a few of these data are available. In addition, as the information generated from the accounts is policy-focussed, the priority should be given to those stocks that are impacted by human activity. Therefore, only the subsoil energy resources i.e. oil, gas, coal resources, which could potentially be extracted, will be included in the carbon account. Following the guidelines of the SEEA CF not only the commercially recoverable energy resource will be taken into account, but all known deposits.

3.2 Methodology

3.2.1 Oil and gas resources

The Netherlands still has significant quantities of natural gas as well as some smaller oil deposits. The physical data of oil and natural gas reserves were obtained from the annual reports 'Oil and gas in the Netherlands' / 'Natural resources and geothermal energy in the Netherlands' (1987-2009), (TNO / Ministry of Economic Affairs, 1988 – 2010). This report provides data on total stocks, discoveries, extraction, i.e. the data needed to compile the physical asset account for these resources. These physical data for the energy asset account are compiled and published annually by Statistics Netherlands (see Statline). Using standard conversion factors the physical amounts of the natural gas and oil resources were converted into Mton C.

[3] Soil is the layer of fine material covering the Earth's land surface influenced by and influencing plants and soil organisms.

3.2.2 Coal resources

The Netherlands has substantial coal resources in the south and east of the Netherlands. Until the 1970's these resources were actively mined. All coalmines were closed down, however, as coal mining became commercially unprofitable. Since 1990, the interest in such coals has increased as a source of coal bed methane. Currently this type of production is not economically feasible, but theoretically the recoverable amounts are large. Estimates on the remaining coal reserves are available from geological surveys. In Table 3.2.1 an overview is provided of the estimated coal reserves for different areas in the Netherlands according to three probability scenario's. P90 indicates an uncertainty of 10 %, P50 an uncertainty of 50 %, and P10 an uncertainty of 90 %. For this study, we used the P50 scenario. The Zeeland Brabant coal deposit potentially contains a large amount of coal. However these estimates are based on very limited data and are thus highly uncertain. Therefore we excluded this area from the total estimated coal reserve. Accordingly, the total estimated coal reserve for the Netherlands amounts to ca. 12700 Mton C.

Table 3.2.1: estimated coal reserves in 1000 Mton and Mton C, according to different probability scenario's. Source: Geology of the Netherlands (2007).

	Depth	P90	P50	p10	P90	P50	p10
		1000 Mton			Mton C		
Limburg	< 1500	1	1.6	2.3	548	877	1261
Peel	< 1500	1.6	3.4	5.2	877	1864	2850
Achterhoek	< 1500	1.4	9.1	30.4	767	4988	16663
	1500 2000	1.4	9.1	20.2	767	4988	11072
Zeeland n brabant	1500 2000	16	36.1	58.7	8770	19787	32175
TOTAL		5.4	23.2	58.1	2960	12717	31846

3.2.3 Shale gas

Shale gas is natural gas that is found trapped within shale formations. Interest for the commercial exploitation of shale gas is increasing, but the decision to start test drilling has been postponed until 2020 due to environmental and social concerns. The amounts of shale gas in Dutch deposits are unknown. A first, uncertain estimate ranges from 200-500 billion m^3 (TNO, 2013). We included the low estimate of the range provided by TNO in the carbon account.

3.2.4 Limestone

Carbon is also an important constituent of the limestone that is exploited for the production of cement and cement-products. As discussed above, these subsoil stocks were not taken into account. However the extraction of limestone is accounted for as a reduction in stock of geocarbon and an addition to stock for carbon in the economy. Data for the extraction of limestone were obtained from the SEEA material flow accounts (MFA).

3.3 Results

Table 3.3.1 and Figure 3.3.1 show the details of the carbon account for geocarbon. Total stocks of carbon in subsoil energy resources amount to around 13,400 Mton C. Coal represents by far the largest stock of carbon, followed by natural gas and shale gas. It should be noted that the values for coal and shale gas have a high degree of uncertainty and the numbers presented here show the conservative estimates.

Table 3.3.1: Geocarbon account for the Netherlands in 2013.

Mton C	oil	gas	shale gas	coal	limestone	TOTAL
Opening stock	54.2	533.0	94.3	12716.5		13398.1
Additions to stock						
Natural expansion						
Managed expansion						
Discoveries		0.1				0.1
Upwards reappraisals	0.3					0.3
Reclassifications						
Imports						
Reductions in stock						
Natural contraction						
Managed contraction	1.5	39.7			0.1	41.3
Downwards reappraisals		1.1				1.1
Reclassifications						0.0
Exports						
Net carbon balance	-1.1	-40.7	0.0	0.0		-41.9
Closing stock	53.1	492.4	94.3	12716.5		13356.4

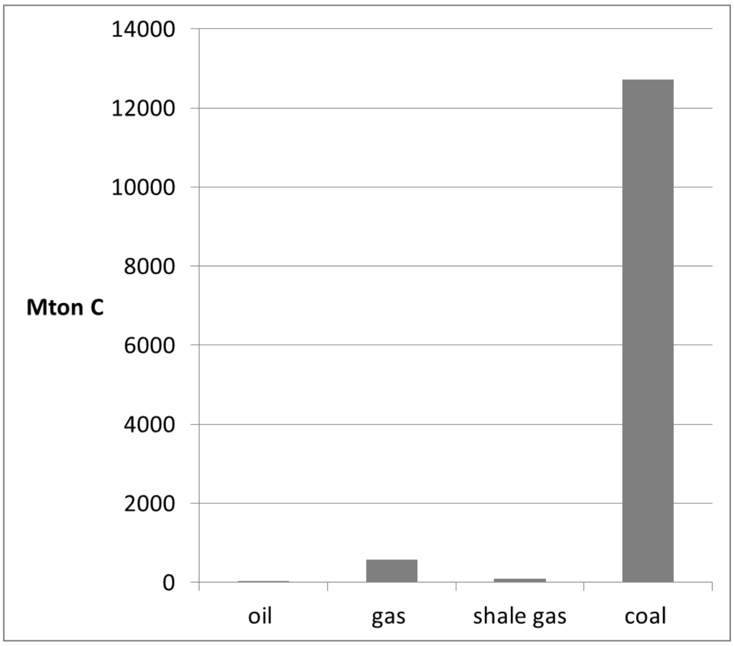


Figure 3.3.1: Geocarbon stock data for the Netherlands in 2013.

4. Carbon in the economy

- Carbon in the economy reflects a wide range of materials that are either in stock or that flow through the economy
- Some flows of materials (including imports and exports) are relatively well known and were derived from the Material Monitor, the Material Flow Accounts, and the water and air emissions accounts,
- The stocks of carbon in the economy are often not well known, as well as the amount of carbon in fixed assets and the flow of carbon associated with fixed capital formation: carbon in e.g. building materials and in waste dumps, bitumen in roads, etc.
- Reductions of stock taken into account here include carbon emissions to the atmosphere and water and to soils (primarily manure)
- The net balance for carbon in the economy in 2013 was 7.2 Mton C
- Carbon in the economy also includes data on recycled products

4.1 Definition and scope

The SEEA EEA carbon account includes C in products accumulated in the economy (SEEA EEA, 2014). Examples include petroleum products in storage, C stored in building materials (wood, concrete, etc.), bitumen in roads and C stored in waste dumps. As mentioned previously, this section also includes carbon in biomass related to agricultural activities: perennial and non-perennial plants and meadows. The flows of carbon that occur within the economy are very significant and essential for understanding the interaction between economy and environment. The level at which geocarbon and biocarbon stock changes can be linked to the economy will determine the policy usefulness of the carbon stock account. This is particularly relevant in cases where raw materials can be extracted from more than one ecosystem type (e.g. biomass fuel from natural ecosystems or agricultural ecosystems; meat from agricultural ecosystems or semi-natural ecosystems) or from geocarbon reservoirs with different carbon contents and emissions profiles.

4.2. Structure of the stock account for carbon in the economy

The setup of the carbon account for the economy follows the general outline presented in section 1.2. Here we describe in more detail how the different carbon stocks in the economy are best classified (i.e. the columns) and what are the most appropriate row entries.

Asset classification: the columns of the carbon stock account for the economy

In the columns the different reservoirs (assets) where carbon can be stored in the economy are recorded (Table 4.2.1). Carbon assets in the economy can be further disaggregated into the following SNA components (SEEA EEA A4.7):

- **Inventories** are produced assets that consist of goods and services, which came into existence in the current period or in an earlier period, and that are held for sale, use in production or other use at a later date. Examples include petroleum products in storage, gas reinjections, food products in storage, etc.

- **Fixed assets** are produced assets that are used repeatedly or continuously in production processes for more than one year. Examples include wood and concrete in buildings, bitumen in roads, etc.
- **Consumer durables:** These are goods that may be used for purposes of consumption repeatedly or continuously over a period of a year or more. Examples include wood and plastic products (furniture, toys etc.).
- **Solid waste** covers discarded materials that are no longer required by the owner or user. Accounting for waste follows the conventions of the SEEA CF, where waste products (e.g., disposed plastic and wood and paper products) stored in controlled landfill sites are treated as part of the economy.

Table 4.2.1: Structure of the carbon stock account. Grey cells are null by definition.

	Carbon in the economy							
	Inventories			Fixed assets and consumer durables		Waste		TOTAL
	fossil fuels	biobased	other	biobased	other	biobased	other	
Opening stock								
Additions to stock								
Managed expansion								
Extraction from geocarbon								
Extraction from biocarbon								
Capture from the atmosphere								
Upwards reappraisals								
Reclassifications								
incorporation in products								
Gross fixed capital formation								
recycled products								
waste production								
Imports								
Reductions in stock								
Managed contraction								
Emissions to the atmosphere								
Respiration of humans								
Respiration of livestock								
Emissions to water								
Emissions to soil								
Downwards reappraisals								
Reclassifications								
incorporation in products								
Gross fixed capital formation								
Recycled products								
Waste production								
Exports								
Net carbon balance								
Closing stock								

In the carbon stock account for the economy presented in Table 4.2.1 fixed assets and consumer durables were put together as one category.

In turn, these main asset categories can be further disaggregated based on the nature of the asset. In this study we have distinguished between 'biobased products' and 'other products' (i.e. mineral (inorganic) products and synthetic materials (plastics)). 'Biobased products' are materials which consist of carbon compounds derived from plants or animals. The carbon in these materials has been sequestered from the atmosphere by plants through the process of photosynthesis. This removal and capture of carbon from the atmosphere is natural CO_2 storage. The carbon is stored in the biobased material until it is released again by decomposition or combustion. In addition, under inventories also 'fossil fuels' have been identified separately.

Cultivated biological resources are a type of produced asset in the SNA and also a type of environmental asset in the SEEA. They may be either fixed assets (e.g., sheep for wool, breeding stocks of fish, and orchards) or inventories (e.g., livestock for slaughter and certain trees for timber) (SEEA CF 5.35). All environmental assets that are classified as cultivated must be recorded as either fixed assets or inventories (SEEA CF 5.38). With respect to the carbon account, the carbon stored in crops should was therefore recorded as carbon accumulation in the economy and not as biocarbon. In this respect, the distinction between cultivated and non-cultivated biological resources is important. Cultivated biological resources cover animal resources yielding repeat products and tree, crop and plant resources yielding repeat products whose natural growth and regeneration are under the direct control, responsibility and management of an institutional unit. Non cultivated biological resources thus yield products that are not under the direct control, responsibility and management of an institutional unit. In this study all carbon in crops (perennial and-non perennial plants), meadows and livestock was allocated to fixed assets. For practical purposes, all carbon in forests and other biomass was allocated to biocarbon (see also previous chapter).

Additions and reductions in stock: the rows

The row entries in principle should follow the standard layout of the carbon account as discussed in section 1.2. However, some row entries are not applicable for carbon in the economy (natural expansion / contraction, discoveries). In addition, some items could be further broken down to provide additional detail and information. Accordingly, we here propose to include the following row entries:

Additions to stock:

Managed expansion

- Extraction of geocarbon: this is the extraction of carbon the form of fossil fuels and mineral deposits (mainly carbonate minerals).
- Extraction of biocarbon: this is the harvesting of non-cultivated assets, i.e. wood extraction, fisheries and extraction of other biological products from the environment
- Capture from the atmosphere: this is all carbon captured from the atmosphere by cultivated biological resources. It is equal to the net carbon sequestered in crops that is subsequently harvested.

Reclassifications

- Incorporation of products: This applies mainly to the production of synthetic materials (plastics) from fossil fuels. For ‘other products’ (inventories) it is an addition to stock, for fossil fuels it is a reduction in stock.
- Recycled materials: These are waste products that are recycled: for inventories it is an addition to stock, for waste it is a reduction in stock.
- Gross fixed capital formation. This is the incorporation of carbon in fixed assets (for example the use of wood and concrete for buildings etc.), it is an addition to stock for fixed assets/consumer durables, for inventories it is a reduction in stock.
- Waste production: these are products that become waste, it is an addition to stock for waste, for inventories it is a reduction in stock.

Reductions in stock

Managed contraction

- Emissions to the atmosphere: These are all carbon emissions (CO_2, CH_4) by economic activities to the atmosphere by economic activities. These include emissions caused by combustion of fossil fuels and biomass, but also emissions from industrial processes. These emissions are consistent with the emissions reported in the SEEA CF air emission accounts (UN et al., 2014). Excluded here are emissions by respiration by humans and livestock, which are reported separately.
- Emissions to the atmosphere by humans / livestock: these are CO_2 emissions caused by respiration.
- Emissions to water: this is total carbon (organic and inorganic) discharged to the surface waters. Carbon here can be both dissolved or as suspended material. These emissions concur to the emissions reported in the SEEA water emission accounts (UN et al., 2014).
- Emissions to soil: this is all carbon that is directly emitted to the soil. This is mainly manure by livestock transmitted to agricultural soils.

Reclassifications

- Incorporation of products: This applies mainly to the production of synthetic materials (plastics) from fossil fuels. For other products (inventories) it is an addition to stock, for fossil fuels it is a reduction in stock.
- Recycled materials: These are waste products that are recycled: for inventories it is an addition to stock, for waste it is a reduction in stock.
- Gross fixed capital formation. This is the incorporation of carbon in fixed assets (for example the use of wood and concrete for buildings etc.), it is an addition to stock for fixed assets/consumer durables, for inventories it is a reduction in stock.
- Waste production: these are products that become waste, it is an addition to stock for waste, for inventories it is a reduction in stock.

Net carbon balance

The net carbon balance is equal to total carbon additions to stock minus total carbon reductions in stock.

An alternative set up by sector

A disadvantage of the asset classification proposed above is that there is no direct link to economic activities as described in the SNA. An alternative would be to classify the carbon in the economy according to the (institutional) sectors, similar as the setup of the asset accounts of the SNA (UN et al., 2009). Accordingly, the economic activities responsible for the carbon flows can be directly identified from the carbon account, which in turn can be linked to other information from the national and environmental accounts. This alternative set up is described in further detail in Annex 3.

4.3 Data sources and methodology

The data needed to compile the carbon account for the economy are closely linked to the assets and flows that are already described in the SEEA CF. The carbon assets and the additions / reductions in stock can be calculated by combining physical data in million kg or PJ from the physical asset accounts and physical flow accounts with carbon conversion factors. Below we describe in detail what data sources were used to fill the carbon account for the economy and what data gaps still exist.

Stock data (opening and closing stock):

- Data for tor the stocks of fossil fuels are available from the energy statistics (e.g. stocks in oil storage tanks). These are data for oil and gas products and oil resources. Some of the natural gas that is extracted is re-injected into empty gas fields as strategic reserves. This gas is considered as a fixed asset that is part of the economy (SEEA EEA A4.8). No data were available for aboveground coal stocks. For the Netherlands, these are probably small.
- No stock data are available for biobased products and carbon in mineral based products. Stocks of biobased products for food consumption probably will be small, as these products are subject to disintegration. These are therefore assumed to equal zero. There may be some stocks for wood(products) and biomass for energetic purposes. However, these stock are probably relatively small. Stocks of cultivated biological resources for non-perennial plants are also considered small, as stocks should be accounted for at the beginning of the accounting period, i.e. the 1st of January, which is winter in the Netherlands. Stocks for perennial plants are available (Table 2.3.2) and have been included. Stocks of cattle as yet have not been included, a first quick estimation showed that this stock represents less than 0.5 Mton C.

Additions to stock

- Data for abstraction of geocarbon is obtained from the energy flows energy accounts (PEFA). Data for extraction of limestone was obtained from the Economy wide material flow accounts.
- Data for the extraction of biocarbon was obtained from the Economy wide material flow accounts. As only non-cultivated biological resources should be taken into account here, we have only included timber extraction and fish extraction. With the appropriate carbon content data these product flows can be converted to carbon flows.

- Data for carbon capture from the atmosphere was obtained from the Economy wide material flow accounts. All carbon harvested from crops (cultivated biological resources) was taken into account here. This is the net flow: crop residuals that are left behind on the fields are thus excluded. With the appropriate carbon content data these product flows can be converted to carbon flows.

Reductions in stock

- Emissions to the atmosphere for fossil fuels were obtained from the air emission accounts and the national emission inventory. Included are both emissions from the combustion of fossil fuels and process related emissions from fossil fuels (for example the production of fertilizer from natural gas). Emissions to the atmosphere for biobased carbon were also obtained from the air emission accounts: these are the so called short cyclic CO_2 emissions which result from the combustion of biomass. In addition the CO_2 emissions that result from organic waste (combustion of organic waste, CO_2 emissions from waste water treatment plants) were identified. CO_2 emissions for other products (for example emissions that result from the production of cement) were also obtained from the air emission accounts and the national emission inventory.
- Respiration data have been calculated separately both for humans and livestock, based on the number of livestock/population and average CO_2 emissions from respiration.
- Data for emission to water were obtained from the water emission accounts and the National emission inventory. The actual discharge of carbon to surface water is very low: most carbon in sewerage is removed in waste water plants by anaerobic processing and removal of the sludge (which is either burned or recycled).
- Carbon is emitted to soils by manure deposition. Data was obtained from statistics on manure which were also integrated in the physical supply and use tables of the SNA.

Imports and exports

- Import and export data (in million kg) was obtained from Economy wide material flow accounts. With the appropriate carbon content data these can be converted to carbon flows. Important here is to correct for the water content of products in order to arrive at the right carbon contents.

Reclassifications

- The amount of carbon incorporated in products (mainly as plastics) was obtained from the physical energy accounts by identifying the amount of fossil fuels used for non-energetic purposes.
- Data on gross fixed capital formation with respect to carbon was obtained from the physical supply and use tables. With respect to fossil fuels the amount of bitumen used in construction was taken into account. For biobased products the amounts are small (mainly wood used in construction), but these may be partly underestimated.
- Carbon in recycled products was calculated based on data from the waste accounts: here the amount of different residuals that are recycled were identified.

- The amount of waste produced was obtained from the waste accounts. Combining the right carbon conversion factors with the different waste categories results in an estimate for total carbon in waste. A distinction was made between carbon in biobased waste and other waste.

Carbon conversion factors

For this study we used carbon conversion factor from numerous sources. The official list on carbon emission factors for the Dutch emission inventory was used for fossil fuel products and some biobased products that are also used for energetic purposes. In addition, we used the Phyllis database developed by ECN, which is a large database containing information on the composition of biomass and waste (https://www.ecn.nl/phyllis2/).

Data gaps and areas for improvement

Although it was possible to fill most of the carbon account for the economy some important data gaps remain:

- Good data on product inventories are only available for fossil fuels. No data for carbon stocks were available for the other inventories (biobased products and 'other' products). However, these are probably small. The stock of carbon in waste dumps is also unknown. Based on historic data, it may be possible to calculate this.
- For the moment data are lacking for carbon stored in fixed assets. This includes carbon stored in plastics (consumer durables), carbon stored in buildings (wood and other biobased products used in constructions) and bitumen used in roads. In principle it would be possible to construct these data, based on the physical supply and use tables.
- Although some information is available on the annual flow of carbon related to gross fixed capital formation (bitumen used in roads etc.) the present figure is probably an underestimation. With more detailed study and additional data sources it may be possible to improve this.
- Waste originating from fixed assets (primarily construction waste, some household waste) cannot be identified separately.

4.4 Results

Table 4.4.1 shows the results for carbon accumulation in the economy (2013). The yellow marked cells indicate where data are still missing or incomplete.

For inventories the net carbon balance is quite significant. For biobased products the calculated net carbon balance is 1.6 Mton. We would expect this figure to be lower, as no significant stock build up (or reduction) of biobased products is expected. This issue needs further investigation and improvement: the difference may be related to inconsistencies in the source data or the carbon conversion factors. Also, for 'other products' the carbon balance is quite high (2.9 Mton). Here, a significant amount of carbon may go to gross fixed capital formation, which is currently largely missing from the data.

Table 4.4.1 Carbon in the economy for the Netherlands (2013). Grey cells are null by definition. Yellow cells represent incomplete or missing data.

Mton C	Carbon in the economy							
	Inventories			Fixed assets and consumer durables		Waste		TOTAL
	fossil fuels	biobased	other	biobased	other	biobased	other	
Opening stock	24.4							
Additions to stock								
Managed expansion								
Extraction from geocarbon	41.1		0.1					41.2
Extraction from biocarbon		0.5						0.5
Capture from the atmosphere		8.5						8.5
Upwards reappraisals								
Reclassifications								
incorporation in products			10.0					10.0
Gross fixed capital formation				1.6	0.5			2.2
recycled products		4.4	0.6					4.9
Waste production						5.1	1.3	6.4
Imports	147.2	17.0	21.9			3.2	0.5	189.8
Reductions in stock								
Managed contraction								
Emissions to the atmosphere	49.6	2.7	0.5			1.9	0.9	55.6
Respiration of humans		1.5						1.5
Respiration of livestock		4.7						4.7
Emissions to water		0.0	0.0			0.0	0.0	0.0
Emissions to soil		0.6	0.0			0.0	0.0	0.6
Downwards reappraisals								
Reclassifications								
incorporation in products	10.0							10.0
Gross fixed capital formation	0.2	1.6	0.4					2.2
Recycled products						4.4	0.6	4.9
Waste production		5.1	1.3					6.4
Exports	127.7	12.5	27.5			2.2	0.3	170.3
Net carbon balance	0.6	1.6	2.9	1.6	0.5	-0.2	0.0	7.2
Closing stock	25.0							

5. Carbon in the atmosphere

5.1 Definition and scope

The atmosphere contains carbon mainly in the form of CO_2 and methane. The atmosphere is a receiving environment with regard to carbon from the primary reservoirs geocarbon and biocarbon but also from emissions from carbon used in the economy. On the other hand, carbon uptake from the atmosphere may take place by carbon sequestration in biocarbon. As CO_2 and methane act as greenhouse gasses in the atmosphere, accounting for these flows is highly policy relevant.

In the context of a 'national' carbon account it is difficult to define the carbon stock for the atmosphere. For this study we have taken the cumulative CO_2 emissions from fossil fuels by Dutch economic activities since 1900 as the stock for carbon in the atmosphere. Although we realise this is an assumption, we have included this figure the provide an indication of the total stock of carbon in the atmosphere that was added due to Dutch economic activities.

5.2 Results and bridge table for carbon emissions to the atmosphere

Table 5.2.1 shows the carbon account for the atmosphere for the Netherlands (2013). The emissions of carbon to the atmosphere are larger than the net sequestration of carbon, resulting in a net carbon balance of 55 Mton C. This is of course mainly due to the burning of fossil fuels. This gives an indication of the amount of carbon added to the atmosphere by Dutch economic activities.

Table 5.2.1 Carbon account for the atmosphere (2013) in Mton C. The opening and closing stock (yellow cells) comprises of cumulative Dutch carbon emissions resulting from fossil fuel combustion since 1900 (see text for explanation of this assumption).

Opening stock	3193.2
Additions to stock	
Short cyclic emissions diue to economic activities	5.1
Other emissions due to economic activities	51.0
Respiration of humans and livestock	6.3
Emissions from biocarbon (natural ecosystems)	1.8
Reductions in stock	
carbon sequestration in cultivated plants	8.5
carbon sequestration in biocarbon (natural ecosystems)	1.0
Net carbon balance	54.8
Closing stock	3248.0

To clarify how the emissions to the atmosphere in the carbon account relate to the greenhouse gas emissions recorded in the air emission accounts (SEEA CF) and the IPCC inventory data, a bridge table was compiled, both in Mton C (the unit of the carbon account) and in CO_2 equivalents (the unit used to record emissions in the air emission accounts and the IPCC inventories).

Table 5.2.2 Bridge table for carbon and other greenhouse gas emissions to the atmosphere in 2013. Yellow cells indicate incomplete or missing data.

		In Mton C	**In greenhousegas equivalents**			
			CO2	Methane	other greenhouse gasses	Total
		Mton C	*Mton CO2 eq*			
1	**Net carbon balance for the atmosphere (carbon account)**	**54.7**	**198.7**	**19.2**		**217.9**
2	Carbon sequestration in biocarbon	1.0	3.6			3.6
3	Carbon sequestered in agricultural crops	8.5	31.0			31.0
4	**Gross carbon emissions to atmosphere (carbon account)**	**64.2**	**233.4**	**19.2**		**252.5**
5	Respiration lifestock and humans (-)	6.3	23.0	0		23.0
6	Emissions from biocarbon (-)	1.8	6.7			6.7
7	CO2 emission from manure on soils	0.6	2.2			
8	**GHG Emissions economic activities (SEEA CF)**	**55.5**	**201.5**	**19.2**	**10.3**	**231.0**
9	Short cyclic emissions (-)	3.6	13.1			13.1
10	Residents abroad (-)	7.0	25.6	0.0		25.8
11	Non residents (+)	1.9	7.0	0.0		7.1
12	Conceptual differences related to transport (-)	1.1	4.1	0.0	0.2	4.1
13	**IPCC emissions**	**45.7**	**165.7**	**19.2**	**10.1**	**195.0**
14	LULUCF (+)	1.7	6.2			6.2
15	**IPCC Kyoto protocol**	**47.4**	**171.9**	**19.2**	**10.1**	**201.2**

The first line of the table shows the net carbon balance for the atmosphere, as recorded in the carbon account. These are the net carbon emissions (CO_2 and CH_4) from geocarbon, biocarbon and carbon in the economy to the atmosphere. This is an important indicator as it shows the annual addition of carbon related greenhouse gasses of a country. The net carbon balance for the atmosphere is equal to gross carbon emissions to the atmosphere minus a) (net) carbon sequestration in biocarbon and b) carbon sequestered by agriculture. The gross emissions to the atmosphere (line 3) thus are equal to all CO_2 and methane that are annually emitted to the atmosphere.

The greenhouse gas emissions by economic activities (line 8) include all emissions caused by the residents of a country, regardless of where the emissions take place. These emissions are calculated according to de guidelines of the SEEA CF (air emissions accounts). Annex 4 provides more disaggregated data on the emissions by industries and households. The emissions by economic activities are not equal to the gross carbon emissions to the atmosphere as they exclude a) emissions from transpiration by humans and livestock (line 5), b) emissions from biocarbon (line 6), i.e. emissions from non-agricultural soils, but also emissions from forest fires would be included here, and c) CO_2 emissions resulting from the oxidation of manure in soils (line 7).

The IPCC emissions are recorded in line 13. The IPCC (Intergovernmental Panel on Climate Change) has drawn up specific guidelines to estimate and report on national inventories of anthropogenic greenhouse gas emissions and removals (IPCC, 2008). “Anthropogenic” refers to greenhouse gas emissions and removals that are a direct result of human activities or from natural processes that have been affected by human activities. In general the IPCC records all emissions that occur on the national territory, with a few specificities. Emissions originating from the so-called short cyclic carbon cycle, such as the combustion of biomass and emission from biochemical processes, are not fully included in IPCC calculations (line 9). It is assumed that these emissions do not structurally contribute to higher greenhouse gas concentrations in the atmosphere. IPCC records emissions as they occur on the national territory and these leave out emissions caused by residents abroad. On the other hand, emissions by non-residents on the national territory are included. These differences are recorded in line 10 and 11. Finally, there are some differences how transport related emissions are determined by the IPCC guidelines (line 12). The emissions by road traffic are calculated according to the total domestic deliveries of motor fuels, regardless of the nationality of the user of the motor fuel or the location where the use takes place. The only emissions considered for air transport and shipping are those caused in domestic transport.

The IPCC guidelines include not only sources but also sinks. Sinks represent the greenhouse gases stored in the atmosphere, either stemming from anthropogenic or natural sources, absorbed by nature for instance through carbon sequestration in organic matter, i.e. in living forests. Emissions and sinks due to land-use changes are also taken into account. These so called Land Use, Land-Use Change and Forestry (LULUCF) emissions (see also section 2.4) and are shown in the bottom of the bridge table (line 14). Note that not all emissions absorbed by nature are included, only those that occur on so-called managed lands including managed forests which are areas under human influence. LULUCF emissions are included in reporting for the Kyoto protocol.

In Figure 5.2.1 the CO_2 emissions to the atmosphere according to different definitions are presented. It shows that gross CO_2 emissions, i.e. the total CO_2 emissions that are transmitted to the atmosphere by anthropogenic activities are 12 % higher than the CO_2 emissions from economic activities and 36 % higher than the IPCC emissions. The net CO_2 emissions are 16 % lower than the gross emissions, due to carbon sequestration in biocarbon and agricultural products.

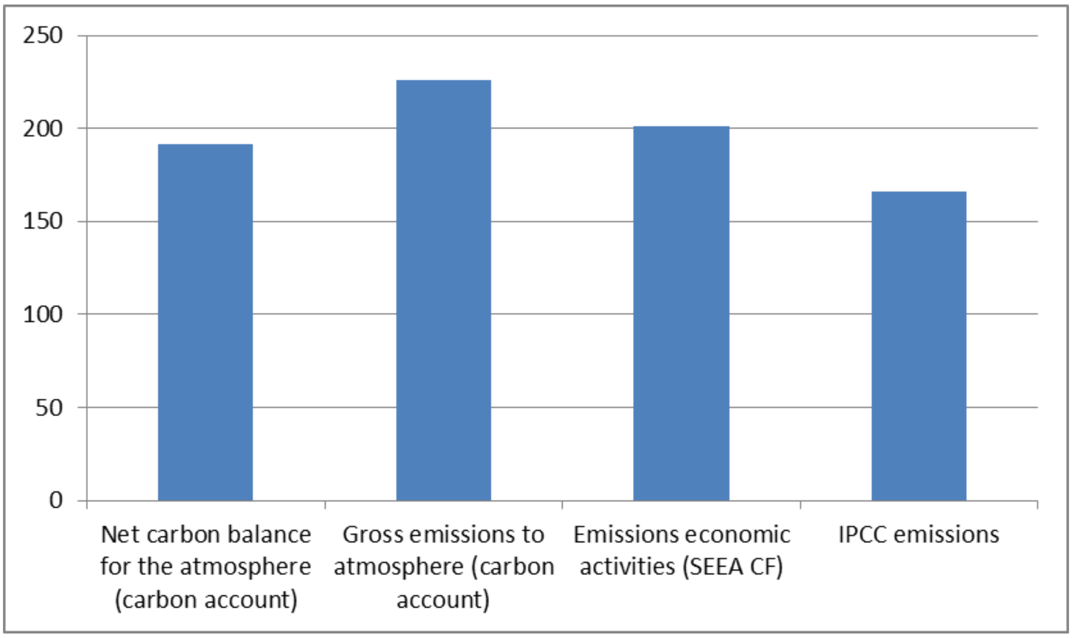


Figure 5.2.1 CO_2 emissions (in Mton CO_2 eq.) according to different frameworks.

6. Uses and applications of the carbon account

6.1 The Netherlands carbon balance

Table 6.1.1 provides an overview of the overall carbon account for the Netherlands. All data presented in the preceding chapters are included, allowing for a full overview of all known major stocks and flows of carbon in the four different 'storage' types included in this study; geocarbon, biocarbon, carbon in the economy and carbon in the atmosphere.

Table 6.1.1: Carbon account for the Netherlands (2013) in Mton C. Grey cells are null by definition.

	Geocarbon					Biocarbon				Carbon in the economy				Carbon in the atmosphere	Total
Mton C	oil	gas and shalegas	coal	limestone and marl	total geocarbon	Forests	Cropland / meadows	Other ecosystems	Total biocarbon	Inventories	fixed assets, cosumer durables	Waste	Total	Total	
Opening stock	54	627	12717		13398	48	206	123	377	24			24	3193	16993
Additions to stock	0	0	0	0	0	0.6	0.2	0.2	1.0	251	2	10	263	64.2	329
Natural expansion						0.6	0.2	0.2	1.0					1.8	3
Managed expansion										50			50	62.4	113
Discoveries	0	0	0		0										0
Upwards reappraisals	0	0	0		0										0
Reclassifications										15	2	6	23		23
Imports										186		4	190		190
Reductions in stock	1	41	0	0	42	0.6	1.3	0.6	2.4	246	0	10	256	9.4	310
Natural contraction						0.1	1.3	0.5	1.9					1.0	3
Managed contraction	1	40	0	0	41	0.5	0.0	0.0	0.5	60		3	62	8.5	113
Downwards reappraisals	0	1	0		1										1
Reclassifications										19	0	5	23		23
Exports										168		3	170		170
Net carbon balance	-1	-41	0	0	-42	0.0	-1.1	-0.4	-1.4	5	2	0	7	54.8	19
Closing stock	53	587	12717		13356	48	205	122	376	30			32	3248	17012

In Section 6.2 we present a non-exhaustive list of key applications that can be obtained from the carbon account shown in Table 6.1.1 (and from the disaggregated data underlying this account, see Annex 4). Below, we discuss some specific insights provided by the carbon balance.

Net carbon balance. The net carbon balance for the economy is equal to total additions minus total reductions in stock and indicates how much carbon is stored in (or released from) the economy (Figure 6.1.2). Similarly, the net Biocarbon balance indicates the change in the total stock of Biocarbon. Negative values imply a loss of biomass. The net Biocarbon balance per ecosystem type may thus also serve as an important input into the condition account and a number of ecosystem services.

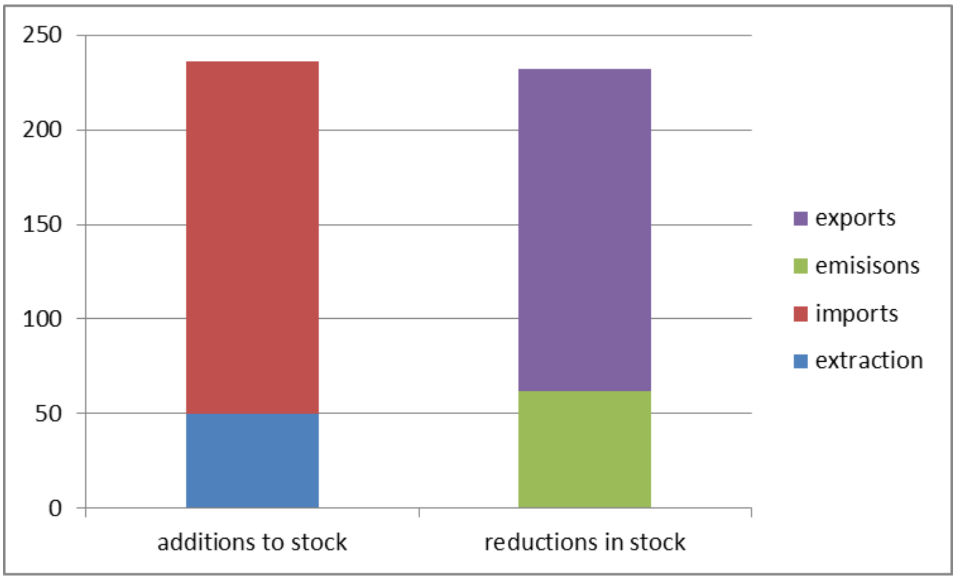


Figure 6.1.2 Carbon balance for the economy (Mton)

Trade balance for carbon in the economy. The trade balance of carbon is calculated as carbon in exported goods minus carbon in imported goods (Figure 6.1.3). The carbon trade balance for the Netherlands is negative. For both fossil fuels as well as biobased products more carbon is imported than exported. Most of this carbon is combusted within Netherlands and emitted as CO_2 to the atmosphere.

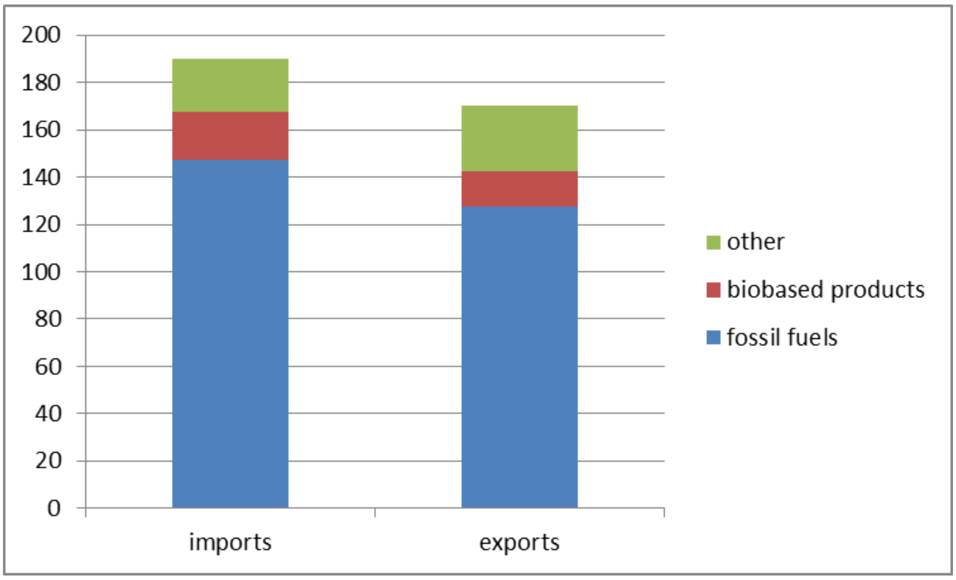


Figure 6.1.3 Trade balance for carbon (Mton).

Extraction of carbon versus emissions of carbon. For the Netherlands extraction of carbon is less than the emission of carbon to the environment (Figure 6.1.4). Extraction of carbon mainly consist of the extraction of natural gas and oil from geocarbon. Capture of CO_2 by harvesting crops (agriculture) is smaller, but still quite significant. Emissions for 99% consist of emissions to the atmosphere: emissions to soil (deposition of manure) and to surface water are in comparison quite low. Respiration by humans and livestock represents 10 % of total carbon emissions.

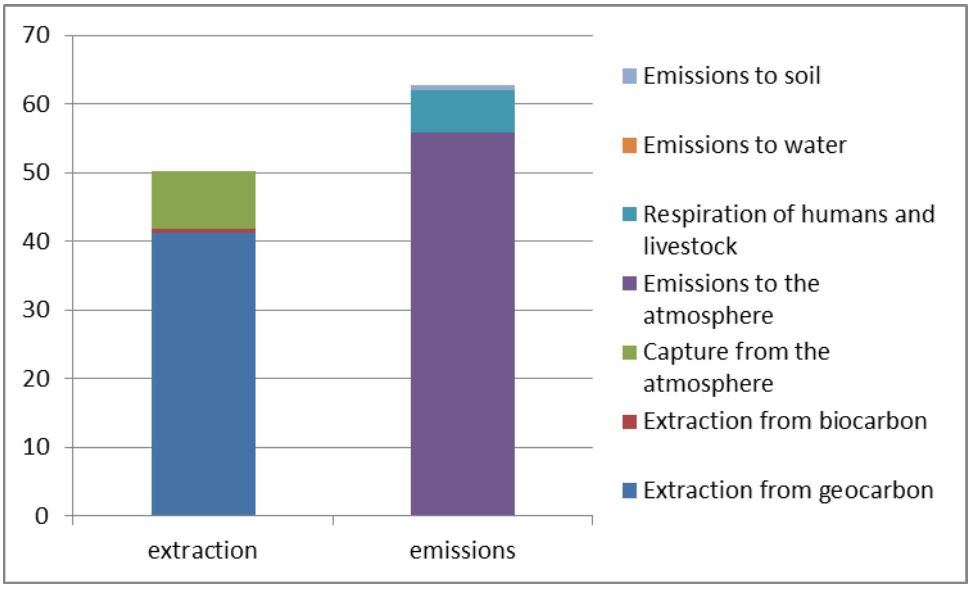


Figure 6.1.4 Extraction and emissions of carbon (Mton)

Recycling of carbon. The carbon account also provides information on how much carbon is recycled in the economy, which is important information with regard to the circular economy (Figure 6.1.5). Recycling of carbon means that this carbon is not (yet) emitted as CO_2 to the atmosphere. In total 4.9 Mton C (or 18.0 Mton CO_2 eq.) is recycled. If this carbon was not recycled but combusted, gross CO_2 emissions to the atmosphere would have been 8% higher. More disaggregated data show that the recycling percentages are highest for paper waste, plastic waste and organic waste. Recycling rates are much lower for mixed waste, wood waste and sludge, which are to a large degree combusted for energetic purposes.

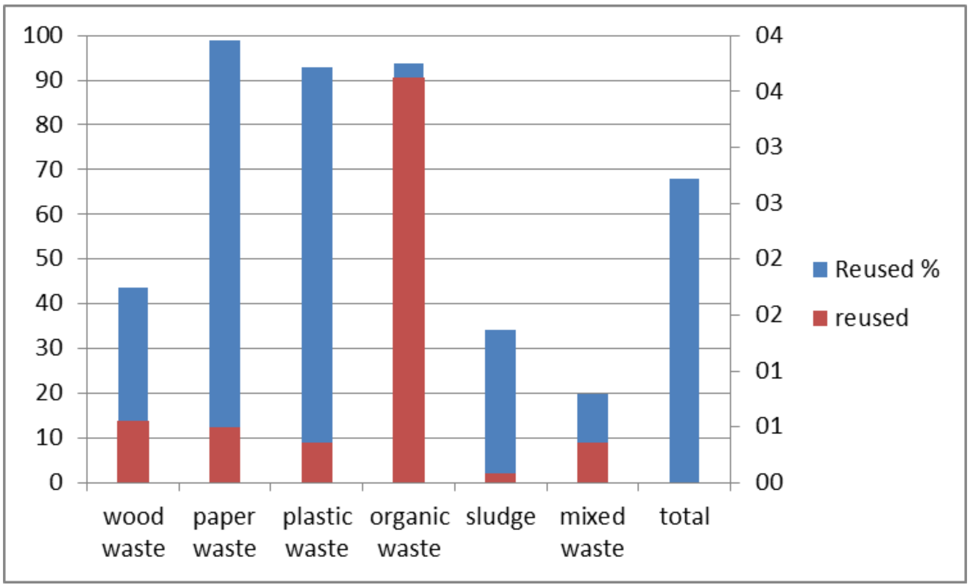


Figure 6.1.5 Recycling of carbon per waste category in absolute (Mton; right y-axis, red bars) and relative (percentage; left y-axis, blue bars) measures.

6.2 Policy relevance

The carbon account can support policy making in the following ways, although it is likely that once the account is published on-line the various stakeholders in the climate arena will develop additional applications of the very detailed, disaggregated and spatially explicit dataset.

1) **Measuring progress towards international climate mitigation obligations including the EU Effort Sharing Regulation.** Development of the carbon account is fully aligned with the current policy debate on enhancing stocks of carbon in EU forests as a mitigation measure. Because of its extended scope, the carbon account is an ideal format to be used for the detailed requirements on carbon emissions reporting to the EU as of 2020 required as part of the Effort Sharing Regulation (ESR) (European Commission, 2016). This because the account includes both the carbon flows in the economy and the carbon flows in the ecosystems. Both are considered in an integrated way and double counting of carbon emissions or sequestration is avoided. The ESR is currently being designed as the EU response to the Paris Agreement, and is likely to involve compulsory emission reduction targets for member states plus the possibility to use a specific amount of carbon credits from the LULUCF sector to comply with the ESR. The biocarbon accounting approach is aligned with the LULUCF monitoring requirements and as much as possible the same assumptions and methodologies have been used in the carbon account compared to the LULUCF reporting. In the future, synergies between the two reporting systems can be enhanced for example by exploring if the (more) detailed information on ecosystem type and use as developed for the production of the Ecosystem Extent account can be integrated into the LULUCF reporting system.

2) **Progress towards a circular economy regarding carbon.** In a fully circular economy, the total stock of geocarbon should remain constant through time as no more extractions are required. Hence, the combined flows of geocarbon to the economy (i.e. extraction) and the import of geocarbon (fossil fuels etc.) included in the Carbon in the economy account, should gradually decrease to zero. The trend in the net flows of geocarbon + import of geocarbon is therefore a useful indicator to indicate progress towards a circular economy regarding the use of carbon. An alternative indicator for progress towards a circular economy regarding carbon can be derived from the biocarbon account. The sum of biocarbon flows (in the biocarbon account as well as in imports and exports) should increase (whereas stocks may remain constant or increase), indicating that more renewable energy from biomass is being used. Simultaneously, carbon stocks in the atmosphere should decrease or remain constant. Note that other accounts part of the SEEA ecosystem accounts are also relevant in this regards, for example the stocks, sustainable and actual harvest rates of biomass are clarified in the Ecosystem services supply and use account (under development).

3) **Supporting specific policy actions in the field of climate change mitigation**. The ecosystem part of the carbon account is spatially explicit. Maps depict where carbon emissions take place and which areas are most important for carbon sequestration. This facilitates climate action by provincial and local stakeholders. For instance, provinces or water boards can identify which areas are most important for carbon emissions (e.g. drained peat areas with a low water table) and use the information to plan interventions in the landscape. This could provide an essential tool for actors in society (companies, NGOs, civil society groups, municipalities, provinces) that want to start climate change actions and that need a baseline to assess current emissions. It is also important in this context that the information in the carbon account is intended to be made available on-line to the general public, using an easy to use viewer. The reliability of the accounts will be tested in the next project phase (see also the section below on uncertainties). It may well be that the accounts are sufficiently reliable to also support climate actions by local stakeholders such as an estate owner or municipality. For example, the carbon account shows where emissions from organic soils are currently highest. Such areas could be targeted with priority with measures such as increasing ground water levels, or adapting land use practices. The carbon account can therefore also be used to support interventions by local stakeholders, and to monitor the effectiveness of their actions. Hence, the account would allow the government to transition from a climate change policy implemented at national scale to facilitate actions by local stakeholders by allowing them to plan and monitor their interventions. In addition, the carbon account allows analysing the national level impacts of the local interventions over time (which requires updating the carbon account around once every two year).

4) **Supporting natural capital accounting.** Natural capital accounting is widely seen as an essential element in any strategy to move towards long-term sustainability and economic efficiency of natural resource use. The most comprehensive and well developed approach to natural capital accounting to date is the SEEA, which contains the Central Framework and ,

for dealing with renewable natural assets, the ecosystem accounting approach. The carbon account is integrated in the SEEA ecosystem accounting approach. The SEEA approach is also gaining traction in the EU where it is currently being tested. The carbon account is an integral and important element of the overall natural capital accounting approach of the SEEA, and allow a better monitoring and planning of natural capital use. This includes information required for a transition to circular economy, which requires closing the flows of matter and energy within the economy. Since the carbon account integrates biocarbon and carbon in the economy it provides a very detailed picture of progress towards closing the carbon cycle.

5) **Showing the total carbon stock per Carbon reservoir: potential future flows that depend upon policy choices.** The total carbon stock per reservoir (i.e. in biocarbon, geocarbon, carbon in the economy) shows how much carbon has accumulated in that reservoir, and how much could be released again to the environment in the future due to, for example, economic or policy driven changes. The total geocarbon stock for example indicates how much carbon may eventually be released into the atmosphere if gas or oil extraction is not ceased, or how much carbon would potentially be released if coal mining would be re-started.

6.3 Uncertainties and future improvement possibilities.

This is the first comprehensive carbon account developed according to the UN SEEA ecosystem accounting framework world-wide. It is based upon the exceptionally detailed datasets available in the Netherlands on carbon stocks and flows, in the economy and in landscapes. Yet, there is of course uncertainty related to the account. This uncertainty limits the degree to which the results can be regionalised, i.e. the degree to which the maps and figures can be used at the provincial scale or below. A full uncertainty analysis in which the reliability of all accounts will be examined and evaluated is planned for phase 3 of the project. Tentatively, the following assessment of the uncertainty can be provided.

Carbon in ecosystems. The basis for the analyses, as in the other ecosystem accounts, is the Ecosystem Unit map and the resulting Ecosystem extent account. We deem this account to be highly reliable since it is based on detailed information extracted from among others the cadastre. Regarding above ground carbon stocks we also deem our estimate reliable at national and provincial scale. We take into account that carbon stock is higher in coniferous forests than in deciduous forests and allocated a higher stock to coniferous forests. We used data from the National Inventory Report for greenhouse gas emissions in the Netherlands and combined the survey results with our detailed Ecosystem extent account. On below ground stocks of carbon, we used several models, and our results are less reliable. For instance, in grasslands we assumed one rate of carbon uptake per year, even though in reality this is also influenced by the use of fertilizers and the soil type, among others. On CO_2 emissions from peat, our account can be seen as fairly accurate. We used the same models and data as recent studies by PBL (van den Born, 2016) and our estimates are strongly aligned with those of PBL. We used some additional data in areas where no information was available on drainage of organic soils we used ground water levels. However, in reality the field level emissions of carbon from peat are not only driven by the groundwater table (even though this is the most important factor). Other factors such as farm management and fertilization also play a role. Hence, our data are not sufficiently accurate to pinpoint the exact CO_2 emissions at the level of an individual field. Instead, we believe that our account shows typical, indicative values of carbon flows and stocks under average farm and forest condition and management regimes. As stated above, the reliability of our results will be assessed further in the third phase of the project.

Carbon in the economy. Most of the data for the carbon in the economy account is directly based on existing statistics. These in turn are based on register data or survey data. As with all statistics, there are uncertainties involved with regard to these data sources. The overall quality of these statistics, which are also reported to Eurostat, is good (quality assessments can be found on the website of statistics Netherlands). An additional source for uncertainty is the carbon content factors. For some products and materials these may vary significantly. However, using average carbon factors will provide good estimates for the overall carbon flows.

Future improvements. The next carbon account could be enhanced significantly compared to the previous version. In the biocarbon account, the main enhancement possible is that more detailed, spatially explicit information on forests, crops and grasses could be added. New maps, based on remote sensing information, are being developed that can contribute to such improvements (e.g. vegetation and Net Primary Productivity maps in the Atlas of Natural Capital). This will increase the accuracy of both the final figures and in particular also the maps. Vice versa, maps and information developed for the carbon account can be incorporated in public locations such as the Atlas of Natural Capital, to support multilevel decision making. In the account on carbon flows in the economy carbon stocks (urban mine) could be calculated to show how much carbon is accumulated in the economy and also hove much is stored by gross fixed capital formation every year. In addition, the different carbon assets in the economy could be shown on a more detailed level and also by industry. Further discussion is needed on how to account for carbon in the atmosphere and national responsibility for (accumulated) atmospheric carbon stocks Finally, by providing carbon accounts for different years the changes in stocks and flows can analysed in detail for the different policy areas described in the previous section.

7. Conclusions and recommendations

The carbon account and underlying accounts for the different reservoirs presented in this study provide detailed insight in the carbon stocks and changes in these stocks for a wide range of different materials and reservoirs containing carbon. Importantly, the account integrates carbon in the economy and carbon in ecosystems in one comprehensive account. More detailed reporting on carbon stocks and flows is likely necessary, as a result of UNFCCC LULUCF requirements and EU regulations in the coming years (in particular in the context of the ESR). Because emissions of carbon to the atmosphere and their contribution to climate change are high on the policy agenda, understanding and monitoring the size and characteristics of the major carbon stocks (because these can potentially turn into flows and finally emissions), and to understand the dependencies of the economy on the flows to and from these reservoirs, is of high importance. A range of policy relevant indicators can be derived from these accounts, providing information on topics such as the circular economy, recycling rates and the total amount of biomass present in the Netherlands.

The carbon account as presented here provides a comprehensive overview of currently available and newly developed data. Currently, data were only provided for one year, 2013. However, changes over time as recorded in these accounts and in the derived indicators will provide a wealth of information that is of direct policy relevance. The carbon account as proposed in this report may serve as an ideal format to improve current reporting on carbon. It is consistent with obligatory reporting of SEEA CF related accounts to Eurostat (Material flow accounts, Air emissions account). Moreover, because the structure, concepts and classifications of the carbon accounts are consistent with the system of National accounts (SNA) the data can be directly compared with all kinds of macroeconomic indicators. Compared to the current LULUCF reporting the accounts are spatially explicit which provides important additional information for policy applications, in particular if the accuracy at provincial or perhaps even municipal level is confirmed in phase 3 of the Dutch Ecosystem Accounting project. In this third phase, a further in-depth comparison with other existing carbon monitoring efforts could also be implemented, to assess synergies and possible duplication of efforts.

Although within the SEEA EEA the carbon account is a stand-alone thematic account, we found that it is well embedded in the other ecosystem accounts. It is directly linked to the physical supply and use tables for ecosystem services (i.e. harvesting of wood, carbon sequestration) and provides direct input for the condition account. So also for the further development of the other ecosystem accounts, it may be worthwhile to (first) compile a carbon account.

The accounts clearly illustrate the heavy dependency on fossil fuels in the Netherlands, and the difficulties of replacing fossil fuels with renewable energy sources from national biomass sources. Emissions to the atmosphere by far exceed carbon sequestration rates, resulting in a net positive balance for carbon in the atmosphere. The Dutch ecosystems at present are a source rather than a sink for carbon. Although carbon sequestration is important in forests, meadows and natural grasslands, the total annual sequestration of carbon in biomass is currently exceeded by the emissions from peat and peaty soils. Similarly, the carbon in the economy account shows that although some materials have recycling rates exceeding 90 %, recycling rates of e.g. wood waste still need substantial improvements.

Tracking the changes in carbon stocks and flows over time will allow for an assessment of the effectiveness of policy measures related to e.g. recycling, land use, water level management and the use of renewable and non-renewable energy sources. For biocarbon, the spatial detail provided in the models presented here allows for an assessment of the most efficient local carbon policy measures. In addition, the carbon account also bridges different policy themes, namely climate policies and the circular economy.

However, improvements to the models and data are still required, as can be seen from all yellow marked cells in the different carbon accounts: these cells still require (better quality) data and more research. Furthermore, the development of time series is essential to fully show potential of the carbon account. Nevertheless, the current report shows the wealth of data on carbon in a directly comparable manner, so that different types of stocks and flows can be compared quantitatively as long as the data uncertainties are taken into account.

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Annex 1 : Complementary data, Greenhouse gas emissions by the agricultural sector

Table A1.1 shows CH_4 emissions from agricultural areas. This map was based on an overlay from the emissions (based on postal code areas (Bridges version 2006)) and the EU_NL map (selection of agricultural classes: annual crops, perennial crops and pastures). Emissions are calculated with MITERRA-NL based on data of 2014 and land use in 2012 (Figure A1.1 and A1.2), following the same approach as was used for the national emission inventory rapport. The total CH_4 emission by agriculture in the Netherlands is 10 Mton CO_2eq per year. Noord Brabant, Gelderland, Overijssel and Friesland have the largest contribution to the total emission, with respectively 1.8, 1.6, 1.5 and 1.5 Mton CO_2 eq emission per year.

Table A1.1 CH_4 emission from agricultural land use (annual crops, perennial crops and meadows) in the Netherlands in ton C yr^{-1} (based on molecular weight), and in CO_2 equivalents (based on global warming potential, i.e. 1 ton CH_4 = 25 ton CO_2eq (GWP)).

	Total CH_4 emission (1000 ton C yr^{-1}(MW))	**Mean CH_4 emission (ton C ha^{-1} yr^{-1} (MW))**	**Total CH_4 emission (1000 ton CO_2 eq (GWP) yr^{-1})**
Groningen	17.0	0.11	565.4
Friesland	44.1	0.20	1,470.2
Drenthe	18.6	0.12	619.0
Overijssel	46.4	0.24	1,545.9
Flevoland	6.0	0.07	198.6
Gelderland	47.7	0.22	1,589.4
Utrecht	14.9	0.24	497.5
Noord Holland	13.5	0.12	450.5
Zuid Holland	16.4	0.14	546.4
Zeeland	4.6	0.04	153.9
Noord Brabant	54.7	0.24	1,822.6
Limburg	17.6	0.20	587.7
Netherlands	301.4	0.17	10,047.0

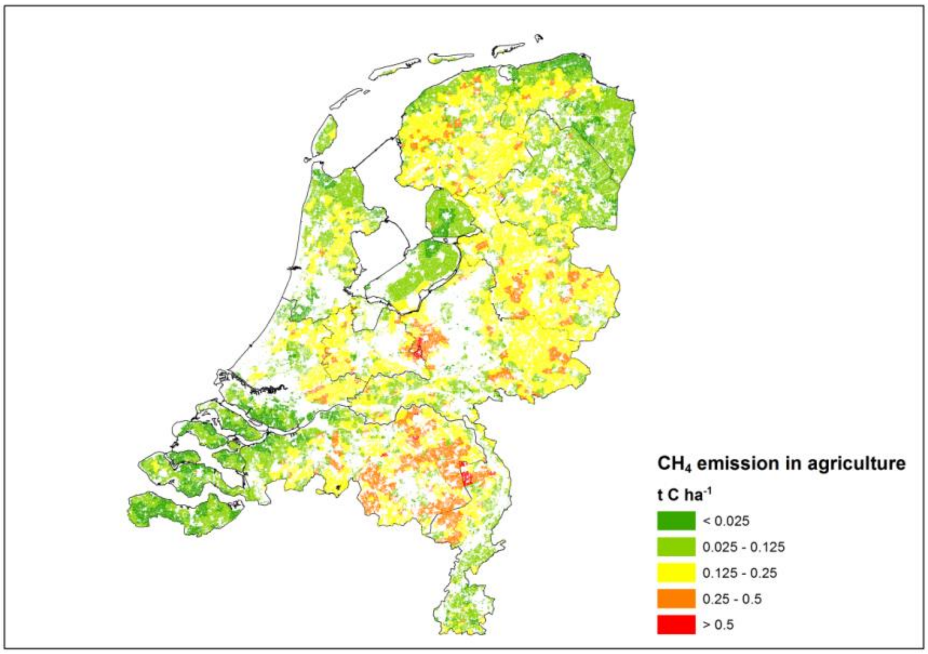

Figure A1.1 CH_4 emission from agriculture. Overlay with emissions calculated with MITERRA-NL and the EU_NL map.

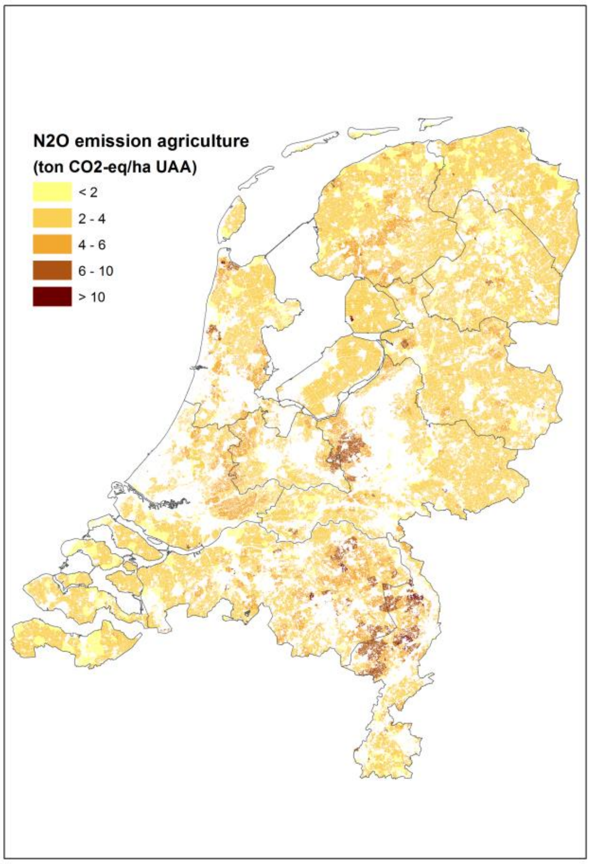

Figure A1.2 N_2O emission from agriculture, excluding agriculture on peat soils. Overlay with emissions calculated with MITERRA-NL and the EU_NL map. Because N_2O does not contain carbon it was not included in the carbon account.

Annex 2: Data supporting the methodology for the calculations of Biocarbon

Table A2.1 Look-up table for carbon sequestration in above and below ground biomass in the Netherlands

Ecosystem unit	Carbon sequestration (ton C/ha/yr)	Reference
Non-perennial plants	0	Kuikman et al. (2003)
Perennial plants	0.38	0.2*forest, Schulp et al. (2008)
Greenhouses	0	Schulp et al. (2008)
Meadow	0.18	Janssens et al. (2005)
Buffer strips	0.17	Janssens et al. (2005)
Farmyards and barns	0	Schulp et al. (2008)
Dunes with permanent vegetation	1.89	Mostly forest, therefore same value as for forest[1]
Active coastal dunes	0	Schulp et al. (2008)
Beaches	0	Schulp et al. (2008)
Deciduous forest	1.89	Coenen et al. (2016)
Coniferous forest	1.89	Coenen et al. (2016)
Mixed forest	1.89	Coenen et al. (2016)
Heath land	0.19	Janssens et al. (2005)
Inland dunes	0	Schulp et al. (2008)
Fresh water wetlands	0.22	Janssens et al. (2005)
Natural grassland	0.19	Janssens et al. (2005)
Public green space	0.27	0.05*forest + 0.95*other unpaved terrain
Other unpaved terrain	0.18	Janssens et al. (2005)
River flood basin	0.20	Janssens et al. (2005)
Tidal salt marshes	4.00	Callaway et al. (1996), Oenema and De Laune, 1988
Paved surfaces (urban area, infrastructure)	0	Schulp et al. (2008)
Sea	0	Coenen et al. (2012)
Lakes and ponds	0	Coenen et al. (2012)
Rivers and streams	0	Coenen et al. (2012)

[1] The outline of dunes with permanent vegetation was defined by the presence of shrubs and bushes.

Table A2.2 Look-up table for carbon stock in above ground biomass

Land cover category	Carbon stock (ton C/ha)	Ecosystem units	Reference
Coniferous forest	86	Coniferous forest	Arets et al. (2015)
Deciduous forest	81	Deciduous forest	Arets et al. (2015)
Mixed forest	84	Mixed forest and Dunes with permanent vegetation	Arets et al. (2015)
Cropland	0	Non-perennial plants	
Permanent cropland	17	Perennial plants	0.2*forest
Grasslands	2	All types of grassland, unpaved terrain and agricultural buffer strips	Range 1- 6, Kooistra et al. (2008)
Heath	8	Heath	Nabuurs et al. (2005)
Peatland	1	Fresh water wetlands	Range 1-2, Verhoeven et al. (1996)
Salt marshes	12	Tidal salt marshes	Kiehl et al., 2001
Sand	0	Dunes, beaches, inland dunes	
Built-up areas	0	Urban areas, buildings in rural areas, infrastructure, glasshouses	
Public green space	6	Public green space	0.05*mixed forest + 0.95*grassland
Water bodies	0	All water bodies	

Annex 3: An alternative set up by sector for Carbon in the economy

A disadvantage of the asset classification proposed in Chapter 5 is that there is no direct link to economic activities as described in the SNA. An alternative would be to classify the carbon in the economy according to the (institutional) sectors, similar as the setup of the asset accounts of the SNA (REF). Accordingly, the economic activities responsible for the carbon flows can be directly identified from the carbon account, which in turn can be linked to other information from the national and environmental accounts.

This alternative set up of the asset classification would also have consequences for the row entries. For reclassifications we would have to include flows from other sectors, namely input of materials (intermediate consumption, use of residuals) and output of materials (production, waste production). In this study we have compiled data using the first set up of the carbon in account for the economy. In principle, it would also be possible to compile data using the second set up, based on data from the physical supply and use tables which are available for the Netherlands (Statistics Netherlands, 2015; 2016).

Table A3.1 Alternative set up of the carbon account for the economy

	Carbon in the economy									
	Agriculture	Mining	Manufactering				Energy	Environmental services	Other services	TOTAL
			Food industry	Refineries	Chemical industry	other				
Opening stock										
Additions to stock										
Managed expansion										
Extraction from geocarbon										
Extraction from biocarbon										
Capture from the atmosphere										
Reclassifications										
Intermediate consumption										
Use of residuals										
Reductions in stock										
Managed contraction										
Emissions to the atmosphere										
Respiration of humans and livestock										
Emissions to water										
Emissions to soil										
Reclassifications										
Production										
Output of waste										
Net carbon balance										
Closing stock										

Annex 4: Carbon emissions by industries and households

Carbon emissions to the atmosphere are available on a more disaggregated level by industries and households. Table A4.1 below is obtained from the Dutch air emission accounts.

Table A4.1: Dutch carbon emissions for industries and households, obtained from the Dutch air emission accounts.

	CO2	CH4	Greenhouse gas equivalents	CO
	mln kg	mln kg	x mln	mln kg
Total Dutch economy	201488	767,1	230984	668,3
A-U All economic activities	160526	608,8	185373	282,5
A Agriculture, forestry and fishing	10732	540,5	30258	10,4
B-E Industry (no construction), energy	104625	85,1	109438	139,1
B Mining and quarrying	2459	28,7	3186	0,3
C Manufacturing	42696	19,8	45485	125,2
10-12 Manufacture of food and beverages	3703	0,6	4404	10,5
13-15 Man. of textile-, leatherproducts	193	0	194	0,5
16-18 Man. wood en paperprod., printing	1230	0,2	1238	2,9
16 Manufacture of wood products	157	0	159	0,3
17 Manufacture of paper	982	0,1	987	2,1
18 Printing and reproduction	91	0	92	0,4
19 Manufacture of coke and petroleum	10316	0,9	10346	6,6
20-21 Chemistry and pharmaceuticals	16891	17,3	18781	13
20 Manufacture of chemicals	16679	17,3	18567	12,9
21 Manufacture of pharmaceuticals	212	0	214	0,1
22-23 Man. plastics and constructionprod	1876	0,3	1885	6,2
22 Manufacture rubber, plastic products	260	0	261	1,3
23 Manufacture of building materials	1616	0,3	1624	4,9
24-25 Man. of basic metals and -products	7114	0,2	7134	72,4
24 Manufacture of basic metals	6640	0,1	6656	67,9
25 Manufacture of metal products	474	0,1	478	4,5
26-27 Elektrical and electron. Industry	233	0	350	0,6
26 Manufacture of electronic products	28	0	144	0,2
27 Manufacture of electric equipment	205	0	206	0,4
28 Manufacture of machinery n.e.c.	275	0,1	278	1,9
29-30 Transport equipment	180	0	182	2,5
31-33 Other manufacturing and repair	685	0,1	693	8,1
D Electricity and gas supply	47294	3	47498	8,7
E Water supply and waste management	9716	5	10084	4,6
F Construction	3133	0,1	3265	14,1

Table A4.1: continued

	CO2	CH4	Greenhouse gas equivalents	CO
	mln kg	mln kg	x mln	mln kg
G-I Trade, transport, hotels, catering	34274	2,3	34993	74,2
G Wholesale and retail trade	4474	0,9	4660	13,5
H Transportation and storage	28667	1	29051	57,3
49 Land transport	5764	0,4	5938	13,9
50 Water transport	8643	0,2	8712	26,2
51 Air transport	13138	0,1	13267	14,5
52 Warehousing, services for transport	967	0,1	977	2,2
53 Postal and courier activities	154	0	156	0,5
I Accommodation and food serving	1133	0,5	1282	3,4
J Information and communication	288	0,1	291	1,1
K Financial institutions	437	0,1	442	0,9
L Renting, buying, selling real estate	360	0,1	364	0,6
M-N Business services	3506	0,4	3537	31,8
M Other specialised business services	851	0,2	860	4,2
N Renting and other business support	2654	0,3	2678	27,6
O-Q Government and care	4403	8,2	4730	8,7
O Public administration and services	1721	7,1	1927	5
P Education	805	0,3	814	1,4
Q Health and social work activities	1878	0,8	1989	2,3
R-U Culture, recreation, other services	1228	0,4	1242	1,9
R Culture, sports and recreation	665	0,2	672	0,9
S Other service activities	563	0,2	570	1
T Activities of households	0	0	0	0
U Extraterritorial organisations	0	0	0	0
Landfill sites (waste dumps)	583	135,5	3969	0,7
Total private households	40380	22,8	41522	385,1
Transport activity by private households	17706	2,2	17868	306,7
Other private households	22673	20,6	23654	78,4