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from Nexus Thinking to Nexus Doing

REXUS

MANAGING RESILIENT NEXUS SYSTEMS THROUGH PARTICIPATORY SYSTEMS DYNAMICS MODELLING

Deliverable 3.10 – Report on Socioeconomic indicators for Nexus analysis and management

WP3 – REXUS OBSERVATORY

www.rexusproject.eu

Edited by: Caterina Righetti, Mauro Masiero, Giorgia Bottaro, Davide Pettenella (UNIPD)

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Abstract

Ecosystem services (ES) are the benefits that humans obtain from ecosystems. Rexus project WP3 aims to investigate the benefits and challenges of applying Nature based Solutions (NBS) within the framework of the Water-Energy-Food (WEF). Task 3.6 oversees considering socio-economic benefits of NBS and addressing the following specific objectives:

- Deepen the ES concept within different classification systems developed so far by the main international initiatives on ES to identify which ES may have a role in addressing the WEF challenges identified by the pilot cases.

- Develop an economic evaluation framework for selected ES and gathering of specific indicators to assess potential ES along with their benefits and values.

- Provide guidance on the selection of the most appropriate NBS to address challenges related to climate resilience and the provision of ES.

The aim of this report is not to assess all the ES involved in the WEF Nexus or in pilot's challenges, rather to provide examples of literature-based indicators and methods for assessing ES that could be applicable in the pilot cases. Thirteen ES have been considered. For each of them a set of three indicators (supply, demand, and economic value) have been identified and reported, including details about the rationale and the meaning of each indicator. To show how to operationalize selected indicators, a test-assessment for the Isonzo-Soča Basin pilot area has been performed and results are shortly presented and discussed.

Finally, to further operationalize the ES analysis and to orient the selection of appropriate NBS, the relation between ES and NBS was investigated via existing literature to provide a preliminary guidance for the selection of NBS by pilots based on the challenges they face and the ES they wish/need to value. The final part of the report is linked with Rexus Task 5.2, where NBS assessment and identification are fully developed and addressed.

Acronyms and abbreviations used within the text

ATO	*Ambito Territoriale Ottimale*
CICES	Common International Classification of Ecosystem Services
EbA	Ecosystem-based Adaptation
ES	Ecosystem services
ESBs	Ecosystem services beneficiaries
GIS	Geographic information system
IPBES	Intergovernmental Platform on Biodiversity and Ecosystem Services
IUCN	International Union for Conservation of Nature
MEA	Millennium Ecosystem Assessment
NBS	Nature-based solution
NCP	Nature's contributions to people
NEAT	National ecosystem approach toolkit
NWRM	Natural water retention measures
PEER	Partnership for European Environmental Research
SBUs	Service benefiting units
SPUs	Service provisioning units
TEEB	The Economics of Ecosystems and Biodiversity
TESSA	Toolkit for Ecosystem Service Site-based Assessment
TEV	Total economic value
WEF Nexus	Water, energy, and food nexus
WP	Working package
WTA	Willingness to Accept
WTP	Willingness to pay

1. Introduction

Due to its complexity and the many interactions among multiple stakeholders, as well as interconnections with other domains, water resource management has been often considered as a wicked problem requiring a multidisciplinary and holistic approach (Reed and Kasprzyk, 2009). Despite this, in many cases challenges posed by water management issues have been addressed from single angles, i.e. faced independently by single sectors and stakeholder groups, thus failing in achieving an integrated and effective approach. The Water-Energy-Food (WEF) approach has been recently proposed to address the inextricable linkages between these critical domains and supporting sustainable development (Adamovic et al., 2019). More in detail, water resources, in addition to being used to meet the needs of households, is essential for the production and conversion of energy and other associated processes, such as refining energy source products. Fresh water is required for every phase of energy extraction and production, refining and processing, transport and storage. Energy, in turn, is consumed to provide water for household, industrial and agricultural uses. Energy is required to capture, transfer, treat, and distribute fresh water as well as to transfer, treat and return to aquatic environments, like rivers. It is not uncommon that water is used to produce energy and that energy is used to create and transfer usable water resources. Finally, food production consumes both water and energy to grow and harvest crops and to process them into food products. Such an approach would allow to identify and to deal with synergies and trade-offs among resource uses by different domains and to promote a sustainable and efficient use of resources taking into account current demographic trends as well as socio-economic and climate change challenges.

Ecosystems and ecosystem-based approaches are key to the Nexus as they represent the biophysical foundations of the multiple connections between water, energy, and food. Nevertheless, they have often been missing concepts in the Nexus assessment frameworks (Hülsmann et al., 2019). So far Nexus assessments have been mainly focused on the water allocation to different sectors and users, while much less attention has been paid to a broader spectrum of ecosystem services (ES) associated to resource management and possible synergies and trade-offs among them. ES include provisioning, regulating and cultural services, and their assessment in biophysical and economic terms is key for a full understanding and complete assessment of the Nexus. The integration of ES concepts into the Nexus approach offers the opportunity to add a new perspective, thus enabling a better understanding of cross-sectoral interlinkages and providing valuable inputs for decision and policy makers as well as practitioners dealing with management solutions.

This report falls within the scope of Task 3.6 of the Rexus H2020 project. The objective of this Task is to identify a set of socio-economic indicators for assessing and mapping ES and their beneficiaries in Nexus systems under different climate and policies scenarios. The indicators will also allow to address trade-offs and synergies among ES. In this perspective, ES linked to the WEF Nexus have been analysed from an economic point of view, taking into account their supply and demand, as well as their monetary value, within the project pilot areas. The theoretical background setting the basis for the Deliverable is presented in Section 2. Section 3 illustrates methodological aspects implemented across Task 3.6. Results of Task 3.6 are then presented in detail and discussed in Sections from 4 to 9. An example of the implementation of a set of these indicators with reference to the Isonzo-Soča Basin pilot area is provided for a better understanding of the framework and a guidance to operators (Section 10). Finally, Section 11 provides some preliminary guidance for linking ES and Nature-based Solutions (NBS) vis-à-vis challenges faced by pilot areas.

2. Theoretical background

Born within the Anglo-Saxon scientific literature[1] (Costanza et al., 1997; Daily, 1997; Ehrlich and Mooney, 1983), between 2001 and 2005, the concept of ES was gradually adopted and integrated into international policies thanks to the Millennium Ecosystem Assessment, MEA (2005). The initiative was conducted under the auspices of the United Nations and marked the debut of a new approach to environmental conservation policies, based on the explanation of dependence of the human societies on a proper functioning of ecosystems.

The MEA puts human wellbeing centre-stage as ecosystems contribute to it through the services they provide. This reflects on an attempt to bring together the multiple interpretations of the concept of ES and its various facets under a single definition: "*Ecosystem services are the benefits that humans obtain from ecosystems*" (Alcamo et al., 2003). Starting from this, the MEA proposed an analysis framework highlighting the relationship between ecosystems and the constituents of human wellbeing, thus highlighting the dependence of human societies on ecosystems, mediated by ES (Figure 1). To this aim, ES have been classified into four categories:

- *provisioning services* i.e., materials and products that are directly used by people, such as food resources, natural fibres, fuel, genetic resources, biochemicals, natural medicines and pharmaceuticals, ornamental resources, fresh water and energy, etc.
- *regulating services* that regulate other environmental media or processes, such as regulation of air quality, climate regulation, water regulation, erosion regulation, water purification and waste treatment, disease regulation, pest regulation, pollination, natural hazards regulation, etc.
- *cultural services* related to the cultural or spiritual needs of people, such as cultural diversity, spiritual and religious values, knowledge systems, educational values, inspiration, aesthetic values, social relations, sense of place, cultural heritage values, green care and human health/wellbeing, recreation and ecotourism, etc.
- *supporting services*, *i.e.*, ES that are necessary to produce all the other ES, such as soil formation, photosynthesis, primary production, nutrient cycling, water cycling, etc.

The conceptual framework and the ES classification system proposed by the MEA highlight the interconnections between ecosystems, their functions, ES, and human wellbeing. This represents one of the main contributions and advancements proposed by the MEA. Before it the environmental assessment approaches were mainly focused on the root causes and broad effects of biodiversity loss, while the MEA gave emphasis to the specific connections between the ecosystem integrity and their capacity to contribute to human safety, health, material, and social wellbeing.

[1] Regarding the theme of material benefits that humans can derive from nature, while the continental European approach have been making reference to "ecosystem functions" (de Groot, 1992), the Anglo-Saxon approach has focused on "ecosystem services".

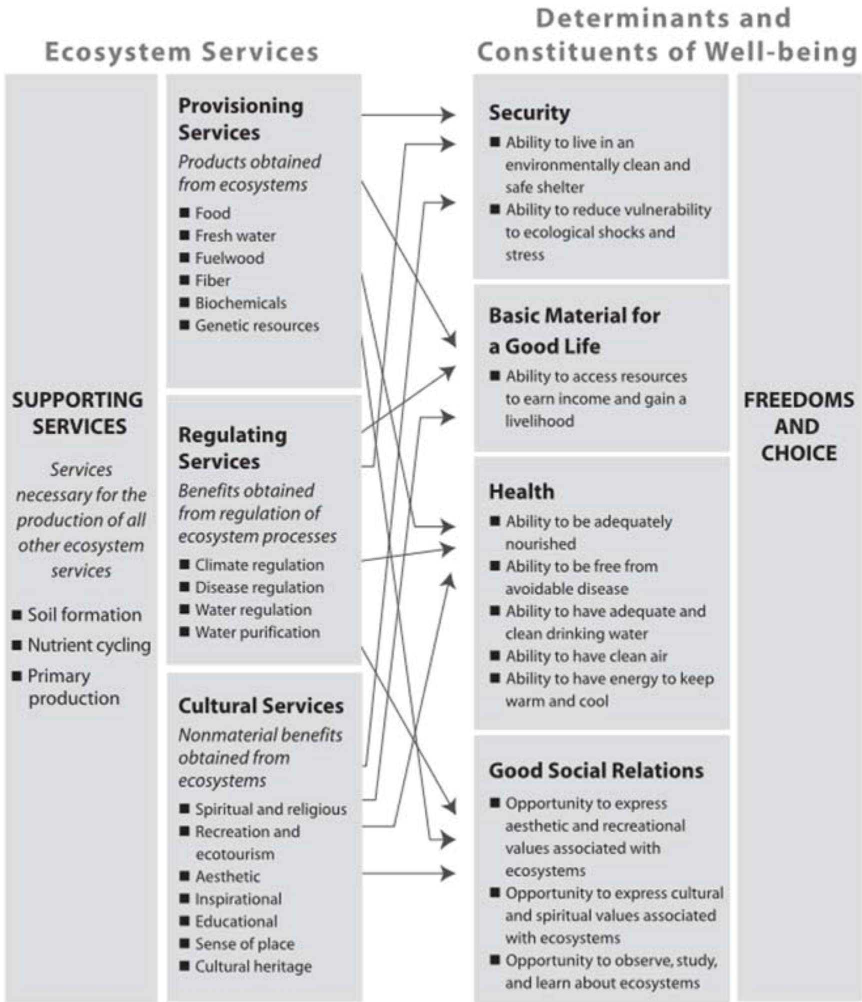

Figure 1. The benefits of ecosystems and their links with human wellbeing. Source: MEA (2003)

Following the publication of the MEA reports, the ES concept gained momentum and other international initiatives emerged. Among these, The Economics of Ecosystems and Biodiversity (TEEB) initiative was launched as a result of the meeting of the Ministers of the Environment at the G8+5 in Potsdam, in May 2007. TEEB aimed to "*promote a better understanding of the real economic value of the services provided by ecosystems [and] offering economic instruments that take these values into account*" (TEEB, 2008).

The conceptual framework developed by the TEEB (2010) is an adaptation of the framework proposed by Haines-Young and Potshin (2010). It links ecological processes with elements of human wellbeing, highlighting societal dependence on ecosystems: from ecological structures/processes and functions generated by ecosystems to the services and benefits eventually derived by humans (Figure 2).

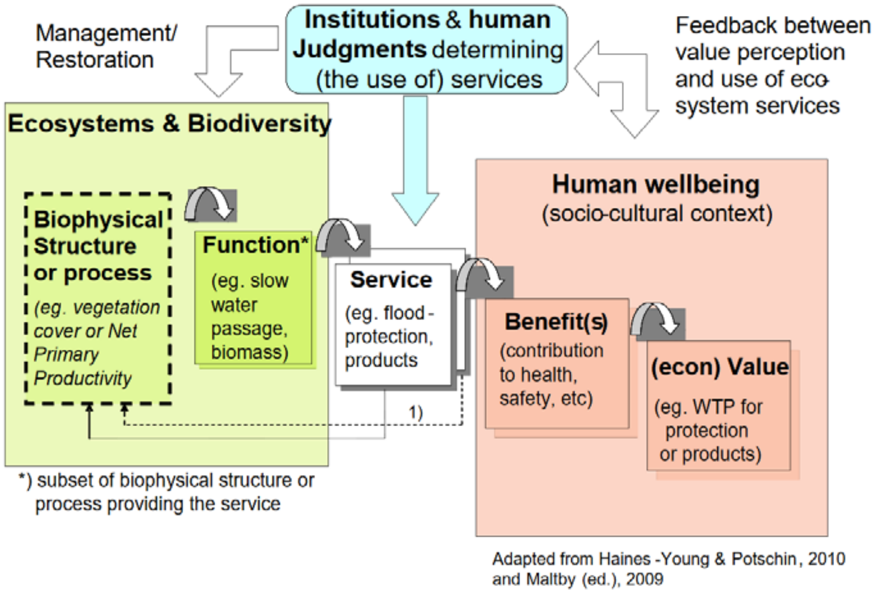

Figure 2. Conceptual diagram adopted by the TEEB. Source: TEEB (2010)

Ecosystem functions are defined as the capacity that ecosystems have to deliver services. They rely on biophysical structures and processes that are the fundamental traits for the functioning of an ecosystem. This distinction between structure/process and functions could be linked to Fisher et al. (2009), however the framework proposed by the TEEB does not consider these processes and functions as stand-alone ES as it was the case of supporting ES within the MEA classification. In other terms, biophysical structures and processes are supported by biodiversity and represent a pre-requirement to the functioning of ecosystems and the delivery of ES. The TEEB considers ES as a bridge and a continuum between the functioning of ecosystems and the benefits for human beings. Services emerge as a conceptualization of the useful elements that ecosystems provide for human wellbeing.

Building on the MEA classification, the TEEB proposes a set of 22 main ES types, classified according to four main categories: provisioning, regulating, habitat, and cultural and amenity services (TEEB, 2010) (Figure 3).

	Main service types
	PROVISIONING SERVICES
1	**Food** (e.g. fish, game, fruit)
2	**Water** (e.g. for drinking, irrigation, cooling)
3	**Raw Materials** (e.g. fiber, timber, fuel wood, fodder, fertilizer)
4	**Genetic resources** (e.g. for crop-improvement and medicinal purposes)
5	**Medicinal resources** (e.g. biochemical products, models & test-organisms)
6	**Ornamental resources** (e.g. artisan work, décorative plants, pet animals, fashion)
	REGULATING SERVICES
7	**Air quality regulation** (e.g. capturing (fine)dust, chemicals, etc)
8	**Climate regulation** (incl. C-sequestration, influence of vegetation on rainfall, etc.)
9	**Moderation of extreme events** (eg. storm protection and flood prevention)
10	**Regulation of water flows** (e.g. natural drainage, irrigation and drought prevention)
11	**Waste treatment** (especially water purification)
12	**Erosion prevention**
13	**Maintenance of soil fertility** (incl. soil formation)
14	**Pollination**
15	**Biological control** (e.g. seed dispersal, pest and disease control)
	HABITAT SERVICES
16	**Maintenance of life cycles of migratory species** (incl. nursery service)
17	**Maintenance of genetic diversity** (especially in gene pool protection)
	CULTURAL & AMENITY SERVICES
18	**Aesthetic information**
19	**Opportunities for recreation & tourism**
20	**Inspiration for culture, art and design**
21	**Spiritual experience**
22	**Information for cognitive development**

Figure 3. Typology of Ecosystem services in TEEB. Source: TEEB (2010)

Given the need for consistency among different ES frameworks and in order to support the integration of the ES concept into environmental accounting, a new common international ES classification system was developed building on Haines-Young and Potschin (2018). This new system, known as the Common International Classification of Ecosystem Goods and Services (CICES), consists in a hierarchical structure of five levels in which ecosystem goods, material and energy products, services and non-material effects (e.g., process regulation) are distinguished (Figure 4). The five levels are:

- Section: referring to three ES macro-categories, i.e. provisioning, regulating/maintenance, and cultural services.
- Division: dividing the sections into main outputs or processes.
- Group: dividing the processes into biological, physical, and cultural.
- Class: providing a further subdivision of groups into (i) biological outputs and materials, and (ii) biophysical and cultural processes that can be directly linked to concretely identifiable resources and services.

- Class type: dividing classes into individual entities and suggesting units of measurement/indicators for measuring ES associated with resources and services.

All ES are identified via a reference code, and the supporting ES are evaluated as part of the underlying structures, processes, and functions that characterise ecosystems. The structure of CICES has been designed around the idea of a hierarchy, to accommodate the fact that people work at different thematic as well as spatial scales and may need to aggregate classes in different ways.

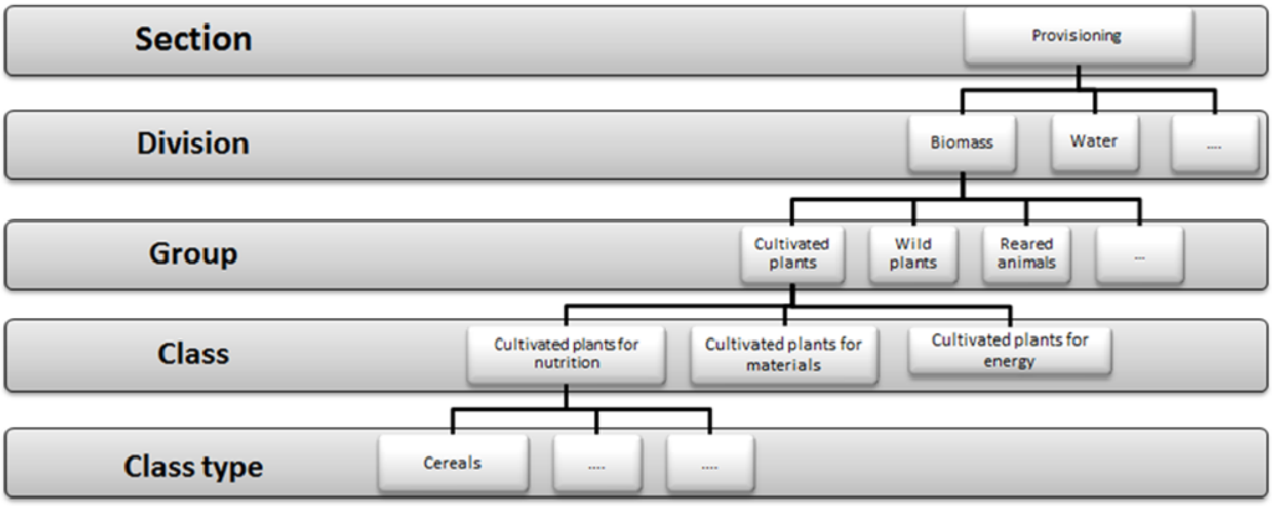

Figure 4. The hierarchical structure of CICES V5.1. Source: Haines-Young and Potschin (2018)

CICES aims to classify the contributions that ecosystems make to human wellbeing. These largely derive from living processes and therefore the biotic benefits from ecosystems remain at the centre of CICES. Nonetheless the version 5.1 of the classification has been expanded to include also abiotic outputs that can contribute to human wellbeing. In this perspective water resources represent an interesting case as they are characterized by the potential of generating both biotic and abiotic outputs.

A fourth ES classification system has been developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), an independent intergovernmental body established by States to strengthen the science-policy interface for biodiversity and ES for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development. On May 2019, the seventh session of the IPBES Plenary, designed to proactively develop assessments matched to policy needs, and to support capacity building across scales and topics, approved the summary for policy makers and accepted the chapters of the Global Assessment on Biodiversity and Ecosystem Services. IPBES scientific community acknowledges that decision making relies to a great extent on “instrumental values” (Pascual et al., 2017) and it supports the integration of multiple assessments of the value of nature to people in decision making.

The IPBES conceptual framework proposes a simplified model of the complex interactions between the natural world and human societies that are most relevant to IPBES’s goal (Diaz et al., 2015). The key components of the framework are nature, the benefits that people derive from nature, and a good quality of life. In a new focus with respect to most of the previous initiatives, the framework also highlights the central role that institutions, governance, and decision-making play. Most importantly, it explicitly includes multiple knowledge systems (Figure 5).

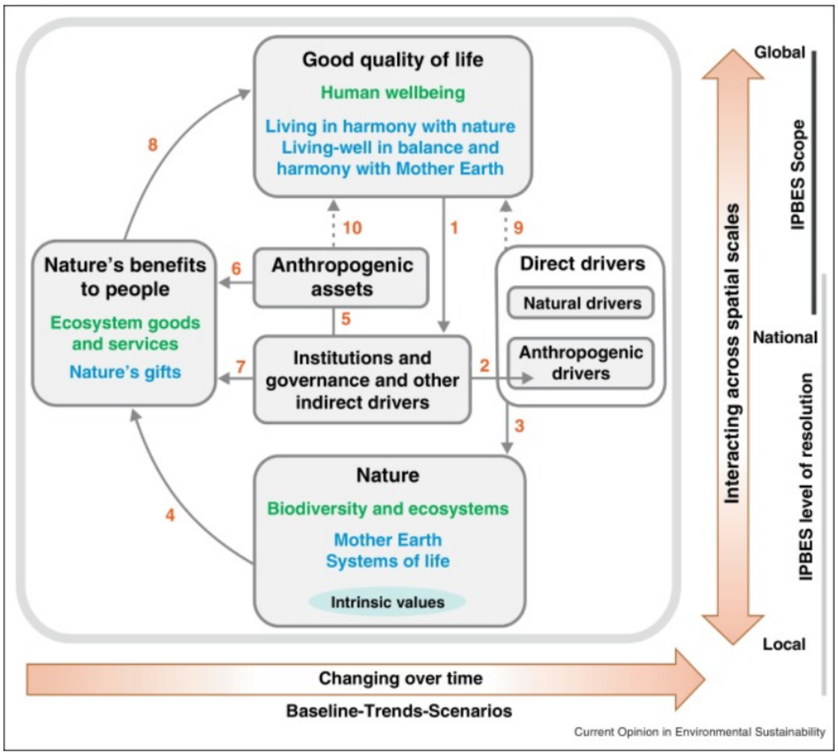

Figure 5. IPBES conceptual framework. Source: Diaz et al. (2015)

IPBES names the relations between the social and ecological components as Nature's Contributions to People (NCP) and divides them in 18 categories organized into three partially overlapping groups: *regulating, material,* and *non-material* contributions (Table 1).

Table 1. Nature's contributions to people used according to IPBES conceptual framework

N.	Reporting categories of nature's contributions to society	Type of contribution
1	Habitat creation and maintenance	Regulating service
2	Pollination and dispersal of seeds and other propagules	Regulating service
3	Regulation of air quality	Regulating service
4	Regulation of climate	Regulating service
5	Regulation of ocean acidification	Regulating service
6	Regulation of freshwater quantity, flow and timing	Regulating service
7	Regulation of freshwater and coastal water quality	Regulating service
8	Formation, protection and decontamination of soils and sediments	Regulating service
9	Regulation of hazards and extreme events	Regulating service
10	Regulation of organisms detrimental to humans	Regulating service
11	Energy	Material

N.	Reporting categories of nature's contributions to society	Type of contribution
12	Food and feed	Material
13	Materials and assistance	Material
14	Medicinal, biochemical and genetic resources	Material
15	Learning and inspiration	Non-material
16	Physical and psychological experiences	Non-material
17	Supporting identities	Non-material
18	Maintenance of options	Material /Non-material/ Regulating service

3. Methodology

To define a list of relevant socio-economic indicators for the assessment of ES in Nexus systems, we firstly frame the concept of ES and deepen some of the most widely accepted ES classification systems developed over time and already presented in section 2 (i.e., MEA (2005), TEEB (2010), CICES (Haines-Young & Potschin, 2018), and IPBES (2017)). We explored how each ES is defined by each classification system, highlighting differences and similarities among the four frameworks. This allowed us to better describe and frame each ES as interpreted for the aims of the project and to define the ES framework used for the analyses developed within this document (section 4).

As a second step we identified and explored the ES that play a central role for the WEF Nexus. These include not only provisioning ES (as originally defined in the project document) but also regulating ones. Then we compared the ES with the Nexus-related challenges reported by each project pilot case to find appropriate matching (Annex 1). Each challenge presented in the baseline document (Osann et al., in press) by each Rexus pilot area has been analysed and two different types of strategies were considered to address them: (i) ES strategies, implying the provision or the enhancement of ES as a possible solution in addressing pilot challenges, and (ii) non-ES strategies, not specifically addressing ES but considering other issues like choice consumption, management, policy or governance dimensions. Pilots were asked to verify and review the challenges, including by adding new ones and deleting those considered not to be important. They were also asked to review and validate the links between the challenges and the ES and non-ES strategies selected. The outputs of this step will be further integrated with inputs from stakeholder consultation workshops and activities performed by Rexus WP4 research team.

As a third step, the most common frameworks and methodologies to assess ES were investigated and a specific assessment approach was developed (section 5.2). This approach consists of three evaluation dimensions linked in a cascade model:

- the **ES supply**, indicating the potential biophysical amount of ES delivered by ecosystems (please refer to section 6 for details).
- the **ES demand**, expressing the potential benefits enjoyed by the human society from the ES (section 7).
- the **ES value** translating the ES supply in monetary terms (section 8).

For each ES identified as relevant for the WEF Nexus and for each pilot's challenges the following were identified (section 9):

- a list of indicators for the assessment of the ES supply, i.e. for measuring each ES in biophysical terms.
- a list of indicators for the assessment of the ES demand, i.e. for measuring the benefits to the possible beneficiary groups.
- a list of indicators for the ES value, i.e. for measuring the economic evaluation of each ES.

Indicators were identified and developed through an extensive scientific literature review. Search terms for each evaluation dimension were identified based on existing literature and matched with the selected ES categories (Table 2). The literature search was performed via the ScienceDirect database, as well as Google search engine, making reference to literature available in English. References found were preliminarily analysed based on their title, keywords and abstracts and 87 publications were finally identified as relevant and analysed in detail.

Table 2. Search terms used to identify ES assessment indicators

ES assessment dimensions	Search terms used for the review
Supply	"ecosystem service* quantification" OR " ecosystem service* biophysical indicator*" OR "food provisioning ecosystem service biophysical indicators" OR "food provisioning ecosystem service quantification" OR "water provisioning service biophysical indicators" OR "water provisioning ecosystem service quantification" OR "energy ecosystem service" OR "energy ecosystem service evaluation" OR " energy ecosystem service quantification" OR "genetic resources ecosystem service evaluation" OR "genetic resources biophysical indicators" OR " materials ecosystem service quantification" OR "materials ecosystem service biophysical indicators" OR "regulation of water flow quantification" OR "regulation of water flow biophysical indicators" OR "climate regulation service quantification" OR "climate regulation biophysical indicators" OR "water purification ecosystem service quantification" OR "water purification ecosystem service biophysical indicators" OR "moderation of extreme events ecosystem service quantification" OR "moderation of extreme events ecosystem service biophysical indicators" OR "erosion prevention ecosystem service quantification" OR "erosion prevention ecosystem service biophysical indicators" OR "biological control ecosystem service quantification" OR "biological control ecosystem service biophysical indicators" OR "lifecycle maintenance ecosystem service evaluation" OR "lifecycle maintenance ecosystem service quantification" OR "lifecycle maintenance ecosystem service biophysical indicators" OR "recreation and tourism ecosystem service evaluation" OR "recreation and tourism ecosystem service quantification" OR "recreation and tourism ecosystem service biophysical indicators"
Demand	"ecosystem service* demand" OR "ecosystem service* demand evaluation" OR "food provisioning demand" OR "water provisioning demand" OR "energy ecosystem service demand" OR "genetic resources ecosystem service demand" OR "materials ecosystem service demand" OR "regulation of water flow ecosystem service demand" OR "climate regulation ecosystem service demand" OR " water purification ecosystem service demand" OR "moderation of extreme events ecosystem service demand" OR "erosion prevention ecosystem service demand" OR "biological control ecosystem service demand" OR "lifecycle maintenance ecosystem service demand" OR "recreation and tourism ecosystem service demand"
Value	"ecosystem service* economic evaluation" or "ecosystem service* economic evaluation techniques" OR "ecosystem service* economic indicators" OR "food provisioning economic evaluation" OR " water provisioning economic evaluation" OR "energy ecosystem service economic evaluation" OR "genetic resources ecosystem service economic evaluation" OR "materials ecosystem service economic evaluation" OR "regulation of water flow ecosystem service economic evaluation" OR "climate regulation ecosystem service economic evaluation" OR "water purification ecosystem service economic evaluation" OR "moderation of extreme events ecosystem service economic evaluation" OR " erosion prevention ecosystem service economic evaluation" OR "biological control ecosystem service economic evaluation" OR "lifecycle maintenance ecosystem service economic evaluation" OR "recreation and tourism ecosystem service economic evaluation"

Based on data availability, and ease of use a set of indicators was then defined for each ES (Annex 2).

Finally, a review of the main existing NBS has been performed to identify those NBS that are more likely to deliver the ES identified as relevant vis-à-vis pilots' challenges to support the WP5 activities specifically the task 5.2 in the selection of appropriate NBS for the Nexus (Restrepo et al., 2022).

Figure 6 provides a visual representation of the methodology described in this section.

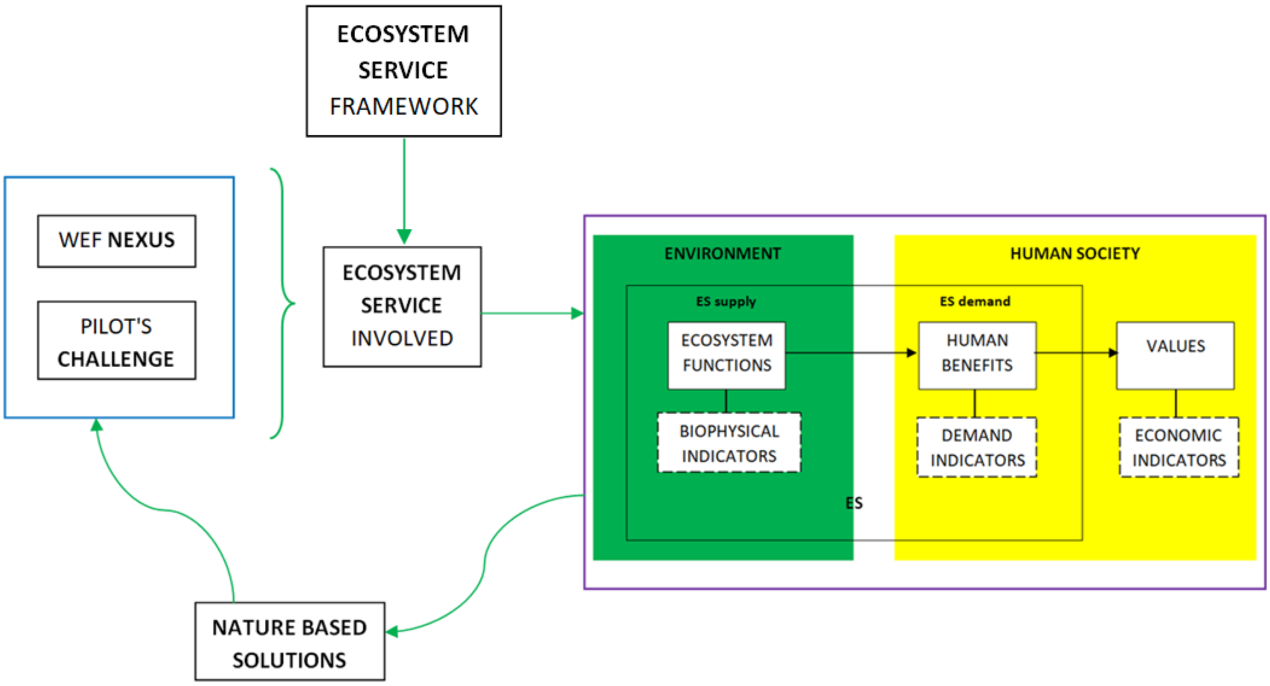

Figure 6. General scheme of the approach for the socio-economic assessment of ES in Nexus systems.
*WEF NEXUS: Water-Energy-Food *NEXUS*

4. Identification of the Nexus-related ecosystem services relevant for pilots' challenges

Water, energy, and food are essential for human wellbeing and sustainable development. The multiple and complex interdependences between the production, use and consumption of water, energy, and food are referred to as WEF Nexus.

The ES analysed by this report are described below to support their identification, thus ensuring appropriate scoping of the study. Moreover, ES description allows grasping the broadest spectrum of ES features and impacts as reported by the existing literature. Selected ES linked to WEF Nexus and to the challenges faced by the Pilots are presented here according to the different ES classification systems referred to in section 2.

Water resources are at the basis of the WEF Nexus. They can be interpreted as a provisioning ES with reference to the provision of drinking water, water for irrigation, hydroelectric power, aquaculture etc. However, the provision of water is also influenced by and closely linked to the regulation of the water cycle in terms of quantity (e.g. infiltration) and quality (e.g. purification) (Laterra et al., 2011; Egoh et al., 2010; Troy and Wilson, 2006; Simonit and Perrings, 2011). Different ES types associated with water resources are described below and summarized in Table 3.

Water provisioning

According to the MEA and TEEB frameworks, water provisioning falls within provisioning ES. The TEEB distinguishes the **water provisioning** service into water for (among others) drinking, irrigation, and cooling. The CICES considers water as an abiotic output and divides it into water resources from surface water or groundwater used for drinking, material uses, energy production, and other uses. In the IPBES framework the hydrological nature's contribution to people is fundamentally conceived as a regulating service, because the primary impact of ecosystems on water consists in the modification of hydrological flows. The service "Regulation of freshwater quantity, flow and timing" refers to: (i) the regulation by ecosystems of the quantity, location, and timing of the flow of surface and groundwater used for drinking, irrigation, transport, hydropower, and as the support of non-material contributions; (ii) regulation of flow to water-dependent natural habitats that in turn positively or negatively affect people downstream, including via flooding (wetlands including ponds, rivers, lakes, swamps); (iii) modification of groundwater levels, which can ameliorate dryland salinization in unirrigated landscapes.

Food

As regarding **food**, the MEA defines it as a provisioning service and includes it within the wide range of food products derived from plants, animals, and microbes. In a similar manner, the TEEB classifies food among the provisioning services and differentiates among fish, game, and fruit. The CICES classifies food as biomass and further differentiates into cultivated terrestrial plants (including fungi and algae) grown for nutritional purposes, cultivated plants grown for nutritional purposes by *in- situ* aquaculture, wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition, animals reared for nutritional purposes, and wild animals (terrestrial and aquatic) used for nutritional purposes. The IPBES classifies food as a material contribution to society and depicts it as production of food from wild, managed, or domesticated organisms, such as fish, beef, poultry, game, dairy products, edible crops, mushrooms, bushmeat and edible invertebrates, honey, edible wild fruits, and tubers.

Energy

With respect to **energy**, the MEA mentions "Fuel" as a provisioning ES, framing it as "Wood, manure and other biological materials act as energy sources*".* The TEEB refers to "Raw materials" describing how ecosystems provide a great diversity of building materials and fuels including – among the latter - biofuels, and vegetable oils that are directly derived from wild and cultivated plant species. The CICES refers to energy within the provisioning biotic group service "Cultivated terrestrial plants for nutrition, materials or energy" in the classes: "Cultivated plants (including mushrooms, algae) grown as a source of energy" and "Plants cultivated by *in-situ* aquaculture grown as an energy source". The provisioning biotic group "Reared animals for nutrition, materials or energy" includes another reference to energy inside the classes: "Animals reared to provide energy (including mechanical)" and "Animals reared by in-situ aquaculture as an energy source". Moreover, within the provisioning biotic group "Wild animals (terrestrial and aquatic) for nutrition, materials or energy" the "Wild animals (terrestrial and aquatic) used as a source of energy" class is included. A more explicit and consistent reference to energy can be found within the provisioning abiotic services that include three different classes: "Groundwater (and subsoil) used as an energy source", "Surface freshwater used as an energy source", "Coastal and marine water used as an energy source". The CICES classification is the only one considering water as an energy source. The class "Mineral substances used for as an energy source" refers to the provisioning abiotic service group "Mineral substances used for nutrition, materials or energy". Finally, the provisioning abiotic service group of "Non-mineral substances or ecosystem properties used for nutrition, materials or energy" includes the classes "Wind energy", "Solar energy" and "Geothermal". The IPBES classifies energy as a material contribution to society and defines it as the production of biomass-based fuels, such as biofuel crops, animal waste, fuelwood and agricultural residue pellets.

Water flow regulation

As presented above, within the MEA classification some ES are defined as benefits obtained from the regulation of ecosystem processes. In this respect, a service that indirectly contributes to the WEF Nexus and, in particular, to the provision of water is the **water flow regulation** service. It is reported that "*the timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, in particular, alterations that change the water storage potential of the system, such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas"* (MEA, p.40). The TEEB refers to this ES in terms of "Regulation of water flow" which is expressed through natural drainage, irrigation, and drought prevention. The CICES includes this ES in the section "Regulation & Maintenance (Biotic)" and classifies it as a service that deals with hydrological cycles and water flow regulation (including flood control and coastal protection). The IPBES names this ES "Regulation of freshwater quantity, flow, and timing" and classifies it as a regulating service. This service is described as the regulation, by ecosystems, of the quantity, location, and timing of the flow of surface water. Additionally, it includes the groundwater used for drinking, irrigation, transport, hydropower and the support of non-material contributions.

The ES described up to here are somehow directly linked to the WEF Nexus. Hereafter, other ES indirectly linked to the WEF Nexus are reported. These ES have been analysed because they can contribute addressing some challenges presented by Rexus pilot cases as presented in Annex 1.

Genetic material

Genetic material is classified in the MEA as a provisioning service and includes the genes and genetic information used for animal and plant breeding, and biotechnology. The TEEB refers to this ES as "Genetic resources" for crop-improvement and medicinal purposes. Similarly, the CICES classification places it within "Genetic material from all biota (including seed, spore or gamete production)" and "Genetic material from plants, algae or fungi group" divisions. All together this includes seeds, spores, and other plant materials collected for maintaining or establishing a population, and higher and lower plants (whole organisms) used to breed new strains or varieties. The IPBES classifies this ES in terms of "Medicinal, biochemical and genetic resources". It mentions the production of genes and genetic information used for plant and animal breeding and biotechnology.

Materials

The MEA refers to the provisioning ES category "Fiber" as a list of materials which includes wood, jute, cotton, hemp, silk, and wool; the "Ornamental resources" are described as "*animal and plant products, such as skins, shells, and flowers*" used "*as ornaments, and whole plants are used for landscaping and ornaments*" (MEA, p.40). The TEEB refers to "Raw material" provisioning service to include materials such as fiber, timber, fuel wood, fodder, fertilizer and to "Ornamental resources" referring to artisan work, decorative plants, pet animals, fashion. The CICES classifies the “Raw material” ES as "Fibres and other materials from wild plants for direct use or processing (excluding genetic materials)". It also refers to "Mineral substances used for material purposes" and "Non-mineral substances used for materials" in the provisioning abiotic service section. The IPBES refers to the material category of **materials** and links it to the "production of materials derived from organisms in crops or wild ecosystems, for construction, clothing, printing, ornamental purposes (e.g. wood, fibres, waxes, paper, resins, dyes, pearls, shells, coral branches)" and to the "direct use of living organisms for decoration (i.e. ornamental plants in parks and households, ornamental fish), company (i.e. pets), transport, and labour (including herding, searching, guidance, guarding)".

Climate regulation

Climate regulation is an ES that is increasingly regarded as relevant in connection to climate change challenges. The MEA classifies this service among regulating services and reports that "*ecosystems influence climate both locally and globally. At a local scale, for example, changes in land cover can affect both temperature and precipitation. At the global scale, ecosystems play an important role in climate by either sequestering or emitting greenhouse gases"* (MEA, p.40). The TEEB labels this service as "Climate regulation" and includes within it both carbon sequestration and the influence of vegetation on rainfall patterns. The CICES includes this ES within the section "Regulation & Maintenance (Biotic)" and classifies it as a service dealing with the regulation of chemical composition of the atmosphere and oceans and with the regulation of temperature and humidity, including ventilation and transpiration. The IPBES indicates that the climate regulation service - including regulation of global warming - includes positive and negative effects in terms of greenhouse gas emissions (e.g. biological carbon storage and sequestration; methane emissions from wetlands), biophysical feedback from vegetation cover to the atmosphere, such as those involving albedo, surface roughness, long-wave radiation, evapotranspiration (including moisture-recycling), as well as direct and indirect processes involving biogenic volatile organic compound, regulation of aerosols, and aerosol precursors.

Water purification and waste treatment

Water purification and waste treatment is referred to in the MEA by stating that *"ecosystems can be a source of impurities (for instance, in fresh water) but also can help filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems and can assimilate and detoxify compounds through soil and subsoil processes"* (MEA, p.40). The TEEB defines the service as "Waste treatment" stressing that it consists especially in water purification. The CICES reports this service within the section "Regulation & Maintenance (Biotic)" and distinguishes two different groups: (i) mediation of wastes or toxic substances of anthropogenic origin by living processes classified as bioremediation by micro-organisms, algae, plants, and animals; and (ii) water conditions classified as regulation of the chemical condition of freshwaters by living processes. The CICES also includes a "Regulation & Maintenance (Abiotic)" section and classifies it as a service that deals with dilution by freshwater and marine ecosystems. The IPBES describes the service as the regulation, through filtration of particles, pathogens, of excess nutrients, and other chemicals, by ecosystems or particular organisms, of the quality of water used directly (e.g., drinking) or indirectly (e.g., aquatic foods, irrigated food and fibre crops, freshwater and coastal habitats of heritage value).

Moderation of extreme events

Natural hazard regulation is a regulating ES exemplified in the MEA as "*the presence of coastal ecosystems such as mangroves and coral reefs can reduce the damage caused by hurricanes or large waves*" (MEA, p.40). The TEEB classification defines this service as "**Moderation of extreme events**". This ES is strictly connected to the water flow regulation service provided by vegetation or other components of the ecosystem acting as a barrier or buffer to water flow and thereby reducing the frequency and severity of flood events. Besides floods, extreme weather events and natural hazards include storms, tsunamis, tidal surges, avalanches, and landslides: ecosystems and living organisms create buffers against natural disasters, thereby preventing or mitigating possible damages. The CICES defines this service as "Hydrological cycle and water flow regulation (including flood control and coastal protection)". Finally, the IPBES includes this ES under two different regulating services categories: the "Regulation of freshwater quantity, flow, and timing" through the regulation of flow to water-dependent natural habitats that in turn positively or negatively affect people downstream, including via flooding (wetlands including ponds, rivers, lakes, swamps) [and] modifying groundwater levels, which can ameliorate dryland salinization in unirrigated landscapes" and the "Regulation of hazards and extreme events" through the amelioration, by ecosystems, of the impacts on humans or their infrastructure caused by e.g. floods, wind, storms, hurricanes, seawater intrusion, tidal waves, heat waves, tsunamis, etc.

This ES is provided by a wide range of ecosystems and often depends on interlinks among different ecosystems as well as on human management practices and other anthropic factors. Regarding river flooding regulation, the most relevant ecosystems are wetlands and forests in watersheds; regarding the regulation of coastal flooding, the most relevant ecosystems are mangroves, coral reefs, and sand dunes, but also marine and non-terrestrial ecosystems like kelp forests, oyster beds, seagrass, and unvegetated sediments. In terrestrial ecosystems the presence of vegetation in floodplains and watersheds can reduce the occurrence and severity of flooding by slowing water flows, enhancing percolation and storage, and allowing gradual release of water, thereby maintaining base flows and reducing peak flows. In coastal ecosystems the physical barrier formed by vegetation and other ecosystem structures reduces wave and storm surge impacts (de Groot et al., 2010).

Soil erosion regulation

Erosion regulation is what the MEA defines as soil retention and conservation as well as the prevention of landslides by vegetation cover. The TEEB refers to "**Erosion prevention**" and the CICES to "Control of erosion rates" division. The IPBES frames this ES within the "Regulation of hazards and extreme events" category and refers to the reduction of hazards like landslides and avalanches by ecosystems.

Biological control

Disease regulation and pest regulation are referred to by the MEA by respectively reporting that "*changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes"* and that *"ecosystem changes affect the prevalence of crop and livestock pests and diseases."* The TEEB classifies the two ES into one called **biological control** consisting in seed dispersal, pest, and disease control. The CICES classifies the ES inside the group "Pest and disease control" and defines it as regulation of physical, chemical, and biological conditions. The IPBES defines this ES as the "Regulation of organisms detrimental to humans" and describes it as regulation, by ecosystems or organisms, of pests, pathogens, predators, competitors that affect humans, plants and animals, including: regulation by predators or parasites of the population size of non-harmful important animals (e.g. large herbivore populations by wolves or lions); regulation (by impediment or facilitation) of the abundance or distribution of potentially harmful organisms (e.g. venomous, toxic, allergenic, predators, parasites, competitors, disease vectors and reservoirs) over the landscape or seascape; removal of animal carcasses and human corpses by scavengers (e.g. vultures in Zoroastrian and some Tibetan Buddhist traditions); regulation (by impediment or facilitation) of biological impairment, and degradation of infrastructure (e.g. damage by pigeons, bats, termites, strangling figs to buildings).

Maintenance of soil fertility

Soil formation is classified by the MEA as a supporting ES and indirectly influences human wellbeing in many ways because a high number of provisioning ES depend on soil. The TEEB refers to **maintenance of soil fertility** as a regulating ES and relates it to soil formation processes. The CICES classifies this ES within the "Regulation of soil quality" group and distinguishes two different classes: (i) weathering processes and their effects on soil quality; (ii) decomposition and fixing processes and their effect on soil quality. The IPBES refers to the regulating service category "Formation, protection and decontamination of soils and sediments" and links it to sediment retention and erosion control, soil formation and maintenance of soil structure and processes (such as decomposition and nutrient cycling) that underlie the continued fertility of soils important to humans.

Lifecycle maintenance

Nutrient cycling and water cycling are classified by the MEA as supporting ES. Regarding the former, the MEA reports that "*approximately 20 nutrients essential for life, including nitrogen and phosphorus, cycle through ecosystems and are maintained at different concentrations in different parts of ecosystems*". As for water cycling, MEA states that "*water cycles through ecosystems and is essential for living organisms"* (MEA, 2005 p.40). These two ES and cycles are grouped by the TEEB under the service "**Lifecycle maintenance"**. TEEB associates the service with the category of habitat services and describes it in terms of maintenance of life cycles of migratory species (including nursery service) and maintenance of genetic diversity (especially in gene pool protection). The CICES refers the service to the "Lifecycle maintenance, habitat and gene pool protection" group and divides it into two different services: (i) regulation of physical, chemical, biological conditions and (ii) maintaining nursery populations and habitats (including gene pool protection). The IPBES classifies this service as the regulating service of "Formation, protection and decontamination of soils and sediments" with reference to the filtration, fixation, degradation or storage of chemical and biological pollutants (pathogens, toxics, excess nutrients) in soils and sediments that are important to humans. The IPBES also refers to another regulating service, "Habitat creation and maintenance", described as the formation and continued production, by ecosystems or organisms within them, of ecological conditions necessary or favourable for organisms important to humans to live in. This includes, for example, nesting, feeding, and mating sites for birds and mammals, resting and overwintering areas for migratory mammals, birds and butterflies, nurseries for juvenile stages of fish, and refuge for fish and invertebrates.

Cultural ecosystem services

Finally, the MEA defines **cultural ES** as the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences. Recreation and ecotourism ES is one of these services and is referred to by the MEA as the characteristics of the natural or cultivated landscapes in a particular area chosen by people to spend leisure time. The TEEB classifies the service under the cultural service category and identifies it as "**Opportunities for recreation and tourism**". The CICES refers to cultural ES and frame them within the "Physical and experiential interactions with natural environment" group. It distinguishes among two different ES categories: (i) characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions and (ii) characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions. The IPBES classifies the service "Physical and psychological experiences" as a non-material contribution to society. It refers to the provision, by landscapes, seascapes, habitats or organisms, of opportunities for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism, or aesthetic enjoyment based on the close contact with nature. This includes, for example, hiking, recreational hunting and fishing, birdwatching, snorkelling, and gardening.

Table 3 reports a summary of the above-presented ES with reference to their classification according to the MEA, TEEB, CICES and IPBES ES classification systems. The ES denominations we chose to adopt for the aims of this report are highlighted with a coloured background. Each ES is linked to a WEF element (W = Water, F = Food, E = Energy) or a pilot's challenge (C) reported in the Baseline Description document (Osann et al., in press).

Table 3. Summary of the ES considered for the aims of this report and their classification according to selected ES classification systems

MEA	TEEB	IPBES	CICES Code[2]	Reference to WEF Nexus
Food provision	Food provision	Food and feed	1.1.1.1	F
			1.1.1.2	F
			1.1.2.1	F
			1.1.2.2	F
			1.1.3.1	F
			1.1.5.1	F
			1.1.6.1	F
Water provision	Water provision	Regulation of freshwater quantity, flow and timing	4.2.1.1	W
			4.2.1.2	W
			4.2.1.3	W
			4.2.2.1	W
			4.2.2.2	W
			4.2.2.3	W
			4.2.X.X	W
Fuel	Raw material	Energy sources	1.1.1.3	E
			1.1.2.3	E
			1.1.3.3	E
			1.1.4.3	E
			1.1.5.3	E
			4.2.1.3	E
			4.2.1.4	E
			4.2.2.3	E
			4.3.1.3	E
			4.3.2.3	E
			4.3.2.4	E
			4.3.2.5	E
Fiber Ornamental resources	Raw material Ornamental resources	Materials resources	1.1.5.2	C
			4.3.1.2	C
			4.3.2.2	C
Genetic materials	Genetic Resources	Medicinal, biochemical and genetic resources	1.2.1.1	F
			1.2.1.2	F
			1.2.1.3	F
			1.2.2.1	F
			1.2.2.3	F
Climate regulation	Climate regulation	Regulation of climate	2.2.6.1	C
			2.2.6.2	C
			5.1.1.2	C
Water regulation	Regulation of water flows	Regulation of freshwater quantity, flow and timing	2.2.1.3	W
			5.2.1.2	W
Water purification and waste	Water purification	Regulation of freshwater and coastal	2.1.1.1	W
			2.1.1.2	W

[2] Please refer to CICES (Haines-Young & Potschin, 2018) for details about these codes.

MEA	TEEB	IPBES	CICES Code[2]	Reference to WEF Nexus
treatment		water quality	2.2.5.1	W
			2.2.5.2	W
			5.1.1.1	W
Natural hazard regulation	Moderation of extreme events (flood protection)	Regulation of hazards and extreme events	2.2.1.2	C
			2.2.1.3	C
			5.2.1.1	C
Erosion regulation	Erosion prevention	Regulation of hazards and extreme events	2.2.1.1	C
Pest regulation	Biological control	Regulation of organisms detrimental to humans	2.2.3.1	C
Disease regulation			2.2.3.2	C
Nutrient cycling	Lifecycle maintenance	Habitat creation and maintenance	2.2.2.1	W/F
			2.2.2.2	W/F
			2.2.2.3	W/F
Water cycling		Formation, protection and decontamination of soils and sediments	5.1.1.3	W/F
			5.1.2.1	W/F
			5.2.2.1	W/F
Recreation and ecotourism	Opportunities for recreation and tourism	Physical and psychological experiences	3.1.1.1	C
			3.1.1.2	C
			3.2.1.3	C
			6.1.1.1	C

Ecosystems may be (and often are) multifunctional, i.e. they deliver multiple ES at the same time (co-benefits). For instance, de Groot et al. (2002) consider the natural hazard regulation ES functionally related to the provision of multiple other services according to synergistic dynamics. For example, a river in a wetland that regulates water flow and flood risk may also contribute to water supply. A coral reef that acts as a physical barrier to storm surges may also provide home to biodiversity and habitats while, at the same time, may offer cultural ES in the form of recreation opportunities such as scuba diving. The same ecosystem can therefore ensure multiple ES and benefits, potentially serving multiple beneficiaries and different beneficiary groups that can be evaluated by different indicators. These aspects will be further expressed when dealing with the ES benefit indicators (chapter 7).

At the same time, however, different ecosystems can generate trade-offs between ES. A trade-off can be an explicit choice or a totally involuntary consequence (Rodriguez et al., 2006). This can occur when interactions between ES are ignored (Ricketts et al., 2004), or when knowledge about ecosystem functioning is incorrect or incomplete (Walker et al., 2002; Kragt and Robertson, 2014) or when the ES involved have no explicit market value (Winthrop, 2014). Trade-offs may occur between ES at different scales, i.e., at:

- site level, for instance when forest vegetation is removed and replaced with agricultural crops (Ayanu et al., 2011) thus creating a trade-off between food production and forest-based ES, e.g. downstream water quality or regulation, carbon sequestration, biodiversity conservation etc.
- river basin level, when upstream farmers intensify their agricultural production (food production or energy-crop production) with excessive use of chemical fertilizers and this leads to a trade-off in terms of deterioration in water quality for downstream communities (Nguyen et al., 2014).
- regional or international level, when intensification of agriculture in certain areas of the world affects global climate change (Koellner et al., 2010; Rosenzweig et al., 2014) as well as water cycle by, for instance, increasing water demand for irrigation or by influencing the water balance through increased evapotranspiration.

Management decisions, indeed, often focus on the short-term (and small scale) provision of one or few ES, at the expense of the provision of the same service or different ones in the future (Rodriguez et al., 2006). In most of the cases, actions aimed at improving the delivery of provisioning services have led to a decline in the delivery of regulating and cultural ES (FAO, 2021).

Various frameworks have been developed to deal with trade-offs (Bennett et al., 2009; Raudsepp-Hearne et al. 2010; Kline and Mazzotta 2012, Smith et al. 2012; White et al. 2012; Bateman et al. 2013; Lawler et al. 2014). Kumar and Wood (2010), for instance, developed a framework based on landscape types and considering highly cultivated landscape, preserved landscape, and degraded landscape. Each of these has a distinct ES level configuration. Although most of landscapes would represent a mix of the three types, it is more useful to discuss them from different starting points, since the transition to more desirable states involves different types of management and policy strategies. The analysis involves drivers of change which move systems towards more unwanted trajectories (dashed arrows in Figure 7) and more desirable alternatives (solid arrows in Figure 7) which, in part, depend on new technologies and innovations. Incentive schemes, policies, and governance structures play a key role as they can encourage the development in one or another direction (Folke et al., 2005). These aspects will be further analysed by task 5.3 of the Rexus project (Rexus, 2021).

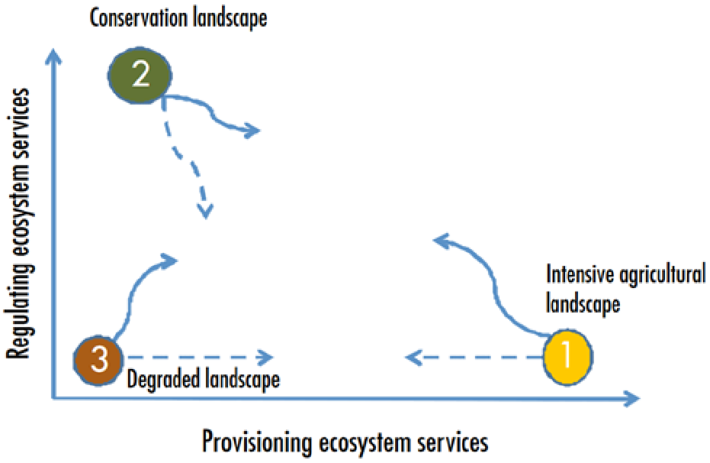

Figure 7. Different trajectories of change for agricultural, conservation, and degraded landscape. Source: Kumar and Wood (2010)

5. Ecosystem services assessment and evaluation methods and frameworks

This chapter provides an overview of the main existing approaches, methods and frameworks for the assessment and evaluation of ES.

5.1 Ecosystem services assessment and valuation concept: the cascade model

Many ES assessment and evaluation approaches as well as frameworks have been developed over time, ensuring a broad range of outputs, including (among others) mapping and modelling of ES supply and demand, and ES evaluation both in economic (i.e. monetary) and non-economic terms (Harrison et al., 2018).

In a similar manner, an increasing number of guidance documents on how to include ES in policy and management decision-making addressed to different sectors or stakeholder groups have been developed (e.g., EC, 2020; Congreve and Cross, 2019). ES assessment and evaluation have also been addressed by substantial scientific literature, including, but not limited to Gómez-Baggethun et al. (2016), Pascual et al. (2016), Jacobs et al. (2015), Seppelt et al. (2012), etc. Guidance papers have been developed through most of the international initiatives mentioned in chapter 2 of this deliverable, such as TEEB (2013) and IPBES guideline on the different conceptualizations of the multiple values of nature and its benefits (IPBES, 2016). Most of these documents define a comprehensive approach to assess ES organised into phases such as ES status/availability quantification and ES value assessment. Sometimes these documents include indicators and specific methodologies for the assessment of ES.

Guidance and operational tools for ES assessment and evaluation are also provided by online resources, such as the Ecosystem Knowledge Network's Tool Assessor[3], the National Ecosystem Approach Toolkit (NEAT tree)[4], the Toolkit for Ecosystem Service Site-Based Assessment (TESSA)[5], and the ValuES Project Methods Database[6]. Most of these online resources provide a limited selection of tools or methods that can be filtered and used.

We based our ES evaluation methodology on an assessment framework inspired by the ES cascade model that dates to the first ES evaluation studies by de Groot (2002) but has been proposed as a conceptual framework for the first time in Haines-Young and Potschin (2010). The ES cascade model is an analytical framework to quantify and assess ES. Despite the importance of this model in supporting the conceptualisation of ES assessment, it is based on strong simplifications as it assumes a linear relation between the ecological processes, the resulting benefits, and the economic value associated to them. This assumption may limit the capability of the model to grasp and describe the complexity of the ecosystems and the ES they provide, nevertheless the cascade model remains functional as it allows a practical approach to ES. It allows to evaluate ecosystems on the basis of the benefits provided to human societies. This implies assuming an utilitarian approach based on an anthropocentric perspective. There are different perspectives, e.g. more bio-centric views, according to which the value of natural resources have an intrinsic value,

[3] https://ecosystemsknowledge.net/tool

[4] https://neat.ecosystemsknowledge.net/tools.html

[5] http://tessa.tools/

[6] http://aboutvalues.net/method_database/

independent from human utility. Economists may accept biocentrism as part of their personal 'moral code' as they are convinced 'non-utilitarian' ethical considerations/arguments will largely influence the present and future state of natural resources, nevertheless in the short-run debates economic arguments often have a pivotal role and utilitarianism is the general framework for them. Economics however do not just deal with prices, markets and profits: attributing a proper economic value to resources is functional to decision-making by policy makers, especially when limiting factors influence the decision-making process. The cascade model framework has undergone several developments and revisions over time (for an overview see e.g. Heink and Jax, 2019). A variant proposed in the framework of accounting evaluation (La Notte et al., 2015; Czúcz and Arany, 2016; Heink and Jax, 2019; Vallecillo et al., 2019) equates structures (and processes) to conditions and capacity to functions. Moreover, ES value can be applied to all levels of the cascading flow (La Notte et al., 2015; Maynard et al., 2015). This version of the cascade model is in line with the conceptual framework by Czúcz et al. (2020) (Figure 8).

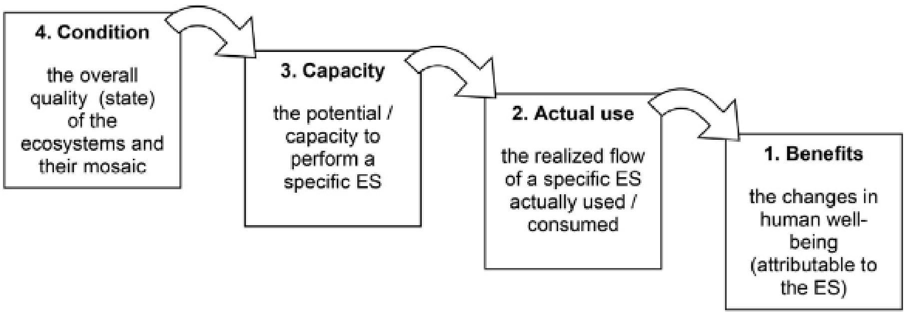

Figure 8. ES cascade model for accounting evaluation. Source: Czúcz et al. (2020)

A second version of the cascade model is structured into two parts: one related to ecosystems and biodiversity, that includes structures and processes generating the functions ES depend on, and another one related to human wellbeing, that translates ES-related benefits into economic terms (e.g. Feeley et al., 2016; Feurer et al., 2019).

As an example of the application of this version of the cascade model, Maes et al. (2012) proposed an analytical framework to map and assess recreational ES within the framework of the Partnership for European Environmental Research (PEER) (Figure 9).

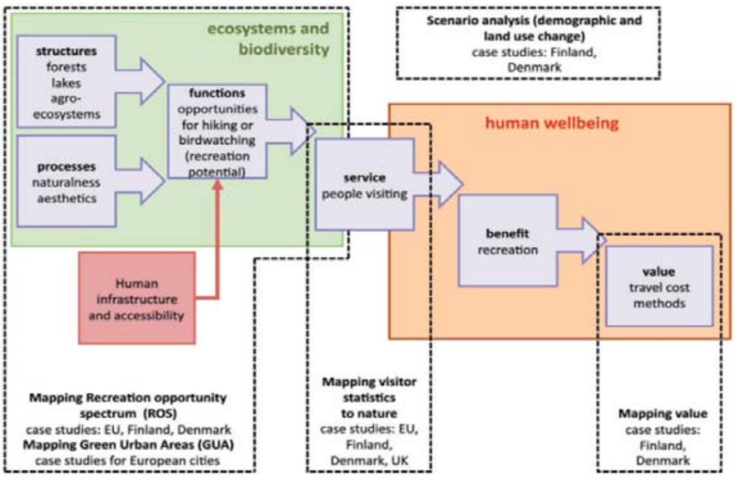

Figure 9. Ecosystem and biodiversity – human wellbeing cascade model. Source: Maes et al. (2012)

The indicators developed according to the cascade flow model consider the ecosystems' ability to provide a service, its flow and the corresponding benefits. It is here important to notice the difference between 'benefit' and the associated 'value'. Benefit is referred to "*something that can change people's 'well-being. […] These benefits are thus important to people, and that importance is therefore expressed by the values they assign to those benefits. 'Value' is therefore the final box in the cascade model, on the right-hand side.*" (Potschin and Haines-Young, 2016). Value can be then expressed in different ways, from the monetary value to the aesthetic/spiritual/existence importance people give to the considered ecosystem service. The ES valuation bring with it many critics, mainly linked with the economic evaluation of ES that is seen as posing the risk of a commodification and financialization of nature (Kill, 2014). On the other hand, valuing ES, despite some limitations, is a powerful instrument to support decision making processes dealing with nature management as it provides information using metrics that are accessible also to non-experts and of particular importance to deal with financial constraints when investments choices have to be made.

O'Higgins et al. (2016) referred to a revised version of the cascade model for the assessment of the water supply ES (Figure 10). In particular, for fresh renewable water reserves the capacity indicator would be the total area of inland water bodies and inland wetlands (ha), the flow indicator would be the total annual supply of renewable fresh water (m^3/year) for surface water, and the benefit indicator would be the total annual fresh water consumption per sector.

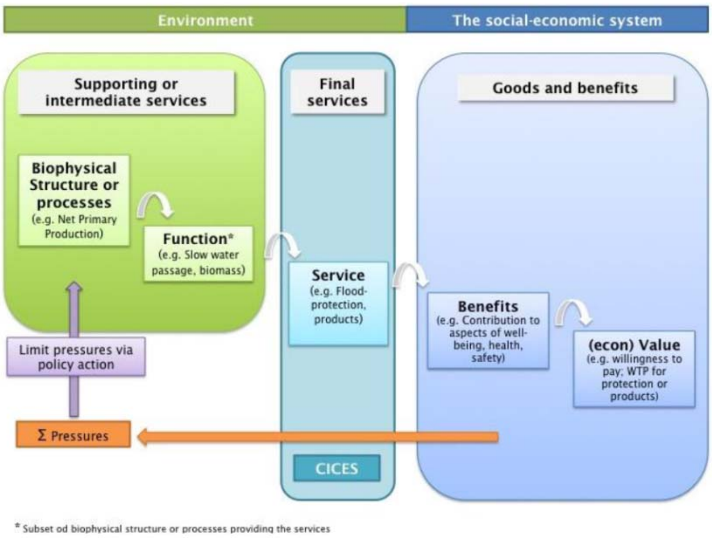

Figure 10. Water supply service cascade model. Source: O'Higgins et al. (2017).

In some variants of the cascade model the indicators are organized into different categories by considering the ES supply and demand sides separately (Barò et al., 2016; Carvalho-Santos et al., 2014). The biophysical structure and the functions are grouped within the supply side while the benefits and the economic value of the ES are clustered within the demand side. In this regard, Wei et al. (2017) further developed the supply-demand cascade framework by introducing spatial issues: service providing units (SPUs) and ecosystem service beneficiaries (ESBs) are proposed as crucial dimensions for a better understanding of the ES process from the supply to the demand side. ESBs are generally distributed within service benefiting units (SBUs), which are the areas that can benefit from the ES.

In the cascade model developed by Boerema et al. (2017), that has been adopted as a main reference for the development of our assessment framework, ES is not a block or a measurable entity but a concept linking supply and demand issues, as represented by the dotted line in Figure 11. According to this framework, the assessment of an ES consists of two parts. A first part addressing the ecosystem functions generating the ES (ES supply) and a second part assessing the benefits perceived or retrieved by humans (ES demand). The full assessment consists of a combination of these two parts. A similar model has been proposed by Mononen et al. (2016) who defined indicators to each of the four parts of the ES cascade scheme (ecosystem properties, ecosystem functions, benefits to humans and value).

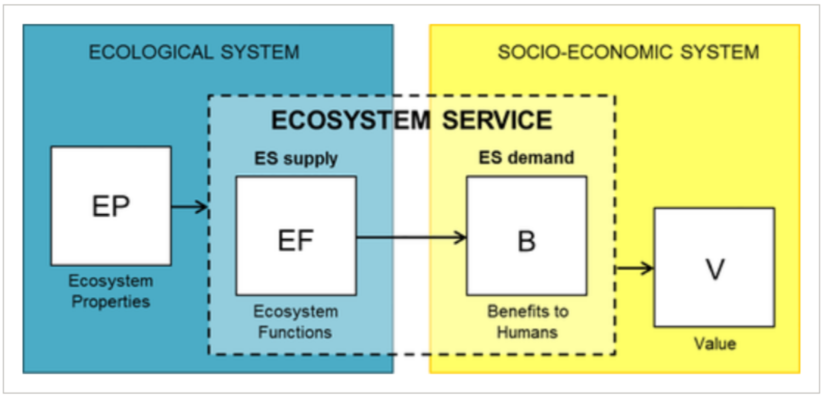

Figure 11. ES supply-demand cascade model. Source: Boerema et al. (2017)

5.2 Development of the project's cascade model

The conceptual framework we adopted for this deliverable builds on existing literature and the above-presented developments of the cascade model, with specific reference to the version of the model developed by Boerema et al. (2017) and referred to in Figure 11. The rationale behind the development of the framework used for Task 3.6 was to avoid duplicating existing frameworks, rather to adapt and operationalize them. The framework spans the ES supply-demand cycle, from ecosystems to human society, and aims to focus on the (i) functioning of ecosystems that support the provision of ES, (ii) the benefits for society, and (iii) the ES value (Figure 12). For each of these three components appropriate indicators have been selected. For ecosystem functions and ES supply, we focused on bio-physical indicators that quantify the ecosystem function intended as the capacity of natural processes and elements to provide goods and services that satisfy human needs, either directly or indirectly (de Groot et al., 2002). In continuation with that, ES demand is measured via indicators related to the benefits produced by ecosystems and demanded by society, while ES value is measured via indicators that translate bio-physical quantities into monetary terms. This flow of interlinked indicators shows the ecological-social nature of the ES provision and the strict interconnection between ecological and socio-economic traits. A visual representation of the cascade model we developed is reported in Figure 12.

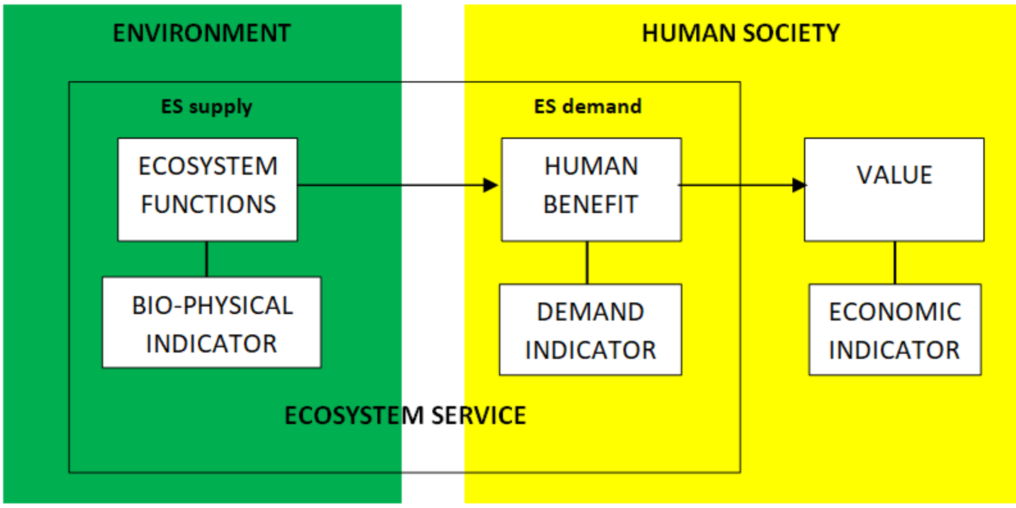

Figure 12. ES assessment framework

6. Indicators for ecosystem services

This chapter provides an overview of potential indicators for the assessment and evaluation of ES. Indicators are reported separately with reference to ES supply, demand and value.

6.1 Indicators for assessing ecosystem service supply

ES supply results from the combination of a set of natural processes and social conditions (Spangenberg et al., 2014) therefore, while assessing ES supply requires to assess the traits, structures, and functions of ecosystems, it also includes to consider the human choices that may have an influence on ecosystem functioning. Definitions of ES supply provided by several scholars and studies (e.g., Burkhard et al., 2012; Crossman et al., 2013; Villamagna et al., 2013) cover all the factors affecting an ecosystem, including ecological functions, bio-physical properties, and socio-economic dimensions. In other terms, the ES supply is influenced by natural external drivers, such as temperature levels or precipitation patterns, and anthropogenic drivers, such as policies and management practices.

While different terms available in the literature can be considered as equivalent to ES supply – e.g., ES managed supply (Geijzendorffer et al., 2015), ES capacity (Villamagna et al., 2013) or ES provision (Mouchet et al., 2014) – it is important to distinguish and define concepts such as ecosystem structures, functions, ES stock, ES real flow. For example, Villamagna et al. (2013) investigated the difference between the ecosystem capacity to deliver ES (i.e., potential ES production) and the actual production and use of ES. Bastian et al. (2012) differentiated between the ecosystem properties, potentials, and services. The rationale behind this, is that ecosystems provide a certain potential service because they exist and operate, but it is the societal demand for these services that finally turns them into ES.

For the aims of this report we make a distinction between potential supply and actual flow of ES. According to the definitions by Burkhard et al. (2014), the provision of ES is based on specific ES potential and additional system inputs which ultimately result in an ES flow towards society. The ES potential represents the hypothetical maximum yield of one or more selected ES based on ecosystem conditions and features (e.g. the area covered by a certain ecosystems and its conservation status), often referred to as ES bundle. The ES flow refers to the ES *de facto* used by humans in a particular area within a given time period.

Based on data availability, including the implementation of future climate change projections for pilot cases, and building on existing studies, we adopted ES potential and associated indicators as a reference. Our list of indicators broken down by ES (see Annex 2) has been adapted from Egoh et al. (2012) and complemented by other scientific studies. Results of the review show that ES biophysical assessment can be done in different ways: (i) suites of models specifically developed to map and value multiple ES, such as InVEST[7], i-Tree[8], Estimap[9], Aries[10] etc.; (ii) models, not necessarily designed in origin for ES assessment and often targeting single ES or ES thematic groups, such as hydrological models (Cong et al., 2020; Egoh et al., 2012), species distribution models (van der Maaten et al., 2017; Charney et al., 2021), agent-based models (Goedhart et al., 2018; Gimona and Polhill, 2011; Bartkowski et al., 2020) etc.; (iii) statistical models, such as regression models, applied to specific datasets (Tang et al., 2014; Sannigrahi et al., 2020); (iv) proxies such as matrix

[7] https://naturalcapitalproject.stanford.edu/software/invest

[8] https://www.itreetools.org/

[9] https://publications.jrc.ec.europa.eu/repository/handle/JRC87585

[10] https://aries.integratedmodelling.org/

approaches or search tables to present ES based on land use maps/land cover classes (Barth and Dölln, 2016; Brenner et al., 2012; Troy and Wilson, 2006); and (v) mapping approaches such as deliberative mapping (Palomo et al., 2013), spatial interpolation (Seidel et al., 2019; Mokondoko et al., 2018) etc.

Metrics and approaches used for quantifying ES may vary depending on targeted ES. For example, the supply of provisioning ES can be directly quantified by biophysical metrics (e.g. the volume of water supply), the supply of regulatory services can be measured by combining a number of ecosystem processes (e.g. carbon capture) (Villamagna et al., 2013), and the supply of cultural services depends on a mix of biophysical/natural (e.g. degree of wilderness) and social features (e.g. individual preferences for recreational activities). These differences emerged on the list of indicators collected (see Annex 3) from which, for example, it appears that the quantification of regulatory ES supply needs more input data and this in most of the cases shall be properly processed and prepared in advance.

Finally, the ES supply often reflects the ecosystems' ability to provide services valued by humans, regardless of whether humans consume these ES or not (Martínez-Harms and Balvanera, 2012).

Table 4 reports examples of biophysical indicators used for assessing the supply different ES.

Table 4. Example of ES biophysical indicators

ES category	**ES**	**Biophysical indicators**
Provisioning service	Water	Fresh and/or process water availability (l/ha per year; m^3/ha per year)
Regulating service	Water flow regulation	Water storage capacity (m3/ha)
Cultural service	Recreation and tourism	Number of facilities (e.g. hotels, restaurants, hiking paths, parking lots; n/ha)

6.2 Indicators for assessing ecosystem services demand

From a supply-side perspective ES have biophysical attributes which can be evaluated through biophysical indicators, while from a demand-side perspective ES have social and economic attributes which can be evaluated based on social and economic indicators (Castro et al., 2014; Martín-López et al., 2014).

Due to the lack of specific research, defining ES demand can be more challenging than defining ES supply. Although some studies have deepened the topic of ES demand and developed assessment methods (Bagstad et al., 2013; Mubareka et al., 2013; García-Nieto et al., 2013; Kroll et al., 2012; Nedkov and Burkhard, 2012; Lautenbach et al., 2012) the current understanding of the ES demand is still liable to different interpretations (Baró et al., 2016; Burkhard et al., 2012; Wolff et al., 2015). A first interpretation has been provided by Burkhard et al. (2012) who reported that human wellbeing (economic, social, and personal) is based on the benefits deriving from the effective use of ES by people. This implies that, from an anthropocentric perspective, an ES can be defined as such only if there is a (human) benefit associated to it. Without human beneficiaries, ecosystem functions and processes do not qualify as services (Fisher et al., 2009). In other terms, there must be a certain demand from people to use a particular ES. The application is, therefore, described as *"ES consumed or used in a particular area in a given period of time, not considering where ES are actually supplied"* (Burkhard et al., 2012).

Schröter (2014), instead, defines demand as the "*expression of individual agent's preferences, for specific attributes of the service, such as biophysical characteristics, location and timing of availability, and associated opportunity costs of use".* ES demand can therefore also be referred to as the level required or desired by human society or the individual preferences for ES specific attributes (Martin-Lopez et al., 2012;

Mcdonald's, 2009; Villamagna et al., 2013). In this perspective, the ES demand is framed as consumption and desire in accordance with the different ES categories (Wolff et al., 2015). Since we decided to refer to Burkhard et al. (2012) and to measure the ES potential rather than the actual ES flow for the supply side, the ES demand refers to the quantity of ES consumed in the case of provisioning ES and to the desired level of ES in the case of regulatory and cultural services. The list of indicators collected for the assessment of ES demand, broken down by ES, is presented in Annex 4.

To assess ES demand, Villamagna et al. (2013) use different indicators according to the type of ES. Thus, provisioning ES are valued as the consumed service quantity per unit of space and time multiplied by the number of potential users (e.g., volume of water consumed per person on yearly basis); regulatory ES are assessed as the amount of regulation required to meet certain pre-established conditions (e.g. % of carbon emission reduction); cultural services are assessed with reference to the desired total use (if rival service[11]) or individual use (if non-rival) of a certain ES or resource delivering the ES (e.g. total visitor-days; individual visitation rates).

The identification of demand indicators for the regulatory ES tends to be more challenging than for provisioning ones because the relationships between ES and human benefits may not be direct. For example, when considering the water retention capacity as an ES, Fu et al. (2019) combined the demand for water by households, agriculture, and industry with the available water supply. They did not consider water demand to produce hydroelectric power because it is not considered to be relevant for the water retention capacity.

Human population density combined with average consumption rates is widely used as an ES demand indicator (Burkhard et al., 2012; Nedkov and Burkhard, 2012), especially for those final services for which a consumptive direct use value is considered, such as water supply or crop production. For cultural services based on non-consumptive, experiential direct use value, such as those referred to recreational activities, demand can be estimated by referring to the number of people experiencing the ES (e.g., park visitors).

Since the regulating services achieve or maintain desirable environmental conditions, their demand refers to the amount of regulation required to meet a desired final condition. Estimating the demand for regulating services is inherently challenging because it requires information on the desired final conditions, the ecological pressures, and the inputs requiring regulation. Due to this complexity, literature on the assessment – both in biophysical and economic terms – of the demand for regulating ES is scarce. In most of the cases the demand for regulating services is quantified in terms of number of beneficiaries of a certain ES or number of people that would be exposed to a certain risk if the ES would not be in place (Burkhard et al., 2012; Nedkov and Burkhard, 2012). For example, Sauter et al. (2019) referred to the number of people living in a certain geographical area highly prone to flooding as a demand indicator for flood risk mitigation.

The demand for regulating and cultural services can also be detected based on preferences expressed via surveys or other interactive approaches and tools, including participatory techniques. Palomo et al. (2013), for instance, used participatory mapping to collect information aimed at the identification of areas where beneficiaries use a particular ES while at the same time gathering beneficiaries' perceptions about degradation risks for these areas.

Interactive and participatory methods, such as interviews, questionnaires focus groups etc., allow to obtain personal information about values, behaviours, preferences of the population of an area and support the understanding of the spatial distribution of demand for intangible services (Hernández-Morcillo et al., 2013). García-Díez et al. (2020), for example, used participatory Geographic Information System (GIS) mapping to evaluate three cultural ES. They adopted Maptionnaire, a public participatory GIS tool based on a web

[11] A rival service is a type of service that may only be possessed or consumed by a single user. It means that if someone uses this service, there will be less for someone else (Pîrvu and Enescu, 2012).

platform on which interactive maps linked to questionnaires can be created and analysed. The program allows users to freely set points on a map and offers the ability to relate these points with the information required through the survey. In this way the participants are actively involved in the process of mapping and evaluating cultural ES: participants directly indicate on a map where and what services are used or valued.

The participatory approaches may also include the participation of experts steering the development of indicators (Casado-Arzuaga et al., 2013) and emphasize the relevance of ES evaluation to support policy-making, including ethical aspects of demand (Orenstein and Groner, 2014).

Finally, participatory approaches can be used for highlighting perceived trade-offs and synergies among ES (Plieninger et al., 2019). For example, Schwartz et al. (2021) used participatory GIS to involve stakeholders and carry out explicit spatial assessments, combining research questions on ES demand with a mapping exercise, to identify spatial ES trade-offs. The study combines demand assessment for selected regulating ES with a digital mapping exercise targeted at different stakeholder groups, ES, and regions. The study addresses perceived ES supply and stated ES demand to identify possible trade-offs that can cause conflicts in resource management and land use decisions. The activities planned within the Rexus project, in collaboration with all relevant stakeholders and carried out within WP2, with special reference to task 2.5, could therefore allow the identification of ES trade-offs and synergies resulting from different Nexus options.

Finally, it should be noted that the ES demand can be generated at different scales (Geijzendorffer and Roche, 2014). For example, the demand for flood regulation pops-up in populated areas presenting a high flood-risk, while the demand for carbon sequestration may emerge at a broader spatial scale. Demand can also change over time, regardless of the actual provision of ES (Villamagna et al., 2013).

Table 5 reports examples of biophysical indicators used for assessing the demand of different ES.

Table 5. Example of ES demand indicators

ES category	**ES**	**Demand indicators**
Provisioning service	Water	Water use (l or m^3 /person per year; l or m^3/industrial sector per year; l or m^3/energy sector per year)
Regulating service	Water flow regulation	Soil field capacity (v%)
Cultural service	Recreation and tourism	Number of facilities (e.g. hotels, restaurants, hiking paths, parking lots; n/ha)

6.3 Indicators for assessing ecosystem services value

ES evaluation allows expressing the ES value in monetary terms, measuring people's preferences for the benefits they obtain from ES. Non-economic valuation of ES is also possible as it allows examining how people's opinions and perceptions are shaped, or their preferences formed and articulated beyond monetary terms. Even though non-economic valuation could be helpful in informing policy choices (Masiero et al., 2019), this document focuses on economic valuation (evaluation). Evaluation methods build on the concept of total economic value (TEV).

Economic values can be categorized broadly as either use or passive-use (sometimes also called non-use) values. The TEV corresponds to the sum of these two value categories (Figure 13). **Use values** are articulated in: *direct use values*, which derived from direct production, consumption, and sale of ecosystem products, such as energy, food , water provision, etc.; *indirect use values* derived from ecological functions that maintain and protect natural and human systems through services, such as water quality and water flow regulation, flood control and storm protection, nutrient retention and micro-climatic stabilization, etc.; *option values*, associated with the option of keeping ecosystem use flexible for future direct and indirect uses, that may be linked to commercial, industrial, agricultural, and leisure activities. The **non-use values** are ecosystem values which disregard their current or future use and are linked to cultural, spiritual, aesthetic, heritage purposes. They include *existence values*, *altruistic values*, and *bequest values*.

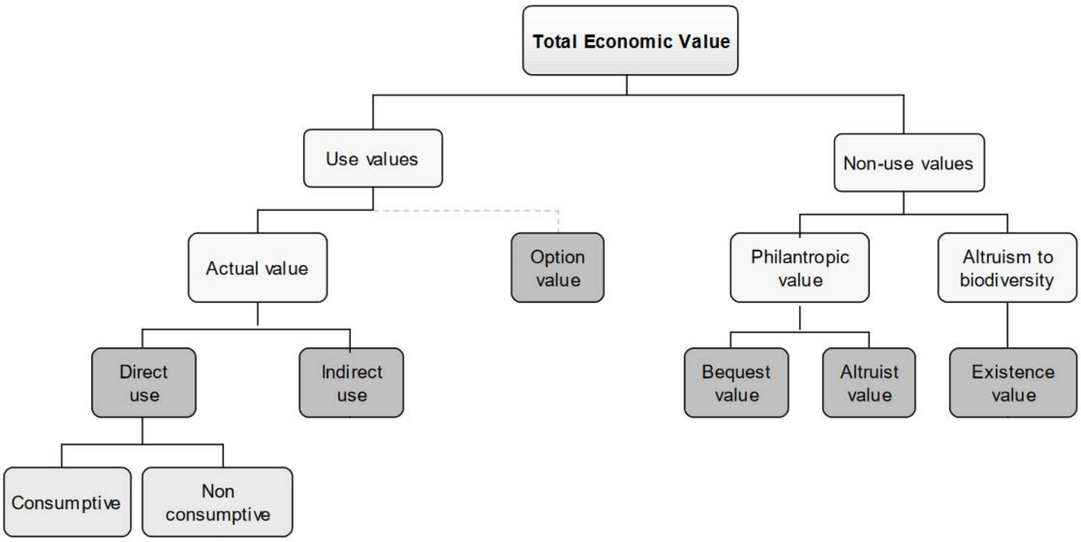

Figure 13. The Total Economic Value concept. Source: TEEB (2010)

Different ES economic evaluation methods can be identified based on the different rationale behind them, methodological steps they take and data type as well as sources they use and depend on. A summary of the main valuation methods and approaches can be retrieved from Grizzetti et al. (2015) as well as from many other literature resources. This report is not intended to deepen valuation methods from a technical point of view, rather to provide an overview of methods linked to topics specifically addressed by this study. Readers are invited to consider additional resources to get familiarity with economic valuation, including strengths and limitations of different methods. As an example, see Masiero et al. (2019).

The economic value may be derived directly from the market, from parallel market transactions indirectly associated to the commodity assessed, or from hypothetical markets created for the purpose of deducting the value. It is possible to summarize the categories of ES economic evaluation methods as: (1) direct market assessment approaches, (2) revealed preferences approaches, and (3) stated preferences approaches (TEEB, 2010).

(1) **Direct market assessment approaches** make use of available and accessible data coming from existing markets. They include different types of approaches. The first one is based on **market prices** and is widely used for the evaluation of many provisioning services, such as agricultural or timber products for which an active market exists. Alternatively, **cost-based approaches** estimate the value of an ES based on the costs associated with it, such as the costs needed to produce (or reproduce) a certain ES or to substitute it with a similar or equivalent one. These approaches include: the *avoided costs*, that refer to the costs that should be incurred in the absence of certain ES; the *replacement costs*, that estimate how much it would cost to replace an ES with artificial technologies providing the same service; and the *restoration costs*, that estimate how much it would cost restoring a lost ES or an ecosystem delivering it. Lastly, the **factor income** (or production function) approach estimates how much a given ES (often referring to regulating services) contributes to the provision of a good or service that is traded on the market. As reported in Barbier (1994

and 2009), the implementation of this approach consists of two main steps: as a first step the physical effects of changes in an ES on a certain economic activity are identified (e.g. changes in agriculture yield due to reduced availability of irrigation water); the second step is to assess these changes in terms of corresponding changes on commodities traded on the market (e.g. changes in the amount of crops actually sold on the market).

(2) The **revealed preferences approaches** are based on the observation of individual behaviours and choices within existing markets, which are linked to the targeted ES. The two most known approaches within this group are the **travel cost** and the **hedonic price** methods. As for the former, the preferences are revealed through the cost, in terms of direct expenses and time-opportunity costs, incurred by the economic agent to enjoy a service. This approach is mostly used to estimate the recreational value of a certain site, by assuming that the willingness to pay to visit a site (i.e., the value of the recreational experience) can be estimated based on the number of trips and their associated travel costs (Bateman et al., 2002; Kontoleon and Pascual, 2007). The hedonic price approach assumes that the market price of a certain goods reflects its characteristics, including environmental features that have not explicit market value. Changes in the amount and quality of such attributes, therefore, influence the price of the marketed good. Statistical analyses (e.g., regression analysis) are used to identify the influence by single attributes and therefore their economic value. The most common application is to the real estate market. The value of houses or properties in general results from the combination of different attributes, some of which are environmental attributes, like proximity to a natural area or an urban park. The value of these environmental attributes will reflect on variations in market prices for the marketed good (e.g., house or property).

The stated preferences approaches simulate a market for ES through surveys on hypothetical changes in the provision of given ES. These approaches can be used to estimate both use and non-use values of an ES and are normally used when it is not possible to refer to a surrogate market. **Contingent valuation** is one of the evaluation methods used within these approaches: it builds on the idea of estimating the value of an ES not traded on the market through surveys targeted at individuals and aimed to elicit people’s willingness to pay (WTP) for increasing the provision of an ES, or alternatively, their willingness to accept (WTA) losses or degradation. The typical questions asked include "how much would you be willing to pay for..?" or "how much would you be willing to accept for...?". Sample surveys are usually used as well as multiple elicitation methods. A second method is the **choice modelling**, which consists in the attempt to model the decision-making process of an individual in a particular context (Hanley and al., 1998; Philip and Macmillan, 2005). Individuals are faced with two or more alternatives presenting different levels of attributes for the ES being assessed (e.g., forest areas having different size and species-mix). The interviewees express their preference inside a set of possible scenarios: each preference is associated to different levels of the attributes. By associating a monetary value with each combination of attributes it is possible to estimate monetary values for given ES based on interviewees’ choices.

Finally, **group evaluation** combines preference techniques with political sciences processes (Spash, 2001; Wilson and Howarth, 2002). The aim is to capture different types of value which elude individual investigations such as pluralism value, non-human values and social justice (Spash, 2008).

Since conducting evaluations tends to be resource-intensive, benefit transfer techniques have been increasingly adopted in the last decades (Wilson and Hoehn, 2006). The rationale behind this approach is to use ES values obtained from certain studies (study site) and extrapolating them to other similar situations (policy site) (Brookshire and Neill, 1992; Desvouges et al., 1992). The possibility to transfer values from one context to another depends on the ES as well as on contextual factors. Some ES, such as carbon sequestration, can be provided on a scale where the benefits are easily transferable. On the contrary, other ES, such as flood control values, may be extremely site-specific and therefore have limited transferability. Different transfer techniques can be used, from simple unit value transfer to meta-analytic benefit transfer: they span different levels of complexity and result in different degrees of output quality.

Table 6 reports examples of indicators used for assessing the economic value of different ES.

Table 6. Example of ES economic indicators

ES category	ES	Economic Indicators
Provisioning service	Water	Market price
Regulating service	Water flow regulation	Avoided costs
Cultural service	Recreation and tourism	Travel-cost method

7. Socio-economic indicators related to the Nexus ecosystem services and the pilots

Based on aspects reported in the previous chapters, we present the list of indicators identified as the most suitable for the evaluation of the socio-economic dimensions related to the WEF Nexus and the pilot's challenges. The selection of the indicators has been done considering data availability and applicability to the case studies. Some of these indicators are derived as such from the existing literature, while others have been developed and adjusted building on existing studies. Different units of measurement are used for different ES. Indeed, some indicators use unit values (e.g., per ha), other total values based on analysis needs and data availability. ES supply indicators are distinguished per ES and according to input information, type of quantification method, extent of study area, source, and more details about the method and the original source (Annex 3). The demand indicators are presented separately per ES and some of them are reported with reference to associated flow service indicators, service benefitting areas, input information, source, and more details about the corresponding methodological details and the original source (Annex 4). No list of economic indicators is provided since these indicators are embedded within the evaluation methodologies presented in Chapter 6.3.

An overview of selected indicators is available in Table 7 at the end of this chapter.

The socio-economic assessment of **food provisioning** builds on the fact that food products/commodities, e.g. farm crops, are traded on the market and, therefore, have an explicit market value. The food provisioning supply can be determined based on the size of farmed areas (per crop) combined with production yields per crop (kg/ha). These data are generally available from local statistics and via privileged stakeholders, like farmers associations. ES demand can be quantified by estimating the average per capita (or per household) consumption of products. Finally, the economic value can be assessed by making reference to market prices of the products supplied (Power, 2010) derived from market analysis, statistics, reports, price-lists (e.g. from local chambers of commerce) etc.

The supply of the **water provisioning** ES can be estimated through an analysis of the hydrological balance of the study area, hydrological models, simple estimates of the basin flow rate (precipitation - evapotranspiration) or annual volumes of water extracted from different sources The demand can be expressed through the annual water consumption by different sectors. The economic value of the ES can be estimated by multiplying water prices, as from water tariffs, by the water volumes supplied, approximated by the basin flow rate, or water abstractions.

The supply of **energy resources** ES is measured based on the installed capacity of the hydroelectric plants. The demand refers to the average consumption of hydropower energy by different users (households, companies etc.). The economic value corresponds to the average market price of hydropower energy multiplied by the amount of energy supplied.

The supply of **material resource** ES is measured as the average amount of natural resource extracted in the study area (kg/ha). The demand refers to the average natural resources consumption per sector (kg/sector per year). The economic value corresponds to the average market price per natural resources type multiplied by the corresponding ES supply (amount of resource extracted).

According to the validation of challenges by pilots, **genetic resources** have been considered as natural resources linked to food provisioning services whereas genetic richness linked to ecosystem conservation has been addressed within the lifecycle maintenance ES. The biological and biochemical diversity provided by ecosystems and organisms (plant and animal genetic resources) supports, among others, agricultural production through the possibility of selecting crop varieties and developing adaptive solutions to face varying environmental conditions (Hoisington et al., 1999). The supply of genetic resources is estimated via the number of crop varieties and livestock breed species living in a certain area. The ES demand consists of the number of crop varieties and livestock breed species used in the same area, while the economic quantification of this ES can be performed through restoration costs that estimate how much it would cost to restore lost genetic resources (e.g. reintroduction of pollinators).

With regard to the **climate regulation** ES, the carbon sequestration ES has been considered. Tools used to quantify carbon fixation in plant biomass include, among others, small- or large-scale forest inventories, land use change estimates, empirical models or biomass expansion factors, empirical growth and production models (ecosystem, population or individual scale), remote sensing etc. At the extremes of a resolution and data-intensity gradient we can distinguish two macro-categories of approaches: at the highest grade we find modelling of basic processes, from plant physiology to soil gas flows and exchanges, with field data or/and satellite data (Freibauer et al., 2004; Post and Kwon, 2008; Scarfò and Mercurio, 2009; Tenhunen et al., 2009; Strohbach et al., 2012; Ferréa et al., 2012) while at the lowest grade we find simplified estimates based on land cover or land use (Eade and Moran, 1996; Backéus et al., 2005; Tallis et al., 2013). By referring to this second group of approaches, the climate regulation potential service supply can be measured as the carbon sequestration rate, quantified in terms of tons of CO_2 sequestered per ha and per year for each land use category (considering one or more out of multiple carbon pools, i.e. above- and belowground biomass, litter, soil and deadwood) multiplied by the area of each land use category. The ES demand refers to per capita (or per household) emissions or emissions per economic sector. The economic value of the ES can be quantified based on the avoided social damage by the non-emission or sequestration of CO_2 in the atmosphere (Stern, 2007). Since the calculation of social costs may result difficult because of the complexity of climate processes and of the difficult estimation of economic values under uncertain conditions. Alternatively, the value of the ES may be estimated by referring to the market price of carbon credits exchanged on carbon markets.

The water retention in a basin has a buffer effect between possible flooding and water scarcity, cutting peaks in rivers flood and increasing the availability of water in dry periods. The **water flow regulation** service, as interpreted by pilots' challenges, refers to groundwater recharge and water retention, in support of water provisioning. As reported in Annex 3, the biophysical estimation of the groundwater recharge service can be data and resource-intensive as it may be based on hydrological models and requires data on precipitation, soil permeability, surface, and underground flow rates (Anuraga et al., 2006). Where such data are available, several dedicated models can be used, such as ARIES, InVEST, SWAT, VIC etc., depending on the issue to be addressed, although the use of these tools requires specialized skills and experience (Vigerstol and Aukema, 2011). Just as an example, Mashayekhi (2010) estimated the potential water storage service by Zagros forests in Western Iran making use of simulation models and GIS to analyse the effects of ecological factors on ES. The inflows and outflows simulation was carried out using the CN (Curve Number) method in the HEC-HMS model. The model requires inputs on land use, soil type and short-term precipitation and runoff data. An alternative, less data-intensive approach was developed by Morri et al. (2014) based on retention coefficients by type of vegetation cover, derived from Hümann et al. (2011). Multiplying areas under each land cover category by the corresponding retention coefficient it is possible to estimate the volumes of water subtracted from the surface flow and "preserved" for future water supply. We have selected this approach and indicator as their implementation requires lower efforts. The demand for this ES can be estimated through water consumption per sector (m^3/person or household per year, m^3/primary and secondary sector per year, m^3/energy sector etc.). For the economic value of the ES reference can be made to the replacement cost method by considering alternative measures that would ensure an equivalent performance level for the required ES. For example, it is possible to consider costs associated to the building of a water reservoir that could store the same volume of water that would be naturally stored by existing ecosystems.

Healthy ecosystems can maintain high water quality, through the minimization of erosion processes, the reduction of sediments, the decomposition of organic material in water bodies, and the capture or filtration of pollutants. For example, forests tend to be an effective land cover type in keeping water free from sediments (Piaggio and Siikamäki, 2021), thus reducing downstream water treatment costs. The **water purification** ES supply is measured through the pollutant retention capacity per soil category. The demand for this ES refers to the difference between the current and the desired level/concentration of pollutants in the water. The economic value of the ES is calculated through the replacement cost method, by estimating the costs of building and using alternative measures (e.g. water treatment facilities) ensuring an equivalent effectiveness in terms of water purification and quality.

With regard to the **moderation of extreme events** ES, reference has been made to flood risk mitigation. This service is closely linked to the water flow regulation and therefore the ES supply can be estimated adopting the same approach, i.e. by measuring the water-storage potential (m^3/ha) per soil type or land use category. The ES demand is measured by referring to the population living or the economic activities located in areas directly exposed to flood risks. The service can be valued in economic terms through the replacement cost method, using retention reservoirs as a substitute good to contain the same volume of water retained by the ecosystem.

The supply of the **erosion prevention** ES can be measured through the amount of soil retained or sediment captured (m^3/ha per year). The demand is measured through the quantification of soil loss by erosion (m^3/ha per year). The economic value of the service is calculated through the replacement cost method.

The maintenance of soil fertility ES, functional to agriculture production, is closely linked to the maintenance of the organic matter status and physical properties of the soil, in order to ensure an adequate nutrient supply (Young and Leeds-Harrison, 1990). Considering the complexity of this ES and considering it is linked to the soil erosion and water quality regulating ES, reference can be made to indicators and approaches suggested for the assessment of these ES.

Lifecycle maintenance refers to services that concern the conservation and proper functioning of the ecosystems including nutrient cycle, water cycle, and biophysical processes for habitat maintenance. Habitat has been defined by Hall et al. (1997) as *"the resources and conditions present in an area that produce occupancy – including survival and reproduction – by a given organism. Habitat is organism-specific; it relates the presence of a species, population, or individual (animal or plant) to an area's physical and biological characteristics. Habitat implies more than vegetation or vegetation structure; it is the sum of the specific resources that are needed by organisms"* (p. 175) and it remains a complex multidimensional concept (Kirk et al., 2018). Habitats provide everything a plant or animal needs to survive and each ecosystem provides/hosts different habitats that can be essential for a species' lifecycle. Moreover, due to their complexity, habitat and lifecycle maintenance services are difficult to describe and analyse. A study by EASME (2018) proposed as indicators for lifecycle maintenance ES provided by forests and referring to the class "Maintaining nursery populations and habitat" the following: tree species distribution, conservation investments, protected areas for nursery populations, and forest area designated for habitat-landscape protection (e.g., Natura 2000 sites). Except for the first indicator which capture partially the ES assessed, all the other indicators have a limited usability. Indicators for the same ES delivered by croplands include the share of High Nature Value farmland and traditional orchards, both largely used. Lastly, indicators for the service provided by freshwater ecosystems include the biodiversity value (species diversity or abundance, endemic or red list species and spawning location), ecological status, and morphological status.

Berghöfer and Schneider (2015) reported that habitat loss mostly occurs as a result of changes in agricultural/forest management practices, climate change, forest fires, and of the expansion of human infrastructures (land development, tourism facilities etc.). Additional factors include large-scale land use changes associated with agriculture or tree plantation expansion, river diversion and the construction of dams. Rova and Pranovi (2017) suggest that a negative trend of lifecycle maintenance service occurred in association with morphological changes. Thus, possible indicators for the quantification of the supply of lifecycle maintenance ES, with reference to structural and qualitative changes in habitats, could be the extent of native vegetation or high nature value farmland, the biodiversity index, or structural changes in habitats and other characteristics related to the ecosystem. The demand for this ES could be measured through participatory approaches able to gather the societal requests for habitat improvement or maintenance, or through expert-based approaches. The economic evaluation can be conducted based on restoration costs, estimating the costs of restoring habitats and other ecosystem characteristics.

The **biological control** service refers to the "*ecosystem ability to control pests and diseases due to genetic variations of plants and animals making them less prone to diseases and actions of predators and parasites*" (Burkhard et al., 2012). The potential supply of the biological control ES is measured in terms of populations of pest control agents. The demand for this ES refers to the number of pest and disease outbreaks. The economic value is based on the replacement costs with reference to the use of pesticides as an alternative measure against pests.

Opportunities for recreation and tourism refers to "*outdoor activities and tourism related to the local environment or landscape, including forms of sport, leisure and outdoor activities*" (Burkhard et al., 2012). The ES supply can be estimated through primary (e.g., from interviews or surveys) and/or secondary data. Possible indicators include the number of recreation and tourism facilities (e.g., hotels, restaurants, trails, parking lots etc.; n/ha) and nature and leisure time preferences (e.g., wildlife observation, hiking, fishing, etc.). The ES demand can be assessed through the number of visitors to a certain area and over a certain period (e.g., one year). The economic value of the ES can be calculated through the travel cost method. For example, the recreation service value of a river can be calculated based on the number of visitors and on the amount of money they spend to visit or navigate the river. Possible limitations of the travel cost method include the fact that it is quite demanding in terms of data collection and analysis, moreover it only allows estimating for the direct use value.

Table 7 reports a summary of the above-presented ES supply, demand, and economic value indicators and the pilot cases they are linked to. In the Annex 2 a list of indicators grouped by evaluation type is presented. In the same Annex references for data sources used for the analysis are also reported. Each supply, demand, and economic value indicator has been classified according to a specific scale defined via different colours: green refers to available indicators where harmonised and spatially-explicit data are available at local, European and global scale. Additionally, indicators reported on a green background tend to be more easily understandable by policy makers and non-experts. A yellow background indicates available harmonised indicators for which however spatially-explicit data at European and global scale is unavailable or which require the combination of different data. This is typically the case for indicators that are used to measure ecosystem conditions. Finally, a red background refers to indicators where no harmonised and explicit data are available and which requires field data collection. This category includes indicators with limited usability for ecosystem assessment due to limited conceptual understanding of how ecosystem condition can be measured.

Table 7. ES demand, supply, and economic indicators and their links with the pilot cases

ES	Supply indicators	Demand indicators	Economic indicators	Pinios River Basin 9	Nima River 11	Lower Danube River 10	Isonzo River 5
Food provisioning	Average production yield (kg/ha)	Crop product consumption (kg/person per year)	Market price per crops (€/kg per year)	x	x	x	x
Water provisioning	Fresh and/or process water availability per water use (m^3/ha per year)	Water consumption (m^3 /person per year; m^3/primary and secondary sector per year; m^3/energy sector per year)	Market price per sector: water (€/m^3 per year)	x	x	x	x
Energy source	Converted energy (kWh/m^3 per year); Produced electricity (kWh/m^3 per year)	Energy consumption (kWh/person per year; kWh/industrial sector per year)	Market price: energy (€/Kwh per year)		x	x	x
Material resource	Natural resources extracted (kg/ha per year)	Natural resources consumption (kg/industrial sector per year)	Market price: natural resources (€/kg per year)		x		
Genetic resources	Number of crop varieties and livestock breed species living in a region/surface	Number of crop varieties and livestock breed species used in a region	Restoration costs (€/ha per year)	x	x		
Climate regulation	Carbon sequestration rate per land use (tons CO_2/ha per year)	Per capita emissions	Market price: carbon credit (€/ton CO2)	x			
Water flow regulation	Water storage capacity per land use (m3/ha per year); groundwater recharge rate (m3/ha per year)	Water consumption (m^3 /person per year; m^3/primary and secondary sector per year; m^3/energy sector per year)	Replacement cost: (unit cost of alternative infrastructures, e.g. €/m^3)	x	x	x	x
Water purification	kg of pollutant retained from soil per soil type	Difference between current and desired pollutant concentration	Replacement costs (€/ton of pollutant removed)	x	x	x	
Moderation of extreme events (flood protection)	Water storage capacity per land use (m^3/ha per year); groundwater recharge rate (mm/ha per year)	Population living / economic activities situated in areas depending (directly) on ecosystem-based regulation (facing risks of flooding)	Replacement cost (unit cost of alternative infrastructures, e.g. €/m^3)	x	x	x	x
Erosion prevention	Amount of soil retained or sediment captured (m3/ha per year)	Soil loss by erosion (m3/ha per year)	Replacement costs (€/ton of soil retained)	x	x	x	
Biological control	Populations of pest control agents (n/ha)	Number of pest and disease outbreaks (n/ha per year)	Replacement costs (€/l of pesticides)		x	x	
Lifecycle maintenance	Native vegetation or high nature value farmland; biodiversity index; structural changes in habitats and other ecosystem characteristics	Societal requests of habitat improvement or maintenance or expert-based approach	Restoration costs (€/ha of habitat restored)	x	x	x	
Opportunities for recreation and tourism	Number of facilities (e.g. hotels, restaurants, hiking paths, parking lots; n/ha); results from questionnaires on nature and leisure preferences (wildlife-viewing, hiking, fishing, sports)	Number of visitors	Visitors' total expenditure (€)			x	

8. Ecosystem services assessment and evaluation: implementation of the selected indicators for the Isonzo-Soča Basin

The Isonzo- Soča is a cross-border basin between Italy and Slovenia. According to the River basin management plan for the Eastern Alps (2010) the basin covers a total area of 3 416 km^2; one third of this (about 1 150 km^2) falls within Italian territory, while the remaining area is located within Slovenian territory.

The Isonzo- Soča river originates in Val di Trenta from springs located at an altitude of 935 m on the sea level. It flows within the Slovenian territory for about 100 km the, around the area of Gorizia, it enters Italy (Friuli-Venezia Giulia) and then it heads south until it flows into the Adriatic Sea after having covered a total of 140 km (Osann et al., in press).

In the Baseline Description document (Osann et al., in press) most of the challenges presented for the Isonzo-Soča basin are linked to the development of a sustainable and integrated cross-border water resource management strategy. From an in-depth analysis of the challenges and pilot consultation, additional ES strategies have been defined with regard to the following ES services: water provisioning ES, food provisioning ES, energy provisioning ES, water flow regulation ES, and mitigation of extreme events. It is important to stress that this assessment exercise is not intended to cover all ES present within the basin, rather to focus on those ES that pilot leaders have identified and confirmed as relevant. Table 8 provides an overview of the challenges and the strategies that have been identified to address them.

Table 8. Isonzo- Soča Basin challenges and strategies

Challenges	ES related challenge /Non-ES related challenge	ES type	Non-ES strategies
Competition for water: for hydropower production upstream and for irrigation downstream.	ES and Non-ES	Food provisioning Energy source Water provisioning Water flow regulation	Management
Understand the status of the actual flood and water management plan in relation to the climate changes and provide scenarios useful to estimate the impact of climate changes in the area and respect to actual strategies (i.e., flood preventions)	Non-ES	-	Management
Find and test best solutions /best practices to guarantee the sustainability. For example, in case of flood risk reduction measure, consider the environment value inside the projects and consider also NBS approaches instead classical grey infrastructures.	Non-ES	-	Policy
Find an equilibrium between several uses of water (flood/food/energy). For example, find a balance between the flood safety and the economic development.	ES and Non-ES	Food provisioning Water provisioning Energy source Water flow regulation Moderation of extreme events	Management

Identifying the barriers to the implementation of policy actions (policy resistance mechanisms in the area (fragmentation, transboundary issues).	Non-ES	-	Governance/ Policy
Define water management strategies for policy makers through the analysis of priorities, pressures, synergies and trade-offs (particularly between energy production, irrigation and flood risk reduction).	ES and Non-ES	**Food provisioning** **Water provisioning** **Energy source** **Water flow regulation** **Moderation of extreme events**	Management / Policy
Propose transboundary water management strategies.	Non-ES	-	Governance
Provide tools to evaluate the effect of climate changes and estimate how they can affect the WEF resources in the area and the flood management.	ES and Non-ES	**Food provisioning** **Water provisioning** **Energy source** **Water flow regulation** **Moderation of extreme events**	Management
Promote NBS Approaches and other best practices in the view of sustainable development.	Non-ES	-	Policy
Provide tools for evaluating the ecosystem services to support management strategies.	Non-ES	-	Management

A socio-economic assessment of each of the ES reported in Table 8 vis-à-vis relevant challenges is presented below. Hereinafter the Italian part of the basin is referred to as Isonzo Basin, while the Slovenian one is referred to as Soča Basin.

8.1 Provisioning ecosystem services: water

Supply

The biophysical quantification of the water provisioning ES refers to the total volume of water as resulting from concession specifications or water average concession within the Isonzo- Soča Basin.
Data related to water extraction have been obtained from the Eastern Alps District Basin Authority. For the Isonzo Basin the sum of the average concession flows from surface water bodies, groundwater and springs included in the Isonzo basin have been considered. Data reported in m^3/s have been originally sourced from land registry derivations of the Region of Friuli-Venezia Giulia[12] and transformed into annual volumes (Table 8).
For the Soča Basin data on annual volumes referred to water concessions have not been found from public available sources. The Slovenian Water Management Agency has been contacted to get access to the Water Book data, however so far, no feedback was received. To overcome this limitation, the water volume extracted from various sources in 2020, as available from the Slovenian Institute of Statistics (SiStat[13]) (Table 9), have been used as a proxy of the ES supply for the Soča Basin.
The **water provisioning supply** corresponds to the sum of the water quantity extracted from different sources in both the Isonzo Basin and the Soča Basin (Table 9).

[12] https://irdat.regione.fvg.it/WebGIS/e

[13] https://pxweb.stat.si/sistat/en/Podrocja/Index/99/environment

Table 9. Water Provisioning Supply for the Isonzo- Soča Basin

Water sources	Quantity (m^3/s)	Quantity (1 000 m^3 /year)
Isonzo Basin		
Water bodies	226.70	7 149 211.20
Groundwater	10.91	344 057.76
Springs	0.18	5 676.48
Total Isonzo Basin		**7 498 945.44**
Soca Basin		
Water bodies		369
Groundwater		440
Springs		9 934
Total Soca Basin		**10 743**
Total Isonzo + Soca Basins		**7 509 688.44**

Demand

Water consumption at basin level was used as an indicator for the ES demand. For the Isonzo Basin, data reported in the Water Management Plan of the District of the Eastern Alps[14] have been used. Data refer to the water volumes from aqueducts, distinguished by final use and referred to the Optimal Territorial Areas (in Italian, *Ambiti Territoriali Ottimali*, ATO) corresponding to the two administrative provinces within the area, i.e., Udine and Gorizia provinces. Water consumption for each ATO was associated to the Isonzo Basin according to the proportion of the ATO falling within the basin itself (Table 10).

Table 10. Water consumption for Isonzo Basin (1 000 m^3 per year)

ATO	Household use	Irrigation use	Commercial use	Industrial use	Other uses	Fire vents	Drinking water self-sufficiency	Total
Udine	29 000.85	795.13	385.80	5 837.43	3 664.91	189.8	41.91	39 915.82
a. % of the ATO within the Basin: 17.5%	4 930.14	135.17	65.58	992.36	623.03	32.27	7.12	6 785.70
Gorizia	7 876.43	28.51	na	3 039.45	na	na	na	10 944.39
b. % of the ATO within the Basin (55.8%)	4 332.03	15.68	na	1 671.7	na	na	na	6 019.41
Total Isonzo Basin (a+b)	**9 262.18**	**150.85**	**65.58**	**2 664.06**	**623.03**	**32.27**	**7.12**	**12 805.10**

For the Soča Basin, data about public water demand - distinguished by households and other uses - for Goriška and Obalno-kraška areas (i.e., the two Slovenian administrative regions corresponding to the Soča Basin) as reported from the SiStat have been used (Table 11).

Table 11. Water consumption for the Soča Basin in 2020 (1 000 m^3 per year)

REGION	Households	Other uses	Supplied but uncharged	Water losses	Total
Goriška	4 938	2 466	126	3 216	10 746
Obalno-kraška	4 656	3 446	332	3 036	11 470
Total Soča Basin	**9 594**	**5 912**	**458**	**6 252**	**22 216**

Economic Value

The economic value of the water provisioning ES was estimated via the average price per m^3 of water multiplied by the above-estimated volume of water provisioning supply.

For the Isonzo Basin different prices were considered for different water uses according to the relative (i.e. %) proportion of each use over the total water use as reported by the Eastern Alps River Basin Management Plan (2009). These relative figures were used to determine flow data for each use by multiplying them by the

[14] https://distrettoalpiorientali.it/wp-content/uplods/2021/03/PPDG_2022-2027_Volume_5_ANALISI_ECONOMICA_18122020.pdf

average concession flow data. Data about water bodies and springs were added to obtain data for surface water (Table 12).

Table 12: Concession flows data per different water uses (1 000 m^3/year)

Isonzo Basin Water Source	Water use	Concession flow data (l/s)	Percentage over single water source	Concession flow data per different water uses (1 000 m^3 /year)
Surface water	Hydroelectric	89 153	73.64%	5 268 859.28
	Irrigation	30 473	25.17%	1 800 885.25
	Aquaculture	1 125	0.93%	66 540.45
	Other uses (ornamental, hygienic, industrial)	3 17	0.26%	18 602.70
			Total for surface water	7 154 887.68
Groundwater	Irrigation	4 285	54.45%	187 339.45
	Industrial	1 288	16.37%	56 322.25
	Drinking water	1 484	18.85%	64 854.88
	Hygienic	664	8.43%	29 004.06
	Aquaculture	110	1.40%	4 816.80
	Other uses	39	0.50%	1 720.28
Total for groundwater				344 057.76
Total water				**7 498 945.44**

Water prices referring to different uses for the Isonzo Basin were identified from the Eastern Alps River Basin Management Plan (2021) (Table 13). All prices were converted into values per 1 000 m^3 of water. For the hydroelectric sector it was assumed that the generation of a single MWh from reservoir technology requires between 5.39 and 68.13 m^3 (Mearac et al., 2018). Consequently, a minimum and a maximum value were used. The economic value for the water provisioning ES in the Isonzo Basin was then estimated by multiplying water provisioning supplies per different uses by their corresponding water prices. Estimated values per source (i.e., surface and groundwater) are reported in Table 14.

Table 13. Water prices for different uses for the Isonzo Basin

Water use	Unit	Unit (1 000 m^3/year)	Minimum or fixed price (€)
Irrigation	100 l/s	3 153.60	3.19
Drinking water	100 l/s	3 153.60	351.22
Industrial	3 000 000 m^3/year	3 000	2 107.38
Hydroelectric	kW (P ≤ 3000)	Minimum 0.02	19.10
		Maximum 0.20	
Other uses	100 l/s	3 153.60	114.63

Table 14. Economic value for the water provisioning ES in the Isonzo Basin

Source	Water use	Supply (1 000 m^3/ year)	Value (1 000 €)
Surface water	Irrigation	1 800 885.25	1.82
	Hydroelectric	5 268 859.28	Min 6 250 708.84
			Max 492 374.44
	Aquaculture	66 540.45	2.42
	Other uses (industrial, ornamental)	18 602.70	13.07
Groundwater	Irrigation	187 339.45	0.19
	Drinking water	64 854.88	7.22
	Industrial	56 322.25	39.55
	Hygienic	29 004.06	1.05
	Aquaculture	4 816.80	0.17
	Other uses	1 720.28	0.06
Total			Min 492 440.01- Max 6 250 774.40

For the Soča Basin an average price of 2.26 €/m^3 has been used (EurEau Report, 2020). Results are reported in Table 15.

Table 15. Economic value for the water provisioning ES in the Soča Basin

Supply (1000 m^3/ year)	Price (€/m^3)	Value (1000 €)
10 743	2.26	24 279.18

The total economic value for the water provisioning ES for the whole Isonzo-Soča Basin was obtained by summing up values estimated for the Isonzo Basin (Min 492 440.01 €; Max 6 250 774.4 €) and the Soča Basin (24 279.18 €) and ranges between 516 719.19 and 6 275 053.58 million € per year. The value for the Soča Basin is very likely underestimated due to the fact that reference has been made to the water volume actually abstracted and not to the potential concession flows.

8.2 Provisioning ecosystem services: food

Supply

The biophysical indicator for food provisioning ES corresponds to the average production yield of farmed areas within the Isonzo-Soča Basin.

For the Isonzo Basin, data on farmed areas per crop type at municipal scale have been obtained from the Agri.Stat database[15]. Municipalities included within the Isonzo Basin were selected and the corresponding percentage of municipal area falling within the Isonzo Basin were obtained from the Eastern Alps District Basin Authority's website[16] (Table 16). Data on farmed areas per crop for each municipality were then multiplied by the percentage of municipal area falling within the Isonzo Basin (Table 17). We are aware of possible limitations linked to proportional downscaling of data, however this was needed due to the lack of data at the desired scale. The municipality of Drenchia was not included because Agri.Stat database doesn't report any data for it, while data for the municipality of Tapogliano are included within data for the municipality of Campolongo Tapogliano.

Table 16. Municipal areas and population falling within the area of the Isonzo Basin

Province	Municipality	a. Total municipal area (Km^2)	b. Total population	c. % of Municipal area included within the Isonzo basin	Municipal area considered Km^2 (a x c)	Population considered (b x c)
Udine	Attimis	33.36	1 754	100	33.36	1 754
	Buttrio	17.75	3 696	100	17.75	3 696
	Campolongo al Torre	5.89	712	4	2.59	313
	Chiopris-Viscone	9.03	651	100	9.03	651
	Cividale del Friuli	50.57	11 215	100	50.57	11 215
	Corno di Rosazzo	12.54	3 193	100	12.54	3 193
	Drenchia	13.28	255	100	13.28	255
	Faedis	46.61	3 013	100	46.61	3 013
	Fiumicello	22.91	4 461	44	10.08	1 963
	Gemona del Friuli	56.26	11 316	4	2.25	453
	Grimacco	16.33	591	100	16.33	591

[15] http://dati-censimentoagricoltura.istat.it/Index.aspx#

[16] http://www.adbve.it/Documenti/isonzocom.html

Province	Municipality	a. Total municipal area (Km^2)	b. Total population	c. % of Municipal area included within the Isonzo basin	Municipal area considered Km^2 (a x c)	Population considered (b x c)
	Lusevera	52.80	781	100	52.80	781
	Manzano	30.86	7 269	100	30.86	7 269
	Moimacco	11.81	1 408	100	11.81	1 408
	Montenars	20.55	607	42	8.63	255
	Nimis	33.82	2 788	100	33.82	2 788
	Pavia di Udine	34.58	5 422	14	4.84	759
	Povoletto	38.21	5 241	100	38.21	5 241
	Pradamano	16.32	2 846	39	6.36	1 110
	Premariacco	39.72	3 784	100	39.72	3 784
	Prepotto	33.24	985	100	33.24	985
	Pulfero	48.03	1 398	100	48.03	1 398
	Reana del Rojale	20.18	4 823	48	9.69	2 315
	Remanzacco	30.60	5 051	100	30.60	5 051
	Resia	119.19	1 318	18	21.45	237
	Ruda	18.80	2 945	50	9.40	1 473
	San Giovanni al Natisone	23.92	5 629	100	23.92	5 629
	San Leonardo	27.00	1 128	100	27.00	1 128
	San Pietro al Natisone	23.98	2 173	100	23.98	2 173
	San Vito al Torre	11.58	1 288	45	5.21	580
	Savogna	22.11	786	100	22.11	786
	Stregna	19.70	538	100	19.70	538
	Taipana	65.47	777	100	65.47	777
	Tapogliano	5.01	466	95	4.76	443
	Tarcento	35.08	8 442	45	15.79	3 799
	Torreano	34.88	2 259	100	34.88	2 259
	Trivignano udinese	18.32	1 704	20	3.66	341
	Udine	56.81	99 189	13	7.39	12 895
	Total				**847.73**	**93 297**
Gorizia	Capriva del Friuli	6.22	1 574	100	6.22	1 574
	Cormons	34.58	7 553	100	34.58	7 553
	Dolegna del Collio	12.49	520	100	12.49	520
	Farra d'Isonzo	10.13	1 647	100	10.13	1 647
	Fogliano Redipuglia	7.77	2 735	68	5.28	1 860
	Gorizia	41.11	38 505	100	41.11	38 505
	Gradisca d'Isonzo	10.80	6 445	100	10.80	6 445
	Grado	115.07	9 073	55	63.29	4 990
	Mariano del Friuli	8.36	1 622	100	8.36	1 622
	Medea	7.30	839	100	7.30	839
	Moraro	3.50	734	100	3.50	734
	Mossa	6.09	1 554	100	6.09	1 554
	Romans d'Isonzo	15.37	3 387	100	15,37	3 387
	Sagrado	14.14	1 961	70	9.90	1 373
	San Canzian d'Isonzo	33.58	5 860	58	19.48	3 399
	San Floriano del Collio	10.57	835	100	10.57	835
	San Lorenzo isontino	4.36	1 372	100	4.36	1 372
	San Pier d'Isonzo	9.09	1 822	33	3.00	601
	Savogna d'Isonzo	22.11	1 767	75	16.58	1 325
	Staranzano	18.71	5 980	5	0.94	299
	Turriaco	5.28	2 163	20	1.06	433
	Villesse	11.75	1 626	100	11.75	1 626
	Total	-	-		**302.15**	**82 493**
	Total Isonzo				**1149.88**	**175 790**

Province	Municipality	a. Total municipal area (Km²)	b. Total population	c. % of Municipal area included within the Isonzo basin	Municipal area considered Km² (a x c)	Population considered (b x c)
	Basin					

Table 17. Total farmed areas (ha) per main crop types falling within the Isonzo Basin

Municipalities	Annual crops							Permanent crops		
	Cereals	Dried legumes	Potatoes	Sugar beet	Industrial crops	Vegetable	Fodder	Vineyards	Olive groves	Fruit orchards
Attimis	15.87	--	0.55	-	5.80	0.50	3.61	14.88	-	1.06
Buttrio	126.22	-	-	-	69.73	0.64	4.52	116.19	3.22	0.30
Campolongo Tapogliano	61.75	-	-	3.08	10.80	0.13	2.53	1.63	0.13	7.70
Chiopris-Viscone	4.85	-	-	-	2.83	-	4.49	19.14	-	80.07
Cividale del Friuli	112.30	-	0.60	-	27.94	5.32	72.48	258.40	6.31	6.34
Corno di Rosazzo	22.19	-	-	-	6.68	0.28	20.85	68.51	2.12	-
Faedis	42.58	-	-	-	7.70	2.99	16.44	67.69	8.08	2.86
Fiumicello	85.70	-	0.19	6.52	177.38	19.89	7.18	6.59	-	24.20
Gemona del Friuli	5.24	-	-	-	0.23	0.02	0.85	0.08	-	0.01
Grimacco	-	-	-	-	-	-	-	-	-	-
Lusevera	-	-	-	-	-	0.35	-	-	-	0.30
Manzano	80.75	-	-	-	65.51	0.52	13.95	46.67	1.82	-
Moimacco	30.59	-	-	-	36.82	0.20	6.04	1.96	-	0.20
Montenars	-	-	-	-	-	-	-	-	-	-
Nimis	13.88	-	0.10	-	-	-	4.75	89.46	1.61	0.22
Pavia di Udine	44.22	-	-	-	24.86	0.94	9.47	1.46	-	-
Povoletto	237.04	-	0.20	-	53.49	1.53	51.84	75.52	1.88	0.85
Pradamano	41.22	-	0.27	-	35.89	1.41	7.66	19.04	-	0.11
Premariacco	195.26	-	-	-	39.91	1.07	34.01	94.70	0.74	0.45
Prepotto	14.07	-	0.08	-	-	0.60	12.32	148.15	0.15	1
Pulfero	2.50	-	-	-	-	0.06	-	-	-	1
Reana del Rojale	28.73	0.04	0.40	-	20.32	1.10	4.07	0.91	-	1.15
Remanzacco	247.52	1	2.50	-	120.81	3.96	14.67	11.14	0.05	3.42
Resia	-	-	0.05	-	-	0.09	-	-	-	-
Ruda	78.19	-	0.14	-	62.66	0.75	5.49	19.42	-	5.87
San Giovanni al Natisone	148.32	20.92	-	-	89.63	-	25.63	44.71	-	-
San Leonardo	7.92	-	0.23	-	-	1.18	5.76	0.07	-	9.41
San Pietro al Natisone	15.69	-	0.30	-	-	-	2.34	0.50	-	0.30
San Vito al Torre	53.42	-	-	-	32.27	0.13	1.12	5.31	-	3.21
Savogna	-	-	-	-	-	-	-	0.03	-	2.84
Stregna	-	-	-	-	-	-	2.3	-	-	14.36
Taipana	-	-	-	-	-	0.20	-	-	-	3.05
Tarcento	23.76	-	0.01	-	1.89	0.22	8.55	5.05	0.54	3.03
Torreano	26.05	-	0.05	-	5.61	-	9.02	27.77	1.10	0.89
Trivignano Udinese	30.61	-	0.20	1.21	34.90	0.47	0.76	4.17	-	0.08
Udine	20.48	-	0.05	-	13.93	1.43	9.32	1.23	-	0.49
Capriva del Friuli	-	0.01	-	-	-	1.52	-	3.41	-	-
Cormons	51.40	-	0.30	-	35.80	7.91	46.36	449.74	1.25	1.30
Dolegna del Collio	8.57	-	-	-	2	0.26	12.38	94.29	2.63	0.80
Farra d'Isonzo	19.32	-	-	-	7.54	0.50	4.32	14.51	0.08	0.60
Fogliano Redipuglia	4.13	-	0.68	-	-	0.74	2.24	4.63	-	-

Municipalities	Annual crops							Permanent crops		
	Cereals	Dried legumes	Potatoes	Sugar beet	Industrial crops	Vegetable	Fodder	Vineyards	Olive groves	Fruit orchards
Gorizia	30.60	0.20	1.31	-	31.52	17.34	38.46	162.37	2.34	3.83
Gradisca d'Isonzo	14.51	-	-	-	2.67	1.12	14.53	39.49	0.10	0.40
Grado	260.65	-	-	3.30	370.87	28.35	79.55	11.34	0.98	9.01
Mariano del Friuli	34.11	-	-	-	25.36	-	16.69	41.38	-	-
Medea	6.11	-	-	-	2.68	0.22	0.70	1.51	-	-
Moraro	10.72	-	0.31	-	-	0.02	0.30	21.5	-	6.98
Mossa	-	-	-	-	7	-	-	19.12	1.01	-
Romans d'Isonzo	109.32	-	0.65	-	50.32	4.75	30.59	47.26	-	15.05
Sagrado	2.10	-	0.07	-	0.70	0.03	0.55	24.57	1.46	-
San Canzian d'Isonzo	55.04	-	-	18.24	77.83	1.09	55.19	14.88	-	1.61
San Floriano del Collio	1.55	-	0.25	-	2.20	0.25	-	111.81	1.70	2.42
San Lorenzo Isontino	3.53	-	-	-	3	-	1.21	16.16	0.40	6
San Pier d'Isonzo	10.62	-	0.16	-	7.26	2.31	1.57	17.21	-	1.33
Savogna d'Isonzo	3.19	-	1.01	-	-	0.71	7.32	1.267	0.65	-
Staranzano	3.95	-	-	-	2.21	0.01	0.25	0.05	0.02	0.01
Turriaco	2.42	-	-	-	1.34	0.52	0.83	1.22	-	0.75
Villesse	43.05	-	-	-	15.76	1.90	7.75	7.19	-	-

The average yield for each crop was calculated as the ratio between crop production and farmed areas per crop. Data on both production and farmed areas have been obtained from Istat[17]. Data for the main crop types were selected for years 2020, 2021 or 2022. For crop categories involving multiple crop types (e.g. cereals), weighed average yields were calculated by considering the farmed area for each crop type (Table 18).

Table 18: Average yield (100kg/ha) of main agricultural products in Isonzo Basin

	Crop category	Crop type	Farmed area (ha)	Total production (100kg)	Average yield (100kg/ha)	Weighted average yield (100kg/ha)	Reference year
Udine	Cereals	**Common wheat**	266	6 900	25.94	55.60	2021
		Barley	6 514	247 532	38		2021
		Maize	30 282	3 028 200	100		2021
		Sorghum	783	29 754	38		2021
		Other cereals	358	7 518	21		2021
	Legume	**Pea protein**	344	11 008	32		2021
		Potatoes	106	40 280	380		2021
		Sugar beet	339	248 640	733.45		2020
	Vegetable	**Artichoke**	2	180	90		2022
	Industrial crops	**Rapeseed**	1 253	34 959	27.90	29.82	2021
		Sunflower	1 685	74 140	44		2021
		Soy	24 257	509 397	21		2021
	Fodder	**Barley at waxy ripening**	1 085	259 315	239	169.22	2021
		Waxy corn	5 697	2 706 075	475		2021
		Rye	345	27 255	79		2021
		Other monophyte herbals	3 271	130 840	40		2021

[17] http://dati.istat.it/Index.aspx?QueryId=33702#

	Crop category	Crop type	Farmed area (ha)	Total production (100kg)	Average yield (100kg/ha)	Weighted average yield (100kg/ha)	Reference year
		Grass	213	23 430	110		2021
		Other, mix	511	49 056	96		2021
		Pulses	563	14 638	26		2021
		Afalfa	5 868	492 912	84		2021
		Apple	657	343 478	522.79		2021
		Pear	86	258	3		2021
		Peach	90	6 545	72.72		2021
		Apricot	9	794	88.22		2021
	Fruit trees	Cherry	14	507	36.21	133.42	2021
		Kiwi	263	19 725	75		2021
		Hazelnut	188	176	0.88		2021
		Chestnut	80	1 280	16		2021
		Nuts	94	1 696	18.04		2021
	Vineyards	Grapes for wine	11 187	1 138 334	101.75		2021
	Olive groves	Table olives and olive oil	161	640	3.97		2021
	Cereals	Barley	312	11 856	38	79.33	2021
		Maize	1 457	145 700	100		2021
	Legume	Pea protein	344	11 008	32		2021
		Potatoes	7	2 660	380		2021
		Sugar beet	13	6 190	476.15		2020
	Vegetable	*Artichoke*	1	90	90		2022
	Industrial plant	*Rapeseed*	294	8 203	27.90		2021
		Sunflower	86	37	44	27.13	2021
		Soy	2 593	54 453	21		2021
		Barley at waxy ripening	108	25 812	239		2021
		Waxy corn	971	461 225	475		2021
Gorizia	Fodder	Other monophyte herbals	448	17 920	40	194.11	2021
		Grass	32	3 520	110		2021
		Other mixtures	59	5 664	96		2021
		Pulses	38	988	26		2021
		Alfalfa	572	48 048	84		2021
		Apple	12	6 312	526		2021
		Pear	23	69	3		2021
	Fruit trees	Peach	18	1 386	77	91.63	2021
		Kiwi	8	600	75		2021
		Hazelnut	25	22	0.88		2021
	Wine trees	Grapes for wine	4 340	534 543	123.16		2021
	Olive trees	Table olives and olive oil	30	133	4.43		2021

The food provisioning ES supply for the Isonzo Basin has been then calculated, for both provinces within the basin (i.e., Udine and Gorizia provinces), by multiplying the average crop yield by the farmed area (Table 19) for each crop.

Values for the two provinces have been then summed-up (Table 20).

Table 19: Farmed areas (ha) per main crop categories within the Isonzo Basin

Province	Annual crops							Permanent crops		
	Cereals	Dried legumes	Potatoes	Sugar beet	Industrial crops	Vegetables	Fodder	Vineyards	Olive groves	Fruit orchards
Udine	2 491.90	22.17	10.69	32.36	1 593.71	115.62	682.88	2 255.38	40.45	224.91
Gorizia	674.92	0.20	4.74	21.54	646.08	68.05	320.81	1 101.55	12.70	50.11

Table 20: Food provisioning supply for the Isonzo Basin (100 kg)

	Annual crops							Permanent crops			Total production
	Cereals	Dried legumes	Potatoes	Sugar beet	Industrial crops	Vegetables	Fodder	Vineyards	Olive groves	Fruit orchards	
Udine	138 549.64	709.69	4 062.77	23 734.44	47 524.58	10 406.51	115 556.95	229 484.92	160.60	30 008.20	600 198.27
Gorizia	53 541.40	6.40	1 804.05	10 256.27	17 528.25	6 125.31	62 273.21	135 666.90	56.27	4 591.95	291 850.01
Isonzo Basin	19 091.04	716.096	5 866.82	33 990.71	65 052.84	16 531.82	17 830.16	365 151.81	216.88	34 600.10	**892 048.28**

For the Soča Basin, data on farmland per crop category as reported from the SiStat have been used. Reference has been made to 2020 data from the AdminStat database[18] for the Zahodna Slovenija region that includes Goriška and Obalno-kraška. Farmed areas per crop type for Goriška and Obalno-kraška have been estimated from the farmed area for the Zahodna Slovenija region adjusted by the relative proportion of Goriška and Obalno-kraška areas included within the whole Zahodna Slovenija region (Table 21).

Table 21. Farmed areas (ha) within the Soča Basin per main crop categories

Crops	**Zahodna Slovenija**	**Goriška**	**Obalno-kraška**
Cereals	8.54	0.29	1.10
Root crops	1.51	0.05	0.19
Industrial crops	383	13.28	49.54
Permanent grassland, including common pastures	101.13	3.50	13.08
Orchards	2.56	0.08	0.33
Vineyards	6.58	0.22	0.85
Olive groves	1.41	0.04	0.18
Total	**504.76**	**17.51**	**65.11**

Data on the average yields for the main crops referred to Goriška and Obalno-kraška areas have been collected from the SiStat[19] and converted from t/ha into 100kg/ha (Table 22). For crop categories involving multiple crop types (e.g., cereals) average yields were calculated. Yield data for each crop (or crop category) were finally multiplied by the corresponding farmed land and then summed up to compute the food provisioning supply for the whole Soča Basin (Table 23).

Table 22. Average yields for main crops farmed in the Soča Basin (100 kg/ha)

		Gorenjska (100kg/ha)	**Average**	**Obalno-kraška (100kg/ha)**	**Average**
Cereals	**Wheat and spelt**	52	124.57	38	109.28
	Barley	47		33	
	Triticale	56		41	
	Oats	30		26	
	Rye and maslin	33		40	
	Grain maize and corn-cob mix	97		65	
	Green maize	557		522	
Industrial crops	**Pumpkins for oil**	7		1	
Root crops	**Potatoes**	338		260	
Permanent grassland, including common pastures	**Grasses (including mixtures)**	89	79.20	43	41.20
	Grass - clover mixtures	75		42	
	Clover - grass mixtures	85		46	
	Clover	86		48	
	Permanent grassland, including common grassland	61		27	
	White cabbage	510		315	
Vineyards	**Grapes**	67		59	

[18] https://ugeo.urbistat.com/AdminStat/en/si/demografia/dati-sintesi/obalno-kraska-litorale-carso/6/3

[19] https://pxweb.stat.si/SiStat/en/Podrocja/Index/85/agriculture-forestry-and-fishery

Orchards	**Apples from intensive orchards**	292	292	391	243
	Peaches and nectarines from intensive orchards	-		95	
Olive grove	**Olives**	-		21	

Table 23. Food provisioning supply for the Soča Basin (100 kg)

Crop	**Goriška**	**Obalno-kraška**	**Soča Basin**
Cereals	36.92	120.78	157.71
Root crops	17.74	50.88	68.62
Industrial crops	93.02	49.54	142.57
Permanent grassland, including common pastures	277.92	539.06	816.99
Orchards	26.01	80.72	106.74
Vineyards	15.31	50.29	65.60
Olive grove		3.84	3.84
Total	466.95	895.15	**1 362.10**

The total food provisioning supply for the whole Basin was finally calculated as the sum of the food provisioning supply for the Isonzo Basin and the Soča Basin, corresponding to 893 410.38 kilograms.

Demand

The food provisioning demand has been estimated via food consumption data at basin scale. For the Isonzo Basin, data on the total number of households in Udine and Gorizia have been retrieved from Istat[20] and refer to the census year 2011. Data have been scaled down to the Isonzo Basin by adjusting them via the proportion of the two provinces included in the Isonzo Basin, i.e., 17.5% for the Province of Udine and 55.8% for the province of Gorizia (Table 24).
Data on the average household monthly expenditure for selected food products have been collected from Istat[21]. The total expenditure for the Isonzo Basin has been calculated by multiplying the average monthly expenditure by number of households. The quantity of products consumed in the Isonzo Basin has been estimated by dividing the expenditure for each crop/product category by the corresponding price for the Isonzo products (Table 25). For this aim, product wholesale prices have been retrieved from the Chambre of Commerce of Pordenone and Udine (as of October 2021).

Table 24. Households in the Isonzo Basin

Area	**Total households**	**Households within the Isonzo Basin**
Udine	152 780	25 972.60
Gorizia	39 718	21 844.90
Isonzo Basin	192 498	47 817.50

Table 25. Food Provisioning Demand in Isonzo Basin

Crops and products	**National monthly expenditure (€)**	**Total Isonzo Basin expenditure (€)**	**Wholesale price (€/kg)**	**Monthly consume (kg)**	**Annual consume (kg)**
Cereals	76.08	3 637 955.40	0,25	14 551 821.6	174 621 859.20
Olive oil	9.96	476 262.30	4.50	105 836.06	1 270 032.72
Other edible oils	1.95	93 244.12	5.82	16 021.32	192 255.84
Fruits	42.69	2 041 329.07	2.23	915 394.20	10 984 730.40
Vegetables	63.85	3 053 147.37	7.69	397 028.26	4 764 339.12
Potatoes	4.25	203 224.37	0.60	338 707.29	4 064 487.48
Other tubers	0.86	41 123.05	1.04	39 541.39	474 496.68
Wine	14.02	670 401.35	1.30	515 693.34	6 188 320.08

[20] http://dati-censimentopopolazione.istat.it/Index.aspx?DataSetCode=DICA_NUCLEI#

[21] http://dati.istat.it/Index.aspx?QueryId=17912

For the Soča Basin, data reported from Slovenian Institute of Statistics (SiStat)[22] have been used. The data refer to the average consumption of products by Slovenian resident in 2020. It is interesting to report that the consumption data are influenced by self-sufficiency (Table 26).

Table 26. Annual food consumption in Slovenia

	Production	Domestic use	Self-sufficiency rate	Consumption per capita
		1000 t	%	kg/cap.
Cereals	749.20	848	88	116.30
Vegetables	137.20	283.30	48	118.90
Potato	89.10	149.60	60	63.70
Fruit	112.90	312.20	36	128.90

From AdminStat database[23] data on Goriška and Obalno-kraška population have been retrieved in order to obtain the total annual food consumption in Soča Basin expressed in tones of product (Table 27).

Table 27. Food provisioning demand in Soča Basin

	Consumption per capita (kg)	Consumption in Soča Basin (t)
Cereals	116.30	16 933.16
Vegetables	118.90	17 311.72
Potato	63.70	9 274.65
Fruit	128.90	18 767.71

Economic Value

The economic value of the food provisioning ES has been estimated based on the average price per different crops/products. For the Isonzo Basin data from wholesale price already used to assess the Food Provisioning Demand have been used (Table 28). For the Soča Basin Selina Wamucii data[24] on Slovenia wholesale product price for 2019 have been used (Table 29). Isonzo olive oil and sugar beet price data were missing in Commerce Chambre list therefore Selina Wamucii data were used instead the price data were converted in quintal values in order to homogenized and calculate the Food Provisioning Value.

Table 28. Wholesale price for Isonzo Basin

Agricultural products	Price (€/kg)	Price (€/100 kg)
Cereals	0.25	25
Vegetable products (legume, sugar beet)	1.25	125
Industrial crops	5.82	582
Fodder	0.28	28
Vegetable	7.69	769
Potatoes	4.25	425
Sugar beet	1.65	165
Fruits	2.23	223
Wine	1.30	130
Olive	4.50	450

Table 29. Wholesale price for Soča Basin

Agricultural products	Price (€/kg)	Price (€/100 kg)
Cereals	0.17	17
Potatoes	0.37	37
Industrial crops	0.88	88

[22] https://www.stat.si/StatWeb/en/News/Index/9954#:~:text=In%202020%2C%20a%20resident%20of,kg%20of%20honey%20for%20food.&text=Self%2Dsufficiency%20rates%20in%20plant,in%202020%20than%20in%202019

[23] https://ugeo.urbistat.com/AdminStat/en/si/demografia/dati-sintesi/obalno-kraska-litorale-carso/6/3

[24] https://www.selinawamucii.com/insights/prices/slovenia/

Agricultural products	Price (€/kg)	Price (€/100 kg)
Fodder	1.84	184
Fruits	0.37	37
Wine	1.42	142
Olive	6.68	668

The economic value for the food provisioning ES for each sub-basin was calculated by multiplying the estimated supply for each crop/product by the corresponding price (Tables 30 and 31). Estimated values for the Isonzo Basin and the Soča Basin were then summed-up totaling 124 013 695.47 euros.

Table 30. Food Provisioning Value for Isonzo Basin

	Cereals	Dried legumes	Potatoes	Sugar beet	Industrial crops	Vegetables	Fodder	Vineyards	Olive groves	Fruit orchards	Total
Supply (100 kg)	192 091.04	716.09	5 866.82	33 990.71	65 052.84	16 531.82	177 830.16	365 151.81	216.88	34 600.10	
Price (€/100 kg)	25	125	425	165	582	769	28	130	450	223	
Value (€)	4 802 276	89 511.25	2 493 398.5	5 608 467.15	37 860 752.88	12 712 969.58	4 979 244.48	47 469 735.3	97 596	7 715 822.3	**123 829 773.44**

Table 31. Food Provisioning Value for Soča Basin

Crop	Soča Basin	Price (€/100 kg)	Value (€)
Cereals	157.71	17	2 681.07
Root crops	68.62	37	2 538.94
Industrial crops	142.57	88	12 546.16
Fodder	816.99	184	150 326.16
Fruits	106.74	37	3 949.38
Wine	65.60	142	9 315.2
Olive	3.84	668	2 565.12
Total			**183 922.03**

8.3 Provisioning ecosystem services: energy

Supply

The biophysical indicator for the energy provisioning ES referrers to the installed capacity of the hydropower plants presented in the Isonzo-Soča Basin. Data have been obtained from the Eastern Alps District Basin Authority and are presented in Table 32.

Table 32: Energy provisioning ES supply: hydropower plants within the Isonzo-Soča Basin (MW)

Hydropower plant	Type	Country	Electricity production (GWh)	Installed capacity (MW)
Canale Dottori cluster of 5 small flowing plants (Fogliano, Redipuglia, Ronchi dei Legionari, Monfalcone Antonetta, Monfalcone Porteo)	Small Hydroelectric	Italy	11	2.36
Total Isonzo Basin			11	**2.36**
Solkan Hydroelectric Power Plant	Hydroelectric	Slovenia	105	32
Pumped-storage hydropower plant Avče on Soča	Hydroelectric	Slovenia	426	185
Doblar I Hydroelectric Power Plant	Hydroelectric	Slovenia	150	30
Doblar II Hydroelectric Power Plant	Hydroelectric	Slovenia	199	40
Plave I Hydroelectric Power Plant	Hydroelectric	Slovenia	80	15
Plave II Hydroelectric Power Plant	Hydroelectric	Slovenia	115	20
Various small plants into the Slovenian part of the Isonzo Basin (Gradisce on Vipava river, Moznica on Koritnica river, Tolmin on Tolminka River, Podemelec on Baca river, Marof on Idrijca River, Trebusa on Trevusica river, Mesto oin idrijca River, Marzla Rupa on Idrjica River, hubelj on Hubelij River, Ajba on Isonzo River)	Small Hydroelectric	Slovenia	20.4	5.61

Total Soča Basins	1 095.4	**327.61**
Total		**2 095.98**

The total **energy provisioning supply** is calculated as the sum of the energy capacity installed in the Isonzo and Soča Basins and corresponds to 2 095.98 MW.

Demand

The demand for energy provisioning has been estimated with reference to the annual energy consumption. For the Isonzo Basin, data reported in the Friuli-Venezia Giulia Region Yearbook "Region in figures 2021[25]" have been used. Data are expressed in millions of KWh, divided by sectors and provinces and refer to 2019. Data were scaled to the Isonzo Basin by assuming they correspond to the percentage of Gorizia (55.8%) and Udine (17.5%) included within the Isonzo Basin. Consumption data have been broken-down into different sectors (Table 33).

Table 33. Isonzo Basin energy consumption (2019)

Energy consumption per sector and province (Millions of kWh)			**Data for the Isonzo Basin (Millions of kWh)**		
Sector	**Total Udine province**	**Total Gorizia province**	**a. Proportion of Udine province within the Isonzo Basin (17.5%)**	**b. Proportion of Gorizia province within the Isonzo Basin (55.8%)**	**Total Isonzo Basin (a + b)**
Agriculture	62.5	20.3	10.92	11.31	22.23
Industry	3 007.1	277.0	665.38	154.65	820.03
Manufacturing activities	3 651.2	255.2	638.13	142.47	780.60
Steel industry	2 022.4	5.0	353.46	2.79	356.25
Food	145.6	21.0	25.44	11.71	37.15
Textiles, clothing and leather	16.6	5.4	2.91	3.02	5.92
Wood and furniture	504.8	14.2	88.23	7.90	96.13
Paper making	227.2	39.7	39.70	22.17	61.87
Ceramics, glassware	50.0	8.5	8.74	4.75	13.49
Chemistry	168.1	4.3	29.38	2.40	31.78
Plastic	127.9	22.0	22.35	12.31	34.66
Metal products	145.8	50.7	25.48	28.33	53.81
Electrical and electronic	119.4	16.3	20.87	9.11	29.98
Transport	30.9	53.4	5.40	29.83	35.23
Construction	20.6	3.9	3.60	2.20	5.80
Extraction of materials from quarries and mines	8.6	1.1	1.50	0.62	2.12
Water, sewerage, waste and sanitation	65.6	13.9	11.47	7.78	19.25
Electricity, gas, steam and air conditioner	61.1	2.8	10.68	1.58	12.26
Service sector	1 062.5	238.1	185.70	132.95	318.65
Trade	237.2	50.9	41.45	28.40	69.85
Transportation	182.9	6.9	31.97	3.83	35.80
Public administration and defence	60.2	15.3	10.52	8.57	19.09
Healthcare	45.9	31.0	8.03	17.30	25.32
Public lighting	57.7	12.6	10.08	7.02	17.10
Education	23.9	10.9	4.18	6.07	10.25
Hotels, restaurants and bars	134.9	34.8	23.57	19.41	42.99
Information and communication	32.9	8.2	5.76	4.57	10.33
Finance and insurance	22.9	5.5	3.99	3.10	7.09
Scientific and technical professional activities	103.8	14.8	18.14	8.28	26.42
Other services	122.9	25.8	21.48	14.42	35.91
Domestic	622.7	148.5	108.83	82.93	191.77
Total	**3 402.6**	**1 418**	**2 437.34**	**791.78**	**3 229.13**

For the Soča Basin, data on energy consumption from the SiStat[26] have been used. Data are expressed in GWh, divided by sector, and refer to the entire Slovenia. To scale down them to the Soča Basin, a simple

[25] https://www.regione.fvg.it/rafvg/cms/RAFVG/GEN/statistica/FOGLIA74/

[26] https://pxweb.stat.si/SiStat/en/Podrocja/Index/186/energy

proportion between the entire Slovenian territory and the Soča Basin area was made and energy consumption figures have been adjusted accordingly: this corresponds to considering demand for the the Soča Basin as equal to 11.4% of the total for Slovenia.

Energy consumption data for Slovenia and in detail for the Soča Basin, divided per sector, are presented in Table 34.

Table 34. Slovenia and Soča Basin energy consumption (2020)

Energy consumption (GWh) per sector on yearly basis	Total Slovenia	Soča Basin
Final consumption-Total	13 046.90	1 483.10
Final consumption-Energy sector	95.75	10.88
Final consumption-Manufacturing and construction	5 973.40	679.02
Final consumption-Transport	209.78	23.84
Final consumption-Households	3 634.11	413.10
Final consumption-Agriculture and forestry	18.38	2.08
Final consumption-Other consumers	3 115.47	354.15
Total Consumption	**26 093.81**	**2 966.20**

Economic Value

The economic value of the energy provisioning ES has been computed based on the average energy price per kWh. For the Isonzo Basin, reference has been made to the 2022 average national price for a household with 3000 kW of power engaged as from ARERA[27] statistics. This corresponds to 0.46 euro/kWh. For the Soča Basin, SiStat[28] data for national level prices were used. Since 2022 data are not yet available, the average 2021 price for household was used, i.e. 0.16 euro/kWh. The total economic value of the energy provisioning ES was then computed by multiplying energy provisioning supply times the unit prices for both sub-basins, and then summing-up the two values. Results are shown in Table 35.

Table 35. Energy provisioning ES economic value for the Isonzo-Soča Basin

	Capacity (MW)	Capacity (kW)	Capacity (kWh)	Energy Provisioning Value (€)
Isonzo Basin	1 768 364	1 768 364 000	1 768 364 000	813 447 440
Soča Basin	327 612	327 612 000	327 612 000	52 417 920
Total				**865 865 360**

8.4 Regulating ecosystem services: moderation of extreme events

Supply

The ES moderation of extreme events has been analysed in terms of flood risk reduction using the InVEST 3.9.0 flood risk mitigation model with the aim to assess the retained runoff volume compared to a given precipitation regime. The model calculates the runoff depth and runoff depth reduction from rainfall depth using the Curve Number method (USDA, 1986). Table 36 below summarizes the input data for the model.

Table 36. Input data for the flood risk mitigation InVEST model

Input data	Description	Data source
Land cover map	Raster file of land cover (CLC2018) for each pixel (100 m resolution); 44 classes in the hierarchical 3-level CLC nomenclature; minimum mapping unit (MMU) for status layers is 25 hectares; minimum width of linear elements is 100 meters.	CLC2018 - Copernicus https://land.copernicus.eu/pan-european/corine-land-cover/clc2018?tab=download

[27] https://www.arera.it/it/dati/eep35.htm

[28] https://pxweb.stat.si/SiStat/en/Podrocja/Index/186/energy

Biophysical table	csv file reporting CN values for each land use class (i.e. each of the 44 CLC2018 classes). CN values have been retrieved from USDA (1986) taking into consideration the correspondence to CLC classes as defined by ARPAS (2019)	USDA (1986). Urban Hydrology for Small Watersheds. TR-55. United States Department of Agriculture. Online: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf (Last access: 6th April 2022) ARPAS (2019). Carta del Curve Number Regionale. Agenzia Regionale per la Protezione dell'Ambiente della Sardegna – ARPAS. Online: http://www.sardegnageoportale.it/documenti/40_615_20190329081206.pdf (Last access: 18th February 2022)
Depth of rainfall (mm)	Three values, i.e., minimum (30 mm, return time = 2 years), intermediate (64 mm, return time = 10 years) and maximum (95 mm, return time = 50 years) for 1 hour precipitation	https://www.meteo.fvg.it/clima/clima_fvg/schede/
Soils Hydrological Group Raster	Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modeling (250 m resolution**)**	Ross, C.W., L. Prihodko, J.Y. Anchang, S.S. Kumar, W. Ji, and N.P. Hanan. 2018. Global Hydrologic Soil Groups (HYSOGs250m) for Curve Number-Based Runoff Modeling. ORNL DAAC, Oak Ridge, Tennessee, USA. https://doi.org/10.3334/ORNLDAAC/1566

Figure 14 reports model outputs under the form of maps of the retained runoff volume (m^3), the runoff retention index (i.e., the runoff retention volume relative to the total precipitation volume) and the runoff (mm) for the whole basin and with reference to different precipitation scenarios. The total runoff retention volume corresponds to 93.21, 152.99 and 185.63 million m^3 respectively for rainfall heights of 30 mm, 64 mm and 95 mm.

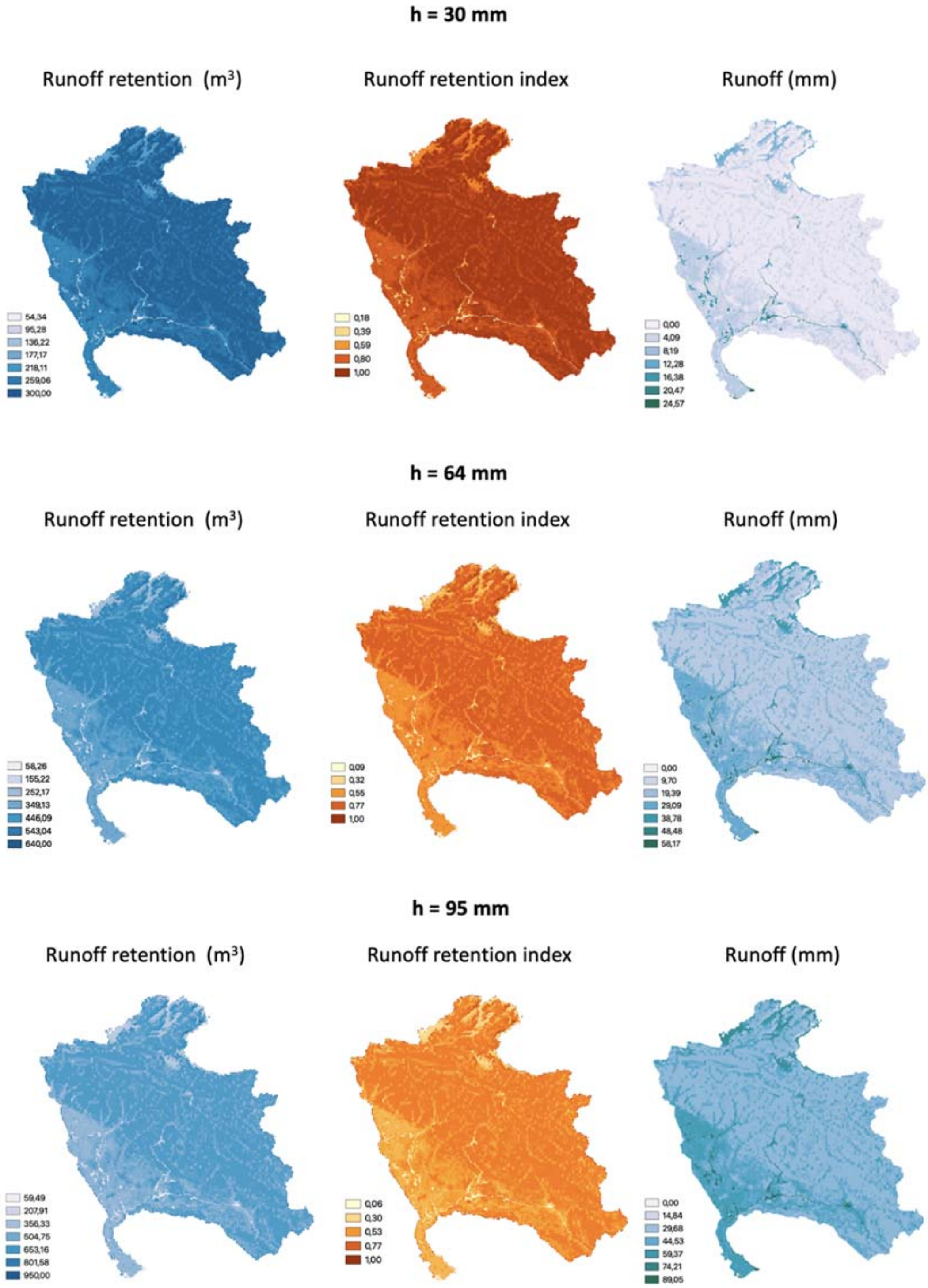

Figure 14. Runoff retention, runoff retention index and runoff for the whole basin under two different precipitation scenarios

Demand

The demand for the moderation of extreme events ES has been estimated via the resident population in the Isonzo-Soča Basin assuming all residents perceive utility from this ES and are therefore interested in demanding for it. The sixty municipalities included within the Isonzo Basin were selected and data on the resident population were obtained from the Eastern Alps District Basin Authority's website[29]. Population data for Goriška and Obalno-kraška regions were obtained from AdminStat[30]. A summary of results is presented in Table 37.

Table 37. Population of Isonzo Basin

Area	Population (units)
Udine	93 299
Gorizia	82 493
Isonzo Basin	**175 792**
Goriška	31 638
Obalno-kraška	113 961
Soča Basin	**145 599**
Total	**321 391**

Economic Value

The economic value of the moderation of extreme events ES was obtained through the replacement cost method, using lamination basins as a substitute good aimed at retaining the same volume of water retained by the ecosystems. A unit cost of 400 €/m^3 was assumed based on the Regional Law of 23rd November 2017, n. 7 of Lombardy Region (art. 16) and adjusted based on Masiero et al. (2021 and 2022).

The economic value of the ES was therefore calculated by multiplying the above reported unit cost by the volume of retained runoff according to each precipitation intensity value. This ultimately corresponds to 37.3, 61.2 and 74.2 billion € respectively for rainfall heights of 30 mm, 64 mm and 95 mm. As highlighted in the next sub-section, this value embodies also the value of other ES, in particular the water flow regulation one.

8.5 Regulating ecosystem services: water flow regulation

For the aims of this study, water flow regulation has been assessed starting from the moderation of extreme events. By adopting a simplified water balance, it has been assumed that water available either as groundwater (i.e., via water table recharge) or as water yield (i.e., via water body recharge) corresponds to the amount of retained runoff per precipitation event diminished by the fraction of the water that undergoes evapotranspiration.

Given the above-described general approach, the value of the water flow regulation ES is already embodied within the moderation of extreme events, of which it represents a sub-set. It is important to underline this, to avoid double-accounting issues and overestimation of the ES.

Supply

[29] http://www.adbve.it/Documenti/isonzocom.html

[30] https://ugeo.urbistat.com/AdminStat/en/si/demografia/dati-sintesi/obalno-kraska-litorale-carso/6/3

Starting from the outputs of the InVEST model reported for the moderation of extreme events, retained runoff volumes have been converted from m^3 to mm by multiplying the runoff retention index by the corresponding rainfall height (i.e., 30 mm, 64 mm or 95 mm). This has been done using the raster calculator tool available in QGIS. Retained runoff values have then been diminished by the baseline evapotranspiration values provided by Task 3.5 with reference to the Isonzo-Soča Basin. As a result, retained water volumes net of evapotranspiration have been obtained (Table 38).

Table 38. Retained water volumes net of evapotranspiration per different rainfall height values and their relative incidence on total retained runoff volumed

Rainfall height (mm)	Retained water volumes net of evapotranspiration (groundwater + water yield) (Million mm)	% of retained runoff volume
30	8.54	91.59%
64	14.51	94.88%
95	17.78	95.78%

Demand

The demand for this ES corresponds to the demand computed for the moderation of extreme events ES.

Economic Value

The value of the water flow regulation ES has been calculated as a proportion of the total value of the moderation of extreme events ES. Such a proportion correspond to the ratio between the retained water volumes net of evapotranspiration and the total retained runoff volume (i.e., to the percentage figures reported in the last column of Table 38). As a result, the economic value has been estimated equal to 34.1, 58.1 and 71.1 billion euros respectively for rainfall heights of 30 mm, 64 mm and 95 mm.

8.6 Summary of results

Hereafter the evaluation results for the Isonzo-Soča Basin are summarized. Table 39 reports the results related to the provisioning ES, while Table 40 reports the results for the regulating ES.

Table 39: Provisioning ES in Isonzo-Soča Basin

Provisioning Services			
	Isonzo Basin	**Soča Basin**	**Isonzo-Soča Basin**
Water provisioning supply (1 000 m^3/year)	7 498 945.443	10 743	7 509 688.44
Water provisioning demand (1 000 m^3/year)	12 805.10	22 216	35 021.10
Water provisioning value (1000 €)	Min 492 440.01- Max 6 250 774.40	24 279.18	Min 516 719.19 - Max 6 275 053.58
Food provisioning supply (100 kg)	892 048.28	1 362.10	893 410.38
Food provisioning demand (100 kg)	2 025 605,21	622 872.4	202 622 808.7
Food provisioning value (€)	123 829 773.44	183 922.03	124 013 695.47
Energy provisioning supply (GWh)	1 768 364	327 612	2 095 976
Energy provisioning demand (GWh)	3 229.13	2 966.20	6 195.33
Energy provisioning value (€)	813 447 440	52 417 920	865 865 360

Table 40: Regulating ES in Isonzo Soča Basin

Regulating Services			
	Rainfall height (mm)		
	30	64	95
Moderation of extreme events supply (million m^3)	93.21	152.99	185.63
Moderation of extreme events demand (residents)	321 391		
Moderation of extreme events value (billion €)	37.3	61.2	74.2
Water flow regulation supply (million mm)	8.54	14.51	17.78
Water flow regulation demand (residents)	321 391		
Water flow regulation value (billion €)	34.1	58.1	71.1

When comparing ES demand and supply, different situations can be observed. For instance, the demand for food provisioning exceeds food provisioning supply at the basin scale. This is the case also when single crop products are considered. On the contrary, the supply of the energy provisioning ES exceeds the demand within the Isonzo-Soča basin. In a similar manner, the potential water provisioning supply fully meets the water provisioning demand. The apparent gap between supply levels reported for the two sub-basins is due to the fact that, due data gaps, for the Soča basin we had to refer to actual water extraction data rather than potential water extraction figures. This explains why when considering just the Soča basin demand for this ES exceeds supply, while when considering the whole Isonzo-Soča basin supply exceeds demand. As a consequence, the exceedance of water supply could be managed in order to support other ES, such as hydropower production or irrigation water, depending on future needs and scenarios.

As for the economic value, the highest value among provisioning ES is reported for water provisioning, followed by energy and food provisioning. Regulating ES, however, show economic values of a much higher magnitude.

9. Nature Based Solutions associated to the NEXUS-Ecosystem Services

This chapter aims to provide some preliminary guidance to identify the most effective NBS for the provision of one or more ES among those selected and analysed for the purposes of this report. This is functional to activities developed by Task 5.2 of the Rexus project.

9.1 Nature Based Solutions conceptualisation

The NBS concept was introduced by the World Bank in 2008 (World Bank, 2008), and its definition was further detailed by the IUCN as "*actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human wellbeing and biodiversity benefits*" (Cohen-Shacham, 2016).

In recent years, the term NBS has been increasingly used and promoted as a key tool to solve various environmental and societal problems, but the concept remains non univocally defined and a bit ambiguous, therefore its practical applications remain a bit unclear too. Such ambiguity depends, among other issues, on the fact that the concept emerged from the integration of multiple scientific fields and there was a delay in the definition of clear standards for NBS (Sowińska-Świerkosz and García, 2021).

The concept of NBS can be linked to a number of concepts that are shortly presented below to support further reflections addressed within this chapter. A first concept refers to green infrastructures defined as an interconnected network of multifunctional green spaces that are strategically planned and managed to provide a range of ecological, social, and economic benefits (Tzoulas et al., 2007). A second concept is Ecosystem-based Adaptation (EbA), officially defined by the Convention on Biological Diversity (2009) as *“the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change".* The EbA measures include a variety of interventions to address adaptation challenges such as high temperatures, changing rainfall and extreme weather patterns, higher risk for certain natural disasters, erosion, and others. A third concept is Natural Water Retention Measures (NWRM) described on the official webpage of the Direction General Environment of the European Union as a support to *"Green Infrastructure by contributing to integrated goals dealing with nature and biodiversity conservation and restoration, landscaping"*. As reported in the European NWRM platform, NWRM are multifunctional measures that generate multiple benefits and aim to protect water resources and address water-related challenges by restoring or maintaining ecosystems as well as natural features and characteristics of water bodies using natural means and processes. The main goal of NWRM is to enhance the retention capacity of aquifers, soil, aquatic and water dependent ecosystems with the aim to improve their status.

Sowińska-Świerkosz and García (2021) have revised existing literature to shed light on the NBC concept, definition and core features. By reviewing 970 papers they extracted a total of 20 NBS definitions. They found that the NBS concept refers to interventions comprising four core ideas, i.e. NBS:

- are inspired and powered by nature,
- address (societal) challenges or resolve problem,
- provide multiple services/benefits, including biodiversity gain, and
- are of high effectiveness and economic efficiency.

The first core idea behind the NBS concept is "the use of nature". For this reason, the NBS have also been defined as green interventions (van der Jagt et al., 2017) or as actions using green or blue infrastructure (Albert et al., 2019). The second core aspect is that NBS address urgent and generally global challenges. Dumitru and Wendling (2021) presented 12 categories of societal challenges that can be addressed by NBS. IUCN (2020) defined seven societal challenges: climate change adaptation and mitigation, disaster risk reduction, ecosystem degradation and biodiversity loss, human health, socio-economic development, food security, and water security. NBS should contribute to address at least one of these challenges. Climate challenges are currently the most discussed within the NBS literature, as climate changes can alter ecosystems and affect the provision of services by them (Science for Environment Policy, 2021). The third core idea is the production of benefits that simultaneously concern the environment and society, including economic issues through creating green jobs and business opportunities, and reducing water and energy costs. The last core is the NBS effectiveness and economic efficiency which includes four dimensions. The first among these four dimensions underlines that effective NBS governance and management models should allow the participation of different actors. The second dimension identifies effective solutions as those which are adapted locally to meet local environmental, social, and political conditions and needs. The third dimension, i.e. economic efficiency, implies that the costs for the implementation, management, monitoring, and maintenance of a NBS over a certain period of time should not exceed the potential benefits. The effectiveness of NBS shall also be considered under different conditions, e.g. vis-à-vis changing climate conditions according to different future scenarios, such as those developed under Task 3.5 of the Rexus project. Finally, the fourth dimension indicates that a solution is effective if it is capable to produce social, environmental, and economic services.

9.2. Association between Nature Based Solutions and ecosystem services

To operationalise the ES analysis presented in this deliverable, and to orient the NBS selection, the relation between ES and NBS was investigated. Indeed, since NBS have an impact on the provision of ES the link between NBS types and potential ES they deliver been shortly analysed. This investigation shall be regarded as a preliminary assessment aiming to support NBS selection by pilots according to the challenges they face. The analysis of the NBS-ES link is specifically targeted by Task 5.2 of the Rexus project.

Existing technical reports and other scientific and grey literature on NBS have been reviewed to identify effective solutions to address the ES selected for this study. Existing literature mostly associates NBS types with societal challenges rather than with ES they deliver (EEA, 2021; Iseman and Miralles-Wilhelm, 2021; Miralles-Wilhelm, 2021; UnaLab, 2019; Sonneveld and Merbis, 2018; Swiderska et al., 2018; Raymond et al., 2017; Cohen-Shacham et al., 2016), although some studies report explicit connections between challenges and ES (Croci and Lucchitta, 2021; Somarakis et al., 2020; Strosser et al., 2015). For instance, Croci and Lucchitta (2021) developed a list of urban NBS associated with the ES they provide. The focus on urban NBS, however, is beyond the scope of Rexus project, moreover the relationship between NBS and ES is not made explicit and described in detail, therefore it is not possible to apply this study to our assessment. We decided to focus on available grey literature. In particular, the Nature-based Solutions Handbook developed by ThinkNature (Somarakis et al., 2020) associates different NBS categories with the corresponding ES. With reference to water provisioning and water flow regulation ES, which underpins the WEF Nexus, the other guide identified is the Practical Guide by NWRM (Strosser et al., 2015) which includes a catalogue of measures. NWRM cover a wide range of actions and land use types. Many different measures can act as NWRM, by encouraging the retention of water within a catchment and, through that, enhancing the natural functioning of the catchment. The NBS catalogue is organised by different sectors (agriculture, forest, hydromorphology, and urban). For each NBS the following information are provided: (i) the benefit(s) produced, including a summary scheme that associates benefit levels (high, medium, low, none) to potential

biophysical effects selected among slowing and storing or reducing runoff, reducing pollution, soil conservation, creating habitat and climate alteration, and (ii) the ES delivered with reference to the corresponding ES category (i.e., provisioning, regulation and maintenance, cultural ES).
For each ES selected for this study, NBS types that may favour them have been selected from the Think Nature (Annex 5) and the NWRM catalogue (Annex 6). Building on the NWRM catalogue which expresses the level of impact of different NBS on ES delivery, the NBS-ES link has been rated, according to the following levels:

- 5 = high level of benefits/impacts in terms of ES delivery
- 3 = intermediate level of benefits/impacts in terms of ES delivery
- 1 = low level of benefits/impacts in terms of ES delivery
- 0 = no benefits/impacts in terms of ES delivery.

This allowed assigning a score to each NBS that highlights and summarizes the effectiveness in delivering the selected ES, thus providing a preliminary screening of NBS potentially associated to the challenges identified by the pilot cases. A more in-depth investigation and analysis of the link and connections between NBS and ES within the framework of the WEF Nexus can be found in the deliverable 5.2 of the Rexus project (Restrepo et al., 2022).

10. Conclusions

The WEF Nexus approach has been proposed to address the linkages between different water uses. Ecosystems and ecosystem-based approaches are key to the Nexus as they represent the biophysical foundations of the multiple connections between water, energy, and food. Therefore, starting from the need to promote an increasing adoption of WEF Nexus-based strategies that consider ecosystems and their services, this report identified and analysed socio-economic indicators to describe the Nexus in terms of socio-economic benefits associated to ES delivery.

Different ES classification systems have been comparatively analysed to identify which ES can play an important role in addressing the challenges related to the WEF Nexus and presented by the pilot cases. The challenges were validated and integrated by the pilots and by stakeholders involved in project's activities. Moreover, building on existing literature and studies, an ES assessment framework has been developed as a reference for our analysis. The framework consists of a cascade model representing the interconnection between environmental resources and mankind, linking together the Es supply, demand and value. The production of goods and services by the ecosystems depends on ecosystem functions and contribute to the ES supply. The request of benefits from nature involves human communities and makes up the ES demand. The monetary value attached to the ES provided by nature quantifies the utility perceived by beneficiaries of ES.

Indicators have been collected and developed to assess the supply, demand and value of ES associated to the WEF Nexus. Biophysical indicators were selected to measure the potential ES supply by ecosystems; demand indicators were used to measure the potential benefits consumed or desired by the human society; economic indicators were used to evaluate the ES in monetary terms. A list of selected indicators was elaborated, including an overview of key input data and data sources. A selection of these indicators was tested with regard to the Isonzo-Soča pilot case. The ES evaluated for the test include: water provisioning, food provisioning, energy provisioning, water flow regulation, and natural hazard protection.

Finally, a preliminary analysis of the most appropriate NBS to address pilots' challenges related to climate resilience and ES provision were collected and reviewed. The link between NBS and ES has been expressed via a rating scale assigning a score to each NBS mirroring its effectiveness in delivering the selected ES.

Despite our efforts, this report has some limitations. The most important one consists on the fact that our analyses were limited to ES linked to the challenges reported by the pilots. As a consequence, we did not address the full spectrum of potential ES and therefore there is still room to develop further research activities. A second limitation refers to accuracy of the ES assessment for Isonzo-Soca pilot that was strongly affected by data availability, in particular for the Slovenian sub-basin. We preferred to implement user-friendly approaches and indicators, in order to favor their adoption, extension and up-scaling by pilots, including by non-experts. This may imply some trade-offs in terms of assessment capacity. We are aware that there may be other indicators and tools available and pilots are encouraged to consider them for their future analysis.

Future research development might specifically be targeted at:

- improving the set of ES within the scope of the analysis;

- specifically analysing ES synergies and trade-offs to better inform future management solutions, including NBS selection;

- expanding value assessment beyond monetary values, by including, for instance, stakeholders' preferences.

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Zhao, B., U. Kreuter, B. Li, Z. Ma, J. Chen, and N. Nakagoshi. 2004. An ecosystem service value assessment of land-use change on Chongming Island, China. Land Use Policy 21:139-148.

Annexes

Annex 1: Pilot's challenges and related strategies

Pilot Case	Challenges	Type of challenge (Ecosystem Services (ES) related challenge/ Non-Ecosystem Services (Non-ES) related challenge)	ES type	Non-ES strategies
Lower Danube	Two major hazards: flooding and riverbank erosion	ES	Erosion prevention Moderation of extreme events (flood protection) Water flow regulation	-
	Poor ecological river status	ES	Lifecycle maintenance Water purification Biological control	-
	Agricultural associations are requesting larger quotas of water needed for irrigation.	ES and Non-ES	Food provisioning Water provisioning Water flow regulation	Choice consumption/ Managemen
	Water for hydropower energy production	ES and Non-ES	Energy source Water provisioning Water flow regulation	Choice consumption
	Satisfy the needs of all the competitive water users: energy sector with hydropower plants, agricultural sector and navigation	ES and Non-ES	Water provisioning Water flow regulation Opportunities for recreation and tourism Energy source Food provisioning	Consumption choice
	Exploitation for navigation	ES and Non-ES	Opportunities for recreation and tourism	Policy
	Shift from traditional grey solutions for flood protection to more green ones (NBS)	ES and Non-ES	Moderation of extreme events (flood protection)	Management/ Policy
	Increased periods with very low water level due to climate change	ES and Non-ES	Climate regulation Water flow regulation	Management

Pilot Case	Challenges	Type of challenge (Ecosystem Services (ES) related challenge/ Non-Ecosystem Services (Non-ES) related challenge)	ES type	Non-ES strategies
Isonzo/Soča River	Competition for water: for hydropower production upstream and for irrigation downstream.	ES and Non-ES	Food provisioning Energy source Water provisioning Water flow regulation	Management
	Understand the status of the actual flood and water management plan in relation to the climate changes and provide scenarios useful to estimate the impact of climate changes in the area and respect to actual strategies (i.e. Flood preventions etc.).	Non-ES	-	Management
	Find and test best solutions /best practices to guarantee the sustainability. For example, in case of flood risk reduction measure, consider the environment value inside the projects and consider also NBS approaches instead classical grey infrastructures.	ES	-	Policy
	Find an equilibrium between several uses of water (flood/food/energy). For example find a balance between the flood safety and the economic development;	ES and Non-ES	Food provisioning Water provisioning Energy source Water flow regulation Moderation of extreme events (flood protection)	Management
	Identifying the barriers to the implementation of policy actions (policy resistance mechanisms in the area (fragmentation, transboundary issues).	Non-ES	-	Governance/ Policy
	Define water management strategies for policy makers through the analysis of priorities, pressures, synergies and trade-offs (particularly between energy production, irrigation and flood risk reduction).	ES and Non-ES	Food provisioning Water provisioning Energy source Water flow regulation Moderation of extreme events (flood protection)	Management / Policy
	Propose transboundary water management strategies.	Non-ES	-	Governance
	Provide tools to evaluate the effect of climate changes and estimate how they can affect the WEF resources in the area and the flood management.	ES and Non-ES	Food provisioning Water provisioning Energy source Water flow regulation Moderation of extreme events (flood protection)	Management
	Promote NBS Approaches and other best practices in the view of sustainable development.	Non-ES	-	Policy
	Provide tools for evaluating the ecosystem services to support management strategies.	Non-ES	-	Management

Pilot Case	Challenges	Type of challenge (Ecosystem Services (ES) related challenge/ Non-Ecosystem Services (Non-ES) related challenge)	ES type	Non-ES strategies
Nima River Watershed	The need of stop the extension of the agricultural and livestock frontier at the Paramo area	Non-ES	-	Policy
	The community recognized an inadequate solid residues management that pollute water bodies	ES	**Water purification** **Biological control** **Lifecycle maintenance**	-
	Replace chemical by organic inputs to fertilize and pests' control and preserve natural resources in the watershed	ES	**Biological control** **Genetic resources** **Lifecycle maintenance**	-
	The need of regulation of material extraction from the Nima river, because the border has been modified increasing the risk of river overflow	Non-ES	-	Management
	Regulation in sugar cane burning as locals live near the plantations	Non-ES	-	Policy/ Management
	The sugar cane cropping system is intensive and uses supplemental irrigation during the dry season. There is a need to increase water use	ES and Non-ES	Water provision **Water flow regulation**	Policy
	The watershed requires more conservation, restoration, and sustainable use to balance hydrological, biophysical, and socioeconomic asymmetries that need to be addressed to maximize the water-related benefits provided by this watershed.	ES and Non-ES	**Erosion prevention** **Water flow regulation** **Lifecycle maintenance** **Water purification** **Water provisioning** **Moderation of extreme events (flood protection)**	Policy/ Management
	There is a need to explore other crop systems and agricultural management alternatives to reduce the environmental impacts of agriculture in this watershed.	ES and Non-ES	**Food provisioning** **Genetic resources** **Lifecycle maintenance**	Management
	Efficiently use water sourced by upstream areas.	Non-ES	-	Choice consumption and Policy
	One of the main goals is to secure future water supply for the human population and ensure water availability for agriculture and industry	ES and Non-ES	**Water provisioning** **Water flow regulation**	Choice consumption/ Management
	Trees plantations for paper production consume water at the upstream areas	Non-ES		Policy/ Management

Pilot Case	Challenges	Related Problems	Type of challenge (Ecosystem Services (ES) related challenge/ Non-Ecosystem Services (Non-ES) related challenge)	ES type	Non-ES strategies
Pinios River Basin	Maintain sufficient water quantity and quality	1. Over-exploitation of water resources and high water deficit, 2. open and old irrigation water networks and low efficiency irrigation systems, 3. Lack of adequate and reliable measurements regarding crop water needs and water consumption in the agricultural sector, 4. Irrational use of agricultural inputs (fertilizers, pesticides etc.), 5. Insufficient control of point and non-point pollution (mainly nitrates), 6.Irrational management and operation of local irrigation water management authorities, 7.Irrational management of pesticides and fertilizers packaging as a source of pollution	ES/ Non-ES	Water provisioning Water flow regulation Water purification Biological control Lifecycle maintenance	Management
	Satisfy the needs of all the competitive water users		Non-ES	-	Choice consumption
	Maintain the environmental flow for ecosystems		ES	Lifecycle maintenance Genetic resources	-
	Adapt to the decreased water availability indicated by the CC scenarios		ES	Climate regulation Genetic resources Water flow regulation Lifecycle maintenance	-
	Deal with climate extremes (floods but mainly with droughts)		ES	Erosion prevention Water flow regulation Moderation of extreme events (flood protection)	-
	Maintaining or increasing energy production through renewable resources to decrease emissions	High installation cost of Renewable Energy Sources, in particular of photovoltaics, improper strategic planning of Renewable Energy Sources / large amount of applications for licensing, defining areas of Renewable Energy Sources development, upgrade public energy system infrastructure, fair licensing process for RES development	Non-ES	-	Policy/ Management
	Satisfy the energy needs of several uses (agricultural, industrial, domestic, etc.)		Non-ES	-	Choice consumption
	Increasing water demand is connected to increasing energy demand		Non-ES	-	Choice consumption/ Policy
	Hydroelectric energy production is directly connected to water availability		ES	Water provisioning	-
	Climate change can potentially increase water demand, thus energy demand		ES	Climate regulation Water provisioning	-
	The ultimate challenge is to maintain the agricultural production of the most productive basin in Greece	Fragmented and small agricultural holdings, agricultural land abandonment, desertidication, Agricultural production costs are increasing substantially,farmers' training on sustainable agricultural practices is not sufficient	ES/ Non-ES	Food provisioning Lifecycle maintenance	Policy
	Agricultural production is related to irrigated agriculture and thus to water availability		ES	Water provisioning	-
	Photovoltaic parks are substituting agricultural land, thus decreasing food production		Non-ES	-	Policy
	Agriculture is vulnerable to climate change, and consequently, food production		ES	Climate regulation	-
	Riparian habitats and forests conservation		ES/ Non-ES	Lifecycle maintenance	Management
	Ensuring safety hydro stocks		ES/ Non-ES	Water provisioning Water flow regulation	Management/Policy
	Agricultural "greening" via CAP & other policies		Non-ES	-	Policy

Pilot Case	Challenges	Type of challenge (Ecosystem Services (ES) related challenge/ Non-Ecosystem Services (Non-ES) related challenge)	ES type	Non-ES strategies
Peninsular Spain & Jucar River Basin	At political level (policies & implementation)	Non-ES	-	Policy
	At scale level: transferability between regions and river basins (e.g. inter-basin water transfers)	Non-ES	-	Governance
	Adaptability to climate change (vulnerability of agriculture-production).	Non-ES	-	Governance
	Adaptability to reduced availability of water resources due to climate change scenarios (droughts).	Non-ES	-	Governance
	Accounting for the water and energy footprint.	Non-ES	-	Governance
	High groundwater extraction in the last decades. Water accounting	Non-ES	-	Governance
	To meet the demands for all uses (quality and quantity).	Non-ES	-	Governance
	Achieve good status of all water bodies (This includes the fulfillment of ecological objectives, pollution reduction, etc.).	Non-ES	-	Governance
	Achieve more resilient systems.	Non-ES	-	Governance

Annex 2: Socio-economic indicators for Rexus pilots

ES	Supply indicators	Demand indicators	Economic indicators	Pinios River Basin	Nima River Watershed	Lower Danube River	Isonzo River
Food provisioning	Average production yield (kg/ha)	Crop product consumption (kg/person per year)	Market price per crops (€/kg per year)	x	x	x	x
Water provisioning	Fresh and/or process water availability per water use (m^3/ha per year)	Water consumption (m^3 /person per year; m^3/primary and secondary sector per year; m^3/energy sector per year)	Market price per sector: water (€/m^3 per year)	x	x	x	x
Energy source	Converted energy (kWh/m^3 per year); Produced electricity (kWh/m^3 per year)	Energy consumption (kWh/person per year; kWh/industrial sector per year)	Market price: energy (€/Kwh per year)		x	x	x
Material resource	Natural resources extracted (kg/ha per year)	Natural resources consumption (kg/industrial sector per year)	Market price: natural resources (€/kg per year)		x		
Genetic resources	Number of crop varieties and livestock breed species living in a region/surface	Number of crop varieties and livestock breed species used in a region	Restoration costs (€/ha per year)	x	x		
Climate regulation	Carbon sequestration rate per land use (tons CO2/ha per year)	Per capita emissions	Market price: carbon credit (€/ton CO2)	x			
Water flow regulation	Water storage capacity per land use (m3/ha per year); groundwater recharge rate (m3/ha per year)	Water consumption (m^3 /person per year; m^3/primary and secondary sector per year; m^3/energy sector per year)	Replacement costs: (€/m3 of costruction material)	x	x	x	x
Water purification	kg of pollutant retained from soil per soil type	Difference between current and desired pollutant concentration	Replacement costs (€/ton of pollutant removed)	x	x	x	
Moderation of extreme events (flood protection)	Water storage capacity per land use (m3/ha per year); groundwater recharge rate (mm/ha per year)	Population living / economic activities situated in areas depending (directly) on ecosystem-based regulation (facing risks of flooding)	Replacement costs (€/m3 of costruction material)	x	x	x	x
Erosion prevention	Amount of soil retained or sediment captured (m3/ha per year)	Soil loss by erosion (m3/ha per year)	Replacement costs (€/ton of soil retained)	x	x	x	
Biological control	Populations of pest control agents (n/ha)	Number of pest and disease outbreaks (n/ha per year)	Replacement costs (€/l of pesticides)		x	x	
Lifecycle maintenance	Native vegetation or high nature value farmland; biodiversity index; structural changes in habitats and othere ecosystem characteristics	Societal requests of habitat improvement or maintenance or expert based approach	Restoration costs (€/ha of habitat restored)	x	x	x	
Opportunities for recreation and tourism	Number of facilities (e.g. hotels, restaurants, hiking paths, parking lots; n/ha); results from questionnaires on nature and leisure preferences (wildlife-viewing, hiking, fishing, sports)	Number of visitors	Visitors' total expenditure (€)			x	

Annex 3: Supply indicators

Extent of data (data sources)	Quantification method	Extent Study Area	Source	More info/details and original sources
Local Local Local Local		Local Local Local Local		Turner, K. G., M. V. Odgaard, P. K. Bøcher, T. Dalgaard, Svenning, J.-,., 2014. Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. Landscape and Urban Planning 125:89-104
Local Local Local Local		Local Local Local Local		Lautenbach, S., C. Kugel, A. Lausch, and Seppelt, R., 2011. Analysis of historic changes in regional ecosystem service provisioning using land use data. Ecological indicators 11:676-687
				van Oudenhoven, A. P. E., K. Petz, R. Alkemade, L. Hein, and de Groot R.S., 2012. Framework for systematic indicator selection to assess effects of land management on ecosystem services. Ecological indicators 21:110-122
				Pinto, R., V. N. de Jonge, and J. C. Marques. 2014. Linking biodiversity indicators, ecosystem functioning, provision of services and human well-being in estuarine systems: Application of a conceptual framework. Ecological indicators 36:644-655
National	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	O'Farrell, P. J., W. J. De Lange, D. C. Le Maitre, B. Reyers, J. N. Blignaut, S. J. Milton, D. Atkinson, B. Egoh, A. Maherry, C. Colvin, and R. M. Cowling. 2011. The possibilities and pitfalls presented by a pragmatic approach to ecosystem service valuation in an arid biodiversity hotspot. Journal of Arid Environments 75:612-623

Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Shi, N., J. Zhan, F. Wu, and J. Du. 2009. Identification of the core ecosystem services and their spatial heterogeneity in Poyang Lake area. Frontiers of Earth Science in China 3:214-220.
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	The net present value of agricul tural crop production in an area depends on crop type, soil productiv ity, irrigation, crop prices, and pro duction costs. The net present value of timber production depends on the mix of tree species, soil productivity, forestry rotation time, timber price, and harvest cost.
Local	Proxy	Local		Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4-11
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Reyers, B., P. J. O'Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society 14:38.

Local Local	Proxy	Local Global	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Production statistics and prices for each commodity typically grown under each land use type in the study area were derived from the Australian Bureau of Statistics (2007) Agricultural Commodities data. Crossman, N. D., J. D. Connor, B. A. Bryan, D. M. Summers, and J. Ginnivan. 2010. Reconfiguring an irrigation landscape to improve provision of ecosystem services. Ecological Economics 69:1031-1042.
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Eigenbrod, F., P. R. Armsworth, B. J. Anderson, A. Heinemeyer, S. Gillings, D. B. Roy, C. D. Thomas, and K. J. Gaston. 2010. Error propagation associated with benefits transfer-based mapping of ecosystem services. Biological Conservation 143:2487-2493
Local Local Local	Proxy	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Maps at the landscape scale were obtained by extrapolating data collected in 57 plots representing 8 different land-uses. Ecosystem services were identified on the basis of interviews with local farmers on their need and uses of grasslands. For them a good meadow for mowing or grazing (i.e. fodder production services) is the result of quality and quantity of grasses that corresponds to a combination of different ecosystem functions: grass quantity, quality and flowering phenology. Those functions are translated by researchers into measurable indicators such as annual green biomass production to evaluate grass quantity Lamarque, P., F. Quétier, and S. Lavorel. 2011. The diversity of the

Local		Local		ecosystem services concept and its implications for their assessment and management. Comptes Rendus Biologies 334:441-449.
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Helian, L., W. Shilong, J. Guanglei, and Z. Ling. 2011. Changes in land use and ecosystem service values in Jinan, China. Energy Procedia 5:1109-1115
Global Local	Model	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	PI is composed by a series of soil (wetness, drainage, effective depth, texture and structure, alkalinity, soluble-salt concentration, organic matter, cation-exchange capacity, mineral reserves, soil erodability) and climate factors affecting primary productivity. Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67
National	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Function of cultivated land area, family and hired labor, fertilizer, pesticide use, on-farm fallow and off-farm/upstream fallow (survey gathered farm production, land use, and demographic data; data on forest cover). Klemick, H. 2011. Shifting cultivation, forest fallow, and externalities in ecosystem services: Evidence from the Eastern Amazon. Journal of Environmental Economics and Management 61:95-106

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Map showing sustainable livestock carrying capacity (hectares per large stock unit). Egoh, B. N., B. Reyers, J. Carwardine, M. Bode, P. J. O'Farrell, K. A. Wilson, H. P. Possingham, M. Rouget, W. De Lange, D. M. Richardson, and R. M. Cowling. 2010. Safeguarding Biodiversity and Ecosystem Services in the Little Karoo, South Africa. Conservation Biology 24:1021-1030.
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Lautenbach, S., C. Kugel, A. Lausch, and R. Seppelt. 2011. Analysis of historic changes in regional ecosystem service provisioning using land use data. Ecological Indicators 11:676-687
Global	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Jaarsveld, A. S., R. Biggs, R. J. Scholes, E. Bohensky, B. Reyers, T. Lynam, C. Musvoto, and C. Fabricius. 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. Philosophical Transactions of the Royal Society B: Biological Sciences 360:425-441
National National	Primary	National National	Egoh, B. N., Drakou, E., Dunbar,	Chen, N., H. Li, and L. Wang. 2009. A GIS-based approach for mapping

National		National	M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	direct use value of ecosystem services at a county scale: Management implications. Ecological Economics 68:2768-2776.
National National	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Data on climate, primary production of forage species. Chan, K. M. A., M. R. Shaw, D. R. Cameron, E. C. Underwood, and G. C. Daily. 2006. Conservation Planning for Ecosystem Services. PLoS Biology 4:e379
National	Primary	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	van Wilgen, B. W., B. Reyers, D. C. Le Maitre, D. M. Richardson, and L. Schonegevel. 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. Journal of Environmental Management 89:336-349
Continental	Proxy	Continental	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Metzger, M. J., M. D. A. Rounsevell, L. Acosta-Michlik, R. Leemans, and D. Schroter. 2006. The vulnerability of ecosystem services to land use change. Agriculture, Ecosystems & Environment 114:69-85

National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Troy, A. and M. A. Wilson. 2006. Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. Ecological Economics 60:435-449
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Sandhu, H.S., Wratten, S.D., Cullen, R., and Case, B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics 64:835-848
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Sandhu, H.S., Wratten, S.D., Cullen, R., and Case, B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics 64:835-848
National	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and	Model of net primary productivity of landuse is set up by combining ecological characteristics of landuse with energy balance, water balance and the model of regional evapotranspiration.

National		Local	(JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Li, J. and Z.-y. Ren. 2008. Changes in Ecosystem Service Values on the Loess Plateau in Northern Shaanxi Province, China. Agricultural Sciences in China 7:606-614
Global Global	Proxy	Global Global	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Naidoo, R., A. Balmford, R. Costanza, B. Fisher, R. E. Green, B. Lehner, T. R. Malcolm, and T. H. Ricketts. 2008. Global mapping of ecosystem services and conservation priorities. Proceedings of the National Academy of Sciences 105:9495-9500
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Zhang, F., J. Qi, F. M. Li, C. S. Li, and C. B. Li. 2010. Quantifying nitrous oxide emissions from Chinese grasslands with a process-based model. Biogeosciences 7:2039-2050
Local Local Local Local	Model	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	The net present value of agricul tural crop production in an area depends on crop type, soil productiv ity, irrigation, crop prices, and pro duction costs. The net present value of timber production depends on the mix of tree species, soil productivity, forestry rotation time, timber price, and harvest cost. Posthumus, H., J. R. Rouquette, J. Morris, D. J. G. Gowing, and T. M. Hess. 2010. A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics 69:1510-1523

National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences 107:5242-5247
Continental	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vihervaara, P., T. Kumpula, A. Tanskanen, and B. Burkhard. 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity 7:410-420
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	O'Farrell, P. J., W. J. De Lange, D. C. Le Maitre, B. Reyers, J. N. Blignaut, S. J. Milton, D. Atkinson, B. Egoh, A. Maherry, C. Colvin, and R. M. Cowling. 2011. The possibilities and pitfalls presented by a pragmatic approach to ecosystem service valuation in an arid biodiversity hotspot. Journal of Arid Environments 75:612-623

			Derak, M. and J. Cortina. 2014. Multi-criteria participative evaluation of Pinus halepensis plantations in a semiarid area of southeast Spain. Ecological indicators 43:56-68	
Local Local Local (FAOSTAT)	Model Invest	Local Local Local	UNEP-WCMC 2011. Developing ecosystem service indicators: Experiences and lessons learned from sub-global assessments and other initiatives. Secretariat of the Convention on Biological Diversity, Montréal, Canada. Technical Series No. 58	Tallis, H.T., Ricketts, T., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Lonsdorf, E., Kennedy, C. (2010). InVEST 1.005 beta User's Guide. The Natural Capital Project, Stanford
Local	Model	Local		Zhao, B., U. Kreuter, B. Li, Z. Ma, J. Chen, and N. Nakagoshi. 2004. An ecosystem service value assessment of land-use change on Chongming Island, China. Land Use Policy 21:139-148
Local	Model	Local		Núñez, D., L. Nahuelhual, and C. Oyarzún. 2006. Forests and water: The value of native temperate forests in supplying water for human consumption. Ecological Economics 58:606-616
Local	Model	Local		Bryan, B. A. and N. D. Crossman. 2013. Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. Ecosystem Services 4:60-72
Local	Model	Local		Baral, H., R. J. Keenan, S. K. Sharma, N. E. Stork, and S. Kasel. 2014. Economic evaluation of ecosystem goods and services under different landscape management scenarios. Land Use Policy 39:54-64

Local	Model	Local		Boerema, A., J. Schoelynck, K. Bal, D. Vrebos, S. Jacobs, J. Staes, and P. Meire. 2014. Economic valuation of ecosystem services, a case study for aquatic vegetation removal in the Nete catchment (Belgium). Ecosystem Services 7:46-56
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	O'Farrell, P. J., W. J. De Lange, D. C. Le Maitre, B. Reyers, J. N. Blignaut, S. J. Milton, D. Atkinson, B. Egoh, A. Maherry, C. Colvin, and R. M. Cowling. 2011. The possibilities and pitfalls presented by a pragmatic approach to ecosystem service valuation in an arid biodiversity hotspot. Journal of Arid Environments 75:612-623
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B. N., B. Reyers, M. Rouget, and D. M. Richardson. 2011. Identifying priority areas for ecosystem service management in South African grasslands. Journal of Environmental Management 92:1642-1650
	InVEST	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Estimation of the annual average quantity and identification of the annual water yield contribution from each part of the landscape. This calculation is used in conjunction with data on mean annual precipitation, annual reference evapotranspiration, and correction factors for vegetation type, soil depth, and plant-available water content Bai, Y., C. Zhuang, Z. Ouyang, H. Zheng, and B. Jiang. 2011. Spatial characteristics between biodiversity and ecosystem services in a human-dominated watershed. Ecological Complexity 8:177-183

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Brenner, J., J. A. Jiménez, R. Sardá, and A. Garola. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53:27-38
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Shi, N., J. Zhan, F. Wu, and J. Du. 2009. Identification of the core ecosystem services and their spatial heterogeneity in Poyang Lake area. Frontiers of Earth Science in China 3:214-220
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Crossman, N. D., J. D. Connor, B. A. Bryan, D. M. Summers, and J. Ginnivan. 2010. Reconfiguring an irrigation landscape to improve provision of ecosystem services. Ecological Economics 69:1031-1042
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No.	Separated the total streamflow in baseflow (sum of groundwater flow and saturated superficial flow) and quickflow (total streamflow minus baseflow). Computed runoff coefficients by dividing both total streamflow volume and quickflow by precipitation (Qt/P and Qq/P, respectively). Assess the effect of different forest cover types.

Local		Local	EUR 25456 EN). Joint Research Centre	Lara, A., C. Little, R. Urrutia, J. McPhee, C. Álvarez-Garretón, C. Oyarzún, D. Soto, P. Donoso, L. Nahuelhual, M. Pino, and I. Arismendi. 2009. Assessment of ecosystem services as an opportunity for the conservation and management of native forests in Chile. Forest Ecology and Management 258:415-424
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Helian, L., Shilong, W., Guanglei, J., and Ling, Z. 2011. Changes in land use and ecosystem service values in Jinan, China. Energy Procedia 5:1109-1115
Local	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B., B. Reyers, M. Rouget, M. Bode, and D. M. Richardson. 2009. Spatial congruence between biodiversity and ecosystem services in South Africa. Biological Conservation 142:553-562

Local	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	van Jaarsveld, A. S., R. Biggs, R. J. Scholes, E. Bohensky, B. Reyers, T. Lynam, C. Musvoto, and C. Fabricius. 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SAfMA) experience. Philosophical Transactions of the Royal Society B: Biological Sciences 360:425-441
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Maps of the extent of invasive alien species infestations in each biome to estimate impacts on surface water runoff (map of land cover of each species was used to estimate the impacts in terms of reductions in surface water runoff). Chosed vegetation types with a high likelihood of groundwater dependence. Assumed that invasive alien plants would reduce groundwater recharge by 20% of the mean annual runoff in the area van Wilgen, B. W., B. Reyers, D. C. Le Maitre, D. M. Richardson, and L. Schonegevel. 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. Journal of Environmental Management 89:336-349
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Chan, K. M. A., M. R. Shaw, D. R. Cameron, E. C. Underwood, and G. C. Daily. 2006. Conservation Planning for Ecosystem Services. PLoS Biology 4:e379

National	Proxy	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Data on the percentage contribution of groundwater to base flows per quaternary catchment were extracted from DWAF (2005) and used to map water flow regulation Li, J. and Z.-y. Ren. 2008. Changes in Ecosystem Service Values on the Loess Plateau in Northern Shaanxi Province, China. Agricultural Sciences in China 7:606-614
Global	Proxy	Global	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Map of water provision based on the global hydrological model WaterGAP, which provides spatially explicit estimates of water availability and water use for various economic sectors.Naidoo, R., A. Balmford, R. Costanza, B. Fisher, R. E. Green, B. Lehner, T. R. Malcolm, and T. H. Ricketts. 2008. Global mapping of ecosystem services and conservation priorities. Proceedings of the National Academy of Sciences 105:9495-9500
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le Maitre, and A. S. van Jaarsveld. 2008. Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment 127:135-140

National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Drinking water pumping license (m3/yr) Willemen, L., P. H. Verburg, L. Hein, and M. E. F. Van Mensvoort. 2008. Spatial characterization of landscape functions. Landscape and Urban Planning 88:34-43
Continental	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vihervaara, P., T. Kumpula, A. Tanskanen, and B. Burkhard. 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity 7:410-420
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Drinking water function is described by the amount of water extracted by drinking water companies per year. In the study area, all drinking water is extracted from protected groundwater extraction zones. Annual extraction volumes are used to quantify the function. Willemen, L., L. Hein, and P. H. Verburg. 2010b. Evaluating the impact of regional development policies on future landscape services. Ecological Economics 69:2244-2254
	InVEST Water Yield mode	Local	Cong, W., Sun, X., Guo, H., Shan, R., 2020. Comparison of the SWAT and InVEST models to determine hydrological ecosystem service spatial patterns, priorities and trade-offs in a complex	The model is based on land use and average annual rainfall data, and adopts the Budyko curve approach to estimate the annual average amount of water runoff based on pixels and then calculates the water yield in the whole watershed through summation

			basin. Ecological Indicator 112, 106089	
	hydrological SWAT model	Local	Cong, W., Sun, X., Guo, H., Shan, R., 2020. Comparison of the SWAT and InVEST models to determine hydrological ecosystem service spatial patterns, priorities and trade-offs in a complex basin. Ecological Indicator 112,	
		Local, regional	Burkhard, B., Kandziora, M., Hou, Y. and Müller, F., 2014. Ecosystem service potentials, flows and demands-concepts for	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Local Local (data power stations)	Model	Local Local		Kroll, F., F. Müller, D. Haase, and N. Fohrer. 2012. Rural–urban gradient analysis of ecosystem services supply and demand dynamics. Land Use Policy 29:521-535
Local Local Local	Invest Model	Local Local Local	UNEP-WCMC 2011. Developing ecosystem service indicators: Experiences and lessons learned from sub-global assessments and other initiatives. Secretariat of the Convention on Biological Diversity, Montréal, Canada. Technical Series No. 58	Tallis, H.T., Ricketts, T., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., Vigerstol, K., Pennington, D., Mendoza, G., Aukema, J., Foster, J., Forrest, J., Cameron, D., Lonsdorf, E., Kennedy, C. (2010). InVEST 1.005 beta User’s Guide. The Natural Capital Project, Stanford
Local Local	ArcGIS SWAT model	Local Local		Notter, B., H. Hurni, U. Wiesmann, and J. O. Ngana. 2013. Evaluating watershed service availability under future management and

Local		Local		climate change scenarios in the Pangani Basin. Physics and Chemistry of the Earth, Parts A/B/C 61–62:1-11.
Local		Local	Burkhard, B., Kandziora, M., Hou, Y. and Müller, F., 2014. Ecosystem service potentials, flows and demands-concepts for spatial	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
		Local, regional		
				Kandziora, M., B. Burkhard, and F. Müller. 2013. Interactions of ecosystem properties, ecosystem integrity and ecosystem service indicators—A theoretical matrix exercise. Ecological indicators 28:54-78
				Rodríguez, L. C., U. Pascual, and H. M. Niemeyer. 2006. Local identification and valuation of ecosystem goods and services from Opuntia scrublands of Ayacucho, Peru. Ecological Economics 57:30-44
Local, regional		Local, regional		Berghöfer A, Schneider A, 2015. Indicators for Ma naging Ecosystem Services – Options & Examples. ValuES Project Report. Helmholtz Zentrum für Umweltforschung (UFZ) GmbH, Leipzig, and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, Germany
Local, regional		Local, regional		Björklund, J., K. E. Limburg, and T. Rydberg. 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. Ecological Economics 29:269-291

Continental	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vihervaara, P., T. Kumpula, A. Tanskanen, and B. Burkhard. 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity 7:410-420
Local Local Local Local	NPP Model	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Forest inventory data, soil inventory data, vegetation distribution map, satellite image, soil distribution map Deng, S., Y. Shi, Y. Jin, and L. Wang. 2011. A GIS-based approach for quantifying and mapping carbon sink and stock values of forest ecosystem: A case study. Energy Procedia
Local Local Global National	Proxy	Local Local Global Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Land cover map; Spatial dataset: Elevation and slope, Protected area outlines, Road and rail networks, Settlements, Soils Swetnam, R. D., B. Fisher, B. P. Mbilinyi, P. K. T. Munishi, S. Willcock, T. Ricketts, S. Mwakalila, A. Balmford, N. D. Burgess, A. R. Marshall, and S. L. Lewis. 2010. Mapping socio-economic scenarios of land cover change: A GIS method to enable ecosystem service modelling. Journal of Environmental Management In Press, Corrected Proof.

Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Bastian, O., D. Haase, and K. Grunewald. 2011. Ecosystem properties, potentials and services – The EPPS conceptual framework and an urban application example. Ecological Indicators
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Bastian, O., D. Haase, and K. Grunewald. 2011. Ecosystem properties, potentials and services – The EPPS conceptual framework and an urban application example. Ecological Indicators
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Crossman, N. D., B. A. Bryan, and D. King. 2011. Contribution of site assessment toward prioritising investment in natural capital. Environmental Modelling and Software 26:30-37

Global	Terrestrial Ecosystem Model	Global	TEEB, 2010. Chapter 3: Measuring biophysical quantities and the use of indicators *In: TEEB. Ecological and Economic Foundations* (P. Kumar, dir.). New York, Routledge, 1-39	The model simulates carbon exchange between the atmosphere and terrestrial biosphere on the basis of vegetation types, soils, climate, atmospheric CO_2, and land use history
Global	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B. N., B. Reyers, M. Rouget, and D. M. Richardson. 2011. Identifying priority areas for ecosystem service management in South African grasslands. Journal of Environmental Management 92:1642-1650
	Proxy	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Maps of land use and land cover types; data on stocks in four carbon pools (above-ground biomass, below-ground bio- mass, soil, and dead organic matter) Bai, Y., C. Zhuang, Z. Ouyang, H. Zheng, and B. Jiang. 2011. Spatial characteristics between biodiversity and ecosystem services in a human-dominated watershed. Ecological Complexity 8:177-183

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Cartography for land use/land cover types, vegetation communities and habitats datas present in the area Brenner, J., J. A. Jiménez, R. Sardá, and A. Garola. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53:27-38.
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Escobedo, F. J., T. Kroeger, and J. E. Wagner. Urban forests and pollution mitigation: Analyzing ecosystem services and disservices. Environmental Pollution 159:2078-2087
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	variables identified ecosystem services and they are disaggregated spatially onto the 1 km_1 km grids using the ArcGIS software Shi, N., J. Zhan, F. Wu, and J. Du. 2009. Identification of the core ecosystem services and their spatial heterogeneity in Poyang Lake area. Frontiers of Earth Science in China 3:214-220

Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Gascoigne, W. R., D. Hoag, L. Koontz, B. A. Tangen, T. L. Shaffer, and R. A. Gleason. 2011. Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole Region of the Dakotas, USA. Ecological Economics 70:1715-1725
Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Gascoigne, W. R., D. Hoag, L. Koontz, B. A. Tangen, T. L. Shaffer, and R. A. Gleason. 2011. Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole Region of the Dakotas, USA. Ecological Economics 70:1715-1725
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Land cover map and habitat type data (quantification: tons of carbon stored per hectare per habitat type) Reyers, B., P. J. O'Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society 14:38

Local Local Local Local Local	InVest	Local Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Estimated above- and belowground biomass and soil carbon pools as a function of the area's distribution of present and historic LU/LC and biomass age. estimated how much timber was removed from the area in previous time periods to determine the carbon that remained stored in HWP. The amount of carbon sequestered in an area across a particular time period is determined by subtracting the carbon stored in the area at the beginning of the time period from that stored in the area at the end of the time period. Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4-11
Local	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Spatially explicit version of 3-PG tree productivity simulations (spatial soil and climate input layers and stand management variables) Crossman, N. D., J. D. Connor, B. A. Bryan, D. M. Summers, and J. Ginnivan. 2010. Reconfiguring an irrigation landscape to improve provision of ecosystem services. Ecological Economics 69:1031-1042
National National	Proxy	National National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Land cover type, extensive field data Eigenbrod, F., P. R. Armsworth, B. J. Anderson, A. Heinemeyer, S. Gillings, D. B. Roy, C. D. Thomas, and K. J. Gaston. 2010. Error propagation associated with benefits transfer-based mapping of ecosystem services. Biological Conservation 143:2487-2493

Local	Primary	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Field samples taken from all three tea cultivation zones; soil organic matter (SOM) and soil bulk density (BD) data; information concerning tea plantations (e.g., stand age, time of pruning, fertilization, and harvest)
Local	Primary	Local		Li, S., X. Wu, H. Xue, B. Gu, H. Cheng, J. Zeng, C. Peng, Y. Ge, and J. Chang. 2011. Quantifying carbon storage for tea plantations in China. Agriculture, Ecosystems & Environment 141:390-398
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Helian, L., Shilong, W., Guanglei, J., and Ling, Z. 2011. Changes in land use and ecosystem service values in Jinan, China. Energy Procedia 5:1109-1115
Global	Proxy	Global	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Youn, C., S. Chandra, E. H. Fegraus, K. Lin, and C. Baru. 2011. TEAM Network: Building Web-based Data Access and Analysis Environments for Ecosystem Services. Procedia Computer Science 4:146-155.
Global	Proxy	Global		

National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Land use (evaluate the soil carbon storage as the SOC of top soils according to soil types and their properties). Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67.
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B. N., B. Reyers, J. Carwardine, M. Bode, P. J. O'Farrell, K. A. Wilson, H. P. Possingham, M. Rouget, W. De Lange, D. M. Richardson, and R. M. Cowling. 2010. Safeguarding Biodiversity and Ecosystem Services in the Little Karoo, South Africa. Conservation Biology 24:1021-1030.
National National Global	Proxy	National National National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	GIS database consisted of: grassland types with plant properties (e.g. maximal production, maximal height, and root/shoot ratio); soil properties (e.g. maximum and minimum soil organic carbon(SOC) content, bulk density, clay fraction and pH); daily climate data (e.g. maximum and minimum air temperatures and precipitation); and areas and geographic locations of grassland types at county level. Zhang, F., J. Qi, F. M. Li, C. S. Li, and C. B. Li. 2010. Quantifying nitrous oxide emissions from Chinese grasslands with a process-based model. Biogeosciences 7:2039-2050.

National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B. N., B. Reyers, M. Rouget, and D. M. Richardson. 2011. Identifying priority areas for ecosystem service management in South African grasslands. Journal of Environmental Management 92:1642-1650
Local Local National	Proxy	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vegetation and land use datasets clipped and unioned with the riparian buffers to retain the various Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honzák, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. Ecological Complexity 7:378-388
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Brenner, J., J. A. Jiménez, R. Sardá, and A. Garola. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53:27-38
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., &	Reyers, B., P. J. O'Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem

Local		Local	M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	and J. H. J. Vlok. 2009. Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society 14:38
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Huang, S.-L., Y.-H. Chen, F.-Y. Kuo, and S.-H. Wang. 2011. Emergy-based evaluation of peri-urban ecosystem services. Ecological Complexity 8:38-50
Local Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Crossman, N. D., J. D. Connor, B. A. Bryan, D. M. Summers, and J. Ginnivan. 2010. Reconfiguring an irrigation landscape to improve provision of ecosystem services. Ecological Economics 69:1031-1042
National National Local Local	Model	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Simonit, S. and C. Perrings. 2011. Sustainability and the value of the ‘regulating’ services: Wetlands and water quality in Lake Victoria. Ecological Economics 70:1189-1199

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67.
National National National	Model	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67.
	Model		Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67.
National National National	Model	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping	Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67.

		Local	ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	
National National	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B. N., B. Reyers, J. Carwardine, M. Bode, P. J. O'Farrell, K. A. Wilson, H. P. Possingham, M. Rouget, W. De Lange, D. M. Richardson, and R. M. Cowling. 2010. Safeguarding Biodiversity and Ecosystem Services in the Little Karoo, South Africa. Conservation Biology 24:1021-1030.
Local local local	Proxy	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Guo, Z., X. Xiao, and D. Li. 2000. An assessment of ecosystem services: water flow regulation and hydroelectric power production. Ecological Applications 10:925-936
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Lautenbach, S., C. Kugel, A. Lausch, and R. Seppelt. 2011. Analysis of historic changes in regional ecosystem service provisioning using land use data. Ecological Indicators 11:676-687

National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B., B. Reyers, M. Rouget, M. Bode, and D. M. Richardson. 2009. Spatial congruence between biodiversity and ecosystem services in South Africa. Biological Conservation 142:553-562
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions, services and their values – a case study in Xingshan County of China. Ecological Economics 38:141-154
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Troy, A. and M. A. Wilson. 2006. Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. Ecological Economics 60:435-449
National National	Proxy	National National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping	Sandhu, H.S., Wratten, S.D., Cullen, R., and Case, B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics

National		National	for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	approach. Ecological Economics 64:835-848
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le Maitre, and A. S. van Jaarsveld. 2008. Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment 127:135-140
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Tratalos, J., R. A. Fuller, P. H. Warren, R. G. Davies, and K. J. Gaston. 2007. Urban form, biodiversity potential and ecosystem services. Landscape and Urban Planning 83:308-317
National Local Local National	Proxy	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honzák, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. Ecological Complexity 7:378-388
Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators	Posthumus, H., J. R. Rouquette, J. Morris, D. J. G. Gowing, and T. M. Hess. 2010. A framework for the assessment of ecosystem goods and services: a case study on lowland

		Local	for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	floodplains in England. Ecological Economics 69:1510-1523
	Model	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Chisholm, R. A. 2010. Trade-offs between ecosystem services: Water and carbon in a biodiversity hotspot. Ecological Economics 69:1973-1987
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Crossman, N. D., B. A. Bryan, and D. King. 2011. Contribution of site assessment toward prioritising investment in natural capital. Environmental Modelling and Software 26:30-37

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Crossman, N. D., B. A. Bryan, and D. King. 2011. Contribution of site assessment toward prioritising investment in natural capital. Environmental Modelling and Software 26:30-37
Local	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Bai, Y., C. Zhuang, Z. Ouyang, H. Zheng, and B. Jiang. 2011. Spatial characteristics between biodiversity and ecosystem services in a human-dominated watershed. Ecological Complexity 8:177-183
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4-11
Local Local	Primary	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L.	Martínez, M. L., O. Pérez-Maqueo, G. Vázquez, G. Castillo-Campos, J. García-Franco, K. Mehltreter, M. Equihua, and R. Landgrave. 2009. Effects of

Local		Local	Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	and R. Landgrave. 2009. Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. Forest Ecology and Management 258:1856-1863
Local	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Simonit, S. and C. Perrings. 2011. Sustainability and the value of the 'regulating' services: Wetlands and water quality in Lake Victoria. Ecological Economics 70:1189-1199
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Brenner, J., J. A. Jiménez, R. Sardá, and A. Garola. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53:27-38
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Jansson, Å., C. Folke, and S. Langaas. 1998. Quantifying the nitrogen retention capacity of natural wetlands in the large-scale drainage basin of the baltic sea. Landscape Ecology 13:249-262

Local	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Compute the nitrate prevented from entering the local waterways by applying average annual values for nitrate lost in surface-water runoff, in lateral subsurface flow, and in leachate (N kg/ha/year) from agricultural sites using output from the EPIC model. Jenkins, W. A., B. C. Murray, R. A. Kramer, and S. P. Faulkner. 2010. Valuing ecosystem services from wetlands restoration in the Mississippi Alluvial Valley. Ecological Economics 69:1051-1061
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Troy, A. and M. A. Wilson. 2006. Mapping ecosystem services: Practical challenges and opportunities in linking GIS and value transfer. Ecological Economics 60:435-449
National National	Proxy	National National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Sandhu, H.S., Wratten, S.D., Cullen, R., and Case, B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics 64:835-848

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Posthumus, H., J. R. Rouquette, J. Morris, D. J. G. Gowing, and T. M. Hess. 2010. A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics 69:1510-1523
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences 107:5242-5247
Continental	Proxy	Continental	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vihervaara, P., T. Kumpula, A. Tanskanen, and B. Burkhard. 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity 7:410-420

National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Soil Conservation Service curve-number (SCS-CN) approach (combined hydrologic effect of soil, land cover, land treatment, and antecedent soil moisture). Laterra, P., Orúe, M.E., and Booman, G.C. 2011. Spatial complexity and ecosystem services in rural landscapes. Agriculture, Ecosystems & Environment 154:56-67
National National	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Chan, K. M. A., M. R. Shaw, D. R. Cameron, E. C. Underwood, and G. C. Daily. 2006. Conservation Planning for Ecosystem Services. PLoS Biology 4:e379
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	The degree of attenuation depends on the volume of storage relative to the flows in the river. Thus an index of flood storage capacity estimated from Storage volume (m3)/ Qmed Median annual flood (m3 s−1) Posthumus, H., J. R. Rouquette, J. Morris, D. J. G. Gowing, and T. M. Hess. 2010. A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. Ecological Economics 69:1510-1523
Local Local Local	Model	Local Local Local	I. Gallay, B. Olah, Z. Gallayová, T. Lepeška. 2021. Monetary Valuation of Flood Protection Ecosystem Service Based on	SWAT model (for runoff) HEC-RAS model (showed whether the river channel safely discharges the modelled flow or if it is spilled from the banks) HEC-GeoRAS extension (extent of the flood)

Local Local Local Local Local Local Local		Local Local Local Local Local Local Local	Hydrological Modelling and Avoided Damage Costs. An Example from the Cierny Hron River Basin, Slovakia. Water, 13, 198	
Local Local Local Local	Proxy	Local	Barth, N., C., Dölln, P., 2016. Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach. Ecosystem Services, vol. 21, issue PA, 39-52	Flood hazard maps (provide inundation heights and areas) Flood risks maps (different land use) Direct runoff, evapotranspiration and groundwater recharge rate (data on climate, soil, depth to water table and land use) used in soil water balance model
Continental	Proxy	Continental	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vihervaara, P., T. Kumpula, A. Tanskanen, and B. Burkhard. 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity 7:410-420

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Modelled hillslope erosion using RUSLE, scaled up to sub-catchment level. Crossman, N. D., B. A. Bryan, and D. King. 2011. Contribution of site assessment toward prioritising investment in natural capital. Environmental Modelling and Software 26:30-37
National National	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Soil retention was mapped as a function of vegetation cover and soil erosion potential (summarised in ha of soil retention hotspot per quaternary catchment) Egoh, B. N., B. Reyers, M. Rouget, and D. M. Richardson. 2011. Identifying priority areas for ecosystem service management in South African grasslands. Journal of Environmental Management 92:1642-1650.
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Cartography for land use/land cover types, and the vegetation communities and habitats present in the area. Brenner, J., J. A. Jiménez, R. Sardá, and A. Garola. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53:27-38
Local Local Local	Proxy	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping	Data on geomorphology, climate, vegetation and management practices. Bai, Y., C. Zhuang, Z. Ouyang, H. Zheng, and B. Jiang. 2011. Spatial characteristics between biodiversity

Local		Local	ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	and ecosystem services in a human-dominated watershed. Ecological Complexity 8:177-183
	USLE model (Universal Soil Loss Equation)	Local Local Local Local Local Local		M Alam.2018. Ecological and economic indicators for measuring erosion control services provided by ecosystems. Ecological Indicators 95, 695-701
Local Local Local Local Local Local Local	USLE model	Local Local Local Local Local Local Local		B. Fu, Y. Liu, Y. Lü, C. He, Y. Zeng, B. Wu. 2011. Assessing the soil erosion control service of ecosystems change in the Loess Plateau of China. Ecological Complexity Volume: 8, Issue: 4, pp 284-293
Local Local Local Local Local	RUSLE model (revised universal soil loss equation)	Local Local Local Local Local		S. Xu, Y. Liu, J. Gong, C. & Z. Wang. 2020. Comparing differences among three ecosystem service proxies for soil erosion pre-vention and their combination characteristics at local scales. Ecolological Indicator 110, 105929
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Assessed the interaction between rainfall, soil depth and texture for each habitat type. Reyers, B., P. J. O'Farrell, R. M. Cowling, B. N. Egoh, D. C. Le Maitre, and J. H. J. Vlok. 2009. Ecosystem services, land-cover change, and stakeholders: finding a sustainable foothold for a semiarid biodiversity hotspot. Ecology and Society 14:38

Local	InVEST	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	The model estimates the volume and timing of water flow from an area to its catchments outlet. Both the volume and timing of water flow across the landscape are affected by water retention on the land. Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4-11
Local	InVEST	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	The rate of soil erosion is a function of the area's LU/LC, soil type, rainfall intensity, and topography Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4-11
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Helian, L., Shilong, W., Guanglei, J., and Ling, Z. 2011. Changes in land use and ecosystem service values in Jinan, China. Energy Procedia 5:1109-1115
National	Model	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and	They modelled soil retention as a function of vegetation cover and erodibility. Schoeman et al. (2002) modelled soil erodibility for the whole of South Africa based on soil structure, geology, water, wind, and slope. Data on vegetation potential to curb erosion was based on expert knowledge.

National		National	Policy Reports; No. EUR 25456 EN). Joint Research Centre	Egoh, B., B. Reyers, M. Rouget, M. Bode, and D. M. Richardson. 2009. Spatial congruence between biodiversity and ecosystem services in South Africa. Biological Conservation 142:553-562
Local	Model	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Difference between precipitation and evaporation as the amount of water retention and storage
Local	Model	Local		Guo, Z., X. Xiao, Y. Gan, and Y. Zheng. 2001. Ecosystem functions, services and their values – a case study in Xingshan County of China. Ecological Economics 38:141-154
Local	Model	Local		
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Soil retention was modelled as a function of vegetation or litter cover and soil erosion potential (Schulze index of litter cover).
National		National		The range of soil retention was mapped by selecting all areas that had vegetation or litter cover of more than 30% for both the expert classified vegetation types and litter accumulation index within areas with moderate to severe erosion potential.
National		National		Egoh, B., B. Reyers, M. Rouget, D. M. Richardson, D. C. Le Maitre, and A. S. van Jaarsveld. 2008. Mapping ecosystem services for planning and management. Agriculture, Ecosystems & Environment 127:135-140.
National	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Regional ecosystems vegetation and land use datasets were clipped and unioned with the riparian buffers to retain the various attributes.
Local		Local		Pert, P. L., J. R. A. Butler, J. E. Brodie, C. Bruce, M. Honzák, D. Metcalfe, D. Mitchell, and G. Wong. 2010. A catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. Ecological Complexity 7:378-388
Local		Local		

Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Brenner, J., J. A. Jiménez, R. Sardá, and A. Garola. 2010. An assessment of the non-market value of the ecosystem services provided by the Catalan coastal zone, Spain. Ocean & Coastal Management 53:27-38
Local	Primary	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Sandhu, H.S., Wratten, S.D., Cullen, R., and Case, B. 2008. The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecological Economics 64:835-848
Local Local	Proxy	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Shi, N., J. Zhan, F. Wu, and J. Du. 2009. Identification of the core ecosystem services and their spatial heterogeneity in Poyang Lake area. Frontiers of Earth Science in China 3:214-220.
Local	Proxy	Local	Egoh, B. N.,	Nelson, E., G. Mendoza, J. Regetz, S.

Local		Local	Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment 7:4-11
national National National Local	Model	Local Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Willemen, L., P. H. Verburg, L. Hein, and M. E. F. Van Mensvoort. 2008. Spatial characterization of landscape functions. Landscape and Urban Planning 88:34-43
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Vihervaara, P., T. Kumpula, A. Tanskanen, and B. Burkhard. 2010. Ecosystem services–A tool for sustainable management of human–environment systems. Case study Finnish Forest Lapland. Ecological Complexity 7:410-420
national National National	Model	Local Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., &	Willemen, L., L. Hein, M. E. F. Van Mensvoort, and P. H. Verburg. 2010a. Space for people, plants, and

Local		Local	Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	livestock? Quantifying interactions between multiple landscape functions in a Dutch rural region. Ecological Indicators 10:62-73
Local National	Primary	Local Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	O'Farrell, P. J., W. J. De Lange, D. C. Le Maitre, B. Reyers, J. N. Blignaut, S. J. Milton, D. Atkinson, B. Egoh, A. Maherry, C. Colvin, and R. M. Cowling. 2011. The possibilities and pitfalls presented by a pragmatic approach to ecosystem service valuation in an arid biodiversity hotspot. Journal of Arid Environments 75:612-623
Local	Proxy	Local	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Huang, S.-L., Y.-H. Chen, F.-Y. Kuo, and S.-H. Wang. 2011. Emergy-based evaluation of peri-urban ecosystem services. Ecological Complexity 8:38-50
National	Primary	National	Egoh, B. N., Drakou, E., Dunbar, M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	Eigenbrod, F., P. R. Armsworth, B. J. Anderson, A. Heinemeyer, S. Gillings, D. B. Roy, C. D. Thomas, and K. J. Gaston. 2010. Error propagation associated with benefits transfer-based mapping of ecosystem services. Biological Conservation 143:2487-2493
National	Proxy	National	Egoh, B. N., Drakou, E., Dunbar,	Lange, G.-M. and N. Jiddawi. 2009. Economic value of marine ecosystem

National National		National National	M. B., Maes, J., & Willemen, L. (2012). Indicators for mapping ecosystem services: a review. (JRC Scientific and Policy Reports; No. EUR 25456 EN). Joint Research Centre	services in Zanzibar: Implications for marine conservation and sustainable development. Ocean & Coastal Management 52:521-532

Annex 4: Demand indicators

ES	Flow service indicator	Demand indicator	Service benefitting areas	Data	Source	More info/details and original sources
Provisioning service	Quantity harvested, consumed, or used; number of people served; number of industries served	Amount of service desired per unit space and time multiplied by the number of potential users (rival service) (e.g. liters of water per person)			Villamagna, A., P. Angermeier, and E. Bennett. 2013. Capacity, Demand, Pressure, and Flow: A conceptual framework for analyzing ecosystem service provision and delivery. Ecological Complexity 15:114-121	
Food provisioning		Per capita grain demand			Bin Fu, 2019. Integrating Ecosystem Services and Human Demand for a New Ecosystem Management Approach: A Case Study from the Giant Panda World Heritage Site	
	Harvested crops (t/ha per year, kJ/ha per year); Yield (€/ha per year)	Crop product consumption (kg/person per year; kJ/person per year)	Farms, food industry, communities, household		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
	Respective animal products (t/ha per year); Yield (€/ha per year)	Meat consumption (kg/person per year); Related products consumption (kg/person per year)	Farms, communities, households		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Water provisioning		Water use for irrigation, extraction and transport			Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. Ecological Indicators, 55, 159–17	Locatelli, B., Imbach, P., Wunder, S., 2013. Synergies and trade-offs between ecosystem services in Costa Rica. Environ. Conserv. 41, 27–36
		Total water consumption including public, municipal, irrigation, and industrial water use (m3				Chang, H., Jung, I.-W., Strecker, A., Wise, D., Lafrenz, M., Shandas, V., Moradkhani,H., Yeakley, A., Pan, Y., Bean, R., Johnson, G., Psaris, M., 2013. Water supply,demand, and quality indicators for assessing the spatial distribution of water resource vulnerability in the columbia river basin. Atmos. Ocean 51, 339–356
		Water consumption of different user groups (e.g. household, industry, agriculture, forestry)				Boithias, L., Acũna, V., Vergőnós, L., Ziv, G., Marcé, R., Sabater, S., 2014. Assessment of the water supply: demand ratios in a Mediterranean basin under different global change scenarios and mitigation alternatives. Sci. Total Environ. 470–471, 567–577
	Water withdrawal (l/region per year; m^3/region per year)	Water use (l or m^3 /person per year; l or m^3/industrial sector per year)	Water supply companies, agriculture, industry, communities, households		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Energy source		Hydropower consumption (statistical electricity consumption)		Generated hydropower (kwh)	Bin Fu, 2019. Integrating Ecosystem Services and Human Demand for a New Ecosystem Management Approach: A Case Study from the Giant Panda World Heritage Site	
	Converted energy (kWh/m3 per year); Produced electricity (kWh/m3 per year); water (€/m3 per year)	Energy use (kWh/person per year; kWh/industrial sector per year)	Wind or solar farmer, energy companies, communities, households		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010

		Average consumption rates and energy use			Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. Ecological Indicators, 55, 159–17	Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indic. 21, 17–29
		Consumption of final energy (GJ) per hectare of each land cover type			Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. Ecological Indicators, 55, 159–17	Kroll, F., Müller, F., Haase, D., Fohrer, N., 2012. Rural–urban gradient analysis of ecosystem services supply and demand dynamics. Land Use Policy 29, 521–535
Material resource	Excavated minerals (t/ha per year); Earnings (€/a)	Minerals used (t/person per year; t/industrial sector per year)	Mining companies, industry, construction, communities, households		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
	Catch of fish; game taken (kg/ha per year); Harvested plant biomass (t C/ha per year); Yield (€/ha per year)	Catch of fish; game taken (kg/ha per year); Harvested plant biomass (t C/ha per year); Yield (€/ha per year)	Wild food consumption (kg/person per year); Ornamental item sale (n/region per year); Business volumes (€/a)		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Regulation services	Ecological work = ecological pressures minus environmental quality (same units) (e.g. nitrogen inputs-minus in-stream load)	Amount of regulation needed to meet pre-determined condition (e.g.% nitrogen reduction; Total Maximum Daily Load [TMDL])			Villamagna, A., P. Angermeier, and E. Bennett. 2013. Capacity, Demand, Pressure, and Flow: A conceptual framework for analyzing ecosystem service provision and delivery. Ecological Complexity 15:114-121	
Climate regulation	Temperature amplitudes (K); precipitation, wind or evapotranspiration deviation from surrounding areas (%)	Excess heat, rain or storm performance (°C, mm. Bft) or periods (d/a); Air conditioning use (kWh/a)	Residential and recreation areas		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Water flow regulation	Water released for hydrological process use, e.g. plant or animal uptake, soil processes (m3/ha per year); available water content (v%);amount of excess water (m^3/ha per year)	Periods at permanent wilting point (d/a); soil field capacity (v%); periods of excess water or floods (d/a)	Agricultural areas, residential areas, industrial areas		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Water purification	Elements removed from water (kg/m^3 per year); water quality standards amplitudes (ppb; mg/l)	Level of pollutants in the water (ppb); water quality standard deviation (ppb; mg/l)	Residential or recreation areas, agriculture, industry		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Moderation of extreme events (flood protection)		Value of protective function, i.e. infrastructure / economic activity / human well-being protected by ecosystem-based regulation (real or estimated)			TEEB - The Economics of Ecosystems and Biodiversity (2013): Guidance Manual for TEEB Country Studies. Version 1.0	
		Population living / economic activities situated in areas depending (directly) on ecosystem-based regulation (i.e. facing risks of flooding)			TEEB - The Economics of Ecosystems and Biodiversity (2013): Guidance Manual for TEEB Country Studies. Version 1.0	
		Vulnerability of assets (monetary potential flood damages and economic value of assets) Flood sensitive land use (water storage capacity of land cover)			Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. Ecological Indicators, 55, 159–17	Stürck, J., Poortinga, A., Verburg, P.H., 2014. Mapping ecosystem services: the supply and demand of flood regulation services in Europe. Ecol. Indic. 38, 198–211
		Vulnerability of land use (Population density, average consumption rates, water storage capacity in m3,reduction of flood danger, prevented damage to infrastructure)			Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. Ecological Indicators, 55, 159–17	Nedkov, S., Burkhard, B., 2012. Flood regulating ecosystem services – mapping sup-ply and demand, in the Etropole municipality, Bulgaria. Ecol. Indic. 21, 67–79

		The demands for flood regulation are linked to the benefits that people obtain by this service. Benefits are the protection of property such as houses infrastructure, farmlands and of course, human life	Map of the demand for flood regulation	data for topography of the area used to outline the floodplains CORINE land cover data used to define the areas with properties with flood regulation demands; field work and statistical data for the areas which have been flooded during the recent flood events and the damages caused by them—used to define the most vulnerable areas	Nedkov, S., Burkhard, B., 2012. Flood regulating ecosystem services – mapping sup- ply and demand, in the Etropole municipality, Bulgaria. Ecol. Indic. 21, 67–79	
	Number of prevented hazards (n/a); Prevented fatalities, damage to property or infrastructure (n/a; €/a)	Number of hazards and fatalities (n/a); damage costs (€/a)	Built areas, land uses, infrastructure and industry within hazard-prone zones		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
		Domestic water consumption (combined water source distribution with the population distribution)	Residential area		Bin Fu, 2019. Integrating Ecosystem Services and Human Demand for a New Ecosystem Management Approach: A Case Study from the Giant Panda World Heritage Site	
		Industrial water consumption (the industrial output value of water consumption)	Residential area		Bin Fu, 2019. Integrating Ecosystem Services and Human Demand for a New Ecosystem Management Approach: A Case Study from the Giant Panda World Heritage Site	
		Agricultural water consumption (determined the water consumption of irrigated farmlands and their spatial distribution)			Bin Fu, 2019. Integrating Ecosystem Services and Human Demand for a New Ecosystem Management Approach: A Case Study from the Giant Panda World Heritage Site	
Erosion prevention	Amount of soil retained or sediment captured (kg/ha per year); amount of prevented erosion events (n/a)	Number of erosion events (n/ha per year); soil loss by erosion (kg/ha per year)	Agricultural fields, infrastructure, residential areas		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Biological control	Number of prevented pest and disease outbreaks or predator and parasite actions (n/ha per year; %/a)	Number of pest and disease outbreaks (n/ha per year); Plants and animals damaged (%/a; n/a); Yield losses (%/a; €/a)	Communities, transport facilities, agricultural fields, farms, stables, crops, animals, farmers		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
Cultural services	Amount of service used measured in units of time and/or space (e.g. total visitor-days from current year; individual visitation rates)	Desired total use (if rival service) or individual use (if non-rival) (e.g. total visitor-days from year prior; individual visitation rates)			Villamagna, A., P. Angermeier, and E. Bennett. 2013. Capacity, Demand, Pressure, and Flow: A conceptual framework for analyzing ecosystem service provision and delivery. Ecological Complexity 15:114-121	
Opportunities for recreation and tourism		Willingness to contribute to the maintenance of service			Wolff, S., Schulp, C. J. E., & Verburg, P. H. (2015). Mapping ecosystem services demand: A review of current research and future perspectives. Ecological Indicators, 55, 159–17	Casado-Arzuaga, I., Madariaga, I., Onaindia, M., 2013. Perception, demand and user contribution to ecosystem services in the Bilbao Metropolitan Greenbelt. J. Environ. Manag. 129, 33–43,
		Willingness to pay				Nahuelhual, L., Carmona, A., Laterra, P., Barrena, J., Aguayo, M., 2014. A mapping approach to assess intangible cultural ecosystem services: the case of agriculture heritage in Southern Chile. Ecol. Indic. 40, 90–101
		Common recreation preferences for recreational destinations				Paracchini, M.L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J.P., Ter-mansen, M., Zandersen, M., Perez-Soba, M., Scholefield, P.A., Bidoglio, G.,2014. Mapping cultural ecosystem services: a framework to assess the potential for outdoor recreation across the EU. Ecol. Indic. 45, 371–385

		Most important perceived ES				Palomo, I., Martín-López, B., Potschin, M., Haines-Young, R., Montes, C., 2013.National Parks, buffer zones and surrounding lands: mapping ecosystem service flows. Ecosyst. Serv. 4, 104–116
	Number of facility visitors (n/facility per year); Turnover from tourism (€/ha per year)	Results from questionnaires on holiday plans and expectations	Touristic infrastructure, visitors, communities, households (at home location)		B. Burkhard, 2012. Ecosystem Service Potentials, Flows and Demands – Concepts for Spatial Localisation, Indication and Quantification	based on Kandziora et al. 2013a; Burkhard et al. 2009 and 2012; Schröter et al. 2014; Syrbe and Walz 2012; de Groot et al. 2010
		Normalized tourist numbers			Bin Fu, 2019. Integrating Ecosystem Services and Human Demand for a New Ecosystem Management Approach: A Case Study from the Giant Panda World Heritage Site	
		Money / time invested in carrying out activities (e.g.travel costs, accommodations, equipment)			TEEB - The Economics of Ecosystems and Biodiversity (2013): Guidance Manual for TEEB Country Studies. Version 1.0	
		Number of tourists / visitors			TEEB - The Economics of Ecosystems and Biodiversity (2013): Guidance Manual for TEEB Country Studies. Version 1.0	
		Number of people engaged with an activity			TEEB - The Economics of Ecosystems and Biodiversity (2013): Guidance Manual for TEEB Country Studies. Version 1.0	

Annex 5: Nature-based solutions from Think Nature and related ecosystem services

NBS	Food provisioning	Energy resource	Water provisioning	Lyfe cycle maintenance	Climate regulation	Natural hazard regulation	Soil erosion regulation	Water purification	Recreation and tourism	Total score
Limit or prevent specific uses and practices	0	0	1	0	1	1	1	0	1	5
Maintain and enhance natural wetlands	1	0	1	1	0	1	0	1	1	6
Agro-ecological practices	1	0	1	0	1	0	0	1	1	5
Change crop rotation	0	0	1	0	0	0	0	1	0	2
Increase soil water holding capacity and infiltration rates	0	0	1	0	0	1	0	0	0	2
Incorporating manure, compost, biosolids, or	0	0	1	0	0	0	0	0	0	1
Integrated coastal zone management	0	0	1	0	0	0	0	0	0	1
Assessment of NBS benefits	0	0	1	0	0	1	0	0	0	2
Systems for erosion control	0	0	1	0	0	0	0	0	0	1
Use of pre-existing vegetation	0	0	1	0	0	1	0	0	0	2
Re-meander rivers (where they havebeen artificially straightened) to help reduce speed and height of flood peak	0	0	1	0	0	1	0	0	1	3
Constructed wetlands and built structures for water management	0	1	1	1	0	0	0	1	1	5
Re-establish and restore previous intertidal habitat by de-poldering or coastal realignment	1	0	1	1	1	1	1	0	1	7
Protect remaining intertidal muds, saltmarshes and mangrove communities, seagrass beds, and vegetated dunes from further degradation, fragmentation, and loss	1	0	0	1	0	1	0	0	1	4
Integrated coastal zone management	1	0	0	0	1	0	0	1	0	3
Rivers or streams, including re-meandering, re-opening Blue corridors	1	0	0	1	1	1	1	1	1	7
Protect forests from clearing and degradation from logging, fire, and unsustainable levels of non-timber resource extraction	0	0	0	1	1	1	1	0	0	4
Soil improvement and conservation measures	0	0	0		1	0	1	1	0	3
Assessment of NBS benefits	0	0	0	1		0	1	0	0	2
Systems for erosion control	0	0	1	1	1	1	1	1	1	7
Use of pre-existing vegetation	0	0	1	0	1	0	1	1	1	5
Integrated coastal zone management	0	0	0	0		1	0	0	1	2
Re-meander rivers (where they havebeen artificially straightened) to help reduce speed and height of flood peak	0	0	0	0	0	1	0	0	1	2
Use engineered reedbeds/wetlands for tertiary treatment of effluent	0	0	1	1		1	0	1	1	5
Enrichment planting in degraded and regenerating forests	0	0	0	1	1	0	0	0	1	3
Forest patches	0	0	0	1	1	0	0	0	1	3
Agroforestry	0	0	0	1	1	0	0	0	1	3
Use grazing management and animal impact as farm and ecosystem development tools	0	0	0	1	0	0	0	0	0	1
Incorporating manure, compost, biosolids, or incorporating crop residues to enhance carbon storage	0	0	0	1	0	0	0	0	0	1
Deep-rooted plants and minimum or conservation tillage	0	0	0	1	0	0	0	0	1	2
Bio-indicators	0	0	0	1	0	0	0	0	1	2
MPA network structure	0	0	0		0	0	0	0	1	1
Integrated and ecological management - spatial aspects	0	0	1	1	1	1		1	1	6
Create and preserve habitats and shelters for biodiversity	0	1	0	1	1	1	0	0	1	5
Choices of plants	0	0	0	0	0	0	0	0		0
Large urban park	0	1	0	1	1	1	1	1	1	7
Pocket garden/park	0	1	0	1	1	1	0		1	5
Community garden	0	1	0	1	1	1	0		1	5
Private garden	0	0	0	0	1	1	0	1	1	4
Urban forest	0	0	0	0	1	0	0	0	1	2
Street trees	0	0	0	0	1	0	0	0	0	1
Intensive green roof/Semi-intensive green roof/Extensive green roof	0	0	1	0	1	1	0	1	1	5
Climber green wall	0	0	0	0	1	0	0	0	1	2
Green wall system	0	0	0	1	1	0	0	0	0	2
Planter green wall	0	0	0	0	0	0	0	0	0	0
Vegetable garden	0	1	0	1	1	0	0	0	1	4
Urban orchards	1	1	0	0	0	0	0	0	0	2
Urban network structures	0	0	0	1	1	0	0	0	1	3
Use of fauna	0	1	0	1	1	0	0	0	1	4
Account for distribution of public green spaces through the city	0	0	0	1	1	1	0	0	1	4
Mapping of urban green connectivity and biodiversity	0	0	1	0	1	1	0	1	0	4
Develop urban blue infrastructure	0	1	1	0	1	1	0	1	1	6
Sustainable Urban Drainage Systems	0	0	1	1	1	1	0	1	1	6
Integrated water management	0	0	1	0	1	1	0	1	1	5

Annex 6: Nature water retention measures and related ecosystem services

NBS	Food provisioning	Energy resource	Water provisioning	Material resources	Lyfe cycle maintenance	Climate regulation	Water flow regulation	Natural hazard regulation	Soil erosion regulation	Water purification	Recreation and tourism	Total effect score
Meadows and pastures	0	0	0	0	0	3	3	5	5	3	0	19
Buffer strips and hedges	1	0	0	1	1	3	3	5	5	5	0	24
Crop rotation	1	0	0	0	1	0	3	1	1	3	0	10
Strip cropping along contours		0	0	0	0	0	3	3	5	3	0	14
Intercropping	5	0	1	0	3	1	0	3	3	5	0	21
No-till agriculture	1 (+/-)	0	0	0	3	3 (+/-)	3	0	5	3	0	14
Low-till agriculture	1	0	0	0	0	1	3	0	0	0	0	5
Green cover	3	0	0	1	1	3	3	5	5	5	0	26
Early sowing	5	0	0	0	0	3	5	5	5	3	0	26
Traditional terracing	0	0	0	0	0	0		3	5	3	0	11
Controlled traffic farming	3	0	0	0	0	0	1	3	3	3	0	13
Reduced stocking density	0	0	0	0	0	0	1	3	3	3	0	10
Mulching	0	0	0	0	0	0	3	3	1	0	0	7
Forest riparian buffers	0	0	1	1	5	0	1	1	5	3	0	17
Maintenance of forest cover in headwater areas	0	0	5	5	3	5	5	5	5	5	5	38
Afforestation of reservoir catchments	0	0	3	5	5	5	5	3	5	5	5	36
Targeted planting for 'catching' precipitation	0	0	0	5	3	5	5	3	5	0	0	26
Land use conversion	0	0	5	5	5	5	5	5	5	5	5	40
Continuous cover forestry	0	0	3	3	5	5	1	3	3	3	3	26
Water sensitive' driving	0	0	0	0	5	0	0	1	5	3	0	14
Appropriate design of roads and stream crossings	0	0	0	0	5	0	0	1	5	1	1	12
Sediment capture ponds	0	0	3	0	5	1	1	3	5	5	0	23
Coarse woody debris	0	0	0	0	5	0		3	1		3	9
Urban forest parks	0	0	3	3	5	5	3	1	3	3	5	26
Trees in urban areas	0	0	3	3	5	5	3	1	1	5	5	26
Peak flow control structures in managed forests	0	0	3	0	3	0	1	5	5	5	0	22
Overland flow areas in peatland forests	0	0	3	0	3	1	3	1	5	5	1	21
Basins and ponds	0	0	5	1	1	0	5	5	1	3	3	21
Wetland restoration and management	0	0	3	3	5	3	3	3	1	3	3	24
Floodplain restoration and management	0	0	5	5	5	3	5	5	5	3	5	36
Re-meandering	0	0	3	5	5	3	5	5	5	3	5	34
Stream bed re-naturalisation	0	0	1	3	5	0	1	3	5	3	3	21
Restoration and reconnection of seasonal streams	0	0	3	1	5	3	3	3	5	3	0	26
Reconnection of oxbow lakes and similar features	0	0	3	1	5	3	3	3	5	3	1	26
Riverbed material restoration	0	0	3	3	5	0	0	3	5	3	0	22
Removal of dams and other longitudinal barriers	0	3	0	0	5	0	0	1	3	0	3	12
Natural bank stabilisation	0	0	1	5	5	1	1	3	5	5	5	26
Elimination of riverbank protection	0	0	3	3	3	0	1	5	3	3	3	21
Lake restoration	0	0	5	5	5	0	1	3	5	1	5	25
Restoration of natural infiltration to groundwater	0	0	3	0		1	3	1	1	0	0	9
Renaturalisation of polder areas	0	0	5	3	5	0	3	3	3	1	1	23
Green roofs	0	0	0	1	1	3	0	3	0	1	1	9
Rainwater harvesting	0	0	5	0	0	3	0	1	0	0	0	9
Permeable surfaces	0	0	3	0	0	1	3	3	1	1	0	12
Swales	0	0	1	1	3	3	3	3	1	3	0	18
Channels and rills	0	0	0	1	1	1	0	1	1	1	0	6
Filter strips	0	0	0	1	3	1	1	1	3	5	0	15
Soakaways	0	0	1	0	0	1	5	5	0	1	0	13
Infiltration trenches	0	0	1	0	0	1	5	5	1	3	0	16
Rain gardens	0	0	1	1	3	3	3	5	1	3	3	20
Detention basins	0	0	3	1	3	3	1	5	3	3	3	22
Retention ponds	0	0	3	3	5	3	0	5	3	5	3	27
Infiltration Basins	0	0	3	1	3	3	5	5	1	5	1	26