Technical report

Natural Capital Accounting in the Netherlands - Technical report 2022

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1. Introduction

1.1 Objective of this report

Natural capital accounting (SEEA 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 – Ecosystem Accounting (SEEA EA) has been developed to guide the implementation of ecosystem accounting (UN, 2021). Statistics Netherlands and Wageningen University have been working since 2015 to develop and implement natural capital accounting for the Netherlands following the conceptual guidance of the SEEA EA.

This report provides detailed information on the data sources used, methodologies and models applied to compile the Dutch Natural Capital Accounts. In addition, technical notes on the interpretation and quality of the outcomes are provided. This technical report is a background document for publications related to the terrestrial part of ecosystem accounting (in Dutch Natuurlijk Kapitaalrekeningen) on the website of CBS: Natural Capital (cbs.nl). This report provides an overview of updates and improvements of research on natural capital accounting according to SEEA EA (System of Environmental Economic Accounting Ecosystem Accounting) by Statistics Netherlands (CBS) and Wageningen University and Research (WUR).

Numerous data sources are used in the development of the Dutch Natural Capital Accounts. These data sources are either internally available for Statistics Netherlands and WUR, or are gathered from external sources. Data sources can be used with either small alterations or more far-reaching processing of data is necessary for the data to fit in the models and reach the desired results. Steps taken in the use and processing of data sources are described in detail in this report. The structure of the developed models are discussed intensively throughout the report. Not only methodologies that have been used to create the desired output are described. This ensures a clear overview of the choices made throughout the development of the natural capital Accounts. In summary, this report provides the reader the necessary background information for understanding how the Dutch Natural Capital Accounts were compiled.

1.2 Introduction to SEEA ecosystem accounting

The System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) is a spatially-based, integrated statistical framework for organizing biophysical information about ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity (UN, 2021). It was developed to respond to a range of policy demands and challenges with a focus on making visible the contributions of nature to the economy and people.

The 52nd United Nations Statistical Commission, on March 2021, has adopted SEEA EA. Chapters 1-7 on physical accounting were adapted as a statistical standard, while chapter 8-11 on monetary accounting were recognised as providing the statistical principles and recommendations for the valuation of ecosystem services and assets in a context that is coherent with the concepts of System of National Accounts The new statistical framework will enable countries to measure their natural capital and understand the immense contributions of nature to our prosperity and the importance of protecting it.

The SEEA EA complements the measurement of the relationship between the environment and the economy described in the System of Environmental-Economic Accounting 2012—Central Framework (SEEA Central Framework) (UN et al., 2014a). The SEEA, encompassing the SEEA Central Framework and the SEEA EA, provides a system that complements the System of National Accounts (SNA) using accounting principles to integrate physical and monetary measures concerning the environment in a way that allows for comparison to the data from the national accounts.

SEEA EA applies the accounting principles of the System of National Accounts 2008 (2008 SNA) (UN et al., 2010). In the context of monetary valuation, the SEEA EA applies the SNA concept of exchange values. While estimates based on this value concept are useful in many contexts there are some limitations. For example, they do not include the value of the wider social benefits of ecosystems, including their non-use values, which some users may find useful.
More generally, monetary values will not fully reflect the importance of ecosystems for people and the economy. Assessing the importance of ecosystems will therefore require consideration of a wide range of information beyond data on the monetary value of ecosystems and their services. This will include data on the biophysical characteristics of ecosystems and data on the characteristics of the people, businesses and communities that are dependent on them.

The SEEA EA consists of a system of integrated *ecosystem accounts*. These constitute the heart of the ecosystem accounting system (see list below). The SEEA EA also supports ‘thematic accounting’, which organizes data around specific policy-relevant environmental themes, such as biodiversity, climate change, oceans and urban areas. The carbon account is part of the thematic accounts for climate change.

1. Ecosystem extent account – physical terms
2. Ecosystem condition account – physical terms
3. Ecosystem services flow account – physical terms
4. Ecosystem services flow account – monetary terms
5. Monetary ecosystem asset account – monetary terms

The Dutch Natural Capital accounts cover the five core accounts of the SEEA EA, plus the carbon stock account. They are compiled following, as much as possible, the conceptual guidelines provided by the revised SEEA EA. However, some parts of the Dutch accounts still need to be updated to make them fully consistent with the revised guidelines.

1.3 How to read this report

This report is constantly updated. Although not all SEEA EA accounts are regularly updated for the Netherlands, the methods and data sources of the most recent update can be found in the chapters below. The exception is the Biodiversity account, which has, until now, its own publication.

The following six chapters describe the technical background for compiling the Dutch natural capital accounts. Chapter 2 covers the extent account. Chapter 3 describes the condition account, with different elements such as vegetation and water quality. Chapter 4 addresses physical and monetary ecosystem services, separated in different types of ecosystem services: provisioning (e.g. crops), regulating and intermediary (e.g. pollination) and cultural (e.g. nature tourism). Also, the compilation of the supply and use of ecosystem services is covered. Chapter 5 covers the asset account. Chapter 6 describes the thematic account of carbon. The references are split into references to literature and data sources. Any questions or comments related to this report can be addressed to milieurekeningen@cbs.nl.

2. Extent account

2.1 Introduction

The Extent Account forms the foundation of ecosystem accounting, because it defines the individual ecosystem assets that make up the accounting area. These ecosystem assets are contiguous spaces of a specific ecosystem type characterized by a distinct set of biotic and abiotic components and their interactions. Examples are an individual forest stand, an agricultural parcel, a lake or a public park. Ecosystem assets are thus the spatial units that represent a specified ecosystem type and generate a basket op specified ecosystem services.

Ecosystem extent accounts organize data on the extent or area of different ecosystem types. Data from extent accounts can support the derivation of indicators of composition and change in ecosystem types and thus provide a common basis for discussion among stakeholders including related to conversions between different ecosystem types within a country. Compilation of these accounts is also relevant in determining the appropriate set of ecosystem types that will underpin the structure of other accounts.

The ecosystem extent account in its strict sense is a table registering the total area (“extent”) of each ecosystem type at the opening and closing dates of the account; and the various forms of changes, registered as additions or reductions in extent.

This table is constructed from an ecosystem asset map in which all assets are delineated and classified.

2.2 The ecosystem type classification for the Netherlands

Because existing maps of the Netherlands focus on the biophysical land cover (the topographic maps) or land use (the Statistics Netherlands land use maps) or only include specific regions (nature management or agriculture) a new map and legend were constructed with a focus on ecology and ecosystem services, and maximal compliance with the SEEA-EA guidelines and the IUCN global ecosystem typology (see below)

In the Netherlands, 49 different ecosystem types are being recognized (50, if we allow for a catch-all “Other” type). These are shown in table 2.2.1.

The ecosystem type classification is designed to meet the following goals:

- For the natural ecosystems, match as much as possible level 3 (“ecosystem functional groups”, EFGs) of the IUCN Global Ecosystem Typology (GET)[1]
- For the agricultural areas, aggregate formal crop types into groups that either link to GET EFGs and/or represent agricultural intensity, (taken as a proxy for a different mode of ecological functioning)
- For the urban and other built-up areas: group together land cover and land use classes to represent areas with a typical signature in ecology and ecosystem services.

[1] The IUCN GET (https://global-ecosystems.org/) is a global typological framework that applies an ecosystem process-based approach to ecosystem classification for all ecosystems around the world (Keith et al., 2020). The SEEA Ecosystem Type reference classification is equivalent to IUCN GET Levels 1-3, which differentiate the functional properties of ecosystems. The use of the IUCN GET as the reference classification of ecosystem types reflects the need for a globally applicable classification of ecosystem types covering all realms.

For reasons of clarity, accounting tables in this report are not presented for all 50 ecosystem , but instead make use of 13 aggregated “publication level” groups, which are subsequently divided into 3 main groups representing roughly “nature”, “agriculture” and “urban and other build-up areas”.

Table 2.2.1 Ecosystem type classification for the Netherlands

Main category	Publication level	Code	Ecosystem Type	(Dutch)
Natural	Forest	111	(Semi-)natural forest	Natuurbos
		112	Hedges and treelines	Houtsingel
		113	Plantation forest	Productiebos
		421	Other forest	Overig bos
	Open nature	114	Tall herbs	Ruigte
		115	Heathland	Heide
		116	Drift sand	Stuifzand
		117	Semi-natural grassland	Natuurgras
		118	Biodiverse cropland	Akkerland_nat
	Wetlands	121	Swamp forest	Moerasbos
		122	Bogs	Hoogveen
		123	Fens	Laagveen
	Water	131	Streams and rivers	Waterloop
		132	Lakes	Meer, plas
		133	Brackish	Brakwater
	Coastal	141	Coastal dunes	Kustduinen
		142	Salt marshes	Kwelder
		143	Beach	Strand
	Marine	144	Intertidal and mud flats	Intertidal
		145	Shoals	Zandplaat
		146	Estuarium	Estuarium
		147	North sea	Noordzee
		148	Wadden sea	Waddenzee
Agriculture	Cropland	211	Cropland, regular	Akkerbouw_reg
		212	Cropland, extensive	Akkerbouw_ext
		213	Perannuals, regular	Meerjarig_reg
		214	Perannuals, extensive	Meerjarig_ext
	Grassland	221	Pasture, permanent	Grasland_blv
		222	Pasture, temporal	Grasland_tijd
		223	Pasture, extensive	Grasland_ext
	Horticulture	231	Greenhouse horticulture	Glastuinbouw
		232	Nursery container fields	Pot_Container
	Other	241	Fallow land	Braakliggend
		242	Arable field margins	Faunarand
Urban and other (semi-) built-up	Urban & Infra	311	Built-up (urban)	Built-up (urban)
		312	Built-up (rural)	Built-up (rural)
		321	Business park	Bedrijfsterrein
		322	Mining, land fills, etc.	Grondgebonden
		331	Infrastructural	Infrastructuur
		411	Marine, other	Zee, overig
		351	Sport park	Sportterrein
		352	Residential recreation	Verblijfsrecreatie
	Public green space	341	Landscape garden	Landschapstuin
		342	Public park (large)	Park
		343	Public park (small)	Plantsoen
		344	Public green space, other	Groenvoorziening
		345	Semi-public green space	Semi-op. groen
	Other unpaved	422	Grassland, other	Overig grasland
		423	Other terrain	Overig terrein

These ecosystem types are defined as follows (see section 2.3 for the data sources mentioned)

Natural

Forest

- **(Semi-) natural forests.** These include natural land anthropogenic forest. The defining feature is that “nature” is the main management goal, as recorded in the provincial nature management plans (PNMP) and the associated nature management types (MT).
    - PNMP natural and semi/natural forests (MT N14.01/03; N15.*; N17.*; L01.02/03/07/08/11/16)
    - Top10NL forested map units within PNMP coastal dune rewilding areas (MT N01.02)
    - Idem within PNMP sandy rewilding areas (MT N01.04)
- **Hedges and treelines.** Linear landscape features.
    - Top10NL 1D vector tree lines and hedges
    - TOP10NL forested polygons that have a length of >100m and width <10m (when approximated as rectangle), and are not part of a larger forested landscape patch.
- **Plantation forest.** Forest where timber production is an explicit policy goal.
    - PNMP plantation / production forest types (MT N16.*)
- **Other forest.** All forest assets that are not explicity labeled as nature or production or are associated with any other ecosystem type.
    - Top10NL forest map units that remain unclassified.

Open nature

- **Tall herbs.** Tall herb communities
    - MT N12.06
- **Heathland.** Shrublands dominated by *Calluna* and *Erica***.**
    - PNMP heathlands (MT N07.01)
    - Top10NL heathland within PNMP sandy rewilding areas (MT N01.04)
    - Top10NL heathland outside of any PNMP
- **Drift sand.** Drift sand areas.
    - PNMP drift sand areas (MT N07.02)
    - Top10NL sandy areas within PNMP sandy rewilding areas (MT N01.04)
    - Top10NL sandy areas outside any PNMP, but not classified otherwise (beach, etc.)
- **Semi-natural grassland.** Natural and managed grassland with “nature”as the main policy goal
    - “N”-type grassland from the PNMP (MT N10.01 /02; N11.01; N12.01/02/03/-04)
    - Top10NL grassland within PNMP sandy rewilding area (MT 01.04)
    - Dry Top10NL grassland within PNMP marshland rewilding areas (MT N01.03)
    - Top10NL grasslands within PNMP “A”-type agricultural nature management (MT A01.*; A02.*; A11.*; A12.*), but not classified as extensive pasture.
- **Biodiverse cropland.** Extensively managed croplands where management is aiming at biodiversity rather than agricultural use.
    - “N”-type cropland from the PNMP (MT 12.05)
    - Top10NL Cropland overlapping with PNMP “A”-type agricultural nature management (MT A01.*; A02.*; A11.*; A12.*), but not classified as extensive cropland

Wetlands

- **Swamp forest.** Wetland forests
    - PNMP swamp forest (MT N14.02)
    - Top10NL forest polygons within PNMP marshy rewilding areas (MT N01.03)

    - Top10NL forest outside of PNMP that has a Top10NL “marshland” attribute.
- **Bogs.** Mostly (remains of) ombrotrophic peat bogs.
    - PNMP peat bog types (MT N06.03 to N06.06)
    - PNMP marshland (MT N05.01) bordering above
- **Fens.** Mostly (remains of) minerotrophic fens.
    - PNMP mashland and fen types (MT N05.01/02; N06.01/02)
    - Top10NL grasslands with ”marshland”attributes within PNMP marsh rewilding areas (MT N01.03)

Fresh water

- **Streams and rivers.** Predominantly long and narrow flowing water bodies.
    - Top10NL streams and rivers
- **Lakes.** Wider water bodies with none or less flow
    - Top10NL ponds and lakes.
- **Brackish.** Specific lakes with brackish water
    - PNMP brackish water type (MT N04.03)

Coastal

- **Coastal dunes.** Aeolian landforms consisting of sandy deposits of marine origin, and the ecosystems associated with these landforms.
    - PNMP coastal dune types (MT N08.*)
    - Top10NL coastal dunes
    - Top10NL sandy map units connected to above, but not to any marine ecosystem type.
    - VEGWAD coastal dune types (Dd, Ddk, Dv, Dvk)
- **Salt marshes.** Permanently vegetated coastal ecosystems that are (in)frequently flooded.
    - VEGWAD salt marsh types (Kp, Kpb, Kl, Klb, Km, Kmb, Kh, Kb, Kn, Kv)
- **Beaches.** Sandy areas between land and sea
    - Top10NL sand map units spatially connected to both marine elements (intertidal) and terrestrial coastal elements (coastal dunes, artificial coastal levees, etc.)
- **Intertidal and mud flats**
    - Top10NL intertidal map units

Marine

- **Shoals.** Permanent dry sandbanks not connected to other terrestrial ecosystems.
    - Top10NL sandy map units connected to intertidal but not no terrestrial elements (i.e., not beaches)
- **Estuarium.** Specific semi-marine areas (*Westerschelde*; *Oosterschelde*; etc.)
    - Top10NL labeled marine sea map units.
- **North sea.**
    - Top10NL labeled marine sea map units
- **Wadden sea.**
    - Top10NL labeled marine sea map units

Agriculture

Croplands

- **Cropland, regular.** Agricultural parcels, with annual crops; not classified as *extensive*.
    - Top10NL cropland map units dominated by selected crop types according to the agricultural parcel registry.
- **Cropland, extensive.** As regular cropland, but with crops to which some form of nature management applies.

- Top10NL cropland map units dominated by selected crop types according to the agricultural parcel registry.

- **Perannuals, regular.** Commercial orchards, berries etc.
  - Top10NL cropland and/or orchard map units dominated by perannual crop types according to the agricultural parcel registry.
- **Perannuals, extensive.** Non-commercial orchards
  - Top10NL orchard map units that fall outside the agricultural parcel registry.

Grassland

- **Pasture, permanent.** Intensively used permanent grassland, i.e. in use for at least 5 consecutive years.
  - Top10 grassland map units dominated by permanent grassland according to the agricultural parcel registry
- **Pasture, temporal.** Intensively used grassland in use for less than 5 years.
  - Top10 grassland map units dominated by temporal grassland according to the agricultural parcel registry
- **Pasture, extensive.** Agricultural grassland under extensive management (less than 5 ton dm per ha/year)
  - Top10 grassland map units dominated by specified grassland types according to the agricultural parcel registry

Horticulture

- **Greenhouse horticulture.** Greenhouse complexes (greenhouses; infrastructure; terrain; water reservoirs)
  - Top10NL terrain parcels with a dominant cover of greenhouses.
  - Top10NL ponds within these parcels.
- **Nursery container fields.** Pot and container based plant and tree nurseries.
  - Top10NL map units dominated by selected crop types according to the agricultural parcel registry.

Other agricultural

- **Fallow land.** Land that is officially fallow.
  - Top10NL map units dominated by selected “fallow” crop types according to the agricultural parcel registry.
- **Arable field margins.** Field margins covered with herbs, providing a habitat for fauna.
  - Top10NL map units dominated by selected “field margin” crop types according to the agricultural parcel registry.

Urban and other (semi-) built up

Urban and infrastructure

- **Built-up (urban).** Built up areas within city, town and village boundaries.
  - Top10NL terrain units within built-up area perimeter
  - Top10NL streets and smaller roads along above areas.
- **Built-up (rural).** Similar, but outside of cities, towns and village boundaries
- **Business park.**
  - Top10NL specified “functional”polygons
- **Mining, landfills, etc.** Economic activities that depend on, or define soil resources.
  - Top10NL specified “functional”polygons
- **Infrastructural.** Larger roads; sluice complexes; airports etc.
  - All Top10NL infrastructure units not classified as otherwise.
- **Marine, other.** Mostly harbours
  - Top10NL sea water map units without label.

- **Sport parks.** Including soccer fields; golf courses; open-air swimming pools; race tracks; etc.
    - Top10NL specified “functional” polygons
- **Residential recreation.** Including camping sites; holiday resorts etc.
    - Top10NL specified “functional” polygons

Public green space

- **Landscape garden.** Grass and forest within historical gardens
    - Top10NL grass and forest map units, not classified elsewhere, within PNMP historical gardens (L02.*)
- **Public park (large).** Larger public parks (labeled as such; contains foot paths)
    - Top10NL grass and forest patches that are public green space according to the BGT registry. One of these must be covered by a Top10NL “park” label.
    - Top10NL footpaths etc along these patches.
    - Top10NL water within the park area
- **Public park (small).** Similar; but without a “park” label. Must have at least one junction of footpaths within the area.
- **Public green space, other.** Individual public green space patches; too small to be classified as “park” (ie. no junction of foot paths)
    - Top10NL grass and forest patches that are public green space according to the BGT registry.
- **Semi-public green space.** These include zoos, botanical gardens, cemeteries, open air museums, etc.
    - Top10NL specified “functional” polygons

Other unpaved terrain

- **Grassland, other.** Grassland that is not associated with any other ecosystem type. Usually these are part of the rural landscape and include gardens, informal pastures for hobby horses etc.
    - Top10 grassland map units that remain unclassified
- **Other terrain.** Any other terrain that is not associated with any other ecosystem type.
    - Top10 other terrain units that remain unclassified.

2.3 Ecosystem type map

2.3.1 Data sources

- Topographic maps (1:10,000) (TOP10NL; BRT[2]). These are mainly used for information on land cover and delineation of map units outside of natural areas. These vector maps are produced by the The Netherlands’ Cadastre, Land Registry and Mapping Agency, and updates are published 4 times a year. We have used the last update for every accounting year

- Nature management types[3]. These are used to delineate and classify natural areas. Vector maps are published[4] annually by the individual provinces, who are responsible for nature management.

[2] https://www.pdok.nl/introductie/-/article/basisregistratie-topografie-brt-topnl
[3] https://www.bij12.nl/onderwerpen/natuur-en-landschap/index-natuur-en-landschap/
[4] https://www.bij12.nl/onderwerpen/natuur-en-landschap/subsidiestelsel-natuur-en-landschap/het-natuurbeheerplan/

- Agricultural parcel registration (BRP[5]). These are mainly used for information which crops are grown on agricultural BRT map units. These maps are published annually by the Netherlands Enterprise Agency.
- Salt marsh ecotopes. These provide specific information on salt marsh vegetation. These so called VEGWAD maps are published by the Ministry of Infrastructure and Water Management with 6 year intervals using a rolling scheme

2.3.2 Scope of the map

The scope of the map is formed by the formal administrative borders of the 12 provinces. This includes all land areas, all inland waters, and a (variable width) strip of the North Sea.

2.3.3 Construction

Ecosystem types maps for 2013, 2015 and 2018 were constructed using a fully automated process implemented in ArcGIS, as arcpy scripts. The end result of this process is a vector map, where each map units is an ecosystem asset, each characterized by the following attributes

- Ecotype – the ecosystem type (as in table 2.2., in Dutch)
- Ecocode – 3-digit numerical code for each ecosystem type
- Subtype – Sub type. Used to specify the nature management type (Nature); dominant crop type (Agriculture) or land cover (urban, built up, and other). This information could be used to increase the number of ecosystem types, if required, or to be used as condition variables, to allow more detailed analyses

Along with the original vector maps, raster maps are constructed with multiple resolutions (2.5m; 10m; 25m; 100m).

2.4 Ecosystem extent account and change matrix

The ecosystem extent account tables are constructed from the highest resolution (2.5m) rasterized ecosystem types map. Although the original vector maps have still a higher accuracy, measuring change between two vector maps is not straightforward, and therefore the raster maps were used to reliable track changes in ecosystem type through time.

This results in tables on

- Total area of each ecosystem type in all years (2013; 2015; 2018), e.g. total area of heathland in 2018
- Total area of changes from ET x to ET y from one year to another; e.g., total area of heathland in 2015 that became semi-natural forest in 2018.

The ecosystem type change matrix shows the area of different ecosystem types at the beginning of the accounting period (opening extent); the increases and decreases in this area according to the ecosystem type it was converted from (in the case of increases) or the ecosystem type it was converted to (in the case of decreases) and, finally, the area covered by different ecosystem types at the end of the accounting period (closing extent). It is compiled by directly comparing the maps of two accounting periods and observing what changes have taken place.

[5] https://www.pdok.nl/introductie/-/article/basisregistratie-gewaspercelen-brp-

2.5 Time series consistent corrections

A few corrections in the extent account and change matrix are necessary because the above methodology, unfortunately, provides not always consistent time series. Most specifically, corrections are made in the ecosystem types business parks (321), mining/ landfills (322) and residential recreation (352). The approach taken for business parks and mining/landfills is the assumption that between 2015 and 2018 none of these ecosystem types have increased. This because military terrains were in 2018 categorized in the source data as business parks while in 2015 they were classified as the underlying land cover (e.g. forest, buildings, roads). For residential recreation the reason for a correction is slightly different: this was introduces as a new ecosystem type from 2018 onward because data before 2018 was missing. However, to be consistent, the artificial increase in residential recreation in 2018 has been corrected in order to develop a consistent time series.

Because of these corrections data retrieved directly from the ecosystem types maps slightly differ from the data published in the publications and tables. The above mentioned ecosystem types have the largest corrections. However, because of the balanced system, these corrections have a slight impact on all ecosystem types.

3. Condition account

3.1 Introduction

The ecosystem condition account is one of the core accounts of the System of Environmental Economic Accounting Ecosystem Accounts (SEEA-EA). Ecosystem condition is the quality of an ecosystem measured in terms of biotic and abiotic characteristics. These condition indicators reflect the state or functioning of the ecosystem in relation to both its ecological condition and its capacity to supply ecosystem services. The condition indicators can be divided into state indicators and pressure indicators. State indicators capture the state of ecosystems and relate to vegetation, biodiversity, soil, water and air. Pressure indicators reflect external pressures exerted on ecosystems, such as for example eutrophication or urbanization. The key methods and assumptions for obtaining each condition indicator are described below.

The condition account can be complemented by a thematic biodiversity Account. For the current reporting period we chose not to compile a biodiversity account separately, but to include a selection of the biodiversity indicators in the condition account. The full biodiversity account can be found on SEEA EEA Biodiversity Account (cbs.nl).

3.2 State indicators

3.2.1 Vegetation cover

Above ground vegetation facilitates several ecosystem services such as carbon sequestration, air filtration and water infiltration. Vegetation also has a positive effect on human health. People that live in a green environment do not only feel healthier, they are healthier. A study in the Netherlands shows that the annual prevalence rate of several diseases was lower in living environments with more green space in a 1 km radius. The relation was strongest for anxiety disorder and depression (Maas et al., 2009).

High resolution maps are available for cover with trees, shrubs and low vegetation (data: Atlas Natuurlijk Kapitaal (ANK), 2017; 2020). These maps provide additional information to land cover maps, as these maps also show tree and shrub cover within individual ecosystem type units like urban land uses. The vegetation cover maps are based on the AHN (Actueel Hoogtebestand Nederland) at a resolution of 0.5 meter and Infrared Aerial Photographs (CIR file,) in infra-red at a resolution of 0.25 meter. Vegetation with a minimum height of 2.5 meter is classified as trees, vegetation with heights between 1 meter and 2.5 meter are classified as shrubs, and vegetation lower than 1 meter is classified as low vegetation.

3.2.2 Density of hedges

Linear landscape elements such as hedges and rows of trees are not always reflected in the extent account due to their limited surface area. However this does not mean that they should be ignored, in fact they are often a meaningful part of the landscape and ecosystems. The indicator ‘density of hedges’ captures these linear features and makes them explicit on the map and as an ecosystem condition attribute. During the creation of the extent map an analysis was carried out to classify elongated plots of forest with a length greater than 100m and a width smaller than 10m as the separate ecosystem type ‘hedges and treelines’. Besides this ‘hedges and treelines’ ecosystem type taken from the extent map, two linear features from the topographic map (Top10NL) were used, namely hedges (visualization code 15180) and tree rows (visualization code 15020). In contrast to the ecosystem type 'hedges and treelines' the two linear features from the topographic map are not represented in the extent account because they are too narrow and therefore recorded as one-dimensional. See the table below for an overview of these three types of linear features and their total length for the year 2018. These three data sources were combined and density was calculated using the length of all the features and a centroid approach to aggregate the results to a grid with cell size 500m. Separately, to associate the linear features with nearby ecosystems a maximum distance of 10m was used, one row of trees may thus be linked to more than one ecosystem.

Table 3.2.1 Three types of linear features used for the calculation of density of hedges for the year 2018

Source	Number of features	Total length (m)
Top10NL tree rows	262574	61172643
Top10NL hedges	63340	12370725
Ecosystem type 'hedges and treelines'	64949	13965436

3.2.3 Managed area

Managed areas are defined as the areas in the Netherlands with managed nature aiming at for example the restoration of biodiversity. Managed areas are therefore an indicator in the condition account measured as a percentage of the total area of the Netherlands.

In the Netherlands, several data sources are available for this indicator. The most comprehensive one is Natuur Netwerk Nederland (NNN). Data on NNN is taken from VRN "Voortgangsrapportage Natuur" (LNV, IPO and Bij12, 2019). Within NNN, provinces and the national government work together to increase the amount of nature areas and to improve its condition. NNN includes, but is not limited to, Natura2000 areas.

3.2.4 Living Planet Index

The Living Planet Index (LPI) is widely used in the international context to describe changes in biodiversity over time (WWF, 2020; CLO-1569). The rationale of the LPI is that the more species show negative population trends and the stronger the overall decrease is, the worse the state of nature is (and vice versa). The Living Planet Index of the Netherlands, published on Environmental Data Compendium, reflects the average trend in population size of 357 species of mammals, breeding birds, reptiles, amphibians, butterflies, dragonflies and fresh water fish together (CLO-1569). The LPI can be broken down by ecosystem by measuring the trend in population size of species typically associated with certain habitats (WWF Nederland, 2015). The LPI is available for the Netherlands in total as well as for the following broad ecosystem types: forests (CLO-1162), heathland (CLO-1134), open dunes (CLO-1123), freshwater and wetlands (CLO-1577), agricultural area (CLO-1580) and urban area (CLO-1585). It should be noted that the division into ecosystems used for the calculation of the LPI is not the same as the division in ecosystem types reported in the condition Account. For example, the LPI reported for the category open nature consists only of the LPI calculated for heathland, as there is no LPI available for the other open nature ecosystem types. See the table below for an overview of the LPI that was used for each ecosystem type. The values reported in the condition account reflect the trend values and not the actual observations. The trend values were calculated using the Kalman filtering method.

Table 3.2.2 Overview of the LPI indicator that was used for each ecosystem type.

Ecosystem type (publication level)	LPI indicator
Forest	Forests (CLO-1162)
Open nature	Heathland (CLO-1134)
Wetlands	Freshwater and wetlands (CLO-1577)
Water	Freshwater and wetlands (CLO-1577)
Coastal	Open dunes (CLO-1123)
Cropland	Agricultural area (CLO-1580)
Grassland	
Horticulture	
Other agriculture	
Urban & Infra	Urban area (CLO-1585)
Public green space	
Total	Terrestrial and fresh water (CLO-1569)

3.2.5 Ecological quality

The indicator “ecological quality” uses the degree of occurrence of characteristic and target species as a proxy for the mean quality of an ecosystem. It relates the current species abundance data to that of a relatively intact ecosystem, i.e. an ecosystem that is not affected by eutrophication, desiccation, acidification, or fragmentation (CLO-2052). In the Netherlands this approach has been applied using monitoring data that was collected by the Network Ecological Monitoring (NEM) for 457 species in total, selected from four groups (breeding birds, butterflies, reptiles and vascular plants). Ecosystem-scale indices are expressed by means of the Mean Species Abundance (MSA), which is the average abundance for all species considered, each scaled to a value of 100 for the reference level, corresponding to the intact situation around 1950, and capped at that level to prevent that species that do very well under present anthropogenic conditions compensate for species that don’t (Reijnen et al., 2010). The ecological quality indicator is available for the ecosystems forest, heathland, wetlands, open dunes, and semi-natural grasslands, as well as a total for terrestrial and freshwater ecosystems (CLO-2052). See the table below for the connections between these ecosystem types and the ones published in the condition account. The values reported in the condition account reflect the trend values and not the actual observations. The trend values were calculated using the Kalman filtering method.

Table 3.2.3 Overview of the indicator that was used for each ecosystem type.

Ecosystem type (publication level)	Ecological Quality indicator, CLO-2052
Forest	Forest
Open nature	Heathland Semi-natural grassland
Coastal	Open dunes
Wetlands	Wetlands
Water	Fresh water
Total	Terrestrial ecosystems

3.2.6 Structure and function

Article 17 of the Habitats Directive requires EU member states to report the conservation status of habitat types and species every six years. For a habitat type to be considered to have a Favourable Conservation Status, the directive requires the natural range and areas it covers to be stable or increasing, structure and functions to be favourable and its “typical species” to be at Favourable Conservation Status (Röschel et al., 2020). Structures are considered to be the physical components of a habitat type. These will often be formed by assemblages of species (both living and dead), e.g. trees and shrubs in a woodland, corals in some forms of reef, but can also include abiotic features, such as gravel used for spawning. Functions are the ecological processes occurring at a number of temporal and spatial scales and they vary greatly between habitat types (DG Environment, 2017). The methods for determining the structure and function in the Netherlands vary per habitat type and are described in (Janssen et al., 2020) for the 2013-2018 reporting period and in (Bijlsma & Janssen, 2014) for the 2007-2012 reporting period. Since the methods for estimating structure and function changed between these periods, we only look at the most recent period and not the development over time. In the condition Account we use the structure and function in the strict sense, namely without the incorporation of typical species, since the ecological quality indicator already focusses on species abundance. For each habitat type the area is classified according to the status of its structure and function into good condition, not-good condition or unknown condition. The results per habitat type can be found on the European Commission website (Article 17 web tool). For the condition account the percentage of habitat area in good condition was aggregated to the level of ecosystem types represented in the natural capital accounts. It should be noted that the indicator only applies to the area that is covered by the habitat directive and not the whole country.

Table 3.2.4 Overview of the habitat types included in the structure and function indicator.

Ecosystem type (publication level)	Habitats Directive habitat type
Forest	H9110, H9120, H9160, H9190, H91F0, H2180
Open nature	H2310, H2320, H4030, H5130, H2330, H6120, H6130, H6210, H6230, H6410, H6510, H6430
Wetlands	H91D0, H91E0, H7140, H7210, H7230, H3110, H3130, H3160, H4010, H7110, H7120, H7150
Coastal	H2110, H2120, H2130, H2140, H2150, H2160, H2170, H2190, H1310, H1320, H1330
Water	H3260, H3270, H3140, H3150, H2110, H2120, H2130, H2140, H2150, H2160, H2170, H2190, H1310, H1320, H1330, H1140, H1130, H1110

3.2.7 Soil

Soil organic matter (SOM) is the organic matter content of soil and consists of plant residue, soil microbes, and dead plant and animal material at various stages of decomposition. It is an indicator for soil fertility and plant productivity and is very important for water infiltration and water retention. SOM also improves the soil structure and reduces soil loss by erosion. The exact lower threshold for the positive effects of SOM is not known, but it is assumed that a SOM content higher than 3% already has a positive effect on soil quality (Conijn and Lesschen, 2015). Therefore we use the percentage of area with more than 3% SOM as a condition indicator. We look at SOM content of the top 30cm of soil because this layer is more prone to disturbances and there is more knowledge and data available on this upper layer. The soil organic content map from Conijn and Lesschen, 2015 and the extent map were used to calculate the percentage of area with more than 3% SOM per ecosystem.

3.2.8 Water quality

The status of European surface water bodies and ground water bodies are assessed by the water Authorities following the methodology of the European Water Framework Directive (EU, 2000). In the Netherlands, the Water Quality Portal (waterkwaliteitsportaal.nl) collects, manages and discloses data for the Water Framework Directive (WFD). The two most important quality aspects are the ecological quality and the chemical quality. The chemical quality is determined based on 45 substances (of which 33 priority substances). The ecological quality is assessed based on four quality indicators that determine the biological quality combined with indicators for general physical-chemical quality and environmental quality. To aggregate the indicators the European legislature chose to adopt the one-out, all-out rule whereby overall classification is defined by the lowest observed individual quality element.

The indicator biological quality is determined based on four metrics, one for phytoplankton, one for macro fauna, one for water plants and one for fish. In the Netherlands most water bodies are artificial or strongly altered. It was possible to set a lower goal for those water bodies, i.e. a Good Ecological Potential (GEP). This is mostly done for the metrics macro fauna and fish, but less often for the metrics phytoplankton and water plants.

The indicator for ecological is determined based on four indicators, the above-mentioned indicator for biological quality, an indicator for physical-chemical quality, and indicator for other relevant polluting substances and a fourth indicator for hydro morphology that is required for a “very good” condition. This last indicator is not used yet in the Netherlands, therefore, the best possible condition for the ecological quality is “good”. The ecological quality is primarily determined by the biological quality. If the biological quality is “good”, then the indicators for physicochemical quality and other polluting substances are considered to distinguish between a “good” or “moderate” ecological condition. The physicochemical indicator is determined based on the assessment of the parameters nitrogen, phosphor, temperature, oxygen, acidity and chloride. The other polluting substances consist of a group of approximately 100 substances, that are specific for a certain catchment area. The thresholds for most of these substances are never exceeded, only a few substances sometimes exceed the threshold.

3.2.9 Air quality

Clean air is a basic requirement of human health and well-being (WHO, 2006). Air pollution continues to pose a significant threat to health and the environment. Air quality affects people, that live, work, commute, recreate or otherwise spend time outside. In Europe, emissions of many air pollutants have decreased substantially over the past decades. However, air pollutant concentrations are still too high. Therefore, air quality problems persist, especially in cities where exceedances of air quality standards for ozone, nitrogen dioxide and particulate matter (PM) pollution pose serious health risks (EEA, 2008). Long-term and peak exposures to these pollutants range in severity of impact, from impairing the respiratory system to premature death. For example, fine particulate matter (PM2.5) in air has been estimated to reduce life expectancy in the EU by more than eight months. European Union policy on air quality aims to develop and implement appropriate instruments to improve air quality with the goal to reduce the health impacts of air pollution in Europe (EU, 2008).

The EU Air Quality Directive (EU, 2008) has set limit values for air quality (Table 3.2.5). Under EU law a limit value is legally binding from the date it enters into force subject to any exceedances permitted by the legislation. To offer guidance in reducing health impacts of air pollution the World Health Organisation has provided air quality guidelines (WHO, 2006). In contrast to the limit values set by the EU, the WHO guidelines are not legally binding.

Table 3.2.5 Overview of EU and WHO air quality thresholds for $PM_{2.5}$, PM_{10} and NO_2

		EU Air Quality Directive		**WHO Guidelines**	
Pollutant	Averaging period	Objective and legal nature and concentration	Permitted exceedances each year	Concentration	Comments
$PM_{2.5}$	24 hours			25 µg/m^3	99th percentile (3 days/year)
$PM_{2.5}$	1 year	Limit value, 25 µg/m^3	n/a	10 µg/m^3	
$PM_{2.5}$	3 years	Limit average exposure*, 20 µg/m^3	n/a		
PM_{10}	24 hours	Limit value, 50 µg/m^3	35		99th percentile (3 days/year)
PM_{10}	1 year	Limit value, 40 µg/m^3	n/a	20 µg/m^3	
NO_2	24 hours	Limit value, 200 µg/m^3	18	200 µg/m^3	
NO_2	1 year	Limit value, 40 µg/m^3	n/a	40 µg/m^3	

*Legally binding in 2015 (based on the years 2013, 2014 and 2015).

RIVM (RIVM, 2020) publishes large scale concentration maps of the annual mean values of among others PM2.5, PM10, NO2 and SO2. These maps are used to assess where the annual mean concentrations exceed the annual EU limit values and WHO thresholds. For PM10 we furthermore assess where the annual mean PM10 concentration exceeds 31.2 µg/m3. This is a proxy for the daily limit value when translated into an annual mean (EEA, 2014; Statistics Netherlands et.al, 2017 a,b,c).

3.3 Pressure indicators

3.3.1 Eutrophication

Eutrophication involves the deposition of plant nutrients, in particular nitrogen and phosphorous. In many terrestrial systems, nitrogen is the most limiting plant nutrient, therefore only information on nitrogen deposition was included in the condition Account for the terrestrial ecosystem types. Nitrogen is an important nutrient for trees and plants. However, an excess of nitrogen has negative effects on species that are adapted to naturally poor soils (for instance heath). Plant species that thrive on poor soil are then outcompeted by fast-growing species that need more nitrogen, such as grasses and nettles. Eutrophication thus can affect vegetation composition by enhancing growth and changing species composition, essentially by favouring the species that are able to best take advantage of the higher nutrient availability. Changes in the plant community also affect the animal community that depend on these nature types. Furthermore, high nitrogen deposition can cause growth disturbances in trees and other plants because high nitrogen content in the soil can affect the absorption of other nutrients such as potassium and magnesium.

For the assessment of eutrophication in a particular nature type, we used a traffic light system. In the Netherlands, the quality of the nature type with respect to eutrophication is assessed as “good”, when the total deposition is lower than the lower limit of the critical load for the nature type, is assessed as “moderate”, when the total deposition is between the lower limit of the critical load and the upper limit of the critical load of a nature type, and is assessed as “bad” when the nitrogen deposition is higher than the upper limit of the critical load (table 3.3.1).

Table 3.3.1 Critical deposition levels for sensitive ecosystems in mol N/ha/yr (data from BIJ12)

Sensitive nature type	Lower limit critical load	Upper limit critical load
N01.02 Duin- en kwelderlandschap	770	1400
N01.03 Rivier- en moeraslandschap	710	1140
N01.04 Zand- en kalklandschap	360	710
N06.01 Veenmosrietland en moerasheide	710	1280
N06.02 Trilveen	710	1140
N06.03 Hoogveen	360	710
N06.04 Vochtige heide	830	1280
N06.05 Zwakgebufferd ven	360	710
N06.06 Zuur ven en hoogveenven	360	710
N07.01 Droge heide	1070	2130
N07.02 Zandverstuiving	710	1070
N08.01 Strand en embryonaal duin	710	1420
N08.02 Open duin	770	1420
N08.03 Vochtige duinvallei	995	1420
N08.04 Duinheide	1070	1280
N09.01 Schor of kwelder*	2400	2400
N10.01 Nat schraalland	780	1070
N10.02 Vochtig hooiland	780	1630
N11.01 Droog schraalgrasland	850	2130
N14.01 Rivier- en beekbegeleidend bos	1850	2420
N14.02 Hoog- en laagveenbos	850	1780
N14.03 Haagbeuken- en essenbos	1420	1990
N15.01 Duinbos	1280	1990
N15.02 Dennen-, eiken- en beukenbos	1070	1420
N16.01/N16.03 Droog bos met productie	1420	2060
N16.02/N16.04 Vochtig bos met productie	1420	2420
N17.01 Vochtig hakhout en middenbos	1420	2420
N17.02 Droog hakhout	1420	2060
N17.03 Park- of stinzenbos	1070	2420
N17.05 Wilgengriend	1775	2429

3.3.2 Acidification

Acidification of soils and water is a result of emission of acidifying pollutants by industry, farms, power plants and traffic to air. The relevant emissions for acidification includes sulphur dioxide (SO2), nitric oxide (NO), nitrogen dioxide (NO2), ammonia (NH3) and volatile organic compounds (VOC). These acidifying substances can end up in the soil. Substances in the soil, like lime, specific minerals, humus, aluminium and iron oxide can buffer the effect of acids. This buffering capacity is very low in dry and low-lime areas, and these are the areas where the vegetation is most vulnerable. In these areas excessive deposition of acidifying substances leads to a change in species composition in vegetation and a decline in biodiversity.

The risks and effects of acidification are assessed based on critical deposition levels or critical loads. The critical deposition levels are based on critical-load functions that translate no-effect levels for nitrogen to maximum permissible levels of sulphur and nitrogen deposition (van Dobben, et. al. 2012). Critical deposition levels differ per ecosystem type. For this account, we used the critical deposition levels that are used by Environmental data compendium (van Dobben, et. al. 2012). For all coniferous forest and mixed forest the critical deposition level for coniferous forest was used, with a lower limit at 1650 mol H+/ha/yr (the start of Al depletion) and an upper limit of 1900 mol H+/ha/yr. For all broad-leaved forest the critical deposition level for broad-leafed forest, were used with a lower limit at 1800 mol H+/ha/yr (the starts of Al depletion) and an upper limit at 2450 mol H+/ha/yr.

The critical deposition level for heath is set at 1100-1400 mol H+/ha/ yr, and for dune vegetation is set at 1000-1500 mol H+/ha/yr. The critical deposition levels for grasslands is set at 1000 - 1500 mol H+/ha/yr (Heij and Erisman, 1997), and for bogs (hoogveen) is set at 400 mol H+/ha/yr, this is the critical limit for weakly buffered water.

3.3.3 Urbanisation

The effect of urbanization puts a pressure on (natural) ecosystems. An increase in paved areas can put pressure on water sewage systems and make water drainage more difficult. Paved and built-up areas can also lead to an increase in summer temperatures. An increase in urbanization can cause the landscape to become more fragmented and limit species mobility as well. The detailed ecosystem types from the extent Account were classified into those that contribute to urbanization and those that do not contribute to urbanization. The ecosystems that were considered to contribute to urbanization include built-up areas, business parks, greenhouses, infrastructure and other paved terrains. To assess the urbanization pressure the percentage of urbanization ecosystems within a 5km radius was calculated for each 10m grid cell of the extent map. It should be noted that the area near the border was assessed using only the area within 5 km that is part of the Netherlands.

3.3.4 Heat sum

Urban areas heat up more than the surrounding rural areas due to the Urban Heat Island (UHI) effect. This additional heating occurs due to the higher absorption of sunlight by darker materials such as asphalt and concrete, and a slower release of this heat by these materials, a reduced wind speeds between buildings and less natural evaporation because of soil sealing. The additional heat can cause health problems during warm periods, especially for the elderly and young infants (e.g. Kovats & Hajat, 2008). By increasing the evaporation capacity, vegetation can have a positive effect on the cooling capacity of an area. Furthermore, vegetation can provide shade and vegetation releases heath more easily than sealed areas, resulting in faster cooling down during the nights.

Vegetated ecosystems within urban areas regulate the local climate. The contribution of vegetation to lowering the UHI effect is calculated in 4.4.10. For the condition account, we assess the cumulative heat sum in the urban areas. This heat sum is calculated as the number of degrees of the maximum temperature above 25.0 ° C cumulative for all days during a heat wave, with a unit in degree-days. This is calculated using the equation for UHI (see 4.4.10) for the temperature in the urban areas.

4. Ecosystem services: physical and monetary

4.1 Introduction

Following the general framework of the SEEA ecosystem accounting, each ecosystem asset supplies a set or bundle of ecosystem services. In SEEA EA, ecosystem services are defined as the contributions of ecosystems to the benefits that are used in economic and other human activity. In this definition, use incorporates direct physical consumption, passive enjoyment and indirect receipt of services. Further, ecosystem services encompass all forms of interaction between ecosystems and people including both in situ and remote interactions (UN, 2021).

Ecosystem services are divided in three broad categories:

- **Provisioning services** are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems.
- **Regulating and maintenance services** are those ecosystem services resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society.
- **Cultural services** are the experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits.

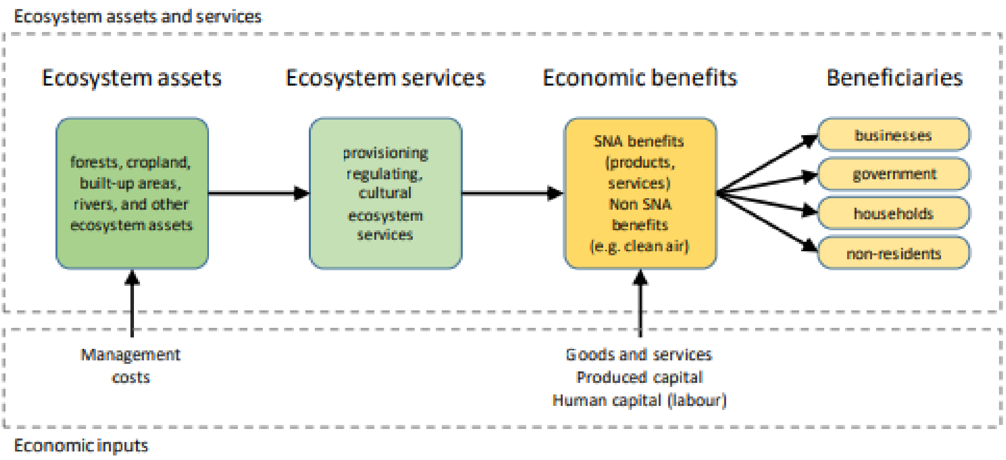
Table 4.1.1 Ecosystem services included in this chapter

Ecosystem service	Included in this study
Provisioning services	
Crop provisioning services	physical and monetary
Fodder and grazed biomass provisioning services	physical and monetary
Wood provisioning services	physical and monetary
Regulating services	
Water purification services	monetary
Carbon sequestration	physical and monetary
Pollination	physical and monetary
Air filtration	physical and monetary
Coastal protection	physical and monetary
Protection against flooding due to heavy rainfall	physical
Local climate regulation	physical
Cultural services	
Nature recreation	physical and monetary
Nature tourism	physical and monetary
Amenity services	monetary

4.2 Key principles for monetary valuation of ecosystem services

Monetary valuation concerns three specific components of the SEEA EEA framework: ecosystem assets, ecosystem services, and the associated benefits. These are shown in Figure 2.1.1 which represents a so-called logic chain that links the ecosystem services supplied by ecosystem assets to the benefits and their specific beneficiaries or economic users.

Figure 2.1.1 Key components for monetary valuation in the SEEA EEA



Exchange values are those values that reflect the price at which ecosystem services and ecosystem assets are exchanged or would be exchanged between willing buyers and sellers if a market existed (Statistics Netherlands and WUR, 2020). Since the ecosystem assets themselves are not actual market participants, the challenge in valuation for accounting lies in establishing the assumptions about the institutional arrangements that would apply if there were an actual market involving ecosystem assets (SEEA TR, 6.13). Exchange values are of interest because they allow direct comparison of values on ecological value and socio-cultural value. The term exchange values was first introduced in the SEEA EEA (2014) since the term market prices, as used in the SNA, is often misunderstood to mean that national accounting only incorporates values of goods and services transacted in markets (SEEA EEA TR, 6.10). Therefore, this is the recommended approach to apply in SEEA ecosystem accounting (Statistics Netherlands and WUR, 2020; UN, 2021).

4.2.1 Limitations of monetary valuation

Valuation inevitably involves assumptions and uncertainties. Valuation according to SNA principles requires exchange values, but most ecosystem services and assets are not traded in markets in the same way as other goods, services, and assets. It has proven necessary to impute ‘missing prices’ and to extract from the price of marketed goods and services that part which is attributable to ecosystem services. A critical caveat of the latter approach is that we must assume that the value of an ecosystem service is fully included in the market price.

We have valued ‘only’ eleven ecosystem services. The scope is not yet comprehensive, as we have not included a number of important ecosystem services, such as marine ecosystem services. In that regard, the aggregated values presented here represent an underestimation. Furthermore, for some ecosystem services we have only included part of the exchange value. For example, for nature tourism and recreation the values now include only the part that is already included in GDP and not the exchange values related to all kinds of (positive) health effects that are not included in GDP.

Assigning an economic value to ecosystems gives rise to a number of ethical and cultural concerns. It can be argued that economic valuation turns nature into a commodity to be used by humans, that efforts to monetize the value of nature detract from its true (intrinsic) value, and that imputed non-market values are misleading (e.g. Silvertown 2015).

There is a risk that the statistics presented in this report may be misinterpreted. For example, a particular method may suggest that the economic value of an ecosystem service is zero or negative. It would be irresponsible to conclude that the associated asset truly has no value. This is particularly relevant when the resulting values are used to compare alternatives in policy decision making. The statistics measure value within a narrow focus. The fact that we explain our focus does not relieve us from the obligation to strongly advise our readers to be careful when using the statistics presented in this report.

Valuation is, however, considered essential for communicating the economic value and scarcity of nature. It should be recognized that monetary values always have to be presented and analyzed together with information from the other ecosystem accounts, that is, on extent, condition, and physical output. Monetary accounting must be developed and presented in parallel with physical accounting in order to provide an overall view of the status and trends in ecosystem assets and the ecosystem services they supply.

Thus, the SEEA EA monetary values should not be considered to provide, and do not intend to estimate, a complete “value of nature.”

4.3 Provisioning ecosystem services

4.3.1 Crop provisioning services – physical

Definition and scope

Crop provisioning services are the ecosystem contributions to the growth of cultivated plants that are harvested by economic units for various uses including food and fibre production, fodder and energy.

Following the recommendations of SEEA EA, there are two ways to measure and record ecosystem services related to cultivated biomass. Under the first approach, it is most common to measure the biomass that is harvested. An ecosystem contribution (or share) should be estimated that varies depending on the production context, but if this is not possible, a proxy measure may be used based on the gross biomass harvested. Alternatively, a range of specific ecosystem services, for example pollination, local climate regulation and water flow regulation, may be measured that collectively reflect the ecosystem contribution to biomass growth. Under this approach, the ecosystem service of crop provisioning is not recorded.

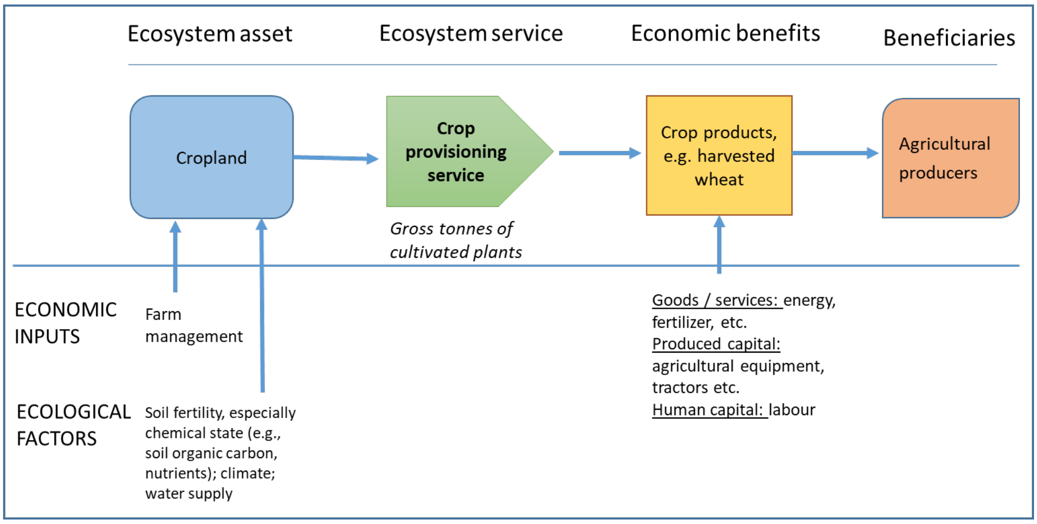
In practice, it is difficult to determine all of the various ecosystem processes as well as intra- and inter-ecosystem flows for different cultivated biological resources. Therefore, we follow the first approach: crop production was used as a proxy for the ecosystem services that together allow for agricultural production. Higher crop yields are thus interpreted as a higher supply of these ecosystem services.

Furthermore, the ecosystem services ‘crop production’ is defined here as the total and combined contributions of ecosystem processes that are directly supplied by the cropland. This includes infiltration, storage and release of soil water, plant nutrient storage and release, and other soil related processes. They are, by themselves, a function of soil type, climate and past and current farm management practices. The ecosystem service as defined here thus includes a mix of different contributions and processes provided by the cropland and grassland. The ecosystem services pollination and pest control are not included as these ecosystem services are primarily provided by adjacent plots of land or ecosystem assets and not by the cropland (or grassland itself). Therefore, these ecosystem services are treated as final ecosystem services and can be separately valued. Their value should be attributed to these adjacent ecosystems (e.g. hedgerows, forest patches that act as habitat for pollinating insects).

Several choices were made with regard to the scope of this ecosystem service, i.e. what agricultural products to include. Crops used to produce fodder for livestock, such as maize, have been excluded and are included in the ecosystem service 'fodder and grazed biomass provisioning service'. Flower bulbs are included because they cover a large area (about 3 percent of arable land) and have a higher monetary value per hectare than other crops. Crops grown in greenhouses are not considered to be related to the ecosystem services and are therefore disregarded in the ecosystem accounts.

Logic chain

Crop provisioning service is (mainly) supplied by cropland, the ecosystem service is expressed in kilotons production per hectare per year and covers arable crops (such as potatoes and cereals), and open-field horticulture (such as vegetables) and the production of flower bulbs. The economic benefits for these services are the crops after harvest. These benefits are the result of a joint production process, where the role of the ecosystem in supplying the biomass intersects with the activity (and associated human inputs, e.g., labour and produced assets) of people and economic units. The beneficiaries are the agricultural producers (e.g. farmers).



Data sources

Two main data sources are used to compile crop provisioning services. First is the registry on agricultural parcels (Basisregistratie Gewaspercelen (BRP)). This is spatial data covering the crop category, crop code and crop name per agricultural parcel in the Netherlands. The organisation that provides the data is RVO.nl (the Netherlands Enterprise Agency), a government agency which operates under the auspices of the Ministry of Economic Affairs and Climate Policy. Annual updates are available in September and cover the growing season of the year the statistics are published. The reference date is on 15th of May of each year. This means that when two types of crops are harvested on the same parcel, that the one growing there on the 15th of May is recorded in the database. It is assumed that double crop production on the same parcel does not occur often in the Netherlands. The registry on agricultural parcels considers a large amount of varying crops. Therefore, in total 88 different crops were used calculating the ecosystem service on crop provision (some adjustments were necessary for 2013 as this data is available with more aggregation). See tables 4.3.1 and 4.3.2 for a list of crops included in the estimation of this ecosystem service.

The crop provisioning services could show a different area than the agricultural area in the extent account. The extent account aims at covering the whole country, in this way agricultural land could be taken more broadly to include little edges. The crop provisioning service strictly takes the agricultural parcels and therefore little inconstancies can occur when comparing the two areas.

Second, data from the agricultural statistics (harvesting data) from Statistics Netherlands is used for an estimate on the amount harvested. It shows the harvested area and corresponding gross yield in kilos of the harvested crops and is annually updated in October of the same year (Statistics Netherlands, 2021g). It shows the cropping area and gross yield of vegetables and is annually updated in April of the next year (Statistics Netherlands, 2021h). It shows the cropping area and corresponding gross yield of fruit and is annually updated in November of the same year (Statistics Netherlands, 2021i).

Method

To compile the spatial data for crop provisioning services of the Netherlands, the data from BRP on parcels and data from StatLine on mean harvest yields are combined. No direct data is available on the harvest of flower bulbs in kilos. Therefore, an estimation for the physical quantities is made based on data from internally available data (by Statistics Netherlands) on the national accounts (supply and use tables), international trade data and harvesting data. Almost all crops in the registry of agricultural parcels are included in the estimation of the ecosystem service except where there is no data on the yield (most notable floriculture, seeds and propagation material).

Table 4.3.1 List of crops 2015, 2018 and 2020

Potatoes, control measure AM	Barley, winter	Turnip greens, production
Potatoes, consumption	Barley, summer	Rhubarb, production
Potatoes, planted NAK	Gladiolus, bulbs and tubers	Radish, production
Potatoes, planted TBM	Oats	Red cabbage, production
Potatoes, starch	Hemp, fiber	Rye (not cutting rye)

Strawberries on racks, production	Hyacinth, flower bulbs and tubers	Savoy cabbage, production
Strawberries on racks, propagation	Iris, other floricultural crops	Salsify, production
Strawberries on racks, waiting bed	Celeriac, production	Celery, bleach and green, production
Strawberries on racks, seeds and propagation material	Fennel / fennel, production	Lettuce, iceberg, production
Strawberries open ground, production	Rutabaga, production	Lettuce, other, production
Strawberries open ground, propagation	Kohlrabi, production	Spinach, production
Strawberries open ground, waiting bed	Rapeseed, winter (incl. Butter seed)	Pointed cabbage, production
Strawberries open ground, seeds and propagation material	Rapeseed, summer (incl. Butter seed)	Brussels sprouts, production
Endive, production	Crocus, flower bulbs and tubers	French green beans, production
Apples, planted current season	Beetroot / beetroot, production	French string beans and French beans, production
Apples, planted prior to current season	Lily, bulbs and tubers	Wheat, winter
Asparagus, surface yielding production	Corn, sugar	Wheat, summer
Beets, sugar	Narcissus, flower bulbs and tubers	Triticale
Cauliflower, winter, production	Other arable crops	Tulip, bulbs and tubers
Cauliflower, summer, production	Other flowers, bulbs and tubers	Onions, seed and plant (incl. Shallots)
Kale, production	Other grains	Onions, sowing
Beans, brown	Other vegetables not mentioned, production	Flax, oil. Linseed not from fiber flax
Beans, garden (green to harvest)	Bok choy, production	Flax, fiber
Carrot, production	Pears, planted current season	Wax carrot, production
Broccoli, production	Pears, planted prior to current season	Winter carrot, production
Chinese cabbage, production	Pods, production	Chicory root, production
Chicory	Pumpkin, production	White cabbage, production
Zucchini, production	Leeks, winter, production	Zantedeschia, flower bulbs and tubers
Dahlia, flower bulbs and tubers	Leeks, summer, production	
Peas, green / yellow (to be harvested green)	Runner beans, production	

Table 4.3.2 List of crops 2013

Potatoes, control measure AM	Harvest peas, green / yellow, green	Corn, sugar
Potatoes, consumption on clay / löss soil	Fruit	Other arable crops
Potatoes, consumption on sand / peat soil	Barley, winter	Rye (not cutting rye)
Potatoes, plant on clay / löss soil	Barley, summer	Wheat, winter
Potatoes, plant on sand / peat soil	Cereals, other	Wheat, summer
Potatoes, starch	Vegetables open ground (including vegetable seeds)	Triticale
Beets, sugar	Oats	Onions, legs and plant (incl. Shallots)
Flower bulbs and tubers	Hemp, fiber	Onions, sowing
Beans, brown	Rapeseed, winter (also butter seed)	Fiber flax
Beans, garden (green to harvest)	Rapeseed, summer (also butter seed)	
Chicory	Linseed not made from fiber flax (oil flax)	

Data on harvesting yields are available per crop type and, mostly per province. Data on parcels and data on harvest yield are linked so that the mean harvest yield per crop (differentiated per province) can be allocated on the agricultural parcels using spatial analysis. Some crop yields only have national data, this value is assigned to the relevant parcels of that crop in all provinces, and otherwise provincial data is used. This gives a geographical representation of the mean harvest per hectare of the crops included in this study. Maps of different categories such as potatoes or flower bulbs can be made.

4.3.2 Fodder and grazed biomass provisioning services – physical

Definition and scope

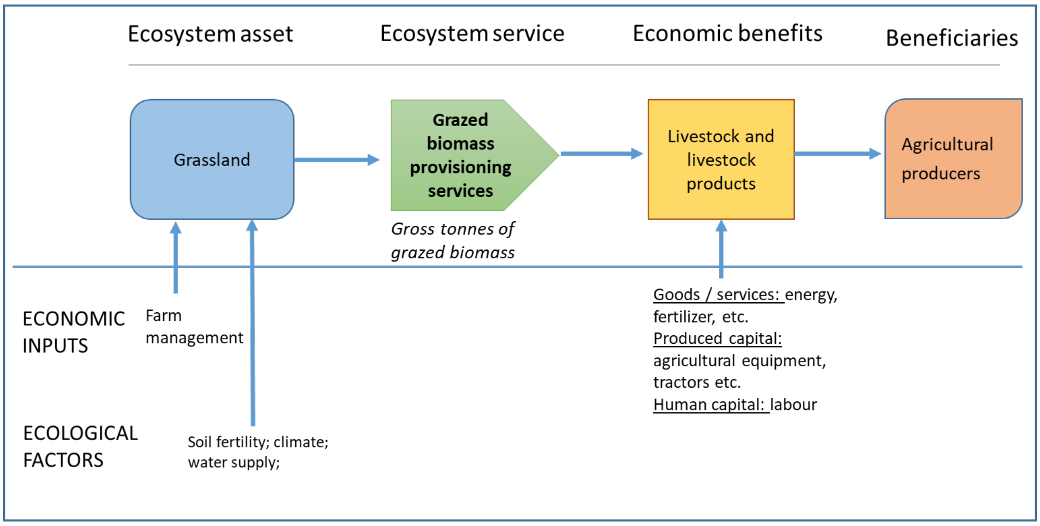
Strictly speaking, following the SEEA EA, grazed biomass provisioning services are the ecosystem contributions to the growth of grazed biomass that is an input to the growth of cultivated livestock (UN, 2021). However, aligned with the SEEA EA, we use physical quantities of fodder and grazed biomass as indicator for the service. This service includes the ecosystem contributions to the growth of crops used to produce fodder for livestock (e.g., hay, soymeal).

For cultivated livestock, the conceptual focus is on the extent of the connection between the livestock and relevant ecosystem assets, primarily natural and cultivated pastures (UN, 2021). Depending on the cultivation context, there may be some disconnect between ecosystems and the production of livestock and livestock products. Therefore, where the livestock production process does not involve direct connection with an ecosystem, as commonly occurs, for example, in some forms of intensive chicken, cattle and pig rearing, no ecosystem services should be recorded. To ensure focus on the ecosystem contribution, it is recommended to measure the grazed biomass provisioning services as the primary ecosystem contribution.

The crops or biomass that are included in this ecosystem service are grass (silage and meadow grass) hay and maize (grain maize, silage maize and corncob mix). Concentrates that are usually added to the livestock diet is not part of this ecosystem service.

Logic chain

Grazed biomass provisioning services are mainly supplies by agricultural grassland and cropland. The supply of this service is dependent by many ecological factors including soil fertility, climate and water supply. This ecosystem service is expressed in yield (kilotons) of fodder and grass per hectare per year. Both permanent and temporary grassland are part of this analysis. The economic benefits are is the livestock (cattle) and livestock products. Similar as crop provisioning services, the benefits are the result of a joint production process, where the role of the ecosystem in supplying the biomass intersects with the activity (and associated human inputs, e.g., labour and produced assets) of people and economic units. The beneficiaries are the agricultural producers.



Data sources

Data sources and method are very similar to the ecosystem service on crop provision. As with the crop provisioning service described in the previous paragraph, the registry on agricultural parcels (Basisregistratie Gewaspercelen (BRP)) is used. This is spatial data covering the crop category, crop code and crop name per agricultural parcel including grassland in the Netherlands. Harvesting data from agricultural statistics (Statistics Netherlands) is used for the data on kilos crops and grass harvested[6]. The Statline table on arable crops and grassland are used (Statistics Netherlands, 2021g and 2021j). Data on grazed pasture grass are from the Statistics Netherlands publication on livestock and agriculture (Statistics Netherlands, 2019).

[6] In a previous study, the net primary production (NPP) was used for the regional allocation of the harvest yield. However, in this study it is left out since it was not available yet when compiling these ecosystem services.

Method

The analysis is similar to crop provisioning services. However, here the grazed pasture grass is also included in the ecosystem service. To compile the spatial data on fodder and grazed biomass provisioning service, data from BRP on parcels and data from Statistics Netherlands on harvest yields are combined. Data on harvesting yields of silage grass, hay and maize are available per province. Data on yields of grazed pasture grass is available per pasture area: north, east, west, south and other. So the first step is to add information to the parcel data on which province or pasture area the parcel lies.

Data on parcels and data on harvest yield are linked so that the harvest yield, differentiated per province or pasture area, can be allocated on the agricultural or grassland parcels on the map. Checks are made using the area from the agricultural parcels and the area from the data on harvesting yield with corresponding harvesting area.

A final step is to allocate the linked data to harvest yield or grazed biomass in tonnes per hectare per crop or grass type to the geographical location of the agricultural or grassland parcels. These maps are converted from polygon to raster so that it can be used for calculating and mapping the total ecosystem services. Maps of different categories (grass and hay and maize) can be made.

4.3.3 Crop, fodder and grazed biomass provisioning services – monetary

The valuation techniques for crop, fodder and grazed biomass provisioning services are very similar and will be described together in this section. There are several valuation techniques that provide SEEA EA consistent values (i.e. exchange values). In a previous report (Statistics Netherlands and WUR, 2020) we have tested and discussed the different methods. Here we will describe in more detail the rental price method, as this is the technique that was used to value these ecosystem services for the Netherlands.

The value of agricultural land incorporates many ecosystem services, at least with regard to those ecosystem services contributing to benefits that are within the scope of the SNA production boundary. When a farmer buys or leases land to grow crops, the price reflects the potential to grow crops as a function of the ecosystem characteristics of the area, such as acreage, soil fertility, and hydrological properties. Therefore, the price (or lease price) of the land reflects the value of the relevant ecosystem services provided by the land. According to the rental price method, the total value is calculated based on rent prices and data on the extent of agricultural land (cropland and grassland). It is assumed that the rental price is also a good approximation for the price of the ecosystem service provided by land owned by farmers.

Leases (rents) on land are a form of property income. They consist of the payments made to a land owner by a tenant for the use of the land over a specified period. Currently, around 30 % of agricultural land in the Netherlands is leased.[7] In the Netherlands rent prices are (partly) regulated by the government. Every year on the 1st of July, the government determines the highest allowable lease prices for agricultural land (Wageningen Economic Research, 2020). These maximum lease prices are based on the five-year average yield of the land and are separately determined for 14 agricultural areas. A tenant and lessor can together arrange the lease price without compulsory intervention of the government, but only if the rent price does not exceed the highest allowable lease price. This regulation rules out the possibility that lease

[7] CBS-Landbouwtelling, Areaal (ha) cultuurgrond naar gebruikstitels, 2012, 2013, 2014, 2015, 2016 en 2017, https://www.cbs.nl/nl-nl/maatwerk/2018/12/areaal-cultuurgrond-naar-gebruikstitels-2012-2017

prices are affected by external market effects, for example the state of the property market. Moreover, the fact that maximum lease prices are linked to the actual yield of the land reinforces the suitability to use lease prices to value the contribution of the land to agricultural output.[8] Based on rent prices and data on the extent of agricultural land the total value was calculated (cropland and grassland). For horticulture separate prices are available.

[8] Agricultural land on which a lease contract rests has a lower value than land that is free of rent. Tenants can derive a number of rights from a lease contract that make the land on which the contract rests less attractive for a buying party.

4.3.4 Wood provisioning services – physical

Wood provisioning services are the ecosystem contributions to the growth of trees and other woody biomass in both cultivated and uncultivated production contexts that are harvested by economic units for various uses including timber production but excluding energy.

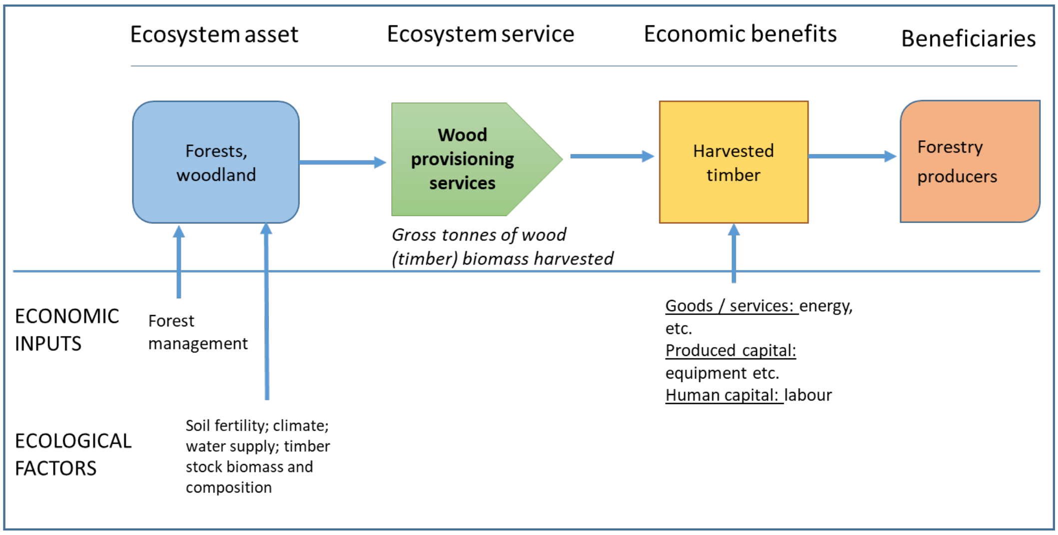
Definition and scope

In natural production processes, all of the biomass that is harvested is considered the ecosystem contribution (UN, 2021). The measurement of the ecosystem service should be aligned with the gross quantity of biomass that is harvested. This will be different from the total stock of biomass available for harvest and different from the biomass that is used in a subsequent production or consumption process. Thus, for example, felling residues and discarded catch should be considered as part of the ecosystem service flow. Thus, focus is solely on the quantity of the biomass that is harvested or accessed since this reflects the total use (or input) of the ecosystem's resources.

The provisioning service timber production only represents roundwood/wood trunks extracted as input for economic activities. It excludes the extraction of timber for energetic purposes.

Logic chain

Wood provisioning services are provided by forests and other ecosystem types with wooded biomass. The ecosystem service is measured in gross tonnes or m3 of wooded biomass. The economic benefit is the harvested timber. These benefits are the result of the combined input of ecosystem services, goods and services, produced capital and human capital. The beneficiaries are the companies engaged in the forestry activities. In the Netherlands, the forestry sector (ISIC 2) is the only economic sector involved in timber production.[9]



[9] In the Netherlands, ISIC 2 includes both private forestry companies and 'Staatsbosbeheer', a governmental body responsible for the management of a large part of the Dutch forests.

Table 4.3.4 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Meetnet Functievervulling (MFV)	Monitoring data	Probos
Zesde Nederlandse Bosinventarisatie (NBI6)	Monitoring data	Probos
EEA 1km reference grid the Netherlands	Spatial data	European Environmental Agency (EEA)

Main assumption

Based on data of the national forest inventory (Probos, 2017), estimates for harvested timber specified for coniferous and deciduous trees were calculated. As timber production in forests with a nature status is only possible at a limited extent, we assume that timber production in forest with a nature type ("natuurdoeltype") is 20% of the timber production of a similar forest type without nature status.

Method description

For the compilation of the physical ecosystem service we used data that were collected in 2012 and 2013 for the sixth Dutch Forest Monitor (Zesde Nederlandse Bosinventarisatie, NBI6) (Schelhaas et al., 2014). The collected data and background information were available online (Probos, 2017). Data were collected at 3190 sample points, of which 1235 were also sampled in the 2001-2005 Forest Monitor (Meetnet Functievervulling, MFV). For privacy reasons, the exact coordinates of the sample points are not available in the public database. Instead, it is noted in which 1x1 km grid cell the coordinate is located (EEA, 2013).

The sample points for MFV and NBI6 data collection were randomly assigned and therefore it is assumed that they are representative for forests in the Netherlands. To calculate timber stock, stock change and harvest, only the sample points that were visited in both inventories could be included. When we assume that the data of the MFV was collected at 2003 (mean of 2001-2005) we can use the differences between the MFV (2003) and NBI6 (2013) to estimate the timber yield in 2003 and 2012, and extrapolate the trend to 2015, 2018 and 2020 (table 4.3.5). In 2022 the 7th Forest Monitor will be ready, at that point the values for 2015, 2018 and 2020 can be updated based on measured data.

Table 4.3.5 Mean timber yield per region per year in m^3/ha

		2013	2015	2018	2020
Deciduous forest	Nord	2.4	2.4	2.5	2.6
	Mid	2.3	2.2	2.2	2.2
	Flevoland	5.1	5.2	5.5	5.6
	West	2.2	2.1	2.0	1.9
	South	2.5	2.4	2.2	2.1
Coniferous forest	Nord	5.9	6.0	6.1	6.2
	Mid	4.2	4.2	4.1	4.1
	Flevoland	6.9	6.8	6.7	6.6
	West	3.6	3.6	3.8	3.8
	South	3.8	3.7	3.7	3.6
Mixed forest	Nord	4.1	4.2	4.3	4.3
	Mid	3.2	3.2	3.2	3.2
	Flevoland	6.0	6.0	6.1	6.1
	West	2.9	2.9	2.9	2.9
	South	3.1	3.1	2.9	2.9

Statistics

First, we applied a linear regression model to test which variables explain timber harvest best. For the analysis, the Netherlands was divided in 5 regions; North (Groningen, Friesland and Drenthe), Mid (Overijssel, Gelderland and Utrecht), West (Noord-Holland, Zuid-Holland, Zeeland), South (Noord-Brabant and Limburg) and Flevoland. A combination of dominant tree type and region could explain harvest best. However, in absence of detailed information about local tree species, a model that includes whether the dominant tree group in a forest is deciduous or coniferous also explains harvest in combination with region. To allocate the estimates for timber harvest per dominant tree group (coniferous or deciduous) the ecosystem type map is combined with the top10NL terrain map, that distinguishes coniferous, deciduous and mixed forests. A raster with this information was co-produced with the ecosystem types map. The predictive power of dominant tree type for a specific location is much lower, the model is meant to be applied at the level of municipalities or above.

4.3.5 Wood provisioning services – monetary

For timber production we applied the stumpage prices method. Stumpage prices (in Dutch 'hout op stam') are the prices paid per standing tree, including bark, for the right to harvest from a given land area. The stumpage prices most directly reflect the value of the ecosystem service, because they are actual market prices paid to harvest wood and thus fully consistent with SNA exchange values. Prices are collected and published by Wageningen Economic Research (Wageningen Economic Research, 2021). Stumpage prices are available for different timber categories (pine, douglas, larix, other coniferous, willow, poplar and other deciduous wood). Here, an average stumpage price for all timber types was taken. There is no further regionalization of the prices. The value of the ecosystem service timber production is calculated by multiplying the stumpage price (euros/m^3) with the total amount of wood harvested (m^3).

4.4 Regulating and maintenance ecosystem services

4.4.1 Water purification services – monetary

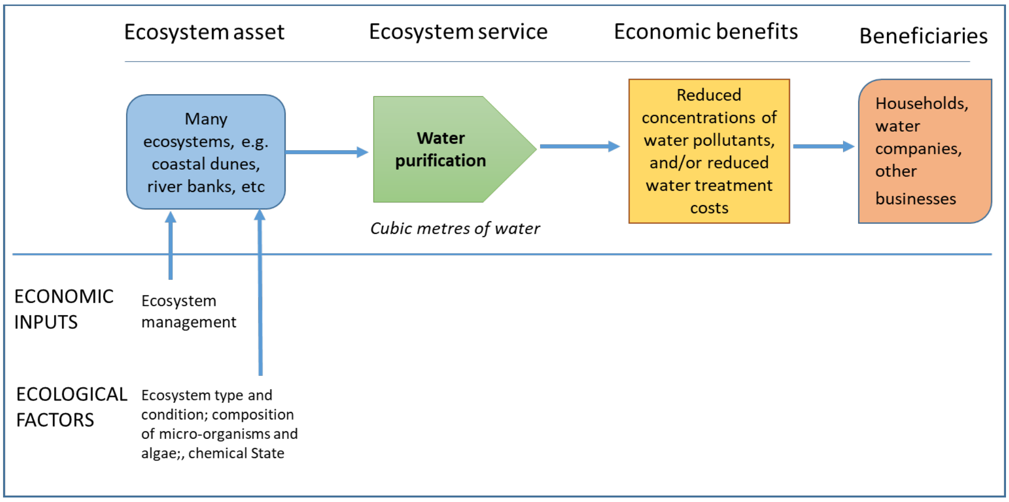
Definition and scope

Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health.

For the Netherlands, we have (for now) focussed on the subsurface natural filtration and storage of groundwater by the ecosystem, which is subsequently pumped up and (after some final treatment) distributed to be used as drinking water. There are different types of drinking water extraction in the Netherlands. Here three types were taken into account. First, surface water that was transported from elsewhere is pumped into filtration basins in the dunes. The dunes thus deliver the service of water filtration. Second, 'river bank filtration water' has its origin in surface water from lakes, rivers and other water bodies. This water is allowed to infiltrate in the ground (riverbanks or other easily permeable layers) before it is pumped up again. Third, groundwater is extracted from the sub-soil. Considering the latter source of drinking water, only phreatic aquifers are taken into account. This means that there is no impermeable layer (seal) on top of the tapped groundwater aquifer. This implies there is a clear connection between the (ecosystem) service being delivered and the ecosystem on top of it. Not included in this ecosystems service is the provision of soil water for agriculture (e.g. irrigation) and groundwater supply for the production of industrial water, used mainly for cooling.

Logic chain

Water purification services for groundwater are supplied overlying ecosystems. Only groundwater abstraction from unconfined aquifers is included, so there is a clear connection with the overlying ecosystems. Several ecological processes support the availability of clean groundwater, namely soil and subsoil characteristics, vegetation etc. In physical terms, the ecosystem service is measured in cubic metres of groundwater extracted, used for the production of drinking water. It is assumed that the physical extraction is a good proxy for the ecosystem service. The economic benefit is the reduced concentration of water pollutants, and the associated reduced water treatment costs for the production of drinking water. The beneficiaries are the water companies that subsequently provide the drinking water to households and industries.



Method – monetary

We have applied the replacement cost approach to estimate the value of water purification, as was first applied in Remme et al. (2015). The replacement costs are estimated by measuring the difference in production costs of drinking water from groundwater relative to surface water. It is likely that, in case groundwater would not be available, the resulting shortage of water for drinking water production would be overcome by using river water. Some Dutch drinking water companies are currently already using river water, although they generally prefer to use groundwater because of its higher quality and lower production costs.

The replacement cost method compares an existing ecosystem asset or service (e.g. groundwater abstraction for drinking water supply) with a substitute. Switching from groundwater to surface water abstraction raises production costs. By valuing the ecosystem service at the difference between the production costs of groundwater and surface water companies, we implicitly assume that the value of groundwater is zero. This is consistent with the SEEA EA focus on final ecosystem services, but disregards the value of groundwater embodied in the price of drinking water. Information on the total volume of drinking water supplied to households within distribution areas as well as the total volume of water abstracted from groundwater, riverbanks, dunes, and surface water in 2013-2020 was obtained from the drinking water statistics of VEWIN (the association of drinking water companies in the Netherlands). Total revenues, total costs, and production costs by cost category (taxes, depreciation, capital costs, and operating costs) were taken from the annual reports of drinking water companies. The following drinking water companies are included: Brabant Water, Dunea, Evides Waterbedrijf, Oasen, PWN, Vitens, Waterbedrijf Groningen and WMD Drinkwater. Drinking water companies WML and Waternet are not included, because there was no sufficient financial data available.

The unit value of the ecosystem service that provides clean drinking water through the natural filtration and storage of groundwater is calculated by measuring the difference in unit production costs of companies that mainly extract groundwater and companies that mainly extract surface water. Each drinking water company has been classified as a groundwater (gw), surface water (sw) or mixed-type company. This is based on confidential VEWIN extraction data received from experts. 'Groundwater companies' are companies that extract water from groundwater reservoirs or riverbank groundwater reservoirs. Production costs concern operating costs, costs of capital, and depreciation; taxes are excluded.

Note that the value of this service as measured in an accounting approach is low compared to the value it would have had in a welfare-based valuation approach, because the willingness to pay for water by people, as expressed in a demand curve, will in general be higher than the price people pay at present for their drinking water. Note also that the method assumes that sufficient river water, of sufficient quality, is available to be used as an alternative to using groundwater. This is in line with the current situation in the Netherlands, especially since several basins have been established that hold river water and act as a buffer during dry spells. River water also presents a natural resource, if it would not be available then as an alternative sea water would have to be desalinated (at substantially higher costs). In the future, this part of the valuation could be reconsidered to assess if a more appropriate value can be retrieved.

4.4.2 Carbon sequestration – physical

Definition and scope

Global climate regulation services are the ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to remove carbon from the atmosphere (UN, 2021). In the SEEA EA, the measurement of the global climate regulation services considers two components, carbon retention and carbon sequestration. For the Netherlands, we have (for now) focussed on carbon sequestration in biomass.

The ecosystem service carbon sequestration is defined as the ability to remove carbon from the atmosphere, contributing to climate regulation. Crucial is that this capture is long-term, carbon that is sequestered but not expected to be stored, e.g., the above ground biomass of crops, and a proportion of the carbon sequestration in forests equal to the mean timber harvest should be excluded from scope. The service of sequestering carbon is equal to the net accumulation of carbon in an ecosystem due to both growth of the vegetation and accumulation in below-ground carbon reservoir.

Logic chain

The ecosystem service carbon sequestration is supplied by many different ecosystem types. It is dependent on several ecological factors, including ecosystem type and condition, net ecosystem productivity (NEP), i.e. the difference between net primary productivity (NPP) and soil respiration. The ecosystem service is measured in tonnes of carbon removed from the atmosphere. The economic benefits of reducing atmospheric CO_2 concentrations are fewer adverse effects and the associated avoided damage costs. Carbon sequestration provides benefits for society as a whole. The beneficiary is therefore the government, as a representative for the whole of society.

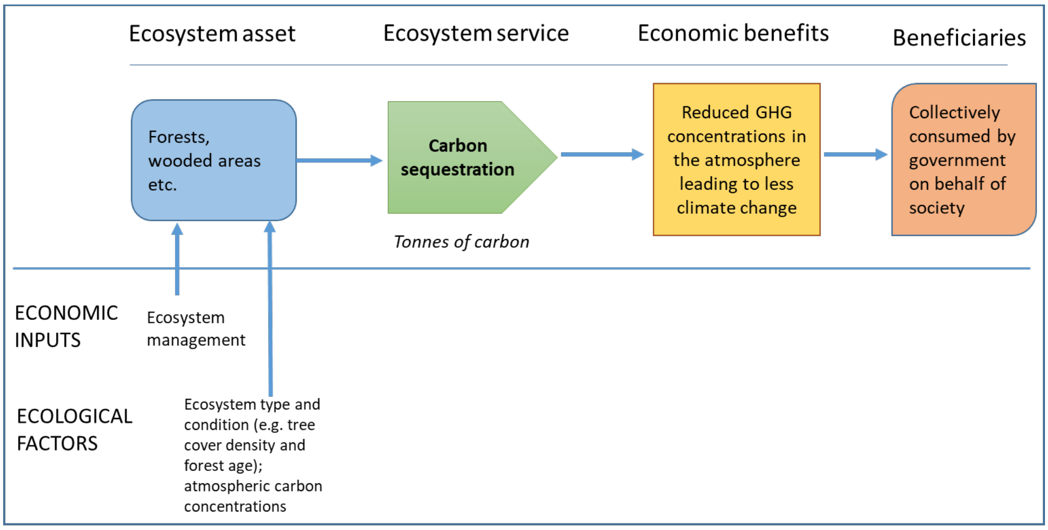


Table 4.4.5 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
-	Reference values	Literature

Method description - physical

The methodology to determine the physical service was based upon a qualitative look-up table (LUT) approach. Each spatial unit (i.e. ecosystem type) in the map was attributed a specific value for carbon sequestration. For carbon sequestration in nature in the Netherlands Arets (2018) makes a distinction between the Net Primary Production (NPP), which is the carbon that is captured in biomass by vegetation as a result of photosynthesis, and net sequestration of carbon over a long period, considering that carbon is lost in the ecosystem through autotrophic respiration, fire and wood harvest. These net sequestration values will be used for the service carbon sequestration. Values for carbon sequestration in agricultural land were derived from an older study on carbon sequestration in Dutch nature and agriculture (Lesschen et al., 2012). The look-up table for carbon sequestration in above and below ground biomass is provided in table 4.3.6 For forests the net sequestration rates depend on timber harvest and management. The given values are based on gross growth, death and harvest based on repeated measurements in the forest inventories MVF (2001-2005) and NBI6 (2012-2013). According to Arets (2018) there are many ecosystems with low vegetation, like heath and grassland, that are already in a steady state. Therefore, it is assumed that even though the NPP in these ecosystems can be high, 1.1 ton C/ha/year for heath and 2.6 ton C/ha/year for natural grasslands, the net sequestration at present will be limited. Based on a publication of Janssens et al. (2005) a net sequestration of 0.19 ton C/ha year is considered in these two ecosystems. We assume that the sequestration rate for arable field margins (“faunarand”), tall herbs (“ruigte”) and natural crop fields (“akkerbouw, natuurlijk”) is similar. The net sequestration for bogs is potentially very high, however due to desiccation this potential is not met in practice. Salt marshes do have a high net sequestration of 1.5 ton C/ha/year. For more details see paragraph 6.2.1.

Table 4.4.6 Look-up table for mean carbon sequestration in above and below ground biomass in the Netherlands

	Sequestration mean (ton C/ha/yr)
Forest, deciduous	1.80
Forest, coniferous	0.50
Forest, mixed	1.10
Natural forest, deciduous	1.70
Natural forest, coniferous	0.80
Natural forest, mixed	1.40
Salt marsh	1.50
Bogs and lowland peat	0.22
Heath and natural grassland	0.19
Grasslands (meadows)	0.18
Tall herbs and arable field margins	0.18
Perennial crop	0.92
Annual crop	0
Beach, sand, coastal dunes	0
Fallow land	0
Built-up, infrastructure	0
Water	0

4.4.3 Carbon sequestration – monetary

The approach to estimate the economic value of carbon sequestration concerns the application of a carbon price based on achieving a policy-defined target of reduction in CO_2 emissions, which represent a measure for the avoided damage costs. By valuing carbon sequestration in biomass at this carbon price, we estimate in monetary terms the contribution of ecosystems to achieving the policy target.

The Netherlands Environmental Assessment Agency (PBL) and the Netherlands Bureau for Economic Policy Analysis (CPB) have calculated CO_2 prices relevant for the Netherlands. This is called the efficient price of CO_2, which is the price at which the necessary cumulative reduction in CO_2 emissions is achieved at the lowest costs (PBL, 2016). PBL and CPB distinguish three scenarios: a high-reduction scenario, a low-reduction scenario, and a two-degree temperature increase scenario.

According to PBL (2016), by 2050 the efficient price is equal to the ETS price of a ton of CO_2 emissions, as all economic actors fall under the ETS. In the high-reduction scenario, the efficient price is 160 euros per ton of CO_2 in 2050; in the low-reduction scenario it is 40 euros per ton; and in the two-degree policy target it ranges from 200 to 1000 euros per ton. The discounted net present value is calculated using a discount rate of 3.5%.[10] For the year 2018, the corresponding figures are 53 euros per ton of CO_2 for the high-reduction scenario, 13 euros per ton of CO_2 for the low-reduction scenario, and 60 to 300 euros per ton for the two-degree policy target. Table 4.4.7 presents the net present value per ton of carbon (C) in 2013 thru 2020.

[10] Normally, this discount rate is 3%. PBL/CPB argue that a higher discount rate is warranted because the growth potential of economies in Southern and Eastern Europe is higher (Aalbers, Renes & Romijn, 2017, p. 10).

Note that these prices are per ton of carbon. The efficient prices per ton of CO_2 should be converted with a conversion factor to the efficient carbon (C) prices per ton,

Table 4.4.7 The efficient carbon price for the Netherlands: net present value per ton of carbon in 2013-2020

	high-reduction scenario	**low-reduction scenario**	**2°-scenario lower boundary**	**2°-scenario upper boundary**
2013	164	41	205	1026
2014	170	42	212	1062
2015	176	44	220	1099
2016	182	46	228	1138
2017	188	47	235	1177
2018	195	49	244	1219
2019	202	50	252	1261
2020	209	52	261	1305

Source: PBL (2018).

CE Delft takes the high-reduction scenario as the central scenario (between low and 2°-scenario). In this report we follow CE Delft's recommendation of the high-reduction scenario resulting in a carbon price of 209 euro per ton in 2020 (equivalent to 57 euro per ton CO_2).

4.4.4 Pollination - physical

Definition and scope

Pollination services are the ecosystem contributions by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy. Crop pollination is a regulating service defined as the fertilization of crops by pollinators that increase crop production. In the pollination service provided by ecosystems, pollination by wild organisms such as wild bees, bumble bees, butterflies and hoverflies was considered. Managed honey bees were excluded.

Logic chain

Crop pollination is primarily provided by the ecosystems in the landscape surrounding the crop fields and not by the cropland itself. Wild pollinators require sufficient resources in the agricultural landscape. These resources include suitable nesting habitats (e.g. tree cavities, or suitable soil substrate) as well as sufficient floral resources (i.e. pollen and nectar).
In physical terms this ecosystem is measured as kton avoided crop loss. The economic benefit is the reduced need for alternative forms of pollination, which van be expressed in monetary terms. monetary value of the crops. Agricultural producers are the beneficiaries of this ecosystem service.

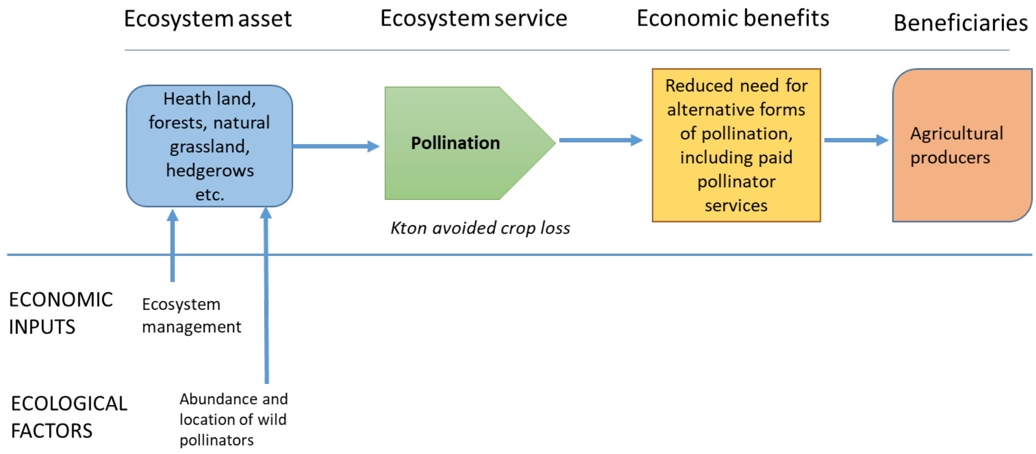


Table 4.4.9 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Basisregistratie Gewaspercelen	Spatial data	RVO.nl
Pollination requirements	Table	Klein et al. (2007)
Habitat suitability for pollinators	Table	Kennedy et al. (2013)

About 75% of the leading global food crops species depend on animal pollination (Klein et al., 2007). Together these crop species produce 35% of the global production volume. Without animal pollination the production of these crops will be up to 90% lower. The majority of crops are most effectively pollinated by bees (Klein et al., 2007; Ricketts et al., 2008). Pollinator visits not only move outcross pollen among individuals but also increase the total amount of pollen deposited on flower stigmas, both of which are known to increase quantity and quality of crops. Animal pollination reduces production loss, thereby increasing production. Wild pollinators can only partly be replaced by commercial beehives. For instance, wild bumble bees are able to fly and pollinate at much lower temperatures than honey bees, which is essential for Dutch fruit production. Also, wild pollinators are required for maintaining the quality of several crops such as pears.

Method description

Crops differ in pollination requirements. Klein et al. (2007) divided crops, depending on degree of production dependence, in five classes (table). These are used to assign pollination demand to crops in the Netherlands (table). Note that the model assumes that pollinators are indeed present in habitats that are suitable for them (actual observation data of wild bees and other pollinators are not available), and that they all contribute to the pollination of nearby planted crops. Pollination by honey bees is not included in the analyses.

Table 4.4.10 Classes for dependence of crops on pollination, based on yield loss in absence of pollinators. Between brackets the class mean that is used to generate maps of pollination demand of crops. Source: Klein et al. (2007).

Degree of dependence	Production reduction in absence of pollinators	Crops
Essential	> 90%	Courgette, pumpkin
Large	40% - 90% (65)	Raspberries, blackberries, other berries, annual fruit cultivation, perennial fruit cultivation (e.g. pear, apple, cherry) and summer rapeseed, and winter rapeseed
Modest	10% - 40% (25)	Strawberries, eggplant, redcurrants, blackcurrants, summer oilseed rape, winter oilseed rape, and sunflower
Little	0% -10% (5)	Other beans and other oilseeds
No increase	no reduction (0)	Other crops

Table 4.4.11 Look-up table for pollination demand of pollination dependent crops classes in the basic registration of crops in the Netherlands (*Basisregistratie Gewaspercelen*). Based on the classification used for the pollination requirements for the Atlas Natuurlijk Kapitaal (ANK) and the classification of Klein et al. (2007).

Crop code	Description	Pollination demand (%)
242	Beans (bruine bonen)	5
311	Field beans	25
258	Alfalfa	5
515	Sunflower	25
663	Lupine	5
664	Rapeseed	65
665	Soybeans	5
666	Linseed	5
853	Broad beans (tuinbonen, droog)	5
854	Broad beans (tuinbonen, groen)	5
1095-1096	Apple	65
1097-1098	Pear	65
1100	Stone fruits	65
1869	Blueberry	65
1870	Plum	65
1872	Sour cherry	65
1873	Blackberry	25
1874	Other small fruits	25
1922	Oilseed rape, winter	25
1923	Oilseed rape, summer	25
2325	Red berry	25
2326	Raspberries	65
2327	Blackberries	65
2328	Sweet cherry	65
2700-2707	Strawberries	25
2731-1732	Gherkin	65
2723-2724	Courgette	95
2729-2730	Cucumber	65
2733-2734	Melon	95
2735-2736	Pumpkin	95
2779-2780	Stem green bean	5
2781-1782	String bean	5

Most studies on natural pollination are focussed on wild bees and bumble bees. Historically, pollination demand was fulfilled by wild pollinators that live in the agricultural landscape. Nowadays, beekeepers place hives with cultivated honey bees, Apis mellifera, close to pollination demanding crops. Many crops, however, are also effectively pollinated by wild bees. Furthermore, honey bees are not always the most efficient pollinator; for some crops wild bees are more efficient than honey bees. As an ecosystem service, we map pollination by wild organisms such as wild bees, bumble bees, butterflies, and hoverflies. Managed honey bees were excluded. Wild pollinators require sufficient resources in the agricultural landscape. These resources include suitable nesting habitats (e.g. tree cavities, or suitable soil substrate) as well as sufficient floral (food) resources (i.e. pollen and nectar). Bees are central place-foragers. This means that they return to their nest site after foraging. The availability of nesting habitats close to agricultural fields is critical for bee-pollinated crops (Ricketts et al., 2006). Ecosystems differ in the suitability for pollinators, because there are differences in the presence of tree cavities or suitable substrates for nesting, and differences in the availability and suitability of floral resources (Kennedy et al., 2013). We used indicators for total nesting and floral resource availability for the suitability of the ecosystem types (table). These indicators were based on a meta-analysis of 39 studies that was conducted by Kennedy et al. (2013). Note that private gardens, whether in rural (farmyards and barns) or in urban areas (residential areas), are set to zero suitability due to the lack of information and the spatial heterogeneity of all 'paved and built- up areas'.

Table 4.4.12 Look-up table for an indicator of combined nesting suitability and floral resource availability for ecosystem types in the Netherlands, on a 0 - 100 scale, with 100 indicating most suitable, and 0 unsuitable (based on Kennedy et al., 2013). *total nesting and floral suitability for regular cultivation of economic crops were not used in the model (assumed value = 0), because these are considered to be the recipients of the pollination service and not suitable year-round for pollinators.

Description ecosystem types	Total nesting and floral suitability
Heath	100
Forest; deciduous	89
Natural grassland, arable field margins	80
Forest; mixed	66
Perennial crop, extensive	58
Grassland, extensive	53
Tall herbs	48
Forest; coniferous	44
Annual crop, natural or extensive	41
Salt marsh, bog and lowland peat	36
Grassland	26
Beach, sand, coastal dunes	26
Fallow land	26
Built-up, infrastructure	0
Water	0

The maps for the pollination account are generated based on the spatial location of crops that require pollination (Basisregistratie Gewaspercelen of the accounting year) and the spatial location of ecosystems that are suitable for pollinators on the Ecosystem Type map of the accounting year. We generated two maps; one map that plots the use of the pollination service of the ecosystems, based on the demand of the crop and the distance between the demanding crop to the pollination providing ecosystem, and one map that plots the supply of the pollination service of the ecosystems, based on the suitability of the ecosystems for pollinators and the distance between the suitable ecosystem and the demanding crop. Different species of pollinators move at different length scales. Large pollinators such as bumble bees forage over long distance (up to 1750 m; Walther-Hellwig and Frankl, 2000), while small pollinators such as solitary bees, forage over shorter distances (up to several hundred meter). We generate the suitability and demand maps for all natural pollinators. Ricketts et al. (2006) found in their meta-analysis on 13 studies in temperate biomes that visitation rates of pollinators declined to half its maximum at 1308 m distance between the nesting sites and the crop. The optimal model for visitation rate (scaled 0 – 1, with 1 the maximum visitation rate) in temperate biomes is exp(-0.00053d). Where d, is distance between the nesting sites and the crop in meters. This model includes both species that forage over long distances and species that remain close to their nesting site. In the model, pollination service is assigned to the nearest suitable habitat. Pollinators leave their nesting sites to forage in the surrounding landscape. We assume that pollinators from all suitable habitats in the local landscape contribute to pollination. To obtain the relative visitation rate (scaled 0 -100) in a crop in map unit c (Lonsdorf et al., 2009) we calculat

$$v_c = \sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{hc}}}{\sum e^{-0.00053 d}}$$

where Sh represents the relative pollinator abundance (scaled 0 – 100, where 100 marks maximum suitability) in map unit h (based on the suitability for nesting and foraging for pollinators of the habitat in map unit h), dhc is the distance between map unit h and the crop in map unit c. Pollination is then a function of the relative visitation rate,

$$P_c = f(v_c)$$

Rader et al. (2016) find a relationship between visitation variation and fruit set variation, based on 39 studies. Variation in fruit set was measured in 14 crops. They found that both bees (not including honey bees) and non-bee pollinators had a positive relationship between fruit set and pollination. Furthermore, studies show that often more pollen are deposited than needed for successful fruit set, 10 to 40 times more pollen have been reported in Sáez et al. (2014) and Pfister et al. (2017). Therefore, we model the function of pollination based on visitation rate as $P_c = 5v_c$, v_c between 0 and 20 and 100 for vc ≥ 20. This is a starting assumption, there can be differences between crops, but we do not take that into account here.

Next, we generate a potential production reduction map in absence of pollination based on the spatial location of crops in 2013, 2015, 2018 and 2020 (Basisregistratie Gewaspercelen 2013, 2015, 2018 and 2020) (RVO.nl, 2020) and table 4.4.14. Pollination service can be calculated as the difference between the production reduction in absence of pollinators and the production reduction in presence of pollinators.

To calculate pollination reduction in presence of pollinators, we combine the pollination map that is based on the Ecosystem Type map and spatial relationships of visitation rates by pollinators with the production reduction map, using the following equation:

"Avoided production reduction" = "potential production reduction" * ("pollination")/100

The avoided production reduction represents the use of the pollination service by the crops. Next, we calculate the contribution (supply) of the ecosystems to the avoided production reduction, APR_h,

$$APR_h = \sum_{c=1}^{C} APR_c \frac{\sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{ch}}}{\sum e^{-0.00053 d}}}{\sum_{h=1}^{H} S_h}$$

Where APR_c is the avoided production loss in the crop in map unit *c*, d_{ch} is the distance between the crop in map unit *c* and the ecosystem in map unit *h*. The relative contribution of all ecosystems in a 15 km radius around the crop is weighted by the sum of the relative pollinator abundances, S_h. Contribution to avoided production loss in crop fields by the ecosystem in map unit *h* is based on all crop fields that require pollination in a 15 km radius around map unit *h*. This is calculated for all map units that contain an ecosystem that is suitable for pollinators.

4.4.5 Pollination - monetary

Table 4.4.13 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Basisregistratie Gewaspercelen 2013, 2015, 2018 and 2020	Spatial data	RVO.nl
Pollination requirements	Table	Klein et al. (2007)
Habitat suitability for pollinators	Table	Kennedy et al. (2013)
Standard yield	Table	Wageningen Economic Research
Yield apples and pears	Table	Statline

Table 4.4.14 Look-up table for pollination dependent crops and crop production per hectare, given per pollination dependent crop in the basic registration of crops in the Netherlands (*Basisregistratie Gewaspercelen*)

Crop code	Description	Production euro/ha 2013	Production euro/ha 2015	Production euro/ha 2018	Production euro/ha 2020
242	Beans	*2,350*	*2,040*	*1,920*	*2310*
311	Field beans	895	895	895	815
258	Alfalfa	900	900	900	980
515	Sunflower	1,440	1,440	1,440	1,540
663	Lupine	1,260	1,260	1,260	1,150
664	Rapeseed	1,440	1,440	1,440	1,540
665	Soybeans	1,270	1,270	1,270	1,270
666	Linseed	1,270	1,270	1,270	1,360
853	Broad beans	2,380	2,380	2,380	2,070
854	Broad beans	2,980	2,980	2,980	2,590
1922	Oilseed rape, winter	1,440	1,440	1,440	1,540
1923	Oilseed rape, summer	1,190	1,190	1,190	1,320
2700	Strawberry, open field, multiplication	102,500	102,500	102,500	107,000
2701	Strawberry, open field, waiting bed	41,100	41,100	41,100	42,600
2702	Strawberry, open field, production	55,900	55,900	55,900	49,100
2703	Strawberry, open field, seed	102,500	102,500	102,500	107,000
2704	Strawberry, rack, multiplication	133,500	133,500	133,500	148,000
2705	Strawberry, rack, waiting bed	53,400	53,400	53,400	55,500
2706	Strawberry, rack, production	72,700	72,700	72,700	83,300
2707	Strawberry, rack, seed	133,500	133,500	133,500	148,000
2731	Gherkin, production	19,100	19,100	19,100	19,100
2732	Gherkin, seed	40,000	40,000	40,000	41,600
2723	Courgette, production	28,800	28,800	28,800	38,200
2724	Courgette, seed	40,000	40,000	40,000	41,600
2729	Cucumber, production	13,700	13,700	13,700	13,700
2735	Pumpkin, production	6,340	6,340	6,340	5,800
2736	Pumpkin, seed	40,000	40,000	40,000	41,600
2779	Stem green bean, production	2,320	2,320	2,320	2,230

Crop code	Description	Production euro/ha 2013	Production euro/ha 2015	Production euro/ha 2018	Production euro/ha 2020
2780	Stem green bean, seed	40,000	40,000	40,000	41,600
2781	String beans, production	13,700	13,700	13,700	12,400
2782	String beans, seed	40,000	40,000	40,000	41,600
1095	Apple, new	14,600*	14,600	21,100	19,300
1096	Apple	14,600*	14,600	21,100	19,300
1097	Pear, new	32,100*	32,100	36,600	42,800
1098	Pear	32,100*	32,100	36,600	42,800
1100	Stone fruits (including peach)	35,000	35,000	35,000	31,500
1869	Blueberry	58,700	58,700	58,700	64,400
1870	Plum	17,100	17,100	17,100	12,600
1872	Cherry, sour	6,340	6,340	6,340	5,710
1873	Blackberry	3,160	3,160	3,160	3,100
1874	Other small fruits	35,200	35,200	35,200	34,500
2325	Redberry	62,500	62,500	62,500	61,300
2326	Raspberries	130,000	130,000	130,000	155,000
2327	Blackberries	177,000	177,000	177,000	184,500
2328	Cherry, sweet	35,000	35,000	35,000	31,500

Notes: Pollination demand is based on the classification used for the pollination requirements of Klein et al. (2007). Crop production is based on production statistics produced by StatLine per year when available (written in *italic*). Remaining data is based on the standard production as calculated by the Wageningen Economic Research (Everdingen and Wisman, 2017; Wisman, 2021) based on average production in 5 consecutive years. Starting from 2015 a distinction was made between fruit types and open field vegetables. Therefore, starting from 2015 it is possible to make a distinction between vegetables that depend on pollination and vegetables that do not depend on pollination. This is not the case for 2013, to calculate the avoided production loss in 2013, we assumed that the pollinator dependent fruit (code 212) and vegetables (code 672) were grown in the same position as in 2015. With crop rotation this is not the case for all fruit and vegetables, but as there is a declining trend in the area of pollinator dependent fruit and vegetables grown it is best to take the areas from the most recent map with the new classification.

The maps for pollination are generated based on the spatial location of crops that require pollination (Basisregistratie Gewaspercelen 2013, 2015, 2018 and 2020; RVO.nl, 2020) and the spatial location of ecosystems that are suitable for pollinators on the Ecosystem Type maps of the corresponding years.

To calculate avoided reduction in crop production due to the presence of pollinators in monetary terms, the pollination rates as calculated for the physical Account are combined with the potential production reduction map, based on standard yield in euro per hectare for each pollination dependent crop (table 4.4.14), using the following equation:

"Avoided production reduction" = "potential production reduction" * ("pollination")/100

The avoided production reduction is calculated in the crop fields and represents the use of the pollination service by the crops.

Next, we calculate the contribution (supply) of the ecosystems to the avoided production reduction, APR_h,

$$APR_h = \sum_{c=1}^{C} APR_c \frac{\sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{ch}}}{\sum e^{-0.00053 d}}}{\sum_{h=1}^{H} S_h}$$

where APR_c is the avoided production loss in the crop in map unit *c* (in euro/hectare), d_{ch} is the distance between the crop in map unit *c* and the ecosystem in map unit *h*. The relative contribution of all ecosystems in a 15 km radius around the crop is weighted by the sum of the relative pollinator abundances, S_h. Contribution to avoided production loss in crop fields by the ecosystem in map unit *h* is based on all crop fields that require pollination in a 15 km radius around map unit *h*. This is calculated for all map units that contain an ecosystem that provides pollination.

4.4.6 Air filtration - physical

Definition and scope

Air filtration services are the ecosystem contributions to the filtering of air-borne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly plants, that mitigates the harmful effects of the pollutants (UN, 2021).
Particulate pollution covers a broad spectrum of pollutant types that permeate the atmosphere. Particulate matter is commonly referred to by size groupings: coarse and fine. PM_{10} includes particles up to < 10 µm in aerodynamic diameter, whereas $PM_{2.5}$ only represents the smallest particles (<2.5 µm). In recent years it has become clear that $PM_{2.5}$ particles pose a higher health risk because these smaller particles penetrate deeper into the lungs. Data from epidemiological studies indicates that long term exposure to $PM_{2.5}$ can increase both human morbidity and human mortality risks (Kunzli et al., 2000). Therefore, here we focus on the smaller particles.

The ecosystem service air filtration is here defined as the contribution of forests and other vegetation to the reduction in $PM_{2.5}$ concentration. Reducing $PM_{2.5}$ concentrations should reduce air-pollution related health costs as well as age-specific mortality risk in a population and consequently result in an increase in population statistical life expectancy.

Logic chain

Trees and other vegetation play an important role in the reduction of air pollution by supplying the ecosystem system air filtration The ecosystem service is measured as the total tonnes of $PM_{2.5}$ absorbed (Powe and Willis, 2004). The economic benefits of lower $PM_{2.5}$ concentrations are improved health outcomes, and the associated avoided damage costs. The increase in air quality provides benefits for society as a whole. Households are the beneficiary.

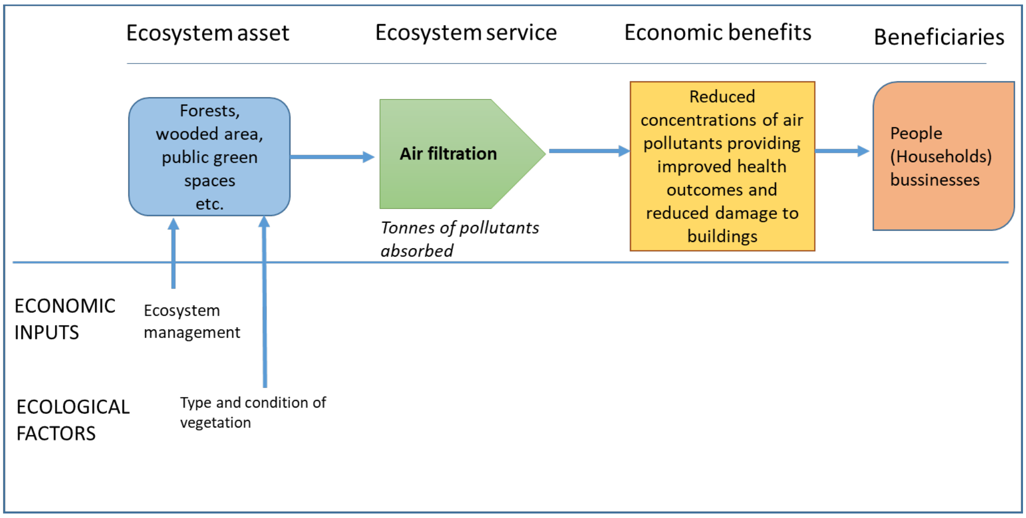


Table 4.4.15 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Yearly average $PM_{2.5}$ 2013, 2015, 2018 and 2020	Spatial data	RIVM
PM_{10} capture parameters	Reference values	Powe and Willis (2014)
Tree phenology	Observations	Nature Today
Rain days	Statistics	Environmental Data Compendium

Main assumptions

The model uses yearly average $PM_{2.5}$ concentration data. Hence an underlying assumption of the model is that $PM_{2.5}$ concentrations are normally distributed over a year. Timing of foliage as well as precipitation are Accounted for in the model. The model for PM_{10} capture by Powe and Willis (2004) is used to calculate $PM_{2.5}$ capture, by assuming that the capture process will be identical, as $PM_{2.5}$ is a fraction of PM_{10}.

Method description

Particulate matter is captured through deposition on leaf and bark surfaces. The process of deposition depends on tree type and meteorological conditions (Powe and Willis, 2004). Deposition varies depending on density of the foliage and leaf form (the leaf area index, LAI). For the calculation of PM_{10} capture by vegetated ecosystems (e.g. forests, natural grasslands, cropland, heath) we combined the Ecosystem Type map with a 10m spatial grain, a spatial raster with a 10m grain that can further distinguish between deciduous, coniferous and mixed forests (based on the TOP10NL) with a map of yearly average $PM_{2.5}$ in µg m^3 (based on 24 hour daily averages) for respectively 2013, 2015 and 2018 on a 1000 m spatial grain (RIVM, 2020). $PM_{2.5}$ capture was estimated using the following equation (as in Powe and Willis, 2004):

$$\text{ABSORPTION} = \text{SURFACE} * \text{PERIOD} * \text{FLUX}$$

where:

ABSORBTION = dry pollution deposition on vegetation cover ($PM_{2.5}$ *capture* in µg m^{-2})

SURFACE = area of land considered (A in m^2) * surface area index (S in m^2 per m^2 of ground area)

PERIOD = period of analysis (t in s (i.e. 31536000 s)) * proportion of dry days per year (p_{dry})* proportion of in-leaf days per year ($p_{on\text{-}leaf}$)

FLUX = deposition velocity (v_d in m s^{-1}) * ambient $PM_{2.5}$ concentration ($C_{PM2.5}$ in µg m^{-3})Or,

$$PM_{2.5}\ capture_{on\text{-}leaf}\ (\text{in } kg\ ha^{-1}) = A * S_{on\text{-}leaf} * t * p_{dry} * p_{on\text{-}leaf} * v_d * (10^{-9}/10^{-4}) * C_{PM2.5}$$

$$PM_{2.5}\ capture_{off\text{-}leaf}\ (\text{in } kg\ ha^{-1}) = A * S_{off\text{-}leaf} * t * p_{dry} * (1 - p_{on\text{-}leaf}) * v_d * (10^{-9}/10^{-4}) * C_{PM2.5}$$

We take,

$$M_{on\text{-}leaf} = A * S_{on\text{-}leaf} * t * p_{dry} * p_{on\text{-}leaf} * v_d * (10^{-9}/10^{-4})*0.5$$

And,

$$M_{off\text{-}leaf} = A * S_{off\text{-}leaf} * t * p_{dry} * (1 - p_{on\text{-}leaf}) * v_d * (10^{-9}/10^{-4})*0.5.$$

where the factor 0.5 denotes the resuspension rate of particles coming back to the atmosphere (Zinke, 1967).

For each vegetated ecosystem type we add these multiplication factors $M_{year} = M_{on\text{-}leaf} + M_{off\text{-}leaf}$ to calculate $PM_{2.5}$ *capture* in *kg* ha^{-1} based on ambient $PM_{2.5}$ concentration, $C_{PM2.5}$ in µg m^{-3}. The deposition velocities, the surface area index and multiplication factors can be divided into four classes of ecosystem types with vegetation cover, and are summarized in table xx. Values for deposition velocity are based on Powe and Willis (2004), however, for coniferous forest, we used a similar LAI as for in-leaf deciduous forest based on a meta-analysis by Asner et al. (2003). Data on phenology of emergence of leaves until the end of leaf fall of trees in the Netherlands (Nature Today, 2017) was used to estimate the proportion of in-leaf days for deciduous forests, on average deciduous trees were on-leaf from mid-April to mid-November (i.e. $p_{on\text{-}eaf}$ = 7/12). Data on average number of rain days with ≥ 1.0 mm precipitation (Environmental Data Compendium, 2017) was used to calculate the proportion of dry days. The average number of rain days in the Netherlands in the period between 1981 and 2010 was 131 (i.e. p_{dry}=234/365).

Table 4.4.16 Deposition velocities ($m\ s^{-1}$), the surface area index ($m^2\ m^{-2}$) and yearly multiplication factors for forest types and other vegetation types.

	Deposition velocity		Surface area		
Ecosystem type	**On-leaf**	**Off-leaf**	**On-leaf**	**Off-leaf**	M_{year}
Deciduous forest	0.0050	0.0014	6	1.7	1.87
Coniferous forest	0.0050	0.0050	6	6	3.03
Mixed forest					2.45[1]
Other vegetation	0.0010	0.0010	2	1.5	0.18

[1] Mixed forest is calculated as the average of the factors for coniferous forest and deciduous forest.

The presence of vegetation affects the observed $PM_{2.5}$ concentration, $CPM2.5_{obs}$. To calculate the service of $PM_{2.5}$ concentration reduction by vegetation, $CPM2.5_{red}$, the observed concentration needs to be corrected for the presence of vegetation in the reference situation. To calculate the reduction on the observed concentration due to the presence of vegetation, the capture of $PM_{2.5}$ measured in kg/ha needs to be converted to a reduction of the annual mean concentration of $PM_{2.5}$ in µg/m^3. Assuming a boundary layer of 2000m with mixing during the day, and converting capture per year to capture per day, results in a conversion factor θ, of 0.137 from kg/hectare/year capture to a reduction of the daily mean ambient $PM_{2.5}$ concentration in µg/m^3. Using this conversion factor we can first calculate the reduction in the observed concentration due to the presence of vegetation,

$CPM2.5_{red} = \theta * Myear * (CPM2.5_{obs} + CPM2.5_{red})$

This results in,

$$C_{PM2.5_{red}} = \frac{\theta * M_{year} * C_{PM2.5_{obs}}}{1 - (\theta * M_{year})}$$

The second step is to calculate the $PM_{2.5}$ concentration without vegetation present,

$$C_{PM2.5_{corrected}} = C_{PM2.5_{obs}} * \left(1 + \frac{\theta * M_{year}}{1 - (\theta * M_{year})}\right)$$

this results in a corrected $PM_{2.5}$ concentration that can be used to calculate the capture of $PM_{2.5}$ by the vegetation,

$$Capture\ PM_{2.5}(kg/ha) = M_{year} * C_{PM2.5_{corrected}}$$

4.4.7 Air filtration – monetary

Data from epidemiological studies indicates that long term exposure to $PM_{2.5}$ can increase both human morbidity and human mortality risks (Kunzli et al., 2000). Therefore, in the monetary Account we focus on the smaller particles (i.e. $PM_{2.5}$). To value the ecosystem service air filtration (or air quality regulation) an avoided damage cost approach was used, with $PM_{2.5}$ capture by forests and other vegetation as biophysical indicator.

Table 4.4.17 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data, raster 10m	Statistics Netherlands
Yearly average $PM_{2.5}$ 2013,2015, 2018, 2020	Spatial data, raster 1000m	RIVM
Yearly average PM_{10} 2013, 2015, 2018, 2020	Spatial data, raster 1000m	RIVM
Neighbourhood statistics 2013, 2015, 2018, 2020 (CBS buurt)	Spatial data, polygon	Statistics Netherlands
Age-dependent mortality, 2013, 2015, 2018, 2020	Statistics	Statline
Life expectancy 2013, 2015, 2018, 2020	Statistics	Statline
$PM_{2.5}$ capture parameters	Reference values	Powe and Willis (2014)
Tree phenology	Observations	Nature Today
Rain days	Statistics	Environmental Data Compendium

The biophysical model calculates $PM_{2.5}$ capture in kg per hectare per year. However, the effect of particulate matter on health is mostly derived from epidemiological studies where frequency of the health outcome is related to the level of exposure in µg/m^3. Therefore, the capture in kg $PM_{2.5}$ per hectare per year needs to be converted to a reduction in annual mean concentration $PM_{2.5}$ in µg/m^3 and an associated reduction in exposure to air pollutants. Assuming an atmospheric boundary layer of 2000m with mixing during the day, and converting capture per year to capture per day, results in a conversion factor of 0.137 from kg/hectare/year capture to a reduction of the daily mean ambient $PM_{2.5}$ concentration in µg/m^3. Some impact categories of the health costs of air pollution are related to $PM_{2.5}$ and others are related to PM_{10}, for the latter the local fraction of $PM_{2.5}$ in PM_{10} is used to calculate the local reduction in PM_{10} concentration.

$$C_{PM2.5_{reduction}} = Capture\ PM_{2.5}(kg/ha) * \theta$$

Several studies use a 1km^2 resolution to calculate the effect of vegetation on air pollution reduction (Remme et al., 2015; Powe and Willis, 2004; Oosterbaan et al., 2006). Furthermore, the yearly average $PM_{2.5}$ concentration in µg m^3 (based on 24 hour daily averages) was also available at a 1km^2 spatial resolution (RIVM, 2013). The reduction in $PM_{2.5}$ concentration due to vegetation was first calculated at a 10m spatial resolution based on the Ecosystem Types map and based on that map an average reduction in $PM_{2.5}$ concentration per km^2 was calculated. This was combined with population distribution data at a local level (CBS buurt 2013, 2015, 2018 and 2020 polygon maps), that included population density, age distribution and number of females and males per neighbourhood. These data were aggregated to a km^2 raster. Based on these data 6 maps for population density per km^2 were generated. One for the total population, which was used to calculate the avoided health costs. Five maps were generated for the population density in the age categories 0-14, 15-24, 25-44, 45-64 and 65 and older, as used to calculate avoided mortality costs. Furthermore, one map for the fraction of females per km^2 was generated.

To value air filtration, we calculated two measures for avoided damage, namely avoided health effects and avoided mortality. The avoided health costs were calculated similar to Remme et al. (2015) for the Dutch province Limburg. Mortality is valued with the maximum societal revenue value of a statistical life year (MSR-VOLY) as proposed by Hein, Roberts and Gonzalez (2016). The MSR-VOLY represents the VOLY that would theoretically apply in case there was 'market' for clean air, based on the demand curve for clean air and assuming that there are no costs related to supplying the ecosystem service. It corresponds with the Simulated Exchange Value proposed by Caparros et al. 2015, and is a type of posited exchange value as stipulated in the UK SEEA Accounting work (White et al., 2015).

Health costs

Similar to Remme et al. (2015) health impact categories were used that were identified in a study by Preiss et al. (2008) on health costs of air pollution in the European Union. In line with the SEEA-EEA approach, categories that were based on direct costs were included while categories that include components of consumer surplus were excluded. Damage costs for a person due to an increase of 1 $\mu g/m^3$ $PM_{2.5}$ was estimated at about 7.39 euros per person (2015 €) and damage cost for a person due to an increase of 1 $\mu g/m^3$ PM_{10} was estimated at 2.72 euros per person (2015 €) (Table 4.4.18). For the costs related to PM_{10}, we correct the reduction in $PM_{2.5}$ concentration with the fraction of $PM_{2.5}$ in PM_{10}. In 2015, this fraction ranges from 0.30 to 0.75, with a mean of 0.58. The value of avoided exposure to 1 $\mu g/m^3$ $PM_{2.5}$ per person is in this case about 12 euros per person (2015 €). For other years these numbers are adjusted based on the fraction of the population in the age groups in the table ("age group factor"), presented in Table 4.4.19, and by correcting the values for inflation.

MSR – VOLY

Next to on air pollution related health costs air pollution related mortality was taken into account and valued based on the maximum societal revenue. It represents the point where the multiplication of a WTP and the number of people expressing at least this WTP is at its maximum (Hein et al., 2016). We used an estimate for the MSR-based on the mean and median value of a WTP survey in several EU countries and Switzerland by Desaigues et al. (2011) in which people were asked to value a three-month increase in life expectancy.

Table 4.4.18 Health impact categories resulting from $PM_{2.5}$ and PM_{10} concentration change, risk group, age group, concentration response functions, physical impact on a person, monetary value per unit and external costs in €(2015) per person per µg/m^3. Risk group, age group and concentration response function are adapted from Preiss et al. (2008), unless stated otherwise. Age group factor is adjusted for the Netherlands (2015, in this table) and monetary value is corrected for inflation (2013€ = 0.9844 2015€, and 2018€ = 1.0335 2015€, 2020€ = 1.0750 2015€).

Health impact categories	Risk group	Risk group factor	Age group	Age group factor	Concentration response function	Physical impact per person per µg/m³	Unit	Monetary value per unit (2015€)	External cost € per person per µg/m³
Nett restricted activity days	all	1	total	1	$9.59*10^{-3}$	$9.59*10^{-3}$	days	145.48	1.40
Work loss days	all	1	15-65	0.655	$2.07*10^{-2}$	$1.35*10^{-2}$	days	330.13	4.48
Minor restricted activity days	all	1	18-65	0.619	$5.77*10^{-2}$	$3.56*10^{-2}$	days	42.52	1.52
Total in € per person per µg/m³ $PM_{2.5}$									7.39
New cases of chronic bronchitis	all	1	≥27	0.685	$2.65*10^{-5}$	$1.81*10^{-5}$	cases	24840[a]	0.45
Respiratory hospital admissions	all	1	total	1	$7.03*10^{-6}$	$7.03*10^{-6}$	cases	2845[b]	0.02
Cardiac hospital admissions	all	1	total	1	$4.34*10^{-6}$	$4.34*10^{-6}$	cases	2845[b]	0.0123
Medication use/brochodilator use child	children meeting PEACE criteria – EU average	0.2	5 - 14	0.115	$1.80*10^{-2}$	$4.10*10^{-4}$	cases	1.12	0.000463
Medication use/brochodilator use adult	astmathics	0.045	≥20	0.773	$9.12*10^{-2}$	$3.18*10^{-3}$	cases	1.12	0.00355
Lower respiratory symptoms (adult)	symptomatic adults	0.3	adults	0.797	$1.30*10^{-1}$	$3.04*10^{-2}$	days	42.52	1.32
Lower respiratory symptoms (child)	all	1	5 - 14	0.115	$1.86*10^{-1}$	$2.12*10^{-2}$	days	42.52	0.91
Total in € per person per µg/m³ PM_{10}									2.72

[a] Adapted from Remme et al. (2015).

[b] Adapted from "passantenprijzen DBC zorgproducten".

Table 4.4.19

Health impact categories	Age group	AGF 2013	AGF 2015	AGF 2018	AGF 2020
Nett restricted activity days	total	1	1	1	1
Work loss days	15-65	0.66	0.655	0.651	0.649
Minor restricted activity days	18-65	0.625	0.619	0.614	0.612
Total in € per person per µg/m³ $PM_{2.5}$					
New cases of chronic bronchitis	≥27	0.682	0.685	0.69	0.694
Respiratory hospital admissions	total	1	1	1	1
Cardiac hospital admissions	total	1	1	1	1
Medication use/brochodilator use child	5 - 14	0.117	0.115	0.11	0.107
Medication use/brochodilator use adult	≥20	0.769	0.773	0.778	0.783
Lower respiratory symptoms (adult)	adults	0.793	0.797	0.803	0.807
Lower respiratory symptoms (child)	5 - 14	0.117	0.115	0.11	0.107

The damage costs based on the MSR for a statistical life year lost due to an increase in $PM_{2.5}$ are estimated at 16,270 euros (2015 €). The mean value of an avoided exposure to 1 µg/m3 per person is in this case about 10.10 euro (2015 €). This mean value is based on the outcomes of our spatial model, based on the spatial distribution of the reduction in $PM_{2.5}$ and the spatial distribution of the population and the spatial age distribution.

Data from epidemiological studies indicate that long-term exposure to $PM_{2.5}$ can increase age-specific mortality by about 6% per 10 µg/m³ (Carey et al., 2013). Avoided statistical life years lost were modelled based on spatial data per neighbourhood regarding population density, age and gender supplemented with statistics on age-dependant mortality and life expectancy. The spatial maps contained spatial data on population size in the age categories 0-14, 15-24, 25-44, 45-64 and 65 and older and number of females per neighbourhood (maps: based on CBS buurt, Statistics Netherland). The density was first sampled at a 10x10m raster and then aggregated to a 1kmx1km raster, using the mean. Age-specific mortality for the above age categories is calculated based on mean mortality rates per 5-year age class and relative abundance of the 5-year age class in the above age categories (data: adapted from StatLine, table 4.4.20). Furthermore, age-dependent life expectancy of males and females was available up to an age of 80 year, age-specific mortality rates were used to estimate life expectancy up to 100 years (data: adapted from StatLine, table 4.4.20).

Table 4.4.20 a) Age specific mortality rate of females and males and b) life expectancy of females and males, as used in the calculations for 2013, 2015 and 2018, c) age specific mortality rates and life expectancy of females and males as used in the calculation of 2020
a)

Age category	Mortality rate					
	Female			Male		
	2013	2015	2018	2013	2015	2018
0 – 14	0.00029	0.00026	0.00026	0.00035	0.00032	0.00032
15 – 24	0.00018	0.00013	0.00016	0.00030	0.00028	0.00030
25 – 44	0.00046	0.00045	0.00043	0.00073	0.00071	0.00068
45 – 64	0.00341	0.00333	0.00315	0.00456	0.00435	0.00418
65+	0.03668	0.03671	0.03601	0.03946	0.03863	0.03767

b)

Age category	Life expectancy (months)					
	Female			Male		
	2013	2015	2018	2013	2015	2018
0 – 14	912.8	913.0	916.0	869.7	872.9	878.6
15 – 24	766.4	766.9	770.2	724.2	727.5	733.5
25 – 44	585.0	587.7	594.3	544.4	550.5	560.2
45 – 64	367.3	367.1	367.8	329.3	332.2	335.9
65+	160.1	160.6	161.0	147.3	148.8	150.1

c)

Age category	2020			
	Mortality rate		Life expectancy (months)	
	Female	Male	Female	Male
0 – 14	0.00029	0.00034	913.4	873.0
15 – 24	0.00016	0.00029	767.2	727.4
25 – 44	0.00045	0.00069	592.9	555.4
45 – 64	0.00303	0.00430	362.9	328.1
65+	0.03751	0.04117	157.5	143.2

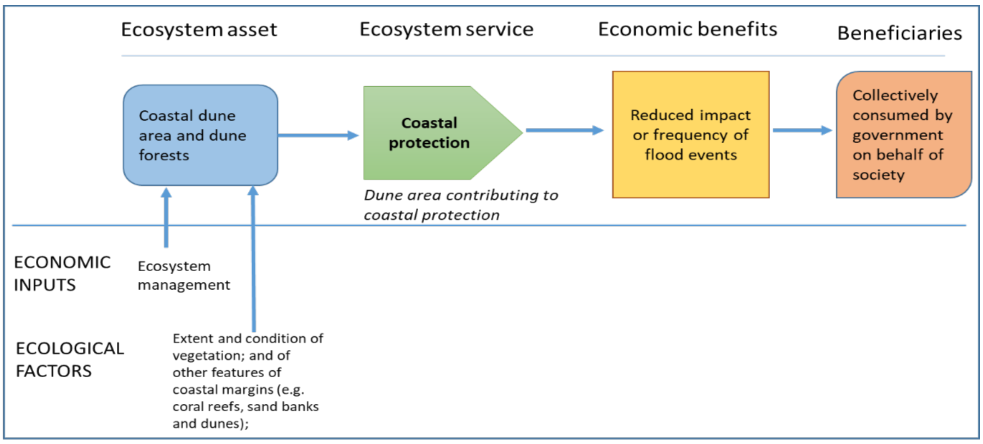
4.4.8 Coastal protection – physical and monetary

Definition and scope

Coastal protection services are the ecosystem contributions of linear elements in the seascape, for instance coral reefs, sand banks, dunes or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities (UN, 2021). The Dutch coast is characterised by coastal dunes that protect the hinterland from intrusions by the sea.

Logic chain

Coastal protection is provided by coastal dunes and dune forests ecosystems. The ecosystem service in physical units is expressed as the total area of dune area that provides coastal protection. The economic benefit is the reduced impact or frequency of flood events. Coastal protection provides benefits for society as a whole. The beneficiary is therefore the government, as a representative for the whole of society.



Method

Roughly one third of the Netherlands are below 0 NAP (Normaal Amsterdams Peil), the mean height of the North sea. Coastal dunes and beaches protect these lower areas of the Netherlands from flooding. In 1957, 4 years after the disastrous storm surge of 1953, the Delta Act came into effect to set requirements for dunes and dikes to protect the Netherlands from storm surges. In 2017, the Water Act stipulated which standards all primary flood defences (both dunes and dikes) must meet by 2050. The complete dune area is considered to play a role in the coastal protection, therefore the total coastal dune area and dune forests is determined for the physical service. The monetary value is calculated based on replacement costs. Dunes could either be replaced by new dikes or by new dunes. The height of these dikes depend on the tide but also on the set norm for flooding. However, the Netherlands has a very long history of using dikes as coastal protection, therefore there are only examples of costs for increasing the height of the dikes, and not for placing a new coastal dike. These costs are in the order of 10 million euro per 1m elevation of 1 km dike. The Delta norm for dikes at the North Sea coast is about 11.5 meter. It is not likely that there are constant costs per meter elevation for this height. In 2015, the Hondsbossche en Pettemer zeewering (a coastal dike of 5.5 km) was replaced by a completely man-made system of dunes and a beach. These dunes and beach completely took over the function of primary coastal defence. This project cost 140 million euro (excl. VAT). Regarding total costs of 140 million euro to replace 5.5 km dike, a resource rent of 2% and a total period of 100 years, the monetary value would be 0.59 million euro per km coastal dune. In total, 264.1 km of the coast is protected by dunes. In 2015, the total value of the coastal protection service was equal to 155.9 million euro.

4.4.9 Protection flooding against heavy rainfall – physical

Definition and scope

Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation services will be supplied together with river flood mitigation services in providing the benefit of flood protection (UN, 2021).
Here, we focussed on the protection against heavy rainfall. The rainwater regulation service is defined as the infiltration capacity of the soil during 1 hour and the interception of rain through the foliage in mm in an unsaturated soil.

Logic chain

Protection against flooding due to heavy rainfall is supplied by all unpaved ecosystems. The infiltration capacity depends on soil type, soil moisture and the presence of vegetation. The ecosystem service is measured in million litres of rainwater infiltration capacity for soils. The economic benefit is the reduced impact of heavy rainfall /flood events. The beneficiary is therefore the government, as a representative for the whole of society.

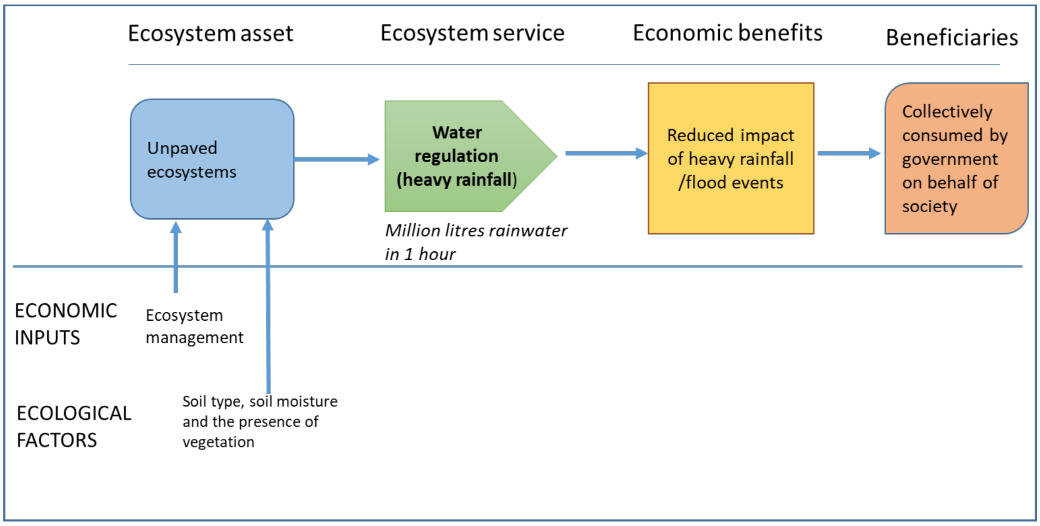


Table 4.4.21 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Tree cover map: bomen 10m	Spatial data	RIVM
Shrub cover map: struik 10m	Spatial data	RIVM
Grass cover map: gras 10m	Spatial data	RIVM
Soil map urban areas: bofek_10m_v2	Spatial data	RIVM
CBS buurt 2013, 2015, 2018 and 2020	Spatial data	Statistics Netherlands
Infiltration capacity data	Reference values	Akan et al. (1993)
Interception of precipitation by vegetation	Reference values	Nedkov and Burkhard (2012)

Main assumptions

It is assumed that the infiltration capacity per soil- and vegetation type provided in the tables below represents reality in the Netherlands reasonably well. Local soil compaction and the possible influence of tilling and ploughing was not taken into Account here though. In addition the occurrence of e.g. clayey and loamy deposits at greater depths below the surface were not taken into Account, possibly leading to local errors where these deposits do occur.

Method description

For the calculation of infiltration capacity of rain water in urban areas we combined the Ecosystem Type map with a 10 m spatial grain with three vegetation of trees, shrubs and grass with a 10 m spatial grain and a soil map that contains soil types in urban areas (RIVM: CLO-0243, CLO-0532, CLO-0231). These present the percentage of the cell that is covered with trees, shrubs and grass, respectively. In the 10 m grain cells, 1% cover equals 1 m^2 cover. To calculate infiltration capacity for different degrees of urbanization, we used an urbanisation level map per neighbourhood of 2013, respectively 2015 and 2018 (Statistics Netherlands,). Infiltration capacity depends on soil type, soil moisture and the presence of vegetation. We used a look up table approach to combine the soil map with initial infiltration rates in saturated and unsaturated soils and for dense and no vegetation (table 4.3.22). While soils are not saturated, vegetation enhances infiltration capacity.

Infiltration capacity for each 10m x 10m cell was calculated as:

$$\text{Infiltration} = p_{\text{vegetated}} * \text{infiltration}_{\text{vegetated}} + p_{\text{open}} * \text{infiltration}_{\text{open}}$$

In these equations, $p_{\text{vegetated}}$ is the total fraction of the cell that is occupied by forest, shrubs and grass and p_{open} is the remaining fraction, i.e. soil without vegetation. In unsaturated soils the infiltration capacity in the vegetated area is higher than in the open area (table 4.4.22), while for a saturated soil the infiltration capacity of the vegetated area and the non-vegetated area is identical (both are equal to the final infiltration capacity (table 4.4.22)). We classified cells as paved or unpaved based on the ecosystem type (table 4.4.23). In unpaved areas, rain water can infiltrate both in vegetated and in open areas, while in paved areas, rain water can only infiltrate in vegetated areas.

Infiltration capacity in unsaturated soil is calculated based on the Horton model that calculates current infiltration rate based on an initial infiltration capacity, f_0, and a final infiltration capacity, f_c, and the time since the start of the infiltration, t, and a constant k that models how fast the infiltration capacity declines. The Horton model (Horton, 1933):

$$f(t) = f_c + (f_0 - f_c)\, e^{-kt}$$

The Horton model can be integrated to calculate the total infiltration in time *t,*

$$F(t) = f_c\, t + ((f_0 - f_c)*(1 - e^{-kt})\, /k)$$

We use the total infiltration in 60 minutes for our calculations for infiltration (table 4.4.22).

To calculate interception by the vegetation, we used a look-up table in combination with the three vegetation maps; tree map, shrub map and grass map (table 4.4.24).

Table 4.4.22 Initial infiltration capacity, final infiltration capacity and total infiltration in 60 minutes, depending on soil type and presence vegetation (Akan et al., 1993).

	Infiltration (mm/h (per m²))			**Infiltration (mm in 1h (per m²)**	
	Initial infiltration capacity, f_0		**Final infiltration capacity, f_c**	**Total infiltration in 60 minutes, *F*(*60*)**	
	Unsaturated soil		**Saturated soil**	**Unsaturated soil**	
Soil type	**Vegetated[1]**	**Open[1]**		**Vegetated**	**Open**
Heavy clay soil	50	25	0.5	12.3	6.3
Clay soil	50	25	1.5	13.0	7.1
Organic soils	50	25	2.2	13.6	7.6
Loam soil	150	75	2.1	37.3	19.4
Sandy loam soil	150	75	6.0	40.2	22.4
Loamy sand soil	150	75	11.0	44.0	26.2
Sandy soils	250	125	20.0	74.7	45.0

[1] Based on a relationship between values of initial infiltration for moist and unsaturated soils and sparse and dense vegetation proposed by Akan et al. (1993) (i.e. infiltration in soil with dense vegetation is 2 * infiltration in soil with sparse to no vegetation).

Table 4.4.23 Division in paved (impermeable for rain water) and unpaved (permeable for rain water) soil based on ecosystem type.

	Ecosystem types
unpaved	All agricultural ecosystems (except green houses and built-up farm yards), all dune ecosystems, all forest and other natural ecosystems and other unpaved terrain, river flood plains and tidal salt marshes
paved	All built up areas, green houses and built-up farm yards.

Table 4.4.24 Interception of precipitation of trees, shrubs and grass (Nedkov and Burkhard, 2012).

	Interception (mm)	
Vegetation type	**Vegetation**	**Litter**
Trees	3.0	5.8
Shrubs	1.0	
Grass	1.3	

4.4.10 Local climate regulation (Mitigation of urban heat island)

Definition and scope

Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production (UN, 2021).

Here we have defined the local climate regulation service as the contribution of vegetation located within a radius of 500m to the cooling capacity of urban areas during a heat wave. This ecosystem service is thus only supplied in urban areas.

Logic chain

Local climate regulation services are supplied by vegetated ecosystems within urban areas. The ecosystem service in physical terms is expressed as the contribution of vegetation to the temperature reduction of the increased temperature in the urban areas due to the urban heat island effect. The temperature reduction is expressed as the reduction of the increased temperature in the city cumulative over a heat wave, with a unit in degree-days. The economic benefits are Improved living conditions and economic production. Beneficiaries ca be both people (households) and businesses.

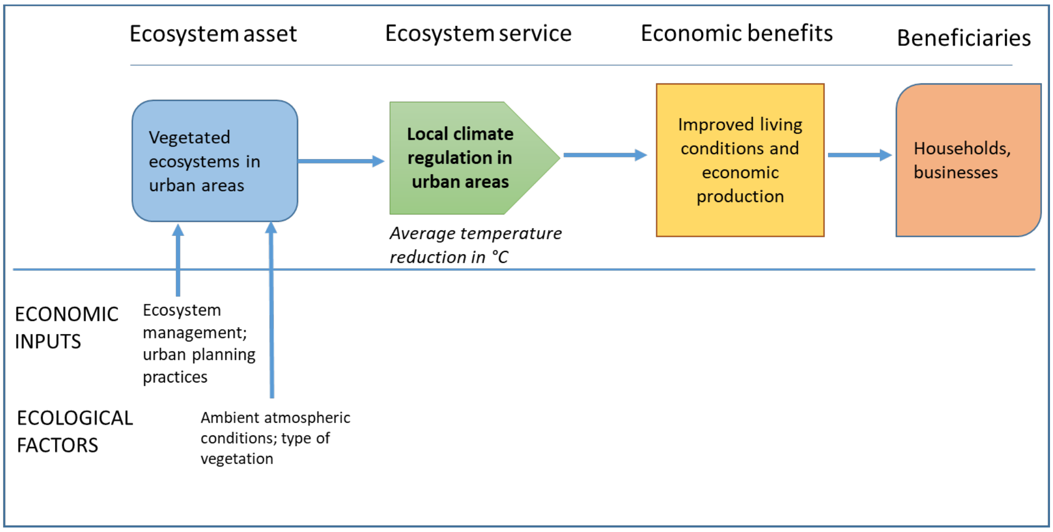


Table 4.4.25 Input data

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Tree cover map: bomen 10m	Spatial data	RIVM
Shrub cover map: struik 10m	Spatial data	RIVM
Grass cover map: gras 10m	Spatial data	RIVM
CBS buurt 2013, 2015, 2018 and 2020	Spatial data	Statistics Netherlands
Sky-view-factor	Spatial data	KNMI
S	Climate data	KNMI
DTR	Climate data	KNMI
U	Climate data	KNMI

Main assumptions

It is assumed that vegetation cover and the sky-view factor (e.g. the fraction of open air that can be seen in a 360 degree radius (Dirksen et al., 2019)) can estimate the increased temperature in the urban areas as compared to rural areas reasonable well. Direct measures for the availability of water for vegetation (which influences the evaporation capacity of the vegetation) is not taken into account, nor is the shading effect explicitly taken into account. During a longer heath wave the effect of vegetation might be overestimated.

Urban areas heat up more than the surrounding rural areas due to the Urban Heat Island (UHI) effect. This additional heating occurs due to the higher absorption of sunlight by darker materials such as asphalt and concrete, and a slower release of this heat by these materials, a reduced wind speeds between buildings and less natural evaporation because of soil sealing. The additional heat can cause health problems during warm periods, especially for the elderly and young infants (e.g. Kovats & Hajat, 2008). By increasing the evaporation capacity, vegetation can have a positive effect on the cooling capacity of an area. Furthermore, vegetation can provide shade and vegetation releases heath more easily than sealed areas, resulting in faster cooling down during the nights.

To increase in temperature in urban areas is calculated with (Theewes et al. 2016):

$$UHI_{max} = \left(2 - SVF - f_{veg}\right) * \sqrt[4]{\frac{S * DTR^3}{U}}$$

Where, UHI_{max} is the maximum difference between the urban and the rural temperature. SVF is the sky-view-factor a value between 0 and 1 that describes the fraction of open air that can be seen in a 360 degree radius, with 0 complete cover and 1 completely open. This is calculated as a spatial mean within a 250 radius. Furthermore, f_{veg} is the fraction vegetation cover within a 500m radius, *S* is the daily mean of the shortwave incoming radiation (based on hourly data), U is the daily average wind speed (based on hourly data) and DTR is the difference between the minimum and maximum temperature in the rural area. U and DTR are the average values from 8AM to 7AM the next day, while S is the average from 1AM to 0AM next day.

To calculate the effect of fraction of vegetation the local climate (reduction of UHI), the increase in temperature without vegetation present is calculated by,

$$UHI_{max,no\ veg} = (2 - SVF - 0) * \sqrt[4]{\frac{S * DTR^3}{U}}$$

The effect of vegetation is thus equal to,

$$\Delta UHI_{max} = f_{veg} * \sqrt[4]{\frac{S * DTR^3}{U}}$$

We derived meteorological data and the sky-view factor from KNMI on a 1x1 meter basis (last modification 2019-08-13). Climatological data from 32 weather stations spread over the Netherlands we use to calculate S, U and DTR for all heath wave days in 2013, 2015, 2018 and 2020. We calculated an weighted average with a 50 kilometer buffer.

In the original SVF map, both high vegetation and buildings decreased the SVF, while only the effect of buildings and streets will increase the UHImax. Furthermore, we are interested at the effects of buildings, but not at the buildings themselves. Therefore, we used information from the BAG (basic registration of buildings) to remove SVF data at locations of buildings. We did this at the original 1x1m maps.

To remove the effect of high vegetation on the SVF we used the following rules of thumb:

If in a 250m radius around a grid cell more than 90 % of the cells contained >80% vegetation cover (the SVF of these cells were assigned as NoData) then the SVF of that cell was assigned as 1, e.g. clear view of the sky.

If in the 250m radius less than 80% of the cells contained >80% vegetation cover the mean SFV value was calculated for that grid cell. In this calculation of the mean SFV value, the original SFV value of the cells with >80% vegetation cover are not included.

If in the 250 m radius, between 80 and 90% of the cells contained >80% vegetation cover the SVF value was set at a value between the mean SFV (not including the SFV of cells containing > 80% vegetation cover) and 1. This is calculated as,

SFV_{new}= 10*(σ – 0.1)*$SFV_{mean250m}$ + 10*(0.2 - σ)*1,

where σ is the fraction of grid cells in the 250m radius with a SFV value.

Then an moving window with a radius of 500 meter was used to calculate the average SVF. The moving window of 250m was conducted on grid cells with a 10m resolution. These spatial averages were input for the calculations of UHI_{max} with and without vegetation, for each day within a heatwave in 2013, 2015 and 2018.

The temperature sum (for all days in a heatwave) of the difference between the UHImax with and without vegetation is the contribution of vegetation to the lowering of het UHI (use).

4.5 Cultural ecosystem services

4.5.1 Nature recreation – physical

Scope and definition

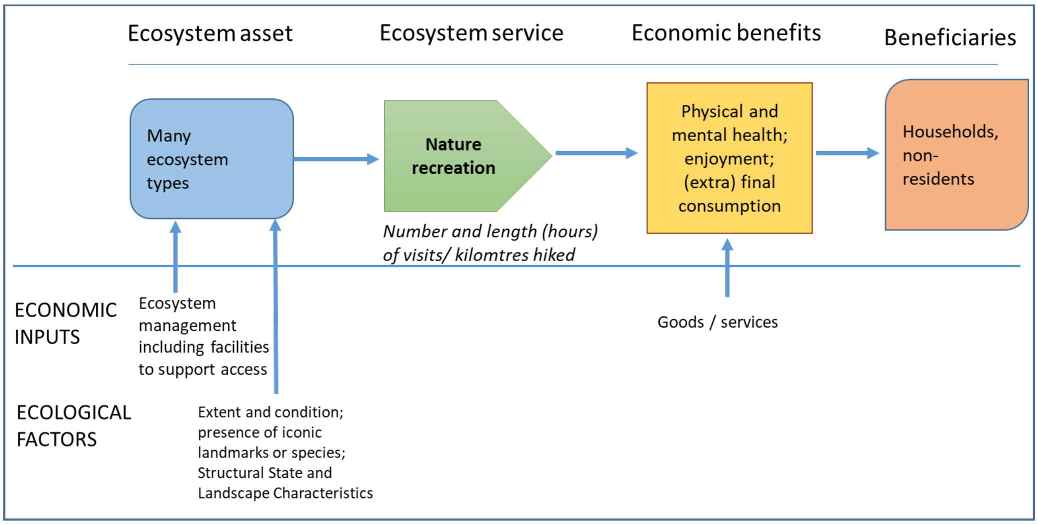
Recreation-related services are the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both residents and non-residents (i.e. visitors, including tourists) (UN, 2021).

Nature provides an important contribution to tourism and recreation-related economic activities and the well-being of people by providing attractive environments for leisure activities. Nature-related tourism and recreation includes a broad range of activities such as hiking, cycling, water sports, but also beach recreation and relaxing in nature areas. These activities have in common that they are outdoor activities taking place in a ‘natural’ or ‘semi natural’ environment.

We can distinguish between nature tourism and nature recreation, where recreation considers only single-day activities and tourism includes only multiple-day activities away from home (with at least one overnight stay at an accommodation).

Logic chain

The ecosystem service nature recreation may be supplied by many ecosystem types, including natural and semi natural ecosystem types, but also public parks etc. Many ecological factors will influence the provision of this service, including the extent and condition of the ecosystems, but also the presence of certain iconic species or special landscape characteristics. In physical terms this ecosystem service can be expressed as the number or durations of the visits, or (in case of hiking) as the total number of kilometres hiked. The benefits provided by this ecosystem service are better physical and mental health conditions, enjoyment, but also (extra) final consumption of products and services associated with recreation which is a direct benefit for the economy. The beneficiaries are (national) households or non-residents (visitors from abroad).



Recreational hiking is taken as a proxy for nature-oriented recreational activities. We use survey data on hiking activities as a data source to develop a related ecosystem service, which is defined as the intensity with which ecosystem types are experienced during hiking. The underlying idea is that hikers look around during hiking, and see the surrounding ecosystems. All cultural ecosystem services can be interpreted as symbolic use of ecosystems and measured by an information flow from the ecosystems to the beneficiary (i.e. the hiker). The ecosystem service is expressed as the total amount of kilometres hiked. See Havinga et al for a full discussion.

Data sources

- Survey data from the ContinuVrijeTijdsOnderzoek (CVTO), (conducted by commercial agency NBTC-NIPO), containing data on:
  - Number of hikes per province per broad environment ("forest", "rural", etc.)
  - Mean length of hike
  - Travel distance distribution
- Statistics on the mobility of persons, which are based on survey data
- Gridded population density maps (500m resolution) by Statistics Netherlands
- Provincial boundaries
- Roads and paths as elements of 1:10,000 topographic maps

Overall approach

The survey data of CVTO includes data on the number of activities. The first step is to calculate the number of activities, in this case hikes longer than 60 minutes that took place in a natural environment, in a certain year. This data is retrieved from the survey for the year 2018, along with the distribution of these hikes over the different provinces and broad environments. To calculate the time series 2013-2020 data from mobility of persons were taken to estimate the trend (CBS Statline 2022). Here we used the overall trend over time in walking trips for leisure purposes. This gives a time series on the number of long nature-related hikes.

Once the number of activities is determined, the next step is to use a spatial allocation model to distribute these activities over the provinces and the specific ecosystem types. For the years

2015 and 2018, the distribution over provinces and broad environments was taken from the survey results. As the survey did not take place for 2020, the same distribution as for 2018 was used in 2020. The survey data are a valuable source on hiking intensity per broad environment, but they do not contain information on precise locations; nor which ecosystem types are being experienced. For instance, forest areas often do contain patches of heathland or grassland; and many rural areas that are known to be attractive for hikers are often a mosaic of cropland, pastures and small groves of forest.

Therefore, we developed an allocation model based on the following premises:

- Hiking intensities per province are strictly conform the time series developed in the first step
- Hiking intensity declines with travel distance from population centres.
- The view on surrounding ecosystem types is limited
- Virtually all hikes will be on smaller paths, so hiking intensity is related to path density
- Hikes in environment “City Centre” and “Local Neighbourhood” are excluded because they are not considered to be nature-oriented.

Because the allocation model by definition is quite uncertain, and e.g. hiking path density is only meaningful on a larger scale, we have adopted the scale of the population density map (500m) as the model resolution. An ecosystem asset is assumed to be ”experienced” if it occurs in the same 500m grid cell as the hiker.

Methodology

The following steps are carried out in order to allocate hiking activities and the associated information transfer from ecosystem types:

1. Gridded 500x500m population density maps are used to model hiking demand by convolving with an exponential decline kernel

   $$p = e^{-d/k}$$

   Where *d* is the distance to the kernel centre and *k* a decay constant. From the CVTO surveys is it known that a large part (40%) of all hiking activities are within a radius of 5 km around the residence. About the same fraction of all hikes are carried out in the environments “city centre”, “local neighbourhood” or “city park”. Environments such as Forest, Heathland and Beach are expected to be located farther away. We therefore used 3 different kernels: *k*=5km for City Centre and Local neighbourhood (not used here); *k*=10km for City Park and *k*=20 for other environments. These kernels ensure that for instance the coastal area near Zandvoort is within reach of residents of Amsterdam.

   This step results in map *D* (demand)

2. All ecosystem types are allocated to one of the survey environments. For each of these environments a 500m raster of fractional coverage by these environments are created. These are maps E_i (“Environment I”)

3. All smaller roads and paths are selected that are likely to be used by hikers. In general these are all foot paths; bike paths and roads smaller than 4m wide. A 500m resolution raster map of path density is created by measuring the total length of these paths and

roads within each 500m grid cell. For ecosystem Beach we assume a path length of 604m per 500m grid cell (being the average of 500m horizontal and 707m diagonal). This is map *P* ("paths")

4. The provincial boundary maps are used to construct per province *j* a 500m raster map of the fractional coverage of all cells by that province. These are maps R_j ("region")
5. From the CVTO surveys it is known how many hikes per province per environment are made and the average hiking length. These data combined yields an amount of km hiked per province per environment, h_{ij}
6. Above inputs and factors are combined as

$$H_{i,j} = h_{i,j} \cdot X_{i,j} / \sum X_{i,j}\,; X_{i,j} = D \cdot E_i \cdot P \cdot R_j$$

   Where the division by the sum of *X* has the effect to normalize the contributions of the various factors, such that effectively the values h_{ij} are distributed spatially according to these factors, but without changing the total amount.

7. All maps H_{ij} are summed to obtain an overall map *H* which contains the total distance hiked within a grid cell.
8. These distanced hiked are allocated to individual ecosystem types based on the fractional coverage of these types within each 500m grid cells.

The final ecosystem service is thus measured as a number of km hiked associated with that ecosystem type. This way double counting is prevented, and the total sum of the service in physical units is the same as the total distance hiked as listed in the survey results.

4.5.2 Nature recreation – monetary

The monetary value of nature recreation was calculated using the consumer expenditure method. Recreational activities include all leisure related activities for which one is away from home for one hour or longer, but that do not include an overnight stay. Data on recreational expenditures were obtained from CVTO (ContinuVrijeTijdsOnderzoek) surveys held by NBTC-NIPO. These statistics provide information on the different kinds of expenditures and the types of recreational activities. These reports are available for the years 2015 and 2018. The remaining years have been estimated with the support of additional statistics from Statline on the consumer price index and fuel costs.

In order to delineate nature related recreation, we selected the following types of recreational activities, which take place outdoors and to a large extent depend on the outdoor environment:

1. *Outdoor recreation*, which includes hiking for pleasure, cycling for pleasure, general outdoor recreation (including beach recreation), touring around in the countryside by car or motor, and trips by tour boats.
2. *Water sports*, which include canoeing, rowing, surfing, fishing, sailing, and boat trips (excluding indoor water sports).
3. *Outdoor sports* (excluding water sports), which include jogging/running, mountain biking, horse riding, hiking (as a sport), and cycle racing.

Nature provides opportunities for these recreational activities for people. This leads to all kinds of expenditures by households. First of all, people have to travel to the recreational site by car, train, or other means, which involves costs. Sometimes admission fees have to be paid to gain access to the site. During the activity, food and drinks are bought from on-site facilities. Finally, people need all kinds of products that they will use during these activities, such as hiking boots, bikes, and camper vans.

The travel cost method is often used to value recreational services (e.g. Barton and Obst, 2019). The travel cost method assumes that travel costs of tourists and recreationists can be taken as an indication for their willingness to pay for the services of nature. However, the consumer expenditure approach is applied in this study and uses the same principle as the travel cost method approach. The consumer expenditure approach as presented here is very similar to the 'simple' travel cost method applied in the United Kingdom to value these ecosystem services (ONS, 2016). A difference is that we consider not only travel costs and admission fees, but also expenditure on (for nature tourism) accommodation. Expenditures by households are also key examples of market transactions and consequently represent exchange values, which is a requirement to be aligned with the SNA. With respect to expenditure categories we thus included admission fees, travel costs and other related costs. In previous editions of the Dutch Natural Capital Accounts, we had also included expenditure on foods and drinks. We have decided to apply a more narrow scope and exclude expenditure on foods and drinks.

The results of the expenditure method remain highly dependent on the cost components that are included. An extensive assessment of three different expenditure scopes can be found in the previous technical report on monetary ecosystem accounting (Statistics Netherlands and WUR, 2020).

The values obtained by consumer expenditure only capture a part of the economic benefits provided by these ecosystem services. Recreational activities in nature provide all kinds of (positive) health effects for people. This will provide economic benefits in the form of reduced healthcare costs. These values are not yet included in the SNA and thus will increase the GDP. The exact health effects are often difficult to quantify, so further research is needed to find out whether this value component can be added for a future update of the monetary accounts. Furthermore, nature based tourism and recreation also provide welfare values that are probably much higher than the exchange values presented here. Consumers are willing to pay much more to enjoy nature than they are actually spending on travel costs or admission fees. In a future update, it may be worthwhile to present welfare values for tourism and recreation alongside the exchange values.

4.5.3 Nature tourism - physical

Nature tourism encompasses all tourist activities related to nature that involve overnight stays, both on land and on inland waters. The ecosystem service was modelled based on Dutch tourism statistics, namely the quantity of overnight stays by tourism type, available at the aggregated scale of provinces (NBTC-NIPO, 2013, 2015, 2018 & 2020) and statistics on the number of overnight stays of domestic and international tourists (Statistics Netherlands, 2020).

From the Dutch tourism statistics the following types of tourism are directly related to nature: active and nature tourism, beach tourism, and water sports tourism. Then there are some categories for which the percentage that is related to nature is unknown, such as the category ‘relax vacation’ and the category ‘seasonal recreation’. Seasonal recreation refers to tourism that is related to accommodations that are owned by the tourists themselves vacation houses and campers. To take these more ambivalent categories into account, the category ‘relax vacation’ was redistributed over ‘seasonal recreation’, nature tourism and beach tourism. The seasonal recreation tourism was subsequently assumed to be nature related for 50%, and this part was distributed proportionally among the other nature related categories (active and nature, beach, water sports).

To estimate the international tourist overnight stays that are nature related the Dutch distribution of tourism types, with the exclusion of seasonal recreation, was imposed on the overnight stays of international tourists. Seasonal recreation was excluded for international tourists since the source data does not include overnight stays at accommodations that are owned by the international tourists themselves (Statistics Netherlands, 2020). Subsequently the total overnight stays were mapped to ecosystems. The method for mapping water sports tourism was different from the other types of nature tourism and the different methods will be described separately.

Nature and active, and beach tourism

For each province, the number of overnight stays were distributed evenly over the ecosystem types that are considered to be the main targets of the tourism type. For nature and active tourism these include forests, wetlands, coastal dunes and open nature such as heathland and natural grasslands. For beach tourism only the ecosystem type beach was used. Water ecosystems were excluded here since water sports tourism was mapped separately. Agricultural land was also excluded; even though some agricultural areas may be the target of active tourism (cycling, walking) this is not considered to be the main attractor of active tourism, and the large surface area of agricultural lands would skew the results in that direction.

Water sports tourism

To allocate the overnight stays related to water sports within the provinces, the quantity and size of marinas were used as a proxy. Marinas were selected from the topographic map (Top10NL) and converted to point data. The surface area of each marina was used in a kernel density analysis using a 10km search radius. The kernel density map was used to distribute the overnight stays proportionally over all water ecosystems and determine the number of overnight stays per ha.

All nature tourism

The maps for the different tourism types were added up to create the final map for nature tourism in the Netherlands. This final map was used to calculate the nature tourism per ecosystem.

4.5.4 Nature tourism – monetary

Tourism is defined as all activities for leisure that include at least one overnight stay. The valuation method is the same as for nature recreation, namely the consumer expenditure approach. Data on the expenditure by residents were obtained from the Dutch tourism statistics, which in turn are based on survey results (the ‘continuous holiday survey’). These statistics provide information on the different kinds of expenditures by residents, the types of holidays and the different regions (provinces) where the holidays take place. In order to delineate nature related tourism, we selected the following holiday types: nature holidays, active holidays (which include hiking and cycling holidays), relaxing holidays, beach holidays, water sports holidays and nature-related seasonal holidays. Expenditure includes costs for (1) accommodation, (2) travel costs, and (3) other costs (entry fees, etcetera). Expenditure related to shopping and on foods and drinks is excluded, similarly to nature recreation.

Data for tourism expenditures by non-residents (inbound tourism) were directly obtained from the Dutch tourism satellite accounts (TSA). Total expenditure by inbound nature tourism (excluding business travel) equals 7.5 billion euro (2018). Most inbound tourism in the Netherlands takes place in the large urban areas (i.e. Amsterdam, The Hague, etc.). No information is available on the main motive of the inbound tourists. Therefore, as an approximation, we took the location where these tourists stay overnight to delineate nature related tourism by non-residents. We selected the following tourism areas: coast, water sport areas, forest and heath areas.
Data on total other consumer expenditure related to tourism was obtained from the TSA. This mainly concerns expenditure on goods and services that households need for their recreational activities, such as camping equipment, walking boots, etcetera. Here we assumed the same percentage as for nature related tourism to calculate the nature related expenditure.

4.5.5 Amenity services – monetary

Definition and scope

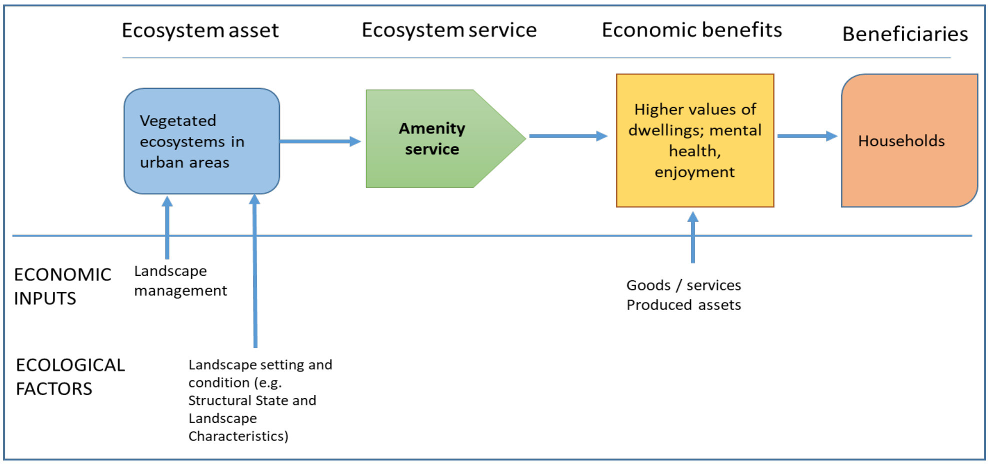
Amenity services are the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide pleasant conditions for living.

In real estate and lodging, an amenity is something considered to benefit a property and thereby it increases the property's value. The amenity services of ecosystems are defined here as benefits for housing related to living near nature, which include recreation, visual aesthetics, and lower levels of air and noise pollution. The value of the service represents the amount house buyers are willing to pay extra for a dwelling and its underlying land for living in green and/or blue surroundings. This ecosystem service is only expressed in monetary terms.

The amenity services may partly overlap with two other ecosystem services. First, recreational activities in nature may be partly captured in the amenity services. To prevent double counting here, we have defined nature recreation as all leisure related activities for which one is away from home for one hour or longer. It is assumed that these activities take place not in the intermediate neighbourhood and consequently will not overlap much with the amenity services as calculated here. Second, there may be an overlap with the ecosystem service air filtration. Reduced air pollution due to a green environment may indeed have an effect on housing prices. However, the way we value these services ensures there is no double counting, namely increased housing prices for the amenity services and reduced health expenditure for air filtration, which should not overlap. The first is already captured in GDP, the second is not.

Logic chain

Amenity services are supplied by ecosystems in the neighbourhood of dwellings. The economic benefit is the value of increased production of housing services by owner-occupiers or house rents provided by the proximity to nature, but also better physical and mental health conditions, enjoyment. The beneficiaries are households.



Methods and data

People usually prefer to live in a green neighbourhood as it provides healthier living conditions and more possibilities for all kinds of recreational activities close to home. Green neighbourhoods thus provide an important ecosystem service to people living nearby. Proximity to nature will thus be reflected in housing prices. The hedonic pricing method is used in the analysis of variations in housing prices in relation to physical attributes, properties of the neighbourhood, and the proximity to and quality of the natural environment (King, Mazzotta & Markowitz, 2004).

The hedonic pricing method has its roots in consumer theory.[11] The basic notion is that consumers assign a value to each of the properties of the good or service they purchase. The method captures revealed preferences as it is based on actual transactions and observed values. The method that has been applied is based on a hedonic pricing model, developed by Daams, Sijtsma and Van der Vlist (2016). Using regression analysis the price of a dwelling is disentangled based on characteristics of the building and the underlying land. The characteristic of interest is the distance to nature.

A common specification of the hedonic price model for dwelling of interest i (i = 1,…, n) may be given by:

$$ln(WOZ_i) = \alpha + \sum_{j=1}^{m} \beta_j \boldsymbol{X}_{i,j} + \varepsilon_i$$

where α is the constant; ln(WOZi) is the natural logarithm of the assessed property value (WOZ) of dwelling i; Xij is the jth characteristic (j = 1,…, m); and εi denotes standard errors that are spatially clustered to mop up remaining local correlations below street-level (PC6 level). The

[11] The classical references are: Lancaster, K. J. (1966). A new approach to consumer theory, Journal of Political Economy, vol. 74, pp. 132-157. Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. Journal of political economy, 82(1), 34-55.

functional form is a semilog, since WOZ is skewed to the right, to mitigate heteroskedasticity (Diewert, 2003).

The main model specification in this study considers the proximity of homes to CANA (Clusters of Attractive Nature Areas) and ONA (Other Nature Areas). CANA is derived from a web-based GIS application Greenmapper (www.greenmapper.org), which identifies cultural ecosystem services in a non-monetary and spatially explicit way (Bijker and Sijtsma, 2017; De Vries et. Al., 2013) and are therefore a holistic proxy of nature areas that are perceived attractive by residents in general. ONA are derived from the ecosystem types maps (as described in chapter 3): all natural ecosystem types are included such as forests, natural crop- and grassland, wetlands and water and urban green areas. The minimum size of ONA is taken to be one hectare with at least 80 percent natural ecosystem types.

Our approach addresses the main limitations that are associated with hedonic pricing models. First, the holistic character of this measure mitigates possible issues with regard to multicollinearity that might arise if CANA were split by land use type (Pendleton and Shonkwiler, 2001). Indeed, attractive forest might be similarly close to a home as attractive grasslands if they constitute the same CANA. Second, to account for omitted variable bias from structural and locational house characteristics that are constant on a local level, for example safety in the neighbourhood or housing market effects, the regression is estimated in spatial first differences. These first differences are taken on neighbourhood-level[12]. This implies that variance of the data that might otherwise lead the model to reveal a higher true impact of CANA is removed from the estimation (Abbott and Klaiber, 2011; Daams et al., 2016). The benefit of this approach, however, is that it is stricter than common so-called spatial fixed effect models (see Von Graevenitz and Panduro, 2015) as it accounts not only for spatial structure in prices but also in terms of house characteristics: within-pair similarity in both observed and unobserved characteristics is cancelled out. This gives the following hedonic price model to be estimated:

$$ln(WOZ_{iz}) - ln(WOZ_{jz}) = \sum_{k=1}^{K} \beta_k(\boldsymbol{X}_{izk} - \boldsymbol{X}_{jzk}) + \sum_{c=1}^{C} \beta_c(\boldsymbol{CANA}_{izc} - \boldsymbol{CANA}_{jzc}) + \sum_{d=1}^{D} \beta_d(\boldsymbol{ONA}_{izd} - \boldsymbol{ONA}_{jzd}) + \varepsilon_{ijz}$$

where *$ln(WOZ_{iz})$-$ln(WOZ_{jz})$* is the difference in assessed property value of paired houses *i* and *j*, both located in the same 4-digit zip code area *z*; $\boldsymbol{X}$ a vector of control variables including year of construction, type of dwelling, size of dwelling, parcel size, and leased status; $CANA_{i,z,c}$ is the vector of dummy variables for dwelling *i* indicating the distance to the closest CANA within interval *c* (*c* = 0-500 m, 500-1,000 m, 1,000-2,000 m, 2,000-3,000 m, 3,000-4,000 m, 4,000-5,000 m, 5,000-6,000 m); and $ONA_{i,d}$ is the vector of dummy variables for dwelling *i* indicating the distance to closest ONA within interval *d* (*d* = 0-50 m, 50-100 m, 100-150 m, 150-200 m, 200-250 m, 250-300 m, 300-350 m, 350-400 m, 400-450 m).

Using the housing stock registry (Statistics Netherlands, 2021a) a dataset was created with information on 7.8 million single-family dwellings and apartments. The information concerns the assessed property value (WOZ-value) as well as characteristics of the dwelling and underlying land. Using the location of each dwelling from the building and address register, Euclidean distances to the nearest CANA and ONA were calculated. Regression analysis of the

[12] www.cbsinuwbuurt.nl

natural logarithm of WOZ-value on the distance to nature areas and other control variables was performed by first differencing on a local level. Different regressions were performed according to urbanity of the location of the dwelling. This analysis gives for each dwelling an estimated portion of the WOZ that is attributed to nearby nature. The value of each individual dwelling were then distributed equally over the nature areas within a certain distance of the dwelling, that is, 6 kilometres for values attributable to CANA-areas and 450 meters for values attributable to ONA-areas. This is in accordance with the results of the analysis. Table 4.5.5 gives an overview of the results of the hedonic price regression.

Table 4.5.5 Results of the hedonic pricing model for the Netherlands and different urbanization levels using data over 2013 (Numbers indicate the percentage of the value of a property that house buyers are willing to pay to live nearby a CANA or ONA)

	(1)	(2) Urbanization level				
	Netherlands	1	2	3	4	5
Distance to nearest CANA						
Within 0-500 m	8,8	19,2	8,8	3,9	3,3	8,9
Within 500-1000 m	5,1	13,5	7,5	1,6	2,4	4,9
Within 1000-2000 m	3,5	9,6	8,4		1,1	4,7
Within 2000-3000 m	2,8	7,8	8,7			1,9
Within 3000-4000 m	1,8	6,6	5,3			0,9
Within 4000-5000 m	0,4	4,4	3,1			
Within 5000-6000 m		2,9				
Distance to nearest ONA						
Within 0-50 m	4,7	4,4	5,8	5,3	4,1	2,8
Within 50-100 m	3,1	3,4	3,8	3,5	2,7	1,7
Within 100-150 m	1,4	1,4	2,3	1,7	1,3	0,6
Within 150-200 m	0,7	0,5	1,7	1,1	0,3	0,4
Within 200-250 m	0,3		1,1	0,8		
Within 250-300 m	0,1		0,7	0,6		
Within 300-350 m			0,5			
Within 350-400 m			0,5			
Within 400-450 m			0,3			

The resulting value of this method is an asset value. We have used the net present value approach to derive the value of the annual flow of ecosystem services (see chapter 5 on the asset accounts). We assume a discount rate of 3% and an asset life of 100 years (which implicitly assumes that existing houses that are replaced by newer houses enjoy the same value increase due to proximity to nature).

4.6 Physical supply and use tables for ecosystem services

The supply of ecosystem services by ecosystem assets and the use of these services by economic units, including households, is one of the central features of ecosystem accounting. The supply and use account records the actual flows of ecosystem services supplied by ecosystem assets and used by economic units during an accounting period and may be compiled in both physical and monetary terms. Here we discuss how the monetary supply and use accounts for the Netherlands are complied.

In the physical supply table the value of ecosystems services, as described in the previous sections, is allocated to different ecosystem types, i.e. the producers of the ecosystem services.

The monetary values calculated on a national level (for example timber production) or on a regional level (for example crop production or nature recreation) were distributed to ecosystem types, based on the physical values in the biophysical maps of ecosystem services.

In the monetary use table the value of ecosystems services is allocated to the users of these services. Users include economic units classified by industry, government sector and household sector units, following the conventions applied in the national accounts. The users of the ecosystem services correspond to the beneficiaries identified for each ecosystem service.

For accounting purposes, the supply of ecosystem services is always equal to the use or receipt of the services during an accounting period. That is, supply is not recorded if there is no asset account

5. Asset accounts

In this chapter, we describe how the value of ecosystem assets has been derived from the estimated value of ecosystem service flows. We have used a net present value (NPV) approach, using assumptions on the future flow of ecosystem services, the discount rate, and the economic lifespan of ecosystem assets.

5.1 Definitions

From a national accounts point of view, an asset is a store of value representing a (series of) benefit(s) for the economic owner (UN, 2010). It follows from this general concept that an asset is limited to those situations in which property rights can be enforced. In the SEEA, environmental assets are defined as the naturally occurring living and non-living components of the earth, together comprising the bio-physical environment, that may provide benefits to humanity (SEEA CF, 2.17). In physical terms, the asset boundary of the SEEA Central Framework is broader than the SNA as the ownership criterion does not apply. The SEEA CF basically includes all natural resources within an economic territory that may provide resources for use in economic activities (SEEA CF, 1.47).

The SEEA EA considers environmental assets from a different perspective than that of the SEEA CF. The focus of the SEEA EA is on the biophysical environment as viewed through the lens of ecosystems in which the various biophysical components (including individual resources) are seen to operate together as a functional unit. Ecosystem assets are environmental assets viewed from a systems perspective. Furthermore, in the SEEA EA the extended asset boundary as defined in SEEA CF is used, which means that all ecosystems (regardless of ownership) are within scope for the (physical) accounts.

In the national accounts, the value of produced assets is commonly derived from investment series, which can be used to determine the economic capital stock through a perpetual inventory method (PIM), making assumptions about depreciation and service life (OECD, 2009). In addition, in some instances, such as the valuation of land, the national accounts capital stock estimates are based directly on available market prices for the pertinent asset.

In the case of natural resources and ecosystem assets, there is no investment, except for possible expenditures on restoration, extension and improvement, which are already recorded in the national accounts. Where market prices are available for the assets that deliver ecosystem services, such as land, it is often difficult to disentangle the part of the price that can be attributed to any of the ecosystem services, from the part that is determined by other market factors.

As an alternative, an estimate of the overall value of an ecosystem asset can be derived from aggregate values of future flows of ecosystem services, following the standard approaches to capital accounting, using the net present value approach (UN, 2021). Such an approach requires assumptions about the future flows of income, as well as about the discount rate used to convert the future income to current values and the corresponding time horizon. Statistics Netherlands applies this method for the valuation of the Dutch oil and gas reserves in the national accounts (see De Bondt and Graveland, 2016). In the following paragraphs, we describe how the NPV approach can be implemented to derive asset values for ecosystem types from the value of the associated services.

5.2 Assumptions

Implementation of the net present value approach for the calculation of the value of ecosystem assets involves three assumptions.

Assumption 1: The future flow of income for each ecosystem services is constant, and equal to the flow observed most recently.
In the case of oil and gas reserves, which are not part of the ecosystem assets considered here, scenarios are available for the physical extraction of these reserves. These scenarios are used in the determination of future flows of income. Similar information on depletion or degradation is lacking for the ecosystem services that are valued in this report. Neither are there scenarios for predicted future flows.

There is insufficient supporting evidence to forecast future flows in real terms over the entire 100-year lifespan of an ecosystem asset. ONS calculate asset values based on a 5-year average or a trend. Because our estimates are more complete for some services than for other services, we have determined asset values based on the flow observed in a single year (e.g. 2018).

This implies a number of assumptions. We assume that no (future) degradation takes place and that the future flow of income in each year equals the flow observed in the most recent year. This assumption is not necessarily realistic. There is no overharvesting (where offtake exceeds mean annual increment) of wood in Dutch forests, but potentially water or air pollution may affect future flows of services from ecosystems. We anticipate that these effects are, for now, modest for most services (given that there are no clear indications that ecosystems reaching a point where they are close to collapse in the Netherlands, and given ongoing efforts to rehabilitate ecosystems). There is one exception. It is likely that the near future may show important changes in amenity services, given the pace of construction and current plans to expand the number of dwellings, in particular in the western part of the country. Such changes should show up in the updated accounts in the coming years. For now there is no clarity on where exactly most of these new houses will be built and such forecasts cannot be made.

Assumption 2: The discount rate equals 3 percent, unless the ecosystem asset is thought to become scarcer and there are limited substitution possibilities.
The discount rate reflects the time preference of money: it captures the trade-off between consumption today and consumption in the future. It takes into account a risk-free return on investment and a risk-premium. The value that is chosen for this discount rate is an important determinant of the asset value.

Over the years, there have been various consecutive interdepartmental working groups to determine the discount rate to be used by the Dutch government in public cost-benefit analyses (Van Ewijk et al., 2015). Since 2009, a risk-weighted discount rate of 5.5% for public investment has been maintained, and 4% for investments with irreversible negative externalities. The latter rate has been used to determine the value of oil and gas reserves in the Dutch national accounts. The 2015 working group advised adjusting the discount rate for public investments to 3 percent.

For nature, the advice is to take into account increases in the relative price, due to increased scarcity and limited substitution possibilities, resulting in an effective discount rate of 2 percent. However, the Netherlands Environmental Assessment Agency (PBL) recommends using the normal discount rate of 3 percent for provisioning services, such as in agriculture or timber production (Koetse et al., 2017). For services that can hardly be replaced, they recommend a discount rate lower than 2 percent.

In line with these recommendations, in this report, we apply a 3 percent discount rate for provisioning services and cultural services. For regulating services, which are scarcer and harder to substitute, we use a discount rate of 2 percent. This is summarized in table 5.2.1. An additional assumption is that the discount rate applies equally to all geographical areas. In other words, we assume that there is no spatial variation in the degree of scarcity and substitutability.

Table 5.2.1. Discount rate used for the different ecosystem services based on assumed relative scarcity and substitutability

Type	Ecosystem service	Discount rate used
Provisioning services	Crop production	3
	Fodder/grass production	3
	Timber production	3
Regulating services	Drinking water filtration	3
	Carbon sequestration in biomass and soil	2
	Pollination	2
	Air filtration	2
	Coastal protection	2
Cultural services	Nature recreation	2
	Nature tourism	2
	Amenity services	2

In this report, we follow the principles used by ONS in its calculation of the monetary value of ecosystem assets. This involves using declining rather than constant discount rates. The ONS principle is based on the Green Book (the equivalent of the Dutch *Handboek milieuprijzen*), which recommends that for appraisals over the long term discount rates should decline to account for uncertainty about future values. The Dutch *Handboek milieuprijzen* (CE Delft, 2017) also refers to the possibility of using lower discount rates for effects that occur on a longer timescale (CE Delft, 2017, p. 172).

The discount rates in Table 5.2.1 are lowered by 0.5 percent after 30 years and by 1 percent after 75 years. For example, for a base discount rate of 3 percent the discount rate is 3 percent up to 30 years, 2.5 percent for 31 to 75 years, and 2.0 percent for 76 to 100 years.

Assumption 3: The asset life is 100 years for all ecosystem assets.
The asset life is the expected period of time over which the ecosystem services are to be delivered and determines the time-horizon over which the net present value is calculated. The longest asset life that is used in the estimation of the value of produced assets is 75 years for dwellings (see Statistics Netherlands, 2019). For nature, it therefore makes sense to set an asset

life substantially longer than 75 years. In their experimental estimates for ecosystem assets, the British Office of National Statistics (ONS, 2018) sets the asset life to 100 years.

5.3 Calculation of net present value

The value of an ecosystem asset can be determined by calculating the net present value of the future flows of income associated with the different ecosystem services. The asset value K_0 is calculated using the NPV formula:

$$K_0 = \sum_{t=1}^{T} \frac{d_t}{(1+r)^t}$$

assuming a flow of income d_t in year t, a discount rate r, and an asset life T.
If we assume that the stream of future of flows is constant, i.e. $d_t = d$, then the formula simplifies to:

$$K_0 = d \times a$$

where a is the annuity factor, given by

$$a = \frac{1}{r} - \frac{1}{r(1+r)^T}$$

Note that when asset life is assumed to be infinite ($T \rightarrow \infty$), the NPV formula is applied to a so-called perpetuity and the asset value is simply equal to the income flow divided by the discount rate ($K_0 = d/r$), as a converges to 1. In addition, the changes over time in the asset values are the same as those for the associated services, because the calculation only entails a multiplication of the flow by a scaling factor. Finally, because the discount rate and the time horizon may differ across asset types and each ecosystem asset may provide a basket of ecosystem services, it is necessary to calculate asset values for the different ecosystem service separately before aggregating to an overall value.

Beyond a certain value, the asset life (T) does not have much impact on the ultimate asset value, for a sufficiently high value of the discount rate. For example, at a discount rate of 3 percent the difference in asset value between choosing an asset life of 100 years versus infinity is 5.5 percent. At a discount rate of 2 percent, the difference amounts to 16 percent. A discount rate lower than 2 percent is unlikely, while a discount rate higher than 3 percent will only have an effect of a few percentage points on the estimated asset value.

5.4 Asset value and service flows of amenity services

Unlike other ecosystem services, for amenity services the method used in this report produces asset values. The value of ecosystem service flows is derived by applying the ratio between the service flow and asset value of another service with a similar base discount rate.

5.5 **Asset accounts**

The monetary ecosystem asset account records the monetary value of opening and closing stocks of all ecosystem assets within an ecosystem accounting area and additions and reductions in those stocks. Additional entries can be incorporated, following the structure of the monetary asset account in the SEEA Central Framework. These additional entries include growth and normal losses of stock, catastrophic losses (e.g. changes due to natural disasters), upward and downward reappraisals and reclassifications. A separate entry is used to record changes between the opening and closing values of ecosystem assets that are due to revaluations – i.e. changes in the value that are due solely to changes in prices rather than changes in volumes. In this report, no attempt has been made to produce these detailed entries.

6. Carbon stock accounts

6.1 Introduction

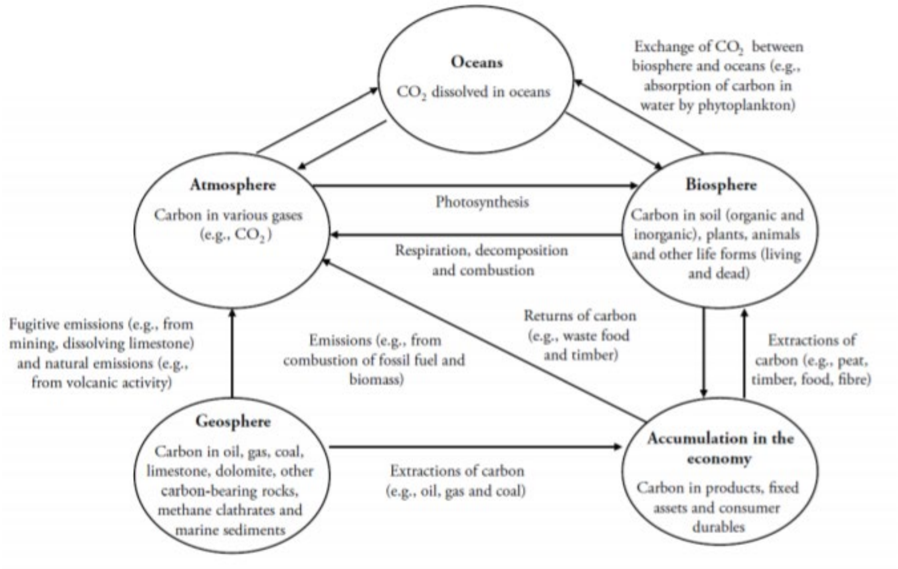
In addition to the core accounts for ecosystem accounting, the SEEA EA promotes the development and implementation of thematic accounts, centered around the themes climate (including the carbon stock account), biodiversity, urban areas and oceans.

Carbon is an important central theme in the SEEA EA 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 stock 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.

6.1.1 The SEEA EA carbon stock account

The SEEA EA carbon stock 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 (UN, 2021). The structure of the carbon stock account is presented in Figure 6.1.1. 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 6.1.1: Main components of the carbon cycle, and the carbon flows between these components. Source: SEEA EA.



The different carbon stocks are shown in the columns of the carbon stock account (Figure 6.1.2). 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.

Figure 6.1.2: The carbon stock account as presented in the SEEA EA. Grey cells are null by definition

	Geocarbon					Biocarbon				Carbon in the economy				Carbon in the atmosphere	Carbon in the ocean	Total
Mton C	Oil	Gas and shalegas	Coal	Limestone	**Total geocarbon**	Forests	Cropland / meadows	Other ecosystems	**Total biocarbon**	Inventories	Fixed assets, cosumer durables	Waste	**Total economy**	**Total atmosphere**	**Total ocean**	
Opening stock																
Additions to stock																
Unmanaged expansion																
Managed expansion																
Discoveries																
Upwards reappraisals																
Reclassifications																
Imports																
Reductions in stock																
Unmanaged contraction																
Managed contraction																
Downwards reappraisals																
Reclassifications																
Exports																
Net carbon balance																
Closing stock																

The row entries in the account follow 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 EA):

- **Unmanaged expansion**: These additions reflects increases in the stock of carbon over an accounting period due to natural growth or the indirect effects of human activities. 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. Basically, these reflect all increases in carbon stock due to carbon input flows from other reservoirs which are directly related to human activities.
- **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 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) that contain carbon.

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

- **Unmanaged 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. Unmanaged 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) that contain carbon.

6.1.2 Study scope and aim

The carbon stock account for the Netherlands provides a comprehensive overview of all relevant carbon stock changes for 2018. 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 carbon stock 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.

All values included in the carbon stock account 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.

The following paragraphs will provide a more detailed elaborate on the specific scopes, methods and results for the main components of the carbon cycle.

6.2 Biocarbon

Biocarbon includes all organic carbon in the biosphere, i.e., carbon in living biomass (plants and animals) and dead biomass (soil organic matter and sedimentary organic matter). Biocarbon includes biomass in crops, grass in meadows, which is thus not considered as carbon accumulated in the economy. Carbon stored in livestock, however, is considered as part of 'carbon in the economy'. Carbon stored in timber products, including timber used for construction, is also included as part of 'carbon in the economy'.
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 analyzed in detail. In general, the methodology was based upon a qualitative look-up table (LUT) approach. Separate LUTs were used for terrestrial carbon sequestration and for terrestrial carbon stock. These LUT were combined with the Ecosystem type map that was developed for the Netherlands (see chapter 3). 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 Tol-Leenders et al. (2019) were used to quantify carbon stock in the upper 30 cm of the soil.

6.2.1 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. The methodology was based upon a qualitative look-up table (LUT) approach. Each spatial unit (i.e. ecosystem type) in the map was attributed a specific value for carbon sequestration. For carbon sequestration in nature in the Netherlands Arets (2018) explicitly makes a distinction between the Net Primary Production (NPP), this is the carbon that is captured in biomass by vegetation as a result of photosynthesis, and net sequestration of carbon over a long period. These net sequestration values will be used for the service carbon sequestration. Values for carbon sequestration in agricultural land uses were derived from an older study on carbon sequestration in Dutch nature and agriculture (Lesschen et al., 2012). The look-up table for carbon sequestration and stock in above ground biomass is provided in table 6.2.1 For forests the net sequestration rates depend on yield and management. The given values are based on gross growth, death and yield based on repeated measurements in the forest inventories MVF (2001-2005) and NBI6 (2012-2013). According to Arets (2018) are many ecosystems with low vegetation, like heath and grassland already in a steady state. Therefore, he assumes that even though the NPP in these ecosystems can be high, 1.1 ton C/ha/year for heath and 2.6 ton C/ha/year for natural grasslands, the net sequestration will be limited. Based on a publication of Janssens et al. (2005) a net sequestration of 0.19 ton C/ha year is considered. We assume that the sequestration rate for arable field margins and tall herbs and natural crop fields is similar. The net sequestration for bogs is potentially very high, however due to desiccation this potential is not met in practice. Salt marshes do have a high net sequestration of 1.5 ton C/ha/year.

As mentioned above, Arets (2018) assumes that in (agricultural) grasslands there is an equilibrium between carbon sequestration and -decomposition. In this case the net sequestration is very limited, i.e. practically zero. Recent experimental studies (Koopmans en Opheusden, 2019; Koopmans et al., 2019; 2020) however show that it takes relatively long to reach this equilibrium. It shows that young grassland have a higher sequestration rate than older grasslands and furthermore that grass on clay soils have a higher sequestration rate than on sandy soils. The net sequestration rates in old grasslands can become 0. Not only grasslands show large variation in carbon sequestration rates also forest can show large variation, depending on timber yield and other management. In table 6.2.1 next to the mean value used to calculate the total carbon sequestered in the Netherlands, we also give the higher values to show the local band width in sequestration rates. We have not used this high value to calculate a sequestration map, as this value will be only valid in some locations and will not produce reliable estimates for the Netherlands.

6.2.2 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., 2013). 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 modelled the 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. Byrne 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.

6.2.3 Carbon stock – biomass

The carbon stock of forest types as given by Arets (2018) can be derived from the most recent National Greenhouse gas report (Ruyssenaars et al., 2020). Between the forest inventories MFV and NBI6 has the mean carbon stock in Dutch forests increased from 83.2 ton C/ha in 2003 to 94.8 ton C/ha in 2012. This is a net increase of 1.3 ton C/ha/year. This can be extrapolated to 2013. Based on the mean trend and the specific carbon sequestration rates for the different forest types (correcting for expected timber yield) the carbon stock in 2013 is calculated. The carbon stocks for 2015 and 2018 are then calculated based on the sequestration rates and the number of years between the Accounts. For coastal dunes, Arets (2018) gives a carbon stock of 2.5 ton C/ha. However, the ecosystem type coastal dunes in the current project not only comprises dunes with European beachgrass, but also heath, shrubs and coniferous and deciduous trees. Based on the mean extent of these categories in the ecosystem type coastal dunes we estimated the mean stock at 6 ton C/ha.

6.2.4 Carbon stock - soil

The organic carbon stock in the soil was mapped based on data from Tol-Leenders et al. (2019), who in 2018 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.

The original LSK ("Landelijke Steekproef Kartering") database (sampled between 1990 and 2000) contained data on approximately 1400 locations, of these locations about 1150 have been sampled again in 2018.

Table 6.2.1 Look-up table for mean carbon sequestration and the starting carbon stock in 2013 in above and below ground biomass in the Netherlands

	Sequestration mean (ton C/ha/yr)	**Sequestration high (ton C/ha/yr)**	**Stock (ton C/ ha)**
Forest, deciduous	1.80	4.60	108.70
Forest, coniferous	0.50	2.20	59.80
Forest, mixed	1.10	3.30	89.40
Natural forest, deciduous	1.70	3.20	107.70
Natural forest, coniferous	0.80	1.90	62.80
Natural forest, mixed	1.40	2.60	92.40
Salt marsh	1.50	1.50	15.00
Bogs and lowland peat	0.22	0.22	1.60
Heath	0.19	0.19	13.00
Natural grassland	0.19	0.19	5.00
Temporary grassland	0.18	1.23	9.00
Grassland, permanent or extensive	0.18	0.73	9.00
Other grassland, field margins, tall herbs	0.18	0.18	9.00
Perennial crop	0.92	0.92	21.70
Annual crop	0	0	0
Beach, sand, coastal dunes	0	0	0
Fallow land	0	0	0
Built-up, infrastructure	0	0	0
Water	0	0	0

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

6.3 Geocarbon

6.3.1 Definition and scope of geocarbon

The term “geocarbon” refers to carbon that is locked in the lithosphere, in either organic or mineral form. Organic geocarbon such as coal, oil and gas originate as fossilized biocarbon, or co-products of the process. Peat deposits of Carboniferous and Permian age (roughly 360–250 Ma) where, after burial under layers of sediment, and subjected to metamorphosis due to high temperatures and pressure in the earth’s crust, are slowly turned into coal. Similarly, oil and gas are formed from buried and fossilized marine plankton. The main difference between biocarbon and geocarbon thus is this fossilization and metamorphosis. Mineral geocarbon is mainly found in carbonate sedimentary rocks, such as limestone (calcium carbonate, CaCO3) or dolomite (containing CaMg (CO3)2 as well). These rocks are initially formed from precipitation of calcite from sea water due to (mainly) biogenic calcification. Subsequent diagenesis (rock-forming processes) turns these deposits into limestone.

Following this definition of geocarbon, all inorganic and organic carbon present in the lithosphere could be accounted for in the carbon stock account. However, only for a few of these data are available. Moreover, it is not very relevant to account for all geocarbon as most of these stocks will not be impacted by human activity. We have therefore limited the geocarbon stocks in the carbon stock account to the reserves that consist of the quantities of natural gas and oil found in the Netherlands that are commercially and socially extractable. Therefore, only the subsoil energy resources i.e. oil, gas, coal resources, which could potentially be extracted, will be included in the carbon stock account. For the current carbon stock account, this means an underestimation of the total geocarbon stocks.

6.3.2 Methodology

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’ (1987-2018), (TNO / Ministry of Economic Affairs, 1988 – 2019). These reports provide data on the total commercially and socially extractable stocks, discoveries, extraction, i.e. the data needed to compile the physical asset account for these resources. The physical data for the energy asset account are compiled and published annually by Statistics Netherlands. Data on the total stock, including non-commercially and socially extractable stocks was not available. Using standard conversion factors the physical amounts of the natural gas and oil resources were converted into Mton C.

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. Accordingly, the total estimated coal reserve for the Netherlands amounts to ca. 12700 Mton C (Geology of the Netherlands, 2007). Following our definition described above, the coals reserves are excluded from the carbon stock account.

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 drilling has been postponed due to environmental and social concerns. The Dutch government has decided that there will be no commercially drilling of shale gas until at least 2023. The reserves of shale gas are therefore excluded from the carbon stock account. The amounts of shale gas in Dutch deposits are unknown. A first, uncertain estimate ranges from 200-500 billion m^3 (TNO, 2015).

Limestone

Carbon is also an important constituent of the limestone that is exploited for the production of cement and cement-products. Due to the lack of reliable data, 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 physical supply and use tables (Statistics Netherlands).

6.3.3 Results

Table 6.3.1 shows the details of the carbon stock account for geocarbon in 2018. Total stocks of carbon in subsoil energy resources amount to around 426 Mton C. Natural gas represents by far the largest stock of carbon, followed by crude oil. An important cause of the fall in the value of the reserves is the government's policy to continue to phase out natural gas extraction from 2014 onwards, which is the main cause for the downwards reappraisal of 237 Mton C in 2018 for natural gas.

Table 6.3.1 Geocarbon stock account for the Netherlands in 2018.

Mton C	Oil	Natural gas	Shale gas	Coal	Limestone	Total
Opening stock	32,2	394,1				426,4
Additions to stock						
Unmanaged expansion						
Managed expansion						
Discoveries						
Upwards reappraisals	1,2					1,2
Reclassifications						
Imports						
Reductions in stock						
Unmanaged contraction						
Managed contraction	1,2	16,9			0,1	18,3
Downwards reappraisals		237,1				237,1
Reclassifications						
Exports						
Net carbon balance	0,0	-253,9			-0,1	-254,1
Closing stock	32,2	140,3				172,3

6.4 Carbon in the economy

6.4.1 Definition and scope

The SEEA EA carbon stock account also includes carbon in products accumulated in the economy (UN, 2021). Examples include petroleum products in storage, carbon stored in building materials (wood, concrete, etc.), bitumen in roads and carbon stored in waste dumps. As mentioned previously, this excludes carbon in biomass in crops, grass in meadows, but includes carbon in livestock. 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.

6.4.2 Structure of the stock account for carbon in the economy

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 6.4.1). Carbon assets in the economy can be further disaggregated into the following SNA components (SEEA EA):

- **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, used 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 6.4.1 Structure of the carbon stock account for the Dutch economy. Grey cells are null by definition

Mton C	Inventories			Fixed assets and consumer durables		Waste		**TOTAL**
	fossil fuels	biobased	mixed	biobased	mixed	biobased	mixed	
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 6.4.1, 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 ’fossil fuels’, ‘biobased products’ and ‘mixed 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.

Additions and reductions in stock: the rows

The row entries in principle should follow the standard layout of the carbon stock 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 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 cultivated (crops, fodder) and non-cultivated assets, i.e. wood extraction, fisheries and extraction of other biological products from the environment

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, 2021). 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 CF water emission accounts (UN, 2021).
- 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.

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

6.4.3 Data sources and methodology

The data needed to compile the carbon stock 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 stock 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) (Statistics Netherlands, 2021b, 20121e, 2021f, 2021g). 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.
- 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.

Additions to stock.

- Data for the extraction of biocarbon, geocarbon and limestone was obtained from the physical supply and use tables. 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 also obtained from the physical supply and use tables. The carbon in cultivated crops enters the economy from the biocarbon stock account. 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 (Statistics Netherlands, 2021c). Included are 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. Besides CO_2, methane (CH_4) emissions (from for example livestock and other agricultural practices) are also included.

- 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 the physical supply and use tables. 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 (Statistics Netherlands, 2021b). In addition, a share of the imports will remain in the economy as fixed assets or consumer durables (furniture, wooden products, etc.). Data on the imports of these product groups was obtained from the physical material supply and use tables
- 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, biobased materials used in furniture, vehicles and machinery (wood, plastics and textiles).
- Carbon in recycled products was calculated based on data from the waste accounts (Statistics Netherlands, 2021d). The amount of different residuals that are recycled were identified.
- The amount of waste produced was obtained from the waste accounts (Statistics Netherlands, 2021d) and the physical supply and use tables. 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, an extensive list of carbon content shares was obtained from experts from the WUR and the NOVA institute. Lastly, 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/).

6.4.4 Results

Table 6.4.2 shows the results for carbon accumulation in the economy (2018). The net carbon balance for the Dutch economy in 2018 is 7,1 Mton C. Around 1,9 Mton of carbon is stored in the waste dumps. Also around 1,9 Mton of carbon is stored in consumer durables and fixed assets such as plastics and wood in furniture, bitumen in roads and building materials such as concrete and wood used in the construction industry.

Table 6.4.2 Carbon in the economy for the Netherlands (2018). Grey cells are null by definition.

Mton C	Inventories			Fixed assets and consumer durables		Waste		**TOTAL**
	fossil fuels	biobased	mixed	biobased	mixed	biobased	mixed	
Opening stock	19,8							
Additions to stock								
Managed expansion								
Extraction from geocarbon	16,1		0,1					16,2
Extraction from biocarbon		0,9						0,9
Capture from the atmosphere		6,8						6,8
Upwards reappraisals								
Reclassifications								
incorporation in products			9,7					9,7
Gross fixed capital formation				1,3	1,5			
recycled products		9,3	1,7					11,1
Waste production						10,4	2,8	13,2
Imports	147,8	28,5	24,3			6,6	1,8	209,1
Reductions in stock								
Managed contraction								
Emissions to the atmosphere	43,4	4,3	3,2			1,7	0,9	53,5
Respiration of humans		1,5						1,5
Respiration of livestock		4,7						4,7
Emissions to water		0,0						
Emissions to soil		0,6						0,6
Downwards reappraisals								
Reclassifications								
incorporation in products	9,7							9,7
Gross fixed capital formation	0,1	1,2	1,5					
Recycled products						9,3	1,7	11,1
Waste production		9,6	2,7	0,7	0,1			13,2
Exports	110,2	20,1	29,0			5,1	1,1	165,4
Net carbon balance	0,4	3,4	-0,4	0,5	1,4	0,9	1,0	7,1
Closing stock	20,8							

6.4.5 Data gaps and areas for improvement

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

- Good data on product inventories are only available for commercially and socially extractable fossil fuels. No data for carbon stocks were available for the other inventories (biobased products and 'mixed 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 in the future.
- 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.

6.5 Carbon in the atmosphere

6.5.1 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 stock 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 1860 as the stock for carbon in the atmosphere. Although we realize this is an assumption, we have included this figure to provide an indication of the total stock of carbon in the atmosphere that was added due to Dutch economic activities. Air emissions from biocarbon and sequestration in biomass by natural ecosystems is not included in the estimate of the cumulative carbon stock. The presented figure of the carbon stock could therefore be an underestimation.

6.5.2 Results of the carbon emissions to the atmosphere

Table 6.5.1 shows the carbon stock account for the atmosphere for the Netherlands (2018). The emissions of carbon to the atmosphere are larger than the net sequestration of carbon, resulting in a net carbon balance of 54,5 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 6.5.1 Carbon stock account for the atmosphere (2018) in Mton C. The opening and closing stock (yellow cells) comprises of cumulative Dutch carbon emissions resulting from fossil fuel combustion since 1860.

Opening stock		3093,8
Additions to stock		
	Short cyclic emissions diue to economic activities	6,6
	Other emissions due to economic activities	47,5
	Respiration of humans and livestock	6,3
	Emissions from biocarbon (natural ecosystems)	1,8
Reductions in stock		
	Carbon uptake in cultivated plants	6,8
	Carbon sequestration in biocarbon (natural ecosystems)	0,8
Net carbon balance		54,5
Closing stock		3148,3

To clarify how the emissions to the atmosphere in the carbon stock 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 stock account) and in CO_2 equivalents (the unit used to record emissions in the air emission accounts and the IPCC inventories). The results of this comparison can be found in the previous edition of the carbon stock account report (Statistics Netherlands and WUR, 2017d).

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