Natural Capital Accounting in the Netherlands - Technical report 2025

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1. Introduction

1.1 Objective of this report

Natural capital accounting or ecosystem accounting is a statistical approach to systematically measure and monitor ecosystem extent, ecosystem condition, and ecosystem services 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). In alignment with this framework, Statistics Netherlands (CBS) and Wageningen University and Research (WUR) have collaborated since 2015 to implement natural capital accounting for the Netherlands.

This report provides a comprehensive technical description detailing the methodologies, models, and data sources employed in compiling the Dutch Natural Capital Accounts. It also includes technical notes on interpreting outcomes and assessing quality. Serving as a background document for publications, this report underlines updates and improvements in natural capital accounting research according to SEEA EA by Statistics Netherlands and WUR.

Numerous data sources contribute to the development of the Dutch Natural Capital Accounts, sourced internally from Statistics Netherlands and WUR or externally. These sources may undergo minor alterations or require more extensive processing to align with the models and statistical guidelines to achieve the desired results. This report provides detailed descriptions of the steps taken in using and processing these data sources. Throughout this report, there is a comprehensive discussion not only of the methodologies used to generate the desired output but also of the structure of the developed models. This thorough approach ensures a clear understanding of the decision-making process throughout the development of the natural capital accounts. In summary, the report provides the necessary background to comprehend how the Dutch Natural Capital Accounts are compiled.

1.2 Introduction to SEEA ecosystem accounting

The SEEA EA stands as an integrated statistical framework with a spatial emphasis, systematically organizing data related to ecosystems. This framework goes beyond measuring ecosystem services to also encompass tracking changes in ecosystem extent and condition, and valuing ecosystem services and assets in monetary terms. Additionally, it establishes links between this ecological information and measures of economic and human activity (UN, 2021). Developed to address various policy demands and challenges, the primary goal of Ecosystem Accounting is to highlight and quantify the contributions of nature to both the economy and human well-being.

The 52nd United Nations Statistical Commission, on March 2021, has endorsed the SEEA EA. Chapters 1-7 on physical accounting were adopted as an international 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. The new statistical framework enables countries to measure their natural capital and understand the contributions of nature to social prosperity. In short, there is international agreement on how to measure the extent and condition of ecosystems and their services.

The SEEA EA complements the System of Environmental-Economic Accounting 2012—Central Framework (SEEA Central Framework), as it expands on measuring the connection between the environment and the economy (UN et al., 2014a). The SEEA, consisting of both the SEEA Central Framework and the SEEA EA, establishes a system that is coherent with the concepts of the System of National Accounts (SNA). It uses accounting principles to integrate physical and monetary measures related to the environment, enabling comparison with national accounts data. When it comes to monetary valuation, SEEA EA adopts the SNA concept of exchange values. While estimates based on this concept are valuable in many contexts, there are limitations, such as excluding the broader social benefits of ecosystems, including non-use values.

In a broader sense, monetary values alone may not fully capture the significance of ecosystems for people and the economy. To assess the importance of ecosystems, a comprehensive approach is needed, considering various information beyond monetary values. This includes data on the physical characteristics of ecosystems and details about the individuals, businesses, and communities that depend on them.

The SEEA EA consists of a system of integrated *ecosystem accounts*. These constitute the core of the ecosystem accounting system:

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 these five core accounts of the SEEA EA. They are compiled following, as much as possible, the conceptual guidelines provided by the revised SEEA EA.

EU member states are required to report on Ecosystem Accounting starting in 2026. This includes the ecosystem extent accounts, ecosystem condition accounts and ecosystem services in physical terms. Statistics Netherlands and WUR have been compiling Ecosystem accounts years before the regulation – and are actively involved in the Eurostat Taskforce that is developing the handbook on Ecosystem Accounting. The work of Statistics Netherlands and WUR, as outlined in this report, follows the Eurostat guidelines. Therefore, necessary adaptations have been made. This way, the outcomes of the Ecosystems accounts are suitable for international comparisons and analyses.

1.3 How to read this report

This report is annually 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 extent account is covered in Chapter 2. The condition account - with indicators on green areas, air quality, soil organic carbon, bird index, deadwood, tree cover density, artificial impervious area and water quality - is described in Chapter 3. Physical and monetary ecosystem services, separated into different types of ecosystem services - provisioning, regulating and cultural - as well as the compilation of the supply and use of ecosystem services, are addressed in Chapter 4. The asset account is covered in Chapter 5. A conclusion is given in chapter 6. References are split into literature and data sources in chapter 7. The appendices can be found in chapter 8.

2. Extent account

2.1 Introduction

The ecosystem extent account forms the foundation of ecosystem accounting. Ecosystem accounting requires delineating areas within an accounting area into distinct spatial units representing ecosystems. Accounting for the ecosystem extent involves identifying, classifying, and measuring the extent of all different ecosystems within the area of interest. Consequently, ecosystem extent accounts organize data of the area (or extent) and location of different ecosystems.

In ecosystem accounting terms, ecosystems are represented by ecosystem assets. Ecosystem assets are the statistical units for ecosystem accounting. They are defined as the spatially-defined units of a specific ecosystems, characterized by a distinct set of biotic and abiotic components and their interactions (SEEA EA 2.11). Each spatial unit of a specific ecosystem, for accounting purposes, is treated as an ecosystem asset. Ecosystem assets include, for example, an individual forest stand, an agricultural parcel, or a single salt marsh. These individual ecosystem assets can be further classified into ecosystem types, such as forest, cropland or marshland.

The ecosystem extent account organizes the data of the area of different ecosystem types. The extent account, in its strict sense, is a table registering the total 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. Additionally, the extent account can support relevant indicators of ecosystem composition and change 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 extent account is derived from an ecosystem map, in which all ecosystem assets are delineated and classified. Statistics Netherlands has developed ecosystem extent accounts and maps for the Netherlands. This chapter described the methodology used for this.

2.2 The ecosystem type classification for the Netherlands

Statistics Netherlands have developed an ecosystem type classification of the Netherlands for ecosystem accounting. Existing maps of the Netherlands focus solely on the biophysical land cover (the topographic maps) or land use (Statistics Netherlands land use maps) or specific regions (e.g., agricultural parcels or nature management areas), and are not fit for ecosystem accounting. The ecosystem map and classifications of Statistics Netherlands is designed with a focus on ecology and ecosystem services, and maximal compliance with the SEEA EA guidelines and the EU Ecosystem typology.

In the Netherlands, 21 different ecosystem types are being recognized in a 2-tier classification scheme. These are shown in 2.2.1. The ecosystem type classification is designed to meet SEEA EA guidelines (including alignment with the IUCN Global Ecosystem Typology[1]) and the (proposed)

[1] The IUCN GET (https://global-ecosystems.org/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.

EU Ecosystem typology. Furthermore, ecosystems in agricultural and urban areas are classified to represent distinct areas with a typical signature in ecology and ecosystem services.

Table 2.2.1: Ecosystem type classification for the Netherlands

Level 1	Definition	Level 2	Definition
Settlements and other artificial areas	This class represents ecosystems charactarized by buildings and other man-made structures, including residential, industrial, commercial, and transport areas. It excludes green ecosystems in the urban environment, which area classified under 'Urban green and recreation'.	**Settlement areas**	Includes residential, commercial and industrial areas and adjacent (small) roads, properties and front- and backyards.
		Infrastructure	Includes land used for transport infrastructure, such as major roads, railways, airports and ports, including associated green areas (such as road verges). Includes extraction sites and dump areas.
Urban greenspace and recreation sites	This class represents urban greenspace such as public parks and other vegetated areas, as well as areas used for recreation and leisure activities such as sports and camping grounds.	**Urban greenspace**	Includes grass and forest patches within urban areas that function as public green space. This covers managed green areas that are not part of designated nature sites, green areas within the built-up area that adjoin nature sites, and other grass and forest patches inside the built-up area. Associated infrastructure such as bicycle and walking trails is included as well.
		Sports and recreation sites	Includes areas used for recreation purposes. Includes among others cemeteries, zoos, theme parks, historical and botanical gardens, community gardens, sports grounds, camping grounds and leisure parks.
Cropland	This class represents areable land including intensively and extensively managed cropland, and temporary grasslands used for crop rotation.	**Annual cropland**	Includes cropland planted for annually or regularly harvested crops. They include arable land for potatoes, vegetables, cereals, industrial crops, pulses, floriculture and horticulture. Fallow land is also included in this category.
		Temporary grassland	Includes temporary grasses (less than 5 years old) sown as intercrop, for silage and grazing. Due to its role in the annual crop rototation, this ecosystem is classified under cropland instead of grassland.
		Permanent cropland	Includes areas with perennial crops. Mainly plantations of woody crops, vineyards, fruit and berry plantations, christmas tree plantations and nurseries.
		(Semi-)natural cropland	Includes cropland with natural and semi-natural elements, such as strip cultivation and arable field margins.
Grassland	This class represents permanent grassland, including managed pastures used for agriculture and (semi-)natural grasslands. Temporary grasslands are excluded, which are classified under 'Cropland'.	**Sown pastures and modified grassland**	Includes pastures and other grassland primarily managed for agriculture use (grazed or mowed). Excludes temporary grasses.
		Natural and semi-natural grassland	Includes grasslands under limited or moderate human influence characterised by natural elements and nature management.
Forest and woodland	This class represents tree-dominated ecosystems, consisting of natural forests and cultivated forests for timber production.	**Deciduous forest**	Includes forests dominated by broadleaved tree species. These are typically seasonal forests where trees shed their leaves in autumn.
		Coniferous forest	Includes forests dominated by needle-leaved tree species. These

			are usually evergreen forests adapted to cooler or drier conditions.
		Mixed forest	Includes forests where both broadleaved and needle-leaved tree species occur together without one group being clearly dominant.
Heathland and other sparsely vegetated ecosystems	This class represents all heathland, inland dunes, drift sand and other inland sandy ecosystems outside of coastal dunes.	**Heathland**	Includes heathlands, characterised by low and closed vegetation cover, dominated by ericaceous shrubs.
		Inland sandy areas	Includes inland land dunes and other inland sandy areas.
Inland wetlands	This class represents all freshwater wetlands, including marshes; bogs; fens etc. It excludes open water.	**Bogs**	Includes (remnants of) raised bogs and and other (potentially) oligotrophic wetlands.
		Eutrophe and mesotrophe fens	Includes base-rich fens and other mesotrophic and eutrophic wetlands.
Rivers and canals	This class represents rivers, streams, canals and other permanent linear inland surface water features.	This ecosystem has no sub-categories	
Lakes and reservoirs	This class represents lakes and all other similar non-linear surface water features.	This ecosystem has no sub-categories	
Coastal beaches, dunes and wetlands	This class presents to all land-based ecosystems next close to the sea, with strong marine influences. This includes beaches, dunes and coastal salt marshes.	**Coastal dunes and beaches**	Includes natural non-vegetated expanses of sand in coastal locations, such as beaches, dunes, shoals and shores.
		Coastal salt marshes	Includes salt marshes and associated coastal wetlands, that are susceptible to periodic flooding by seawater.
Marine waters, inlets and transitional waters	This class represents all marine areas and transitional waters, including the North Sea, the Wadden Sea and other salt-water estuaria and intertidal waters.	This ecosystem has no sub-categories	

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

Settlements and other artificial areas

- **Settlement areas.**
  - Top10NL terrain parcels;
  - Top10NL streets and smaller roads along above areas;
  - Top10NL specified ‘’functional’’ polygons.
- **Infrastructure.**
  - All Top10NL infrastructure units not classified as otherwise;
  - Top10NL specified ‘’functional’’ polygons for economic activities that depend on, or define soil resources.
  - Top10NL grass (small areas) next to or enclosed by infrastructure such as roadsides.

Urban greenspace and recreation sites

- **Urban greenspace.**
  - All Top10NL grass and forest patches classified as public green space, defined as:
    - Patches intersecting with BGT amenity green space but not with NNN or SNL;

        - Patches within the built-up area intersecting with both BGT amenity green space and NNN/SNL (outside the built-up area these are classified as nature);
        - Patches within the built-up area that do not intersect with any of these layers.
- **Sports and recreation sites.**
    - Top10NL specified ''functional'' polygons; Sports sites such as golf courses, tennis courts, racing circuits, outdoor swimming pools and other sports complexes. Recreational sites including among others botanical and community gardens, zoos, amusement parks, bungalow parks and campsites.
    - Top10NL grass and forest map units, not classified elsewhere, within PNMP historical gardens (L02.*).These include for example old forts and other historical buildings with their associated estates and gardens.

Cropland

- **Annual cropland.**
    - Top10NL cropland map units dominated by selected crop types according to the agricultural parcel registry.
    - Top10NL map units dominated by selected ''fallow'' crop types according to the agricultural parcel registry.
- **Temporary grassland.**
    - Top10NL grassland map units dominated by temporal grassland according to the agricultural parcel registry.
- **Permanent cropland.**
    - Top10NL cropland and/or orchard map units dominated by perannual crop types according to the agricultural parcel registry.
    - Top10NL orchard map units that fall outside the agricultural parcel registry.
- **(Semi-)natural cropland.**
    - "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.
    - Top10NL map units dominated by selected "field margin" crop types according to the agricultural parcel registry.

Grassland

- **Sown pastures and modified grassland.**
    - Top10NL grassland map units dominated by selected grassland types according to the agricultural parcel registry.
    - Top10NL grassland map units that remain unclassified outside of specified built-up or natural areas.
- **Natural and semi-natural grassland.**
    - "N"-type grassland from the PNMP within NNN (MT N10.01/02; N11.01; N12.01/02/03/04; N13.01/02).
    - Top10NL grassland within PNMP (MT N01.01/02/03/04; N08.01, for N01.03 only dry grassland).
    - "N"-type grassland from the PNMP (MT N12.06)
    - Top10NL grassland within NNN.

Forest and woodland

- **Deciduous forest.**
    - Top10NL forested map units classified as deciduous forest.
- **Coniferous forest.**
    - Top10NL forested map units classified as coniferous forest.
- **Mixed forest.**
    - Top10NL forest map units classified as mixed forest.

Heathland and other sparsely vegetated ecosystems

- **Heathland.**
    - PNMP heathlands (MT N07.01).
    - Top10NL heathland within PNMP sandy rewilding areas (MT N01.04).
    - Top10NL heathland outside of any PNMP.
- **Inland sandy 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.).

Inland wetlands

- **Bogs.**
    - PNMP peat bog types (MT N06.03 to N06.06)
    - PNMP marshland (MT N05.01) bordering above
- **Eutrophe and mesotrophe 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)

Rivers and canals

- This ecosystem has no sub-categories.
    - Top10NL streams and rivers.

Lakes and reservoirs

- This ecosystem has no sub-categories.
    - Top10NL ponds and lakes.
    - PNMP brackish water type (MT N04.03).

Coastal beaches, dunes and wetlands

- **Coastal dunes and beaches.**
    - 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)
    - Top10NL sand map units spatially connected to both marine elements (intertidal) and terrestrial coastal elements (coastal dunes, artificial coastal levees, etc.)
    - Top10NL sandy map units connected to intertidal but not no terrestrial elements (i.e., not beaches)
- **Coastal salt marshes.**

    - VEGWAD salt marsh types (Kp, Kpb, Kl, Klb, Km, Kmb, Kh, Kb, Kn, Kv)

Coastal defences

- This ecosystem has no sub-categories
    - Artificial marine shorelines (basalt) from Top10NL
    - INSPIRE embankments that intersect the formal coastal defense tracks.

Marine waters. Inlets and transitional waters

- This ecosystem has no sub-categories.
    - Top10NL labeled marine sea map units.
    - Top10NL intertidal map units.

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 Dutch Cadastre, Land Registry and Mapping Agency, and updates are published multiple times each year. The final update of each reference year is used.
- 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.
- 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.
- National Nature Network (NNN, from VRN reports). The NNN boundaries are derived from the provincial Voortgangsrapportage Natuur (VRN), which is published annually and provides information on the extent and progress of designated nature areas.
- INSPIRE dataset – Sea dikes/embankments. This dataset delineates sea dikes along the Dutch coast, published in line with the INSPIRE Directive.
- Floodplains (Rijkswaterstaat). These maps indicate floodplain areas along major rivers, maintained and updated by Rijkswaterstaat.
- KernGIS green infrastructure. This dataset provides information on green areas managed along national transport infrastructure, published by Rijkswaterstaat.

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

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 strip of the North Sea.

2.3.3 Construction

Ecosystem types maps for each year were constructed using a fully automated process implemented in ArcGIS, as arcpy scripts. The process consists of rule-based classification, in which the ecosystem type is determined based on the most detailed ecological information available in the data sources (2.3.1), as well as contextual information regarding the location. For example, the topographic label 'sand' will be reclassified to ecosystem type 'beach' when it is situated next to the sea. The assumption is made that the underlying data sources are correct. Errors in the source data may lead to incorrect outcomes, but it is not yet possible to implement large-scale validation. 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).

Preprocessing of the source data

In the preprocessing phase, three scripts are used to process and structure the raw source data, which originate from various registries such as the BRT (Top10NL) for topographical data, the BRP for agricultural parcels, the nature management types map (NBP/imna) for nature areas, and Vegwad for salt marsh and dune areas. Additionally, datasets like the BGT (Basic Registration of Large-Scale Topography), the Rijkswaterstaat nature management map (BKN), and Rijkswaterstaat core GIS are utilized.

These datasets are first clipped to the appropriate administrative area, followed by source-specific adjustments. For example, agricultural visualization codes are consolidated under a single object to enhance consistency and accessibility, while new columns such as ecotype and subcode are added. Problem-solving steps, like filling in missing years, are implemented, and specific selections and calculations are prepared for subsequent phases.

Allocation of ecotypes and subcodes

After preprocessing, various ecotypes, subtypes, and subcodes are assigned to the data using separate scripts tailored to different themes, such as built-up areas, forests, infrastructure, and agriculture. Each of these scripts applies specific rules to convert the source data into relevant ecosystem types, ensuring a streamlined classification of different land-use types and vegetation. This process ensures that each ecosystem type is consistently named and categorized, providing an accurate representation of Dutch ecosystems.

Flattening of the layers

In the flattening step, all layers are stacked based on their priority. Layers with the highest priority, such as significant nature polygons, are placed at the top. This stacking ensures that areas with higher ecological or policy value remain visible and are not overwritten by less important layers. The result is a hierarchically organized map, where the most ecologically valuable areas are given precedence.

Postprocessing – Rasterising and assigning to categories

During the initial postprocessing phase, the vector map is converted into raster formats with resolutions of 10 and 100 meters, depending on the required scale for analysis and visualization. These maps are also enriched with ecotype codes, StatLine codes, and EU typology codes. These codes are essential for integration with other data sources and ensure consistency with both international and national standards.

Functional areas and secondary postprocessing

Each year, functional areas are added and updated, including in previous versions where they were missing. A second postprocessing phase is carried out to ensure the consistency of the new data and to implement any necessary corrections. This final step ensures that the map remains up-to-date and user-friendly for analyses, policymaking, and reporting.

2.4 Ecosystem extent account and change matrix

The ecosystem extent account tables are constructed from the highest resolution (10m) 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, 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 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.

3. Condition account

3.1 Introduction

The ecosystem condition account is one of the core accounts of the SEEA EA. Ecosystem condition encompasses the quality of an ecosystem measured in terms of biotic and abiotic characteristics. Statistics Netherlands and WUR have been compiling maps and indicators in the context of the condition account for years. Recent developments in the EU regulations regarding these accounts have been the reason to start compiling the indicators that will be mandatory from 2026 reporting onwards. These mandatory condition indicators to measure and monitor the quality of ecosystems are green areas, air quality, soil organic carbon, bird index, deadwood, tree cover density and artificial impervious area. Adding to this, Statistics Netherlands and WUR compile figures on the ecosystem condition indicator water quality. 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 key methods and assumptions for obtaining each condition indicator are described below.

3.2 State indicators

3.2.1 Tree cover density

Tree cover density is the percentage of the earth's surface that is vertically covered by tree crowns. It is an indicator of forest condition and is often used to assess functions such as carbon sequestration, climate regulation, water retention and the provision of habitats for species. This publication has been prepared using European Union's Copernicus Land Monitoring Service information < https://doi.org/10.2909/e677441e-fb94-431c-b4f9-304f10e4dfd8>. Explicitly the data used for this indicator are derived from the Copernicus Tree Cover Density product, which is based on Sentinel-2A and Landsat-8 imagery and available for the years 2012, 2015 and 2018-2021 at a resolution of 10–20 metres. For the Netherlands, the Copernicus layer was combined with the ecosystem extent map, and the indicator was calculated for the ecosystem type forest. Average tree cover density was then determined at national and provincial level.

Tree cover density is a useful measure for monitoring forest ecosystems, but in the Dutch context it has limitations. Dutch forest policy aims to increase structural variation and openness in forests, whereas production forests generally have higher and more uniform crown cover. A lower tree cover density does therefore not necessarily imply a decline in forest condition, but may instead reflect management interventions intended to increase biodiversity (Schelhaas et al., 2022).

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 Table 3.2.1 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 the 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 freshwater 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 Table 3.2.2 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 Table 3.2.3 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, 2021). 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, 2021). 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			15 µg/m^3	99th percentile (3 days/year)
$PM_{2.5}$	1 year	Limit value, 25 µg/m^3	n/a	5 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	45 µg/m^3	99th percentile (3 days/year)
PM_{10}	1 year	Limit value, 40 µg/m^3	n/a	15 µg/m^3	
NO_2	24 hours	Limit value, 200 µg/m^3	18	25 µg/m^3	
NO_2	1 year	Limit value, 40 µg/m^3	n/a	10 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.

3.4 Urban green areas

Urban green spaces constitute a critical component of the urban fabric, as they provide not only recreational opportunities but also benefits for human health and well-being. In addition, they deliver regulating and supporting ecosystem services, such as air filtration, climate regulation, and habitat provision for biodiversity. As such, the relative extent of green space within urban areas can be considered a key condition indicator for urban ecosystems.

Methodology

For the selection of green areas the CLCplus backbone dataset from the Copernicus Land Monitoring Service was used. This is an EU wide land cover dataset based on high resolution satellite data. The following classes were considered ‘green’:

2: Woody – needle leaved trees
3: Woody – Broadleaved deciduous trees
4: Woody – Broadleaved evergreen trees
5: Low-growing woody plants (bushes, shrubs)
6: Permanent herbaceous
8: Lichens and mosses
10: Water*

*Excluding marine waters

The green classes within the urban area were added together to get the total green area. This was then divided by the total urban area to get the percentage of urban green.

3.5 Dead wood in forests

The condition indicator ‘dead wood in forests’ measures the volume of non-living woody biomass in forest ecosystems. Dead wood is a key indicator of ecosystem structure and health. It supports biodiversity by providing a microhabitat for various animal and plant species. Dead wood is also an important factor in nutrient cycling, carbon storage and structural biodiversity. Monitoring dead wood offers therefore valuable insights into the ecosystem condition.

The dead wood indicator includes both standing and lying dead wood, and is expressed in m^3/ha as an annual national average, as defined in accordance with the Eurostat Guidance Note on Ecosystem Condition Accounts. The indicator consists of the sum of the volume of non-living standing and lying woody biomass in forests.

Methodology

Data on dead wood were obtained from the Dutch National Forest Inventory (NFI). For this indicator, data from the sixth (2012-2013) and seventh (2017-2021) NFI of the Netherlands was used. In the NFI, per plot the volume of standing and lying woody biomass is collected. Using the database, the average volume of standing, lying and total dead wood was calculated in cubic meters per hectare (m^3/ha) at the national level. Average dead wood volumes were calculated separately for deciduous and coniferous forests. Based on these values, the volume of dead wood for mixed forests were estimated. Here, it was assumed that mixed forests consist of an equal 50:50 ratio of deciduous and coniferous forests.

3.6 Artificial impervious area in the coastal zone

Impervious area cover is an indicator for ecosystem degradation in coastal areas, reflecting the encroachment of artificial land such as houses, roads and other infrastructure. The indicator reflects whether the naturalness of coastal areas is preserved or if there is a conversion driven for example by tourism.

Methodology

Information on the degree of soil sealing was taken from the ‘High Resolution Layer’ on imperviousness by the Copernicus Land Monitoring Service. It is a raster dataset with a 10m resolution that provides per-pixel estimates of impermeable cover expressed as percentage of imperviousness (0-100%) within each pixel. The coastal zone was defined as 1km land inward from the high tideline.

4. Ecosystem services: physical and monetary

4.1 Introduction

Following the general framework of the SEEA EA, 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, the use of ecosystem services 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 categories:

- **Provisioning ecosystem services** are those ecosystem services representing the contributions to benefits that are extracted or harvested from ecosystems.
- **Regulating ecosystem 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 ecosystem services** are those ecosystem services relating to the enjoyment from nature including 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

How to read this chapter?

Ecosystem services can be presented in physical and monetary terms. The key principles of monetary valuation are explained in 4.2. Provisioning ecosystem services are covered in 4.3. Regulating ecosystem services in 4.4. Cultural ecosystem services in 4.5. Ecosystem services are supplied by ecosystems and used by society, more on the supply and use of ecosystem services in 4.6.

4.2 Key principles for monetary valuation of ecosystem services

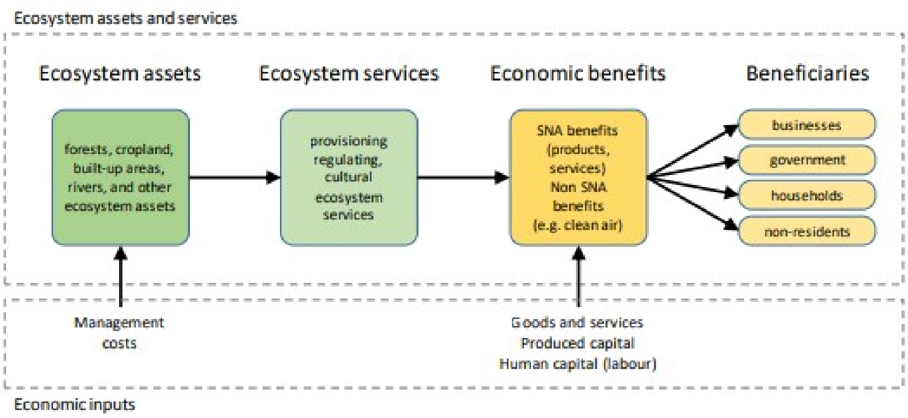
The contribution of nature can be quantified by the monetary valuation of ecosystem services or assigning a monetary amount to the benefit that an ecosystem service gives us. In practice, this is difficult because there is usually no direct payment for these services. It is often a point of discussion whether monetary valuation of nature is actually possible or desirable. After all, our natural environment is of inestimable value. Without clean air, clean water, and healthy soil for our food production, we cannot live and function on this earth. In that respect, the importance of nature cannot be expressed in money.

However, the contribution of nature to our well-being is often left out of the picture in current economic statistics. Nature is, as it were, an invisible force that makes an essential contribution to our economy and society, but which is not reflected in the monetary figures. For example, in the National Accounts the value of forest is based only on the amount of wood produced. The contribution of, among other things, carbon sequestration and air filtration by trees, and recreation in nature, remains out of the picture. By not including the contribution of non-visible ecosystem services, the forest will be undervalued.

Based on the international statistical guidelines of the SEEA ecosystem accounting (UN, 2021), it is possible to express one aspect of the value of nature in monetary terms, namely the instrumental or socio-economic (use) value of nature. This is the value that nature specifically contributes to our economy and society. The values of individual ecosystem services are determined based on methods that are consistent with the National Accounts. According to this approach, we do not determine 'the value of nature', but we do determine the current use value of ecosystems.

Monetary valuation concerns three specific components of the SEEA EA framework: ecosystem assets, ecosystem services, and the associated benefits. These are shown in Figure 4.2.1 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 4.2.1: Key components for monetary valuation in the SEEA EEA in a logic chain



The value of nature

The value of nature can be viewed from different perspectives, where a distinction is usually made between use value or instrumental value, the relational value and the intrinsic value of nature (e.g. UN, 2021; IPBES, 2023; PBL, 2024).

The intrinsic value of nature is the value of nature independent of its use or benefit to humans, or the value that nature (plants and animals) itself derives from it. By definition, the intrinsic value cannot be expressed in monetary terms, but can be approximated using physical indicators, for example in terms of biodiversity, water and soil quality.

The relational value of nature is about the meaningful and often reciprocal relationships that people can have with nature, and through nature with other people. People feel emotionally connected to, or rooted in, nature, find spiritual meaning in nature, draw inspiration from its beauty, and want to take care of nature - alone or together (PBL, 2024). This relational value is also often difficult to quantify or express in monetary terms.

From an economic perspective, nature also has a certain value because it provides services and therefore contributes specific value to the economy and society. This concerns the benefits that companies experience for their production process, but also the benefits that people experience directly from nature, such as clean air or opportunities for response in nature. Nature also provides benefits that are important for society as a whole, such as carbon sequestration and coastal protection. This so-called instrumental or socio-economic use value is therefore the value seen from a human perspective.

This publication focuses on the socio-economic use value of nature, which can be determined according to the statistical guidelines of the SEEA EA.

Interpreting monetary ecosystem values

Monetary values for ecosystem services and ecosystem assets calculated according to the SEEA EA guidelines represent social economic use values. This means that these values indicate the direct benefits that we as a society derive from ecosystems, or, in other words, how much nature contributes to our wellbeing and economic development. High/ higher monetary values represent a high(er) contribution by ecosystems, and low(er) monetary values a low(er) contribution by ecosystems. Likewise, these values express our dependency on ecosystems to provide services that are essential for our wellbeing and economic development. Higher or lower values thus indicate whether we are becoming more or less dependent on nature. As a result of this framing, it also follows that values should always be presented in the right context by providing a kind of comparison between different numbers, i.e. standalone values as such are meaningless (Statistics Netherlands, 2024).

It is also essential to clarify what the SEEA EA monetary ecosystem values do not express. The monetary use values usually do not directly say anything about the quality of ecosystems. The value of an ecosystem service is determined by several factors, including the prices of ecosystem services, the size of the different ecosystem types that provide services, the demand for ecosystem services, and the quality of the ecosystems. A recent study for the Netherlands shows that changes in demand for services are usually more important than changes in quality (Statistics Netherlands, 2024). Monetary values thus do not (usually) tell us how nature is doing. That is why, in addition to monetary values, we also need other indicators, such as biodiversity, water and soil quality, to provide insight into this aspect. The condition account, another important part of the Natural Capital Accounts, provides more information about the quality of ecosystems (link to condition account website).

In addition, monetary ecosystem values may help to describe and evaluate certain aspects of sustainability. However, in general care must be taken to use and interpret them as sustainability indicators as such. The principal objective of sustainability indicators is to inform public policymaking as part of the process of sustainability governance. A change of the indicator should therefor express if a certain process of activity becomes more or less sustainable with regard to our environment and society. Ecosystem services in SEEA describe actual supply and use which is not always the same as the sustainable supply and use. For example, overfishing and overharvesting of timber result in higher values for these services, which express that nature is more used (or exploited) for economic purposes, but obviously this is not good for the environment. Higher or increasing use value in the short term therefore does not mean that there is sustainable development.

Summarizing, monetary values express to what extent society is using and benefiting from our natural environment, and how dependent we are on nature, but these values say nothing with respect to the condition of ecosystems or whether the current use of nature is sustainable.

Strengths and weaknesses

Monetary values for ecosystem services may help to make clear that nature provides a considerable contribution to our well-being and represents a considerable wealth. Accounting for these figures also makes explicit that many economic sectors are dependent on the services provided by nature and thus rely on the good health of these natural assets. This enables policymakers to consider the different interests and thus create policy that better meets the needs of society.

A key strength of valuing ecosystem services and assets in monetary terms is that it expresses its value in one single unit. This has the great advantage that different values can be aggregated and directly compared, namely the values of different ecosystem services, ecosystem types or different areas. In addition, using a monetary metric allows comparisons with other macro-economic variables that are understood universally, such as expenditures, value added, consumption, investments etc.). As such, monetary valuation is often considered essential for communicating the economic value and scarcity of nature. These features enable the inclusion of these figures and indicators in economic and public decision making.

The monetary valuation of ecosystem services and ecosystems and the use of these figures also has several limitations (see also Statistic Netherlands 2024a). Firstly, there are a number of technical restrictions. At present, not all ecosystem services relevant to the Netherlands have yet been valued monetarily. A number of important ecosystem services, such as fishing and other services from the sea and inland waters, are still missing. So-called abiotic services, such as wind and solar energy, and the extraction of sand and gravel, have not yet been included in the calculations. The total figures in this report therefore underestimate the socio-economic contribution of ecosystems. In addition, several different valuation methods are available to determine the monetary value of ecosystem services. The choice of a particular method can influence the results. Together with partners, Statistics Netherlands and WUR are continuously working on improving the methods and expanding the number of ecosystem services, so that the calculated values provide an increasingly more comprehensive and better picture of the contribution of nature.

Second, the calculated values for ecosystem services that are not scarce can be relatively low, zero or even negative. For example, various regulating services such as water purification or coastal protection have a relatively low value. However, it would not be responsible to conclude on this basis that these ecosystem services and the ecosystems that provide them really have less or no value. A low monetary value of an ecosystem service can also be dictated by government policy (e.g. regulation of lease prices and drinking water prices) or a certain market situation. Moreover, just because a service is not scarce and of low value now does not mean that it will remain so in the future.

Third, assigning a monetary economic value to ecosystems may give 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. Converting ecosystem data into monetary values enables all kind of comparisons with macro-economic variables and considerations. This may lead to conclusions and considerations that may not always be meaningful or appropriate and may lead to misinterpretation or even misuse of these figures. A well-known example is the comparison of monetary ecosystem values with GDP. A 'low' share in GDP does not mean that the contribution of ecosystems is 'insignificant'. In addition, such a comparison should take into account which economic sectors are indirectly dependent on ecosystem services, such as part of the food processing industry.

Methods for monetary valuation

The SEEA EA provides internationally recognized statistical principles and recommendations for the valuation of ecosystem services and assets (UN, 2021). According to this methodology, ecosystem services are valued according to the 'exchange value' (use value) concept. **Exchange values** are the values at which goods, services, labor or assets are in fact exchanged or else could be exchanged for cash. This is the same concept by which national accounts value all transactions within the economy. By applying this value concept, the monetary values for ecosystem services can in principle be directly compared with economic statistics. The basic idea is: in the economy you pay the producer of the product the market value when you purchase it. Nature also produces services for us, but we cannot pay nature for them. If that were possible, what would the current market value be? Because ecosystem services often have no direct market value, the key challenge with monetary valuation is to make assumptions as if a market does exist for them.

There are various methods available that can be applied to the monetary valuation of ecosystem services. Sometimes market prices are available that closely approximate the price of an ecosystem service. An example is the rental prices for agricultural land for the ecosystem service provision of food. In other cases a more indirect method should be used. An example is the hedonic price model, with which the additional value of house prices as a result of the proximity of a green area can be determined (the amenity service). Another example is the replacement cost method. Here the value is calculated based on the costs that would be incurred if an ecosystem service were replaced by artificial (man-made) technology. For example, the costs of replacing a natural dunes with a man-made row of dunes (coastal protection ecosystem service). The SEEA EA (chapter 9) and various manuals (e.g. NCAVES and MAIA, 2022) provide an overview of the different available methods and also provide guidance on which method is best used for a particular ecosystem service.

Based on the SEEA EA guidelines and data availability, the most suitable methods for monetary valuation have been selected for each ecosystem service. The detailed method description for the monetary valuation of each ecosystem services is described below.

An important indicator that can be derived from the Natural Capital Accounts is **Gross Ecosystem Product (GEP)** (UN 2021; Statistics Netherlands, 2024a). This indicator is calculated as the sum of all final ecosystem services at their exchange value provided by all ecosystem types within an ecosystem accounting area over an accounting period. The GEP is therefore a measure of the total contribution of nature to the economy and society in a certain area/country. The GEP can be compared to the Gross Domestic Product (GDP) in the sense that the GEP is also a measure of the amount of ecological goods and services that are produced.

4.3 Provisioning ecosystem services

4.3.1 Arable and horticultural crop provisioning services – physical

Definition and scope

Crop provisioning services refer to the ecosystem's contributions to the cultivation and growth of plants that are harvested by economic entities for diverse purposes, such as food production, ornamentation, and energy generation.

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.

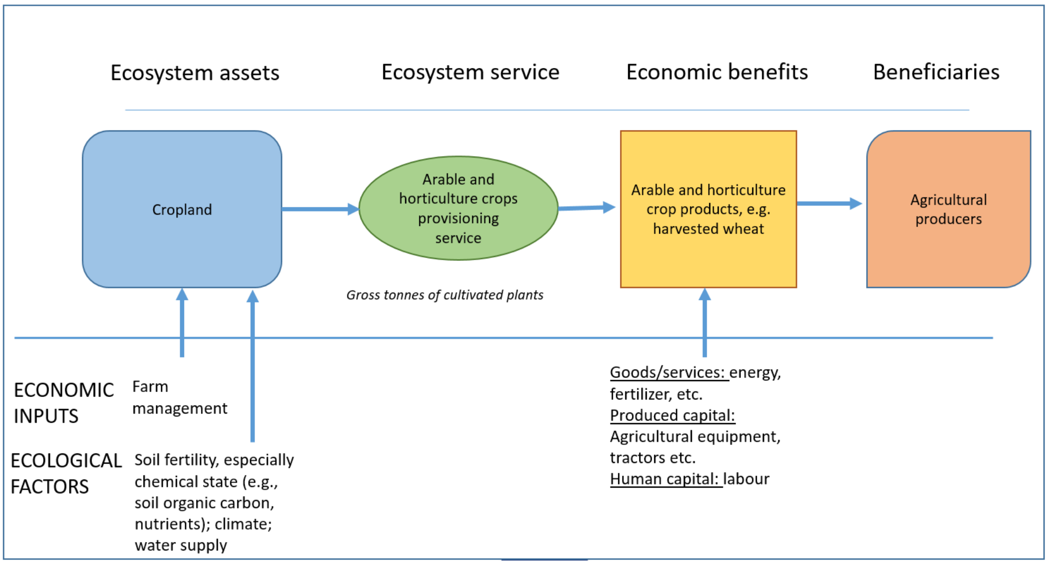
In practice, it is difficult to determine all of the various ecosystem processes as well as intra- and inter-ecosystem flows for different cultivated biological resources. Therefore, we follow the first approach: crop production is used as a proxy for the ecosystem services that together allow for agricultural 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. 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. 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 silage maize, have been excluded and are included in the ecosystem service ‘forage plants 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. However, following the SEEA EA guidelines they should be included. Which means that the service reported by Eurostat will be slightly higher than the value Statistics Netherlands will use in their output.

Logic chain
The 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).

Figure 4.3.1: Logic chain arable and horticulture crop provisioning service



Data sources
Crop provisioning services are compiled from two primary data sources. The first source is the registry on agricultural parcels, known as the Basisregistratie Gewaspercelen (BRP). This spatial data includes information on the crop category, crop code, and crop name for each agricultural parcel in the Netherlands. The data is provided by RVO.nl, the Netherlands Enterprise Agency, a government organization operating under the Ministry of Economic Affairs. Annual updates are accessible in September, reflecting the growing season of the year when the statistics are published, with the reference date set on the 15th of May each year. The database records the crop that was growing on the parcel on the 15th of May, even if multiple crops are harvested on the same parcel. It is assumed that simultaneous double crop production on the same parcel is infrequent in the Netherlands. The registry encompasses a diverse range of crops, totalling around 88 different crops considered in calculating the ecosystem service related to crop provision. See table 4.3.2 for a comprehensive list of crops included in estimating this ecosystem service.

Table 4.3.1: Input data crop provisioning service

Name dataset	Data type	Source
Basisregistratie Gewaspercelen (BRP)	Spatial data	RVO
Agricultural statistics	Monitoring data	Statistics Netherlands

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, 2025a). It shows the cropping area and gross yield of vegetables and is annually updated in April of the next year (Statistics Netherlands, 2025b). It shows the cropping area and corresponding gross yield of fruit and is annually updated in November of the same year (Statistics Netherlands, 2025c).

Methodology

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 4.3.2: List of crops 2016 t/m 2023

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 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 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 (second year)
Kale, production	Other grains	Onions, seed and plant (first year)
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	Shallots
Chicory	Pumpkin, production	White cabbage, production
Zucchini, production	Leeks, winter, production	Zantedeschia, flower bulbs and tubers
Dahlia, flower bulbs and tubers	Leeks, summer, production	Crested hyacinth, flower bulbs and tubers
Peas, green / yellow	Runner beans, production	Amaryllis, flower bulbs and tubers
Chicory root, production	Other vegetables, production	Other grains, production
Naked oats	Rocket	Sown onions, yellow
Sown onions, red		

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, like fruit, vegetables and bulbs, 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 Forage plants provisioning service – physical

Definition and scope

Strictly speaking, following the SEEA EA, Forage plants 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 livestock (e.g., silage maize, grass).

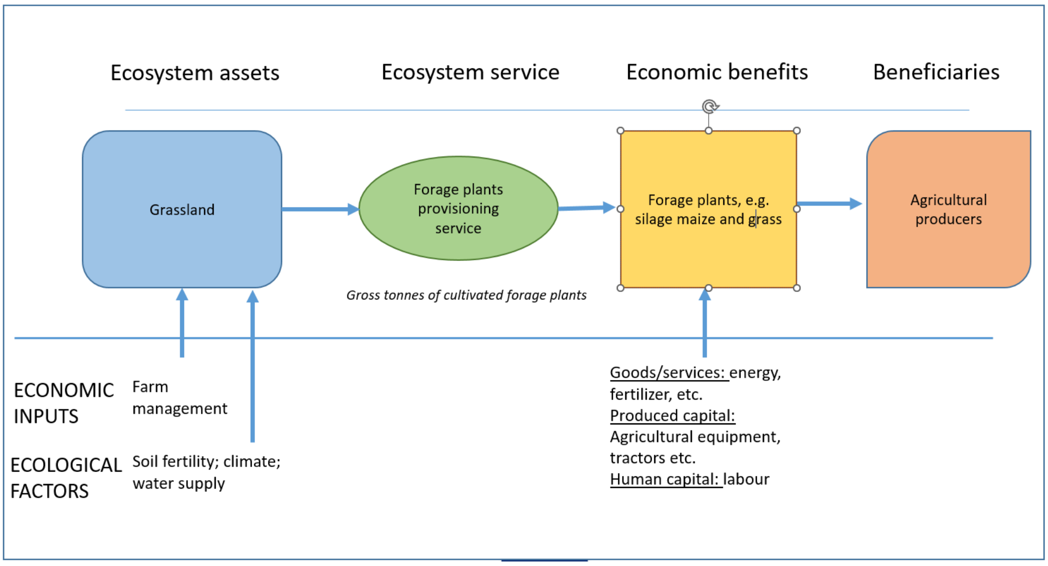
For cultivated livestock, the conceptual focus is on the extent of the connection between the livestock and relevant ecosystem assets, primarily natural and cultivated pastures (UN, 2021). Depending on the cultivation context, there may be some disconnect between ecosystems and the production of livestock 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 and fodder crops provisioning services (i.e. forage plants provisioning service) 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 (silage maize). Concentrates that are usually added to the livestock diet is not part of this ecosystem service.

Logic chain

These services are mainly supplied 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 the livestock (cattle) and livestock products. Similar as Arable and horticulture crops 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.

Figure 4.3.2: Logic chain forage plants provisioning service



Data sources

Table 4.3.3: Input data fodder provisioning service

Name dataset	Data type	Source
Registry on agricultural parcels (BRP)	Spatial data	RVO
Agricultural statistics	Monitoring data	Statistics Netherlands

Data sources and method are very similar to the ecosystem service on arable and horticulture 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

[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.

used (Statistics Netherlands, 2025a and 2025d). Data on grazed pasture grass are from the Statistics Netherlands publication on livestock and agriculture (Statistics Netherlands, 2025).

Methodology

The analysis is similar to arable and horticulture crop provisioning services. However, here the grazed pasture grass is also included in the ecosystem service. To compile the spatial data on forage plants provisioning service, data from BRP on parcels and data from Statistics Netherlands on harvest yields are combined. Following the guidelines of the SEEA EA, the yield should be reported in air dry weight (humidity degree of 15%). The yield data is adjusted based on this requirement. Data on harvesting yields of maize are available per province. Data on yields of silage grass and hay are available per pasture area: north, east, west, south and other. Data on yields of grazed pasture grass is available for two areas: north-west and south-east. It is assumed that even if the data on yields is available on aggregated level, it is a good approximation of the yield per hectare in that area. So, the first step is to add information to the parcel data on which province or pasture area the parcel lies.

To allocate harvest yields to the agricultural or grassland parcels on a map, data on harvest yields are linked with geographic location data on parcels. Yields are differentiated by province and, in the case of grasslands, also by pasture area. Accuracy checks are made by comparing the area data from the agricultural and grassland parcels with the area data from harvest yields and their corresponding harvesting areas.

From the resulting map, data on harvest yield or grazed biomass, measured in tonnes per hectare for each crop or grass type, are extracted. This information is used to create separate maps for different categories, such as horticulture, arable farming, maize and grass, of agricultural or grassland parcel yields. These maps, initially in polygon format, are then converted to raster format to facilitate the calculation and mapping of total ecosystem services.

4.3.3 Arable and horticulture crops and forage plants provisioning services – monetary

The valuation methods for arable and horticulture crops and forage plants provisioning services share significant similarities, and as such, they will be collectively discussed in this section. Various valuation techniques result in SEEA EA-consistent values (exchange values). In a previous report (Statistics Netherlands and WUR, 2020), we conducted testing and discussions on different methods. In this section, our focus will be on providing a more detailed explanation of the rental price method, as this particular technique was used for valuing these specific ecosystem services in the context of 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.

Land leases represent a form of property income, involving payments from a tenant to a landowner for the use of land over a specified period. Currently, approximately 30% of agricultural land in the Netherlands is subject to leasing arrangements[7]. The government in the Netherlands regulates rental prices, and each year on July 1st, the government establishes the maximum allowable lease prices for agricultural land (Wageningen Economic Research, 2023). These prices are determined based on the five-year average yield of the land and are specific to 14 agricultural areas.

While tenants and lessors can negotiate lease prices without compulsory government intervention, the agreed-upon price must not exceed the established maximum lease price. This regulation prevents lease prices from being influenced by external market factors, such as the state of the property market. Additionally, the linkage of maximum lease prices to the actual yield of the land enhances the suitability of using lease prices to assess the land's contribution to agricultural output[8]. The total value, encompassing both cropland and grassland, was calculated based on rent prices and data on the extent of agricultural land. Separate prices are available for horticulture.

4.3.4 Wood provisioning services – physical

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

Definition and scope

In line with the Eurostat Guidance Note on wood provisioning services, a key distinction is made between forests available for wood supply (FAWS) (cultivated forests), and forests not available for wood supply (FNAWS) (uncultivated forests). The differentiation is based on whether any environmental, social or economic restriction have a significant impact on the current or potential supply of wood.

The distinction between FAWS and FNAWS is relevant for the measurement of the ecosystem service flow. Following ESA 2010 (para. 1.102), output is recorded when produced, and ecosystem accounts follow this principle. That means that, for both FAWS and FNAWS, wood provisioning services should be measured at the point when the service is provided, even though the nature of this differs between FAWS and FNAWS:

- For FAWS, the service should be recorded progressively as the timber resources grow, in line with their treatment as economic products in the national accounts. Here, the growth of cultivated wood is an economic product. As a result, wood provisioning from FAWS is measured using net increment as the indicator of service flow. Net increment is defined as the average annual volume growth of live trees, calculated as the growing stock at the start of the year minus the average annual mortality, measured in m^3 over bark.

- For FNAWS, the service flow is measured at the moment the resources cross the production boundary. Here, this is measured in the removals of trees, quantified in m^3 over bark.

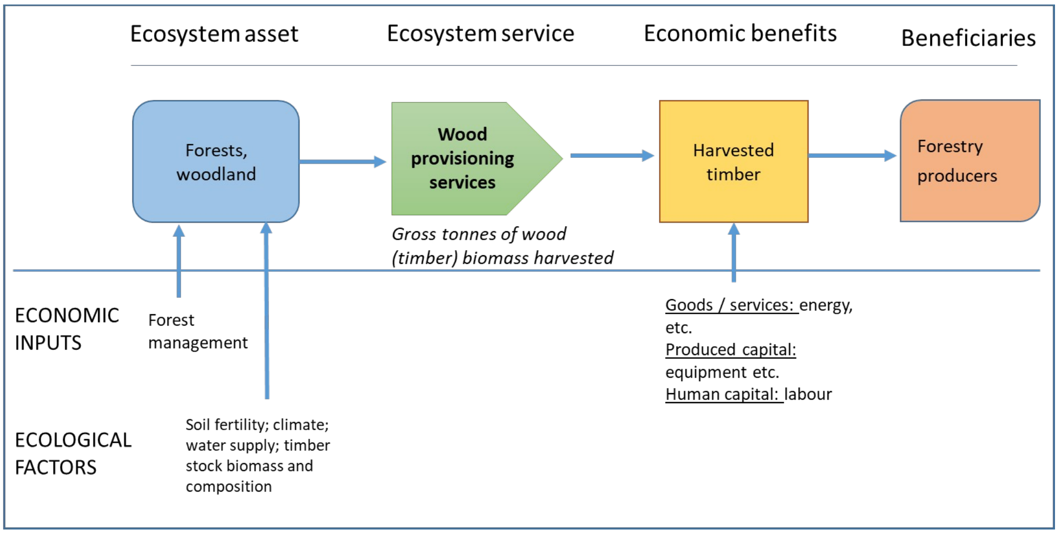
[7] CBS-Landbouwtelling, Areaal (ha) cultuurgrond naar gebruikstitels, 2012, 2013, 2014, 2015, 2016 en 2017, https://www.cbs.nl/nl-nl/maatwerk/2018/12/areaal-cultuurgrond-naar-gebruikstitels-2012-2017
[8] Agricultural land on which a lease contract rests has a lower value than land that is free of rent. 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.

The total wood provisioning service is the combination of the service flows of both FAWS and FNAWS. Consequently, this service combines both the net increment and removals of trees. The service excludes the contributions of non-forest ecosystems, such as the felling residues from trees in the urban environment. Furthermore, this ecosystem service does not include the contribution of forests to non-wood forest products, such as wild growing mushrooms, berries and nuts.

Logic chain

Wood provisioning services are provided by forests. The ecosystem service is measured in m3 of wooded biomass (over bark). The economic benefit is the harvested wooded biomass. 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]

Figure 4.3.5: Logic chain wood provisioning service



Data sources

Table 4.3.4 Input data

Name dataset	Data type	Source
Top10NL Topographic map	Spatial data	Kadaster
Zesde Nederlandse Bosinventarisatie (NBI6)	Monitoring data	Probos
Zevende Nederlandse Bosinventarisatie (NBI7)	Monitoring data	Probos
FAWS / FNAWS in the Netherlands	Reference value	Alberdi et al. (2019)
FAWS / FNAWS in the Netherlands	Reference value	Teeuwen & Velthuis (2024)

Methodology

The physical estimates of wood provisioning services in the Netherlands are based on the sixth (NBI6) and seventh (NBI7) Dutch Forest Inventory. The Dutch NFI constitutes a plot-based

[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.

monitoring database that provides statistically representative information on the composition, structure and development of the forests in the Netherlands.

For both inventories, the average net increment per hectare and average per hectare were calculated separately for coniferous and deciduous forests. Linear interpolation and extrapolation were applied to derive estimates for the period 2016-2023. The estimates were spatially allocated to the Top10NL terrain map, which distinguishes coniferous, deciduous, and mixed forests. Mixed forests were assumed to consists of 50% coniferous and 50% deciduous, for which the average of both groups was applied.

Subsequently, the distinction between FAWS and FNAWS was applied. In Alberdi et al. (2019) and Teeuwen & Velthuis (2024), estimations of the area of FAWS and FNAWS in the Netherlands were made using respectively NBI6 and NBI7 plot data on ownership, harvesting rates and nature management data. Based on this criteria, the total share of FNAWS was calculated for the total forest area in the Netherlands. Linear interpolation was applied to derive an estimated annual share of FNAWS. Following the concepts and definitions stated above, the total supply of wood provisioning is equal to the sum of the volume of net increment of wood in FAWS and the volume of removals in FNAWS.

Forests in the Netherlands often serve multiple purposes, such as timber production and nature conservation. Therefore, the wood provisioning service is assumed to be the same across all forest types, including natural forests, tree lines, production forests, and other forests.

4.3.5 Wood provisioning services – monetary

The monetary valuation of wood provisioning services follows from the physical quantification. In the monetary estimation, stumpage prices were applied to the volume of wood provisioning. Stumpage prices represent the payments per standing tree, inclusive of bark, for the right of harvesting within a designated land area. These prices serve as a direct reflection of the ecosystem service value, as they constitute the actual market prices paid for wood harvesting, ensuring full alignment with SNA exchange values.

Table 4.3.5: Input data wood provisioning services monetary

Name dataset	Data type	Source
Physical wood provisioning services	Spatial data	Statistics Netherlands
Business results in Dutch Private Forestry	Reference value	Wageningen Economic Research

Wageningen Economic Research is responsible for collecting and publishing annual stumpage prices in the Netherlands. Due to data limitations, only the average stumpage price across all timber types is used, without further regional breakdown. The utilization of an average stumpage price across all timber types, without additional regional breakdown, may result in a generalized representation of the ecosystem service value, potentially overlooking variations in timber quality and market dynamics across different regions. Consequently, this approach could lead to a simplified assessment that might not fully capture the nuanced economic contributions of timber production in specific geographic areas. The ecosystem service value for timber production is computed by multiplying the stumpage price (in euro per m^3) by the total volume of the physical wood provisioning (described above).

4.4 Regulating and maintenance ecosystem services

4.4.1 Water purification services – physical

Definition and scope

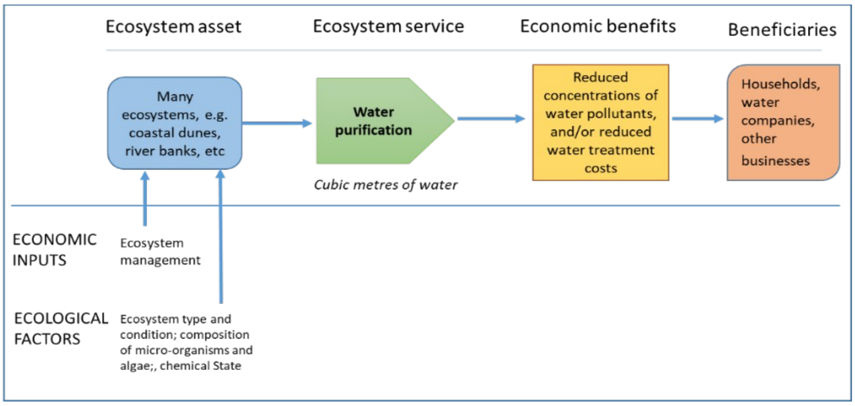
Water purification services are the ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants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

Figure 4.4.1: Logic chain water purification service



Methodology
For the physical supply of the water purification service, a base year was determined using data from the Dutch National Groundwater Register (LGR). The LGR provides detailed information on groundwater abstraction, but consistent annual data are not yet extractable for the full time series. Therefore, to capture the development over time, data from VEWIN on groundwater extraction and natural dune water extraction were used (Vewin, 2025).

As a result, the current assessment represents the national-scale trend in water purification, rather than a spatially detailed analysis. Future work aims to improve the consistency and spatial resolution of the underlying physical data, enabling a more accurate and refined estimation of this ecosystem service in upcoming revisions.

4.4.2 Water purification services – monetary

Data sources
The data for this study were derived from multiple sources. Information regarding the overall 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, was obtained from the drinking water statistics provided by VEWIN, the association of drinking water companies in the Netherlands. To analyse financial aspects, including total revenues, total costs, and production costs categorized by taxes, depreciation, capital costs, and operating costs, we referred to the annual reports of selected drinking water companies. The included companies are Brabant Water, Dunea, Evides Waterbedrijf, Oasen, PWN, Vitens, Waterbedrijf Groningen, and WMD Drinkwater. It is noteworthy that financial data for drinking water companies WML and Waternet were not considered due to the unavailability of sufficient financial information.

Methodology
In estimating the value of water purification, we employed the replacement cost approach, as initially introduced by Remme et al. (2015). This approach involves estimating replacement costs by assessing the difference in production costs for drinking water derived from groundwater as opposed to surface water. In the hypothetical scenario where groundwater is unavailable, it is presumed that the shortfall in water for drinking water production would be compensated by using river water, a practice already adopted by some Dutch drinking water companies, albeit with a preference for groundwater due to its superior quality and lower production costs.

The replacement cost method compares an existing ecosystem asset or service, such as groundwater abstraction for drinking water supply, with a potential substitute. Transitioning from groundwater to surface water abstraction results in increased production costs. The valuation of the ecosystem service is derived from the disparity in production costs between companies relying predominantly on groundwater and those primarily utilizing surface water. Implicit in this method is the assumption that the value of groundwater is zero, aligning with the SEEA EA focus on final ecosystem services but overlooking the intrinsic value of groundwater embedded in the price of drinking water.

To calculate the unit value of the ecosystem service responsible for providing clean drinking water through the natural filtration and storage of groundwater, we measured the difference in unit production costs between companies primarily extracting groundwater and those predominantly extracting surface water. Each drinking water company was categorized as either a groundwater (gw), surface water (sw), or mixed-type company based on confidential VEWIN extraction data provided by experts. 'Groundwater companies' are those extracting water from groundwater reservoirs or riverbank groundwater reservoirs. Production costs considered include operating costs, costs of capital, and depreciation, with taxes excluded from the analysis.

Note that when measured through an accounting approach, the value of this service appears comparatively low in contrast to what it would be in a welfare-based valuation approach. This discrepancy arises because the willingness of people to pay for water, as reflected in a demand curve, is generally higher than the current price paid for drinking water. Additionally, it's important to note that the method assumes the availability of sufficient river water of acceptable quality as an alternative to groundwater. This assumption aligns with the current state in the Netherlands, particularly with the establishment of several basins holding river water, acting as a buffer during dry periods. River water, being a natural resource, obviates the need for alternative, more expensive options like desalinating seawater. However, it is recommended to revisit this aspect of valuation in the future to assess whether a more fitting value can be derived, considering potential changes in water availability and demand dynamics.

4.4.3 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.

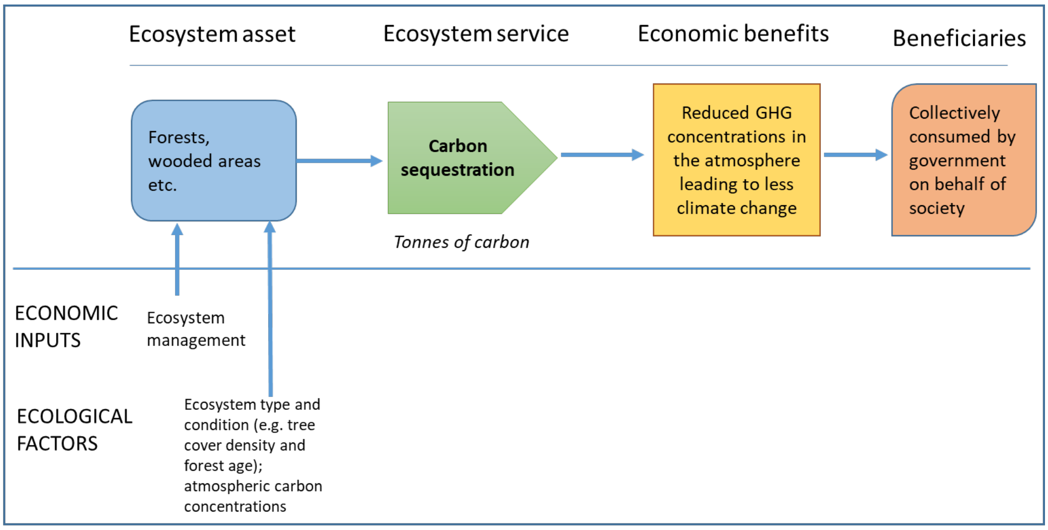
The ecosystem service carbon sequestration is defined as the ability to remove carbon from the atmosphere, contributing to climate regulation. Crucial is that this capture is long-term. Carbon that is sequestered but not expected to be stored long-term, e.g., the above ground biomass of crops, and a proportion of the carbon sequestration in forests equal to the mean timber harvest is therefore 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 of carbon sequestration is delivered by a diverse range of ecosystem types, and its provision relies on various ecological factors. Key determinants include the type and condition of the ecosystem, as well as the net ecosystem productivity (NEP), which is the disparity between net primary productivity (NPP) and soil respiration. Measurement of this ecosystem service is quantified in terms of tonnes of carbon extracted from the atmosphere.

The economic advantages of diminishing atmospheric CO2 concentrations are evident in the reduction of adverse effects and the subsequent avoidance of associated damage costs. Carbon sequestration, by actively removing carbon from the atmosphere, yields substantial benefits for society as a whole. Consequently, the primary beneficiary is the government, acting as a representative for the entire societal framework.

Figure 4.4.2: Logic chain carbon sequestration



Data sources and Methodology

Table 4.4.1: Input data

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

We used a method called a look-up table (LUT) approach to determine how much carbon is captured in the Netherlands. In this approach, each type of area on the map, like forests or agricultural land has a specific value for carbon sequestration. This value is the annual mean amount of carbon per hectare that is captured by a specific ecosystem type per year. Looking at carbon capture by ecosystems, two different measures are available: Net Primary Production (NPP), which is how much carbon plants capture during photosynthesis, and net sequestration, which is the long-term balance of carbon considering losses like respiration, fire, and wood harvest. We're using these long-term net sequestration values for our carbon sequestration service.

For carbon sequestration in farmland, we used an older study by Lesschen et al. (2012). The details for carbon sequestration in both above and below-ground parts of plants are in table 4.4.2. In forests, how much carbon is captured depends on how the forest is managed and timber harvest. The values we use are based on the net sequestration rates from Arets et al. (2018), that were based on forest growth in the period between MVF (2001-2005) and NBI6 (2012,2013). For the new ecosystem type agroforestry, we assumed that the net sequestration rate is equal to a forest.

Some ecosystems, like heath and grasslands, that capture a lot of carbon (with a NPP of 1.1 ton C/ha/year for heath and a NPP of 2.6 ton C/ha/year for natural grasslands) already reached a stable carbon stock (Arets et al., 2018). Meaning that carbon loss by natural processes and carbon sequestration in plant biomass are approximately in balance, therefore, the net sequestration is relatively low. According to Janssens et al. (2005), the net sequestration is about 0.19 ton C/ha/year for heath and grasslands. 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, on the other hand, have a high net sequestration of 1.5 ton C/ha/year. For more details check out paragraph 6.2.1.

Table 4.4.2: Look-up table for yearly 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
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

For the forest ecosystem types treelines and agroforestry, the subdivision over deciduous, coniferous and mixed forest is based on the top10 classification. For urban green spaces a subdivision is made into the three forest types and grassland based on the top10 classification. For business areas, "grondgebonden", infra-green and sport and recreation sites a subdivision is made into the three forest types, grassland and other (paved or water) depending on the top10 classification. For these ecosystem types, the sequestration rates of these ecosystem types is based on the top10 classification.

4.4.4 Carbon sequestration – monetary

The method used to calculate the economic value of carbon sequestration involves applying a carbon price linked to meeting a policy-defined goal for reducing CO_2 emissions. This goal serves as a metric for avoided damage costs. By assigning a monetary value to carbon sequestration in biomass at this established carbon price, we can quantify in monetary terms the contribution of ecosystems toward meeting the policy target.

The CO_2 prices applicable to the Netherlands have been computed by the Netherlands Bureau for Economic Policy Analysis (CPB) and the Netherlands Environmental Assessment Agency (PBL).

Referred to as the efficient price of CO_2, this represents the price at which the essential cumulative reduction in CO_2 emissions is attained with minimal costs (CPB and PBL, 2016). CPB and PBL outline three scenarios: a high-reduction scenario, a low-reduction scenario, and a scenario aiming for a two-degree temperature increase.

According to CPL and 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%. For the year 2023, the corresponding figures are 63 euros per ton of CO_2 for the high-reduction scenario, 16 euros per ton of CO_2 for the low-reduction scenario, and 79 to 395 euros per ton for the two-degree policy target. Table 4.4.3 presents the net present value per ton of carbon (C) in 2016 thru 2023. 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 4.4.3: The efficient carbon price for the Netherlands: net present value per ton of carbon in 2016-2023

	high-reduction scenario	**low-reduction scenario**	**2°-scenario lower boundary**	**2°-scenario upper boundary**
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
2021	216	54	270	1351
2022	224	56	280	1398
2023	232	58	289	1447

Source: PBL (2018).

In line with CE Delft's suggestion, this report adopts the high-reduction scenario, leading to a carbon price of 232 euros per ton in 2023 (equivalent to 63 euros per ton of CO_2).

4.4.5 Pollination - physical

Definition and scope

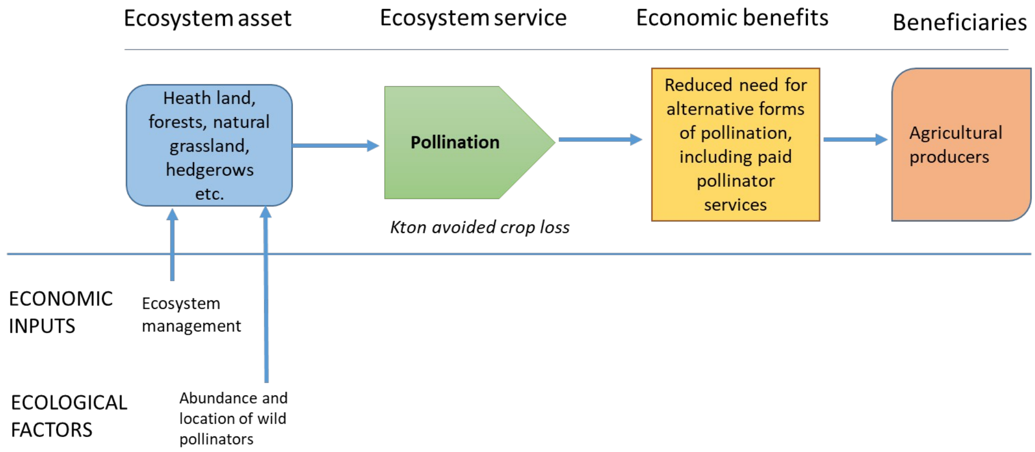
Pollination services are the ecosystem contributions by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy. Crop pollination is a regulating service defined as the fertilization of crops by pollinators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

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 honeybees, which is essential for Dutch fruit production. Also, wild pollinators are required for maintaining the quality of crops such as pears.

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.

Figure 4.4.3: Logic chain pollination



Data sources
Various data sources, as outlined in Table 4.4.4:, have been utilized to compile physical estimates for the pollination service.

Table 4.4.4: 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)

Crops differ in pollination requirements. Klein et al. (2007) divided crops, depending on degree of production dependence, in five classes (table 4.4.5). These are used to assign pollination demand (%) to crops in the Netherlands (table 4.4.6). The pollen demand represents the percentage reduction in production in absence of pollinators.

Table 4.4.5: 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 4.4.6: 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 honeybees, Apis mellifera, close to pollination demanding crops. Many crops, however, are also effectively pollinated by wild bees. Furthermore, honeybees 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 honeybees 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 4.4.7). These indicators were based on a meta-analysis of 39 studies that was conducted by Kennedy et al. (2013). Due to the lack of information and the spatial heterogeneity of all ‘paved and built- up areas’ private gardens, whether in rural (farmyards and barns) or in urban areas (residential areas), are set to zero suitability. 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.

Table 4.4.7: 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, linear element, river flood basin	80
Forest; mixed	66
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
Perennial crop	0
Built-up, infrastructure	0
Water	0

For the forest ecosystem types treelines and agroforestry, the subdivision over deciduous, coniferous and mixed forest is based on the top10 classification. For urban green spaces a subdivision is made into the three forest types and grassland based on the top10 classification. For business areas, “grondgebonden”, infra-green and sport and recreation sites a subdivision is made into the three forest types, grassland and other (paved or water) depending on the top10 classification. For these ecosystem types, the habitat suitability (total nesting and floral suitability) of these ecosystem types is based on the top10 classification.

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.

Methodology

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 calculate:

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

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,

$$P_c = f\left(v_c\right)$$

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 honeybees) 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 the basic registration of crop parcels of the same year as the ecosystem type map ("Basisregistratie Gewaspercelen") (RVO.nl, n.d.). The pollination service can be calculated as the difference between the potential production reduction in absence of pollinators (i.e. pollination demand) 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.

4.4.6 Pollination - monetary

Data sources

To determine the monetary value of the pollination service, we integrate data from various sources as can be seen in Table 4.4.8. Our approach relies on (spatial) data sourced from literature, Statistics Netherlands, WEcR, and RVO, ensuring precise and comprehensive estimates.

Table 4.4.8: Input data monetary pollination service

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)
Standard yield	Table	Wageningen Economic Research

Yield apples and pears	Table	Statline

Pollination demand is based on the classification used for the pollination requirements of Klein et al. (2007). The monetary value of 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 each year (Everdingen and Wisman, 2017; Wisman, 2021) based on average production in 5 consecutive years. Starting from 2016 a differentiation was made between fruit types (formerly in code 212) and open field vegetables (formerly in code 672). Therefore, starting from 2016 it is possible to make a distinction between vegetables that depend on pollination and vegetables that do not depend on pollination.

Table 4.4.9: Look-up table for production per hectare in 2023, given per pollination dependent crop in the basic registration of crops in the Netherlands(*Basisregistratie Gewaspercelen*) (see appendix A1 for years 2016-2023).

Crop code	Description	Production euro/ha 2023
242	Beans	2790
258	Alfalfa	1050
311	Field beans	815
515	Sunflower	1540
663	Lupine	1150
664	Rapeseed	1000
665	Soybeans	1540
666	Linseed	1360
853	Broad beans	2180
854	Broad beans	3250
1922	Oilseed rape, winter	1650
1923	Oilseed rape, summer	1240
2700	Strawberry, open field, multiplication	119000
2701	Strawberry, open field, waiting bed	47500
2702	Strawberry, open field, production	55500
2703	Strawberry, open field, seed	119000
2704	Strawberry, rack, multiplication	164500
2705	Strawberry, rack, waiting bed	61900
2706	Strawberry, rack, production	91900
2707	Strawberry, rack, seed	164500
2731	Gherkin, production	24000
2732	Gherkin, seed	44100
2723	Courgette, production	39000
2724	Courgette, seed	44100
2729	Cucumber, production	12200
2730	Cucumber, seed	44100
2733	Melon, production	16000
2734	Melon, seed	44100
2735	Pumpkin, production	6990
2736	Pumpkin, seed	44100
2779	Stem green bean, production	3380
2780	Stem green bean, seed	44100
2781	String beans, production	17900

Crop code	Description	Production euro/ha 2023
2782	String beans, seed	44100
1095	Apple, new	14200
1096	Apple	14200
1097	Pear, new	30000
1098	Pear	30000
1100	Stone fruits (including peach)	21800
1869	Blueberry	28200
1870	Plum	15600
1872	Cherry, sour	5070
1873	Blackberry	5180
1874	Other small fruits	42700
2325	Redberry	57200
2326	Raspberries	134000
2327	Blackberries	132500
2328	Cherry, sweet	28000

Methodology

The maps for pollination are generated based on the spatial location of crops that require pollination (Basisregistratie Gewaspercelen; 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 4.4.9), 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.

4.4.7 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).

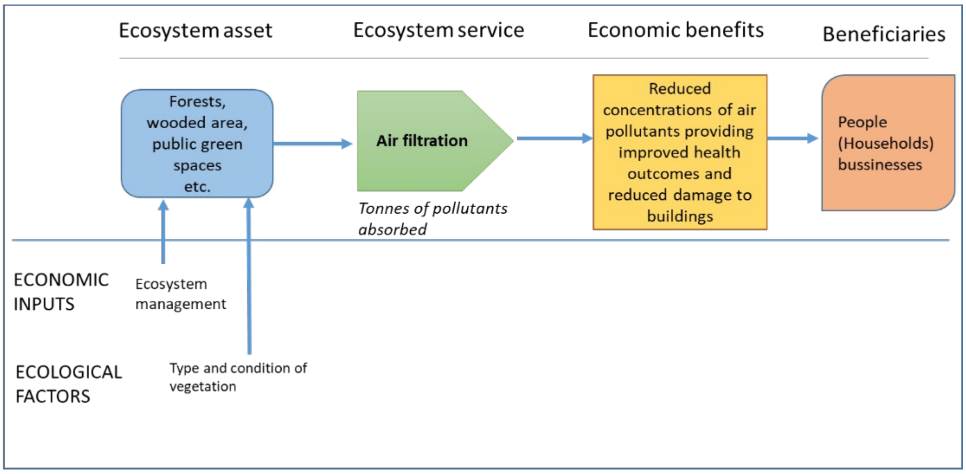
Particulate pollution covers a broad spectrum of pollutant types that permeate the atmosphere. Particulate matter is commonly referred to by size groupings: coarse and fine. PM_{10} includes particles up to < 10 µm in aerodynamic diameter, whereas $PM_{2.5}$ only represents the smallest particles (<2.5 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.

Figure 4.4.4: Logic chain air filtration



Data sources and methodology

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 days with 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}.

Table 4.4.10: Input data physical air filtration service

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

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 the accounting year 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, in one equation per period (on-leaf and off-leaf),

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

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

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 4.4.11. 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 4.4.11: 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		M_{year}
Ecosystem type	**On-leaf**	**Off-leaf**	**On-leaf**	**Off-leaf**	
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/m³. 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/m³. 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,

$$C_{PM\,2.5_{red}} = \frac{\theta * M_{year} * C_{PM\,2.5_{obs}}}{1-(\theta * M_{year})}$$

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

$$C_{PM\,2.5_{corrected}} = C_{PM\,2.5_{obs}} * \left(1 + \frac{\theta * M_{year}}{1-(\theta * M_{year})}\right)$$

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

$$Capture\ PM_{2.5}(kg/ha) = M_{year} * C_{PM\,2.5_{corrected}}$$

4.4.8 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 4.4.12: Input data monetary air filtration service

Name dataset	Data type	Source
Ecosystem Type map	Spatial data, raster 10m	Statistics Netherlands
Yearly average $PM_{2.5}$	Spatial data, raster 1000m	RIVM
Yearly average PM_{10}	Spatial data, raster 1000m	RIVM
Neighbourhood statistics (CBS buurt)	Spatial data, polygon	Statistics Netherlands
Age-dependent mortality	Statistics	Statline
Life expectancy	Statistics	Statline
Population distribution	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 $\mu g/m^3$. 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 $\mu g/m^3$ 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 $\mu g/m^3$. 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.

$$C_{PM\,2.5_{reduction}} = Capture\ PM_{2.5}(kg/ha) * \theta$$

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 $\mu g\ m^3$ (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 for the accounting year (CBS buurt 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 4.4.13). 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 4.4.15, 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 4.4.13: 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/m³. 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 (2023€ = 1.26167 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 4.4.14: Total health costs per person per μg/m³ $PM_{2.5}$ and μg/m³ PM_{10} in 2023 in 2015€. See appendix A2 for years 2016-2023

Total in € per person per μg/m³	**2023**
$PM_{2.5}$	9.21
PM_{10}	3.36

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 4.4.15). 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 4.4.15).

Table 4.4.15: age specific mortality rates (x10,000) and life expectancy (in months) of females and males as used in the calculation of 2023. See appendix A3 for years 2016-2023.

Age category	**2023**			
	Mortality rate		**Life expectancy (months)**	
	Female	**Male**	**Female**	**Male**
0 – 14	2.7	3.4	922.8	887.3
15 – 24	1.6	3.3	774	739.4
25 – 44	4.4	7.1	601.3	569.2
45 – 64	30.1	41.9	367.4	337.9
65+	346.8	372.9	163.6	152.1

4.4.9 Coastal protection – physical and monetary

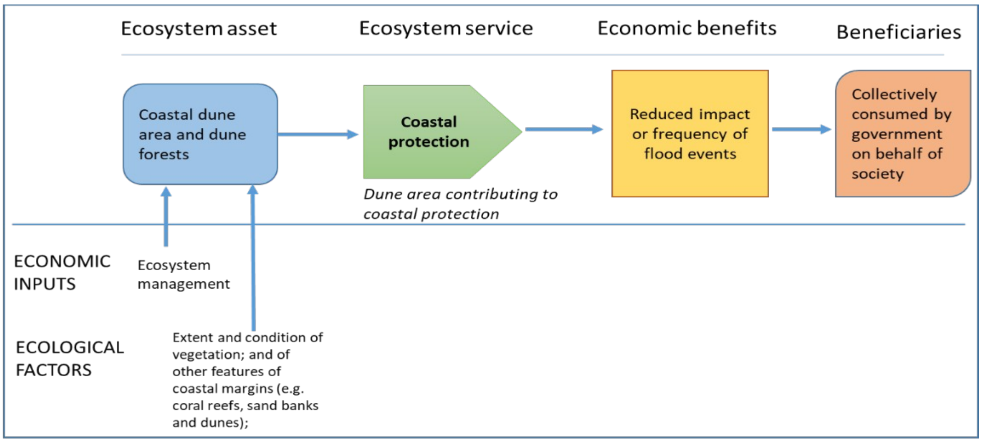
Definition and scope

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 natural 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.

Figure 4.4.5: Logic chain coastal protection



Data sources and methodology

Approximately one-third of the Netherlands lies below 0 NAP (Normaal Amsterdams Peil), the average sea level of the North Sea. Coastal dunes and beaches serve as vital barriers against flooding in these low-lying areas. The Delta Act, introduced in 1957, just four years after the catastrophic 1953 storm surge, set standards for dunes and dikes to protect the Netherlands from severe coastal flooding. In 2017, the Water Act further established updated standards, requiring all primary flood defenses—including both dunes and dikes—to meet stringent safety levels by 2050 (Rijksoverheid, 2022).

Table 4.4.16: Input data coastal protection service

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands

In assessing the physical coastal protection service, we currently rely on manually determined natural dune areas based on extent maps. This method will be revised at the end 2025 to more precisely calculate the physical area of this service. The monetary valuation is based on replacement costs, considering the feasibility of replacing dunes with either new dikes or reconstructed dunes. Dike height requirements depend on tidal factors and established flood protection standards. However, due to historical reliance on existing dikes for coastal defense in the Netherlands, cost data is available only for increasing dike heights, not for constructing entirely new coastal dikes.

The cost of raising dike height averages around 10 million euros per meter of elevation for each kilometer of dike. The Delta standard for North Sea dikes is approximately 11.5 meters, though actual costs for this height vary, and detailed data is limited. In 2015, the 5.5 km Hondsbossche and Pettemer Sea Wall was replaced by an entirely artificial system of dunes and beach at a cost of 140 million euros (excluding VAT). Using this total cost to estimate monetary value—factoring in a 2% resource rent over a 100-year period—yields a value of 0.59 million euros per km of coastal dune. Given that 264.1 km of the coast is protected by dunes, the estimated total value of coastal protection services in 2015 was 155.9 million euros. This value is updated annually for inflation to maintain the time series.

4.4.10 Protection flooding against heavy rainfall – physical

Definition and scope

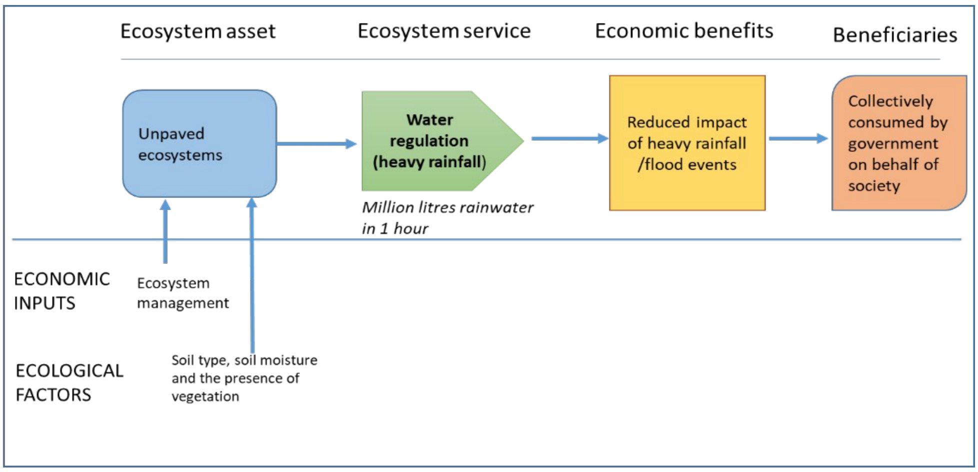
Water regulation services are the ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation 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 the average rainwater infiltration capacity for soils in mm rainwater infiltrated in the first hour of rain. 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.

Figure 4.4.6: Logic chain protection against heavy rainfall



Data sources and methodology
To compile data for the ecosystem service focused on protection against heavy rainfall, we have employed a diverse set of sources. Mainly, spatial data from the RIVM on vegetation cover, Statistics Netherlands for the degree of urbanization of neighbourhoods, and relevant literature with reference values on infiltration capacity have been utilized. Table 4.4.18 details these data sources, and in the course of this chapter, we will discuss them alongside the applied methodology.

First some main assumptions were made. It is assumed that international data on the infiltration capacity per soil- and vegetation type provided in the tables below represents infiltration capacity of Dutch soils reasonably well. Local soil compaction and the possible influence of tilling and ploughing was not taken into account here though, as no local data on local management was available. In addition, the occurrence of e.g. clayey and loamy deposits at greater depths below the surface or high ground water tables were not taken into account, possibly leading to local overestimation of infiltration capacity where these deposits or high water tables do occur.

Table 4.4.17: Input data protection against heavy rainfall

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	Spatial data	Statistics Netherlands
Infiltration capacity data	Reference values	Akan et al. (1993)
Interception of precipitation by vegetation	Reference values	Nedkov and Burkhard (2012)

For the calculation of infiltration capacity of rainwater 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. For 2016-2021 version 2, based on AHN3, of the green cover maps was used, starting in 2022 the 2022 version based on AHN4 is used. 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 (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 4.4.19). 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 4.4.19), 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 4.4.18)). We classified cells as paved or unpaved based on the ecosystem type (table 4.4.19). 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 4.4.18).
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 4.4.20).

Table 4.4.18: 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 4.4.19: 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 farmyards), 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 farmyards.

Table 4.4.20: 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	

4.4.11 Local climate regulation (Mitigation of urban heat island)

Definition and scope

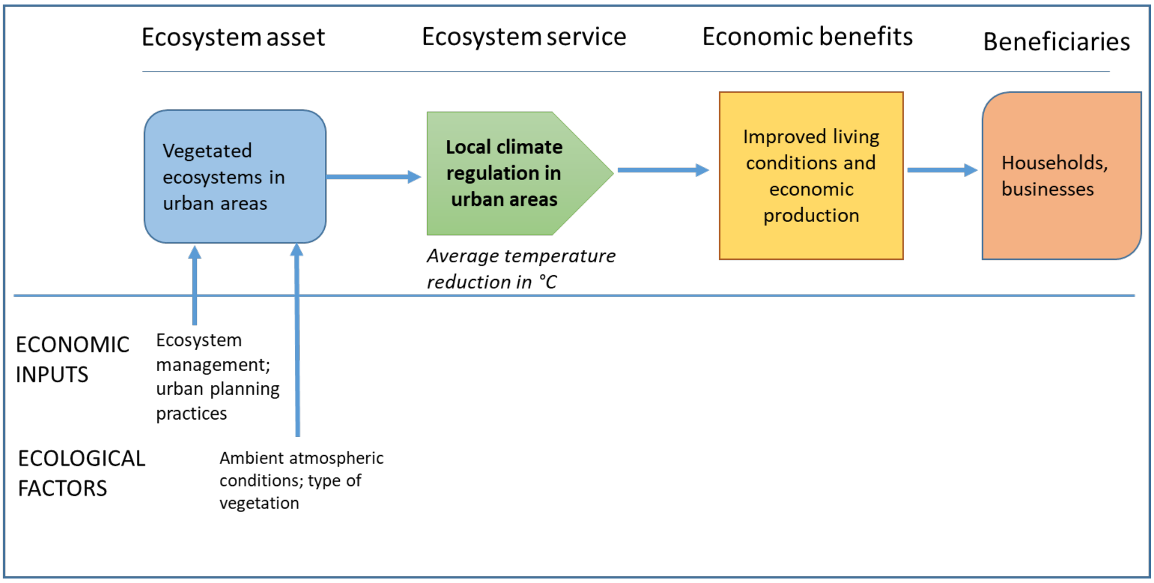
Local climate regulation services are the ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production (UN, 2021).

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 average reduction of the increased temperature in the city cumulative over all days with maximum temperatures ≥ 25 °C in the Bilt, with a unit in degree Celcius. The economic benefits are Improved living conditions and economic production. Beneficiaries' ca be both people (households) and businesses.

Figure 4.4.7: Logic chain local climate regulation (mitigation of urban heat island)



Data sources and methodology

To assemble information for the ecosystem service related to local climate regulation, we have incorporated a variety of data sources. Primarily, spatial data from the RIVM on vegetation cover, Statistics Netherlands on the degree of urbanization of neighborhoods, and climate data from the KNMI. Table 4.4.21 presents these data sources, and throughout this chapter, they will be examined in conjunction with the applied methodology.

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
CBS buurt	Spatial data	Statistics Netherlands
Sky-view-factor	Spatial data	KNMI
S, daily mean of the shortwave incoming radiation	Climate data	KNMI
DTR, difference between daily minimum and maximum temperature	Climate data	KNMI
U, average wind speed	Climate data	KNMI

The methodology incorporates several key 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 reasonably 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):

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

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 days with a maximum temperature ≥ 25 °C (‘zomerse dag’) in the Bilt.. 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 is 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 a 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 with a maximum temperature ≥ 25 °C in the Bilt.

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). These were calculated for all urban neighbourhoods with high to medium urbanization.

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).

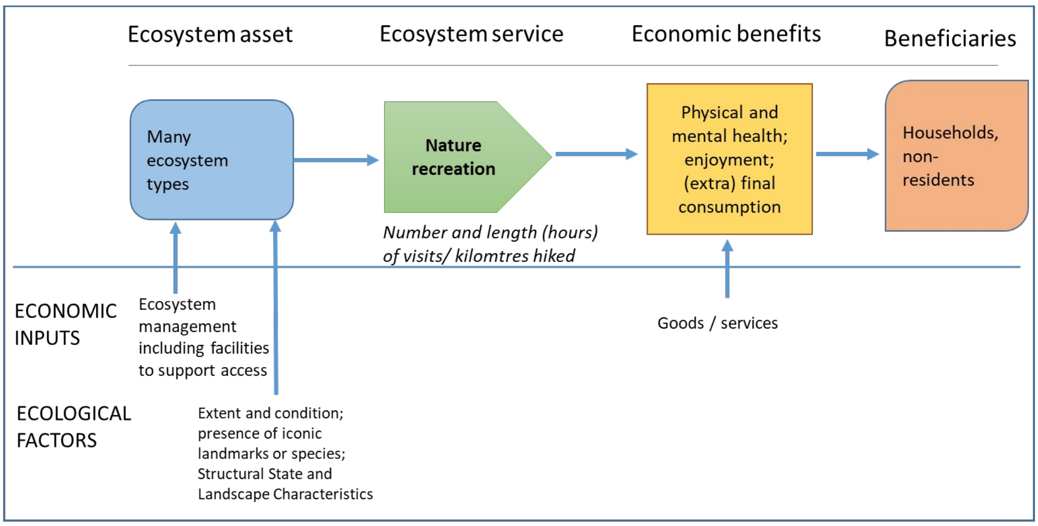
Nature provides an important contribution to tourism and recreation-related economic activities and the well-being of people by providing attractive environments for leisure activities. Nature-related recreation includes a broad range of activities such as hiking, cycling, water sports, but also beach 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). See section 4.5.3 for nature tourism.

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).

Figure 4.5.1: Logic chain nature-based recreation



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 (2020) for a full discussion.

Data sources

Table 4.5.1: Input data physical nature recreation service

Name dataset	Data type	Source
ContinuVrijeTijdsOnderzoek 2015	Survey data	NBTC-NIPO
ContinuVrijeTijdsOnderzoek 2018	Survey data	NBTC-NIPO
ContinuVrijeTijdsOnderzoek 2023	Survey data	NBTC-NIPO
Mobility Statistics	Survey data	Statistics Netherlands
Gridded population density maps	topographic maps	Statistics Netherlands
Roads and paths elements maps	topographic maps	

Methodology

The survey data of CVTO includes data on the number of recreational activities. The first step is to calculate the number of activities that took place in a natural environment, in a certain year. This data is retrieved from the survey for the year 2018 and 2023, along with the distribution of these hikes over the different provinces and broad environments. To calculate the time series 2016-2023 data from mobility of persons were taken to estimate the trend (CBS Statline, 2023). Here we used the overall trend over time in walking trips for leisure purposes. This gives the time series on the number of 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 2018, the distribution over provinces and broad environments was taken from the survey results. As the survey did not take place for the remaining years, the same distribution as for 2018 was used for the year 2016-2023. 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.

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 is 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

Data sources

The monetary value associated with nature recreation was estimated using the consumer expenditure method. This encompasses all leisure-related activities requiring one to be away from home for an hour or longer, excluding overnight stays. Be aware that the monetary valuation for nature recreation is broader than the physical ecosystem service. Now we take all leisure-related activities and for the physical ecosystem service, only hiking was considered. Data on recreational expenditures were sourced from the CVTO (ContinuVrijeTijdsOnderzoek) surveys conducted by NBTC-NIPO. These surveys, available for 2015, 2018 and 2023, offer insights into various expenditure types and recreational activities. For calculating the monetary value only, the data from the 2023 is used. The additional years are estimated, using additional statistics from Statline, specifically focusing on the consumer price index and fuel costs (Statistics Netherlands, 2024a, 2024b). This complementary information has been instrumental in constructing a comprehensive monetary valuation for nature recreation.

Table 4.5.2: Input data monetary nature recreation service

Name dataset	Data type	Source
ContinuVrijeTijdsOnderzoek 2023	Survey data	NBTC-NIPO
Consumer price indices	Monitoring data	Statistics Netherlands
Fuel prices	Monitoring data	Statistics Netherlands

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.

Methodology

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). 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 narrower scope and exclude expenditure on foods and drinks.

To allocate the monetary value of recreational activities to different ecosystem types, the CVTO is used again. In the survey, the environment where the activity takes place is being asked. The shares of the environments per activity are used to allocate the monetary value. This results in the monetary value of activities per province and per ecosystem type.

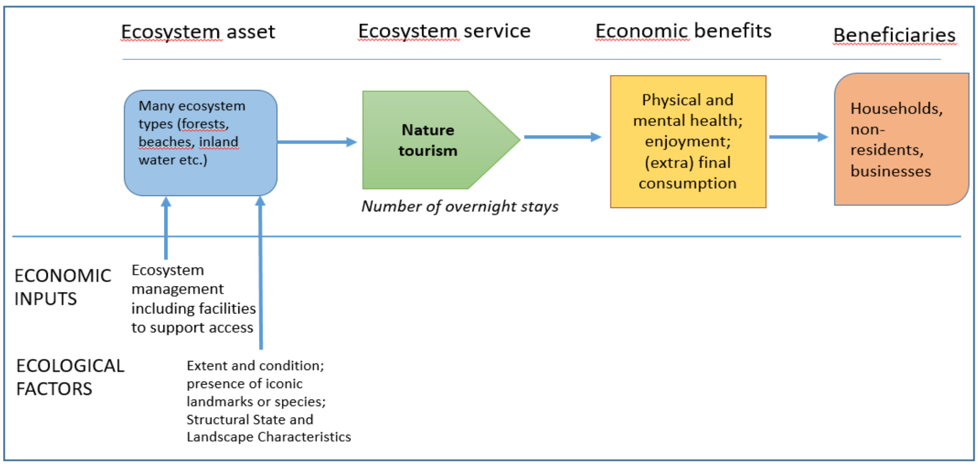
The values obtained by consumer expenditure only capture a part of the economic benefits provided by these ecosystem services. Recreational activities in nature provide all kinds of (positive) health effects for people. This will provide economic benefits in the form of reduced healthcare costs. These 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 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

Scope and definition
Nature tourism encompasses all tourist activities related to nature that involve overnight stays, both on land and on inland waters.

Logic chain
Nature tourism is facilitated by a diverse array of ecosystem assets, including forests, beaches, and inland waters. The quantification of this ecosystem service is based on the number of overnight stays, encompassing both residents and non-residents of the Netherlands. The economic advantage is reflected in the revenues generated by businesses such as hotels, highlighting the financial benefits derived from tourism activities. Additionally, the enjoyment of natural sights by tourists contributes to the overall societal well-being associated with nature tourism.

Figure 4.5.2: Logic chain nature tourism



Data sources

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 (Statistics Netherlands Vakantieonderzoek, 2013, 2015, 2018, 2019, 2020, 2021, 2022 & 2023) and statistics on the number of overnight stays of domestic and international tourists (Statistics Netherlands, 2024c). For the years 2016 and 2017 the total number of overnight stays was available but not the detailed allocation per type and province. Therefore, the distribution of 2015 was used for 2016, and the distribution of 2018 was used for 2017.

Table 4.5.3: Input data physical nature tourism service

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Dutch holiday data	Survey data	Statistics Netherlands
Dutch tourism satellite accounts	Survey data	Statistics Netherlands
Topographic map (Top10NL)	Topographic data	Kadaster

Methodology

In the tourism data on Dutch tourist in the Netherlands, there are categories directly linked to nature like active and nature tourism, beach tourism, and water sports tourism. Other categories such as 'relax vacation' and 'seasonal recreation,' don't have a distinct connection to nature. Seasonal recreation involves tourists using their own accommodations, like vacation houses and campers.

Table 4.5.4: Assumed share of each holiday type related to nature

Vacation type	% allocated to nature tourism
Relaxation	90%
Active	90%
Watersports	100%
Seasonal recreation	90%
Nature	100%
Sun or beach vacation	100%
Voyage, (boat) tour	50%
Religion, spirituality,meaning	50%
Cruise	50%
Other	50%

Table 4.5.4 shows for each relevant type of holiday the percentage that was assumed to be nature-related. This percentage is based on additional information from the survey about the environment (urban, rural, coastal etc.) where the vacation took place, as well as expert opinion. A further distinction was made to divide the overnight stays to either nature and active vacations, beach vacations, and water vacations.

Data on international (non-residents) tourist does not include a distinction to the type of tourism as described above for the Dutch tourists. To distribute the international tourist stays related to nature among the tourism categories, we applied the same distribution that was found for Dutch tourists among the tourism types. This implies that if 10% of the overnight stays of Dutch tourist in Zuid-Holland was related to beach tourism, we dedicate 10% of the overnight stays for international tourist in Zuid-Holland to beach tourism as well. A correction was made for the province of North-Holland, due to the extremely high number of international tourists visiting Amsterdam and the surrounding area. Since most of these overnight stays are not likely to be related to nature it was necessary to account for this. Based on the distribution of Dutch and international tourists within the province, the number of international tourists for North-Holland was reduced.

After the distribution among the different tourism categories, we connected the overnight stays to ecosystem types. The way we did this for water tourism was different from other types of nature tourism, and we'll explain those methods separately.

Nature and active, and beach tourism: In the allocation process, the overnight stays for each province were uniformly distributed across ecosystem types identified as primary targets for specific tourism categories. Notably, for nature and active tourism, these encompassed forests, wetlands, coastal dunes, and open natural spaces, such as heathland and natural grasslands. In the case of beach tourism, the allocation exclusively considered the beach ecosystem type. Given the absence of detailed regional data, we had to assume an even distribution of tourism across the mentioned ecosystem types. Please consider this when interpreting data or examining maps related to this ecosystem service.

Owing to the distinct focus of water tourism, water ecosystems were excluded from this particular allocation and were addressed separately. Agricultural land was also omitted from consideration. Some agricultural areas might attract activities like biking and walking for tourists, but these aren't seen as the main draws for active tourism. Also, considering the large size of agricultural areas could unfairly affect and influence the results.

Water tourism: To allocate the overnight stays related to water 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. We are assuming that all water tourism occurs around Dutch marinas, primarily because we lack additional regional data beyond specifying the province for allocating tourism. Please consider this when interpreting data or examining maps related to this ecosystem service.

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

Data sources

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, nature-related seasonal holidays, voyage/(boat)tour, religious holidays, cruises and other. The same shares are used as mentioned in the previous paragraph on the physical part of this service. 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.

Table 4.5.5: Input data monetary nature tourism service

Name dataset	Data type	Source
Ecosystem Type map	Spatial data	Statistics Netherlands
Dutch holiday data	Survey data	Statistics Netherlands
Dutch tourism satellite accounts	Survey data	Statistics Netherlands
Topographic map (Top10NL)	Topographic data	Kadaster

Data for tourism expenditures by non-residents (inbound tourism) were directly obtained from the Dutch tourism satellite accounts (TSA). 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 nature related expenditure. The "other consumer expenditure", together with non-residential and residential tourism expenditures, equals the value of this ecosystem service.

Methodology

The approach closely resembles the one discussed for nature recreation in chapter 4.5.2. The travel cost method is a commonly employed technique for assessing the value of recreational and tourism services (e.g., Barton and Obst, 2019). This method assumes that the travel costs incurred by tourists serve as an indicator of their willingness to pay for nature-related services. While we apply the consumer expenditure approach, it follows the same principles as the travel cost method. The consumer expenditure approach outlined here closely aligns with the 'simple' travel cost method used in the United Kingdom to assess ecosystem services (ONS, 2016). One distinction is that we consider not only travel costs and admission fees but also expenditures on accommodation, particularly in the context of nature tourism. Household expenditures are market transactions and thus signify exchange values, a requirement for alignment with the System of National Accounts.

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 a previous technical report on monetary ecosystem accounting (Statistics Netherlands and WUR, 2020).

Nature-based tourism likely contributes to welfare values that surpass the exchange values outlined in our results. Consumers often express a willingness to pay considerably more to experience nature than the actual expenses they incur on travel and admission fees. In a forthcoming update, it could be valuable to present both welfare values and exchange values for tourism and recreation, offering a more comprehensive perspective on the broader societal benefits derived from nature-based tourism.

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.

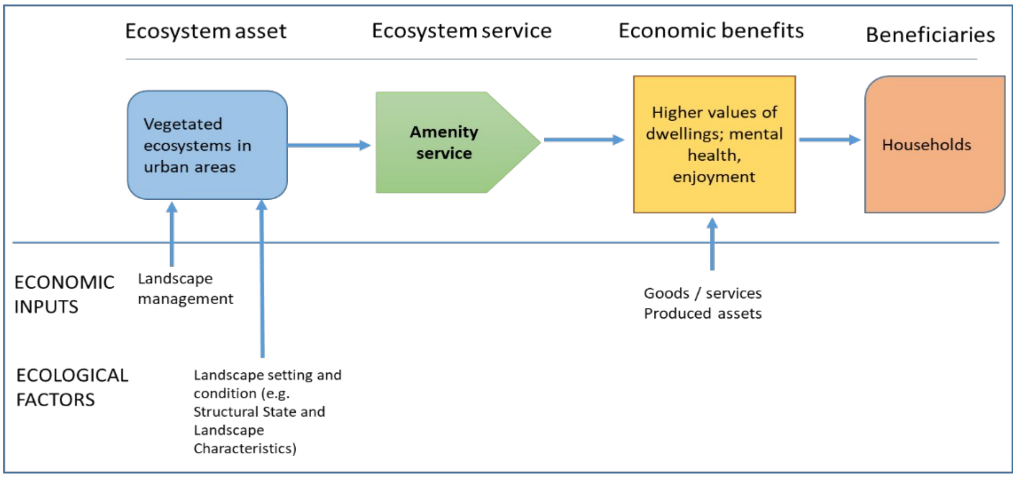
In real estate and lodging, an amenity is something considered to benefit a property and thereby it increases the property's value. The amenity services of ecosystems are defined here as benefits for housing related to living near nature, which include recreation, visual aesthetics, and lower levels 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.

Figure 4.5.4: Logic chain amenity services



Data sources and methodology

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).

Table 4.5.6: Input data amenity services

Name dataset	Data type	Source
CANA (Clusters of Attractive Nature Areas)	Spatial data	Greenmapper
ONA (Other Nature Areas)	Spatial data	Statistics Netherlands (CBS)
The Dutch national register of addresses and buildings (BAG)	Spatial data	Kadaster
Urbanisation levels	Spatial data	Statistics Netherlands (CBS)

The hedonic pricing method has its roots in consumer theory.[10] 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:

$$\ln\left(WOZ_i\right)=\alpha+\sum_{j=1}^{m}\beta_j X_{i,j}+\varepsilon_i$$

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 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.orgwww.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

[10] 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.

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[11]. 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:

$$\ln(WOZ_{iz}) - \ln(WOZ_{jz}) = \sum_{k=1}^{K} \beta_k (X_{izk} - X_{jzk}) + \text{¿} \sum_{c=1}^{C} \beta_c (CANA_{izc} - CANA_{jzc}) + \text{¿¿¿} \sum_{d=1}^{D} \beta_d (ONA_{izd} - ONA_{jzd}) + \text{¿} \varepsilon_{ijz} \text{¿}$$

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*; ***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, 2023) 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 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 4.5.7 gives an overview of the results of the hedonic price regression.

[11] www.cbsinuwbuurt.nl

Table 4.5.7: Results of the hedonic pricing model for different urbanization levels (Numbers indicate the percentage of the value of a property that house buyers are willing to pay to live nearby a CANA or ONA)

	Urbanization level				
	1	2	3	4	5
Distance to nearest CANA					
Within 0-500 m	12,5	4,4	1,1	4,2	4,5
Within 500-1000 m	6,3	1,9	1,3	3,3	1,8
Within 1000-2000 m	4,0	1,0		1,7	1,4
Within 2000-3000 m	3,2	1,0			
Within 3000-4000 m	2,4				
Distance to nearest ONA					
Within 0-50 m	4,5	3,4	5,1	4,8	3,7
Within 50-100 m	3,5	1,7	3,8	3,3	2,2
Within 100-150 m	1,2	1,1	2,1	1,9	0,9
Within 150-200 m		0,7	1,5	1,1	0,4
Within 200-250 m		0,5	0,8	0,7	
Within 250-300 m			0,3	0,6	
Within 300-350 m				0,5	
Within 350-400 m				0,4	
Within 400-450 m				0,4	

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

Ecosystem services are supplied by ecosystem assets and used by society. The supply of ecosystem services and the use of these services is one of the central features of ecosystem accounting. The supply and use may be compiled in both physical and monetary terms.

In the 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. For example, a forest supplies the ecosystem service air filtration and cropland supplies the ecosystem crop provisioning.

In the use table the value of ecosystems services is allocated to the users of these services. Users include economic units classified by industry, and also government sector households and export, following the conventions applied in the national accounts. The users of the ecosystem services correspond to the beneficiaries identified for each ecosystem service. For example, the ecosystem service air filtration is used by households and the ecosystem crop provisioning is used by the economic sector agriculture.

For accounting purposes, the supply of ecosystem services is always equal to the use or receipt of the services during an accounting period.

5. Asset accounts

Goods and services are produced in the economy with the use of capital goods, such as buildings, machines, tools and means of transport. Similarly, ecosystem services can be viewed as produced using ecosystem capital. For example, a forest functions as an ecosystem capital asset by supplying wood, offering recreational opportunities, sequestering CO2 and capturing fine dust particles from the atmosphere.

Ecosystem asset values (ecosystem capital) measure the stream of services (stock) of that natural resource in terms of future expected supply and use over a reasonably predictable time horizon. This contrasts with annual valuations within a particular year (flows). Natural capital asset values thus represent the overall economic worth or wealth of ecosystems based on the social economic use values they provide. 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, except for the cultural service, and equal to average flow observed in the last three years.
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 average flow observed in the last three years (e.g. 2020-2023).

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 last three years. 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. For the cultural services it is likely that the future flows will increase due to population growth. Therefore, for these services the future flow is not constant, but increasing based on the predicted population growth.

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. For regulating services and cultural 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. Summary

This report has presented a comprehensive overview of the methodologies, models, and data sources applied in compiling the Dutch Natural Capital Accounts in accordance with the SEEA EA framework. The full range of accounts—ecosystem extent, condition, services, and assets—has been described, with attention given to both data processing procedures and the interpretation of outcomes. The accounts produced by Statistics Netherlands and WUR provide a basis for monitoring, informed decision-making and international comparison. This report serves as a key technical reference for understanding the compilation of Ecosystem Accounts in the Netherlands.

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- (2025b) Vegetables; yield and cultivated area per kind of vegetable https://opendata.cbs.nl/#/CBS/en/dataset/37738ENG/table?dl=BE9A8
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8. Appendix

Appendix A Look-up tables

Table A1. Look-up table for mean production in euro per hectare per pollination dependent, for years 2016-2021.

Crop code	Description	2016	2017	2018	2019	2020	2021
242	Beans	2100	4000	1920	3600	2310	3240
258	Alfalfa	980	980	980	980	980	980
311	Field beans	815	815	815	815	815	815
515	Sunflower	1540	1540	1540	1540	1540	1540
663	Lupine	1150	1150	1150	1150	1150	1150
664	Rapeseed	1540	1540	1540	1540	1540	1540
665	Soybeans	1270	1270	1270	1270	1270	1270
666	Linseed	1360	1360	1360	1360	1360	1360
853	Broad beans	2070	2070	2070	2070	2070	2070
854	Broad beans	2590	2590	2590	2590	2590	2590
1922	Oilseed rape, winter	1540	1540	1540	1540	1540	1540
1923	Oilseed rape, summer	1320	1320	1320	1320	1320	1320
2700	Strawberry, open field, multiplication	107000	107000	107000	107000	107000	107000
2701	Strawberry, open field, waiting bed	42600	42600	42600	42600	42600	42600
2702	Strawberry, open field, production	49100	49100	49100	49100	49100	49100
2703	Strawberry, open field, seed	107000	107000	107000	107000	107000	107000
2704	Strawberry, rack, multiplication	148000	148000	148000	148000	148000	148000
2705	Strawberry, rack, waiting bed	55500	55500	55500	55500	55500	55500
2706	Strawberry, rack, production	83300	83300	83300	83300	83300	83300
2707	Strawberry, rack, seed	148000	148000	148000	148000	148000	148000
2731	Gherkin, production	19100	19100	19100	19100	19100	19100
2732	Gherkin, seed	41600	41600	41600	41600	41600	41600
2723	Courgette, production	38200	38200	38200	38200	38200	38200
2724	Courgette, seed	41600	41600	41600	41600	41600	41600
2729	Cucumber, production	13700	13700	13700	13700	13700	13700
2730	Cucumber, seed	41600	41600	41600	41600	41600	41600
2733	Melon, production	14300	14300	14300	14300	14300	14300
2734	Melon, seed	41600	41600	41600	41600	41600	41600
2735	Pumpkin, production	5800	5800	5800	5800	5800	5800
2736	Pumpkin, seed	41600	41600	41600	41600	41600	41600
2779	Stem green bean, production	2230	2230	2230	2230	2230	2230
2780	Stem green bean, seed	41600	41600	41600	41600	41600	41600
2781	String beans, production	14300	14300	14300	14300	14300	14300
2782	String beans, seed	41600	41600	41600	41600	41600	41600
1095	Apple, new	14600	17500	21100	17000	19200	21800
1096	Apple	14600	17500	21100	17000	19200	21800
1097	Pear, new	30600	38500	36600	30800	42800	39300
1098	Pear	30600	38500	36600	30800	42800	39300
1100	Stone fruits (including peach)	31500	31500	31500	31500	31500	31500

Crop code	Description	2016	2017	2018	2019	2020	2021
1869	Blueberry	64400	64400	64400	64400	64400	64400
1870	Plum	12600	12600	12600	12600	12600	12600
1872	Cherry, sour	5710	5710	5710	5710	5710	5710
1873	Blackberry	3100	3100	3100	3100	3100	3100
1874	Other small fruits	34500	34500	34500	34500	34500	34500
2325	Redberry	61300	61300	61300	61300	61300	61300
2326	Raspberries	155000	155000	155000	155000	155000	155000
2327	Blackberries	184500	184500	184500	184500	184500	184500
2328	Cherry, sweet	31500	31500	31500	31500	31500	31500

Table A2. Inflation correction relative to 2015€ as was used for the monetary value per unit for health impact categories in table 4.4.15, and total in € per person per µg/m^3 $PM_{2.5}$ respectively PM_{10}

year	2016	2017	2018	2019	2020	2021	2022	2023
2015€	1.00358	1.01716	1.03485	1.06166	1.07507	1.10366	1.213941	1.261667
€/ µg/m^3 $PM_{2.5}$	7.40	7.49	7.60	7.79	7.88	8.08	8.38	9.21
€/ µg/m^3 PM_{10}	2.71	2.74	2.78	2.84	2.87	2.95	3.23	3.36

Table A3. Age specific mortality rate of a) females and b) males (multiplied by 10,000), and life expectancy of c) females and d) males, as used in the calculations for years 2016-2022.

a) Mortality rate female (x10,000)

Age category	Mortality rate 2016	2017	2018	2019	2020	2021	2022	2023
0 – 14	2.8	2.7	2.5	2.8	2.9	2.6	2.8	2.7
15 – 24	1.6	1.5	1.6	1.8	1.6	1.6	1.8	1.6
25 – 44	4.7	4.4	4.3	4.3	4.5	4.7	4.6	4.4
45 – 64	33.1	31.6	31.5	30.2	30.2	32.7	31.3	30.1
65+	348.5	346.6	346.4	334.9	360.7	355.7	355.2	346.8

b) Mortality rate male (x10,000)

Age category	Mortality rate 2016	2017	2018	2019	2020	2021	2022	2023
0 – 14	3.1	3.5	3.2	3.2	3.4	3.0	3.3	3.4
15 – 24	3.0	3.3	3.0	3.0	2.9	3.1	3.5	3.3
25 – 44	6.8	6.9	6.8	6.7	6.9	6.9	6.9	7.1
45 – 64	43.2	41.9	41.7	40.2	42.8	44.6	43.2	41.9
65+	371.6	364.3	365.5	357.3	399.6	397.4	379.0	372.9

c) Life expectancy (months) female

Age category	Life expectancy (months)							
	2016	2017	2018	2019	2020	2021	2022	2023
0 – 14	919.9	922.3	922.5	925.7	920.0	918.5	920.0	922.8
15 – 24	773.4	775.8	775.8	778.8	772.9	771.0	771.9	774.0
25 – 44	595.5	598.9	600.1	604.1	598.7	597.3	598.6	601.3
45 – 64	373.4	374.1	373.3	375.2	368.3	366.2	366.3	367.4
65+	166.2	166.1	165.9	168.0	162.1	162.9	162.4	163.6

d) Life expectancy (months) male

Age category	Life expectancy (months)							
	2016	2017	2018	2019	2020	2021	2022	2023
0 – 14	881.3	883.9	885.1	889.0	879.6	879.2	884.5	887.3
15 – 24	735.3	738.3	739.1	742.7	733.0	732.3	737.2	739.4
25 – 44	559.4	564.1	566.0	570.3	561.2	561.0	566/3	569.2
45 – 64	339.1	341.4	341.1	343.5	333.3	332.0	336.3	337.9
65+	153.8	154.8	154.6	155.7	147.4	147.9	151.0	152.1