RFCS RESEARCH PROJECT

# Recovery of degraded and transformed ecosystems in coal mining-affected areas

*This project has received funding from the Research Fund for Coal and Steel under grant agreement No 847205*

## Deliverable 4.1

Suitable indicators

European Commission

Research Fund for Coal & Steel

## Authors

Prof. Dr. Dagmar Haase, Humboldt-Universität zu Berlin

Dr. Peer von Döhren, Humboldt-Universität zu Berlin

Dr. Łukasz Pierzchała, Central Mining Institute

Prof Dr. Eng. Alicja Krzemień, Central Mining Institute

Prof. Dr. Eng. Pedro Riesgo, Universidad de Oviedo

Assoc. prof. Dr. Eng. Barbara Stalmachová, VSB – Technical University of Ostrava

Vít Kopecký - DIAMO

Dr. Robert Frączek, TAURON

| Deliverable 3.8 | |
|---|---|
| Due date of Deliverable | 31.03.2022 |
| Start - End Date of Project | 01.07.2019 – 30.06.2023 |
| Duration | 4 years |
| Deliverable Lead Partner | UBER |
| Dissemination level | Public |
| Work Package | WP 4 |
| Digital File Name | D4.1 Suitable indicators |
| Keywords | Indicators, ecosystem services, quantification, valuation |

# Table of contents

## List of Figures

## List of Tables

## Executive Summary

This document briefly describes the selection of suitable indicators for each ecosystem service from the different case studies that will allow a proper quantification of every ecosystem service involved in the coal mining-affected areas.

Different ideas about indicator criteria are shortly reviewed using the various reviews covering this topic. A selection of relevant criteria for indicators in RECOVERY is compiled.

The DPSIR framework represents a systematic approach to environmental monitoring in the EU. The advantages of a causal chain approach in reflecting causes and effects and thus being able to guide responses are highlighted. Even though the DPSIR framework provides a general overview to assess environmental challenges it is limited in addressing the complexity of ecosystems. As ecosystems are made up of multiple overlapping interactions between socio-economic and environmental-system elements the causal chains is developed into a causal network to adequately reflect the impacts of coal mining for the landscape and ecosystems. The causal network identifies 12 impact categories, as being potentially relevant for coal mining impacted landscapes. The ES impacted by the pressures of coal mining are mostly regulating ES. This can be explained by the substantial disturbance of the landscape ecosystem structure caused by aboveground as well as underground coal mining.

The methodology for the selection of suitable indicators in the Recovery project is based on a causal network to identify key Impact categories and literature research to identify relevant, meaningful and accepted indicators.

The last section of the deliverable report lists the selection of suitable indicators for each of the study sites based on the methods outlined in the previous sections of the report. In this section the approach using the cause-effect relationships of coal mining, environmental change and ES to identify relevant impact categories is supplemented by the local expertise of the project partners for their respective study sites.

Indicators for provisioning and regulating ES for example agricultural production and climate regulation are established within the scientific community. Locally specific ES, cultural ES require locally specific indicators. This is in accordance with the scientific literature regarding quality and suitability of ES indicators.

The case studies illustrate the application of the approach, which combines a comparable base for the identification of suitable indicators with the flexibility of including the multiple local conditions of coal mining in the EU.

# 1 Introduction

Work Package Nº 4 focuses on developing the formulation that will be used later for the cost-benefit assessment. Specific objectives are:

1. To select suitable indicators for each ecosystem service that will allow a proper quantification of every ecosystem service involved in the coal mining-affected areas.
2. To define the best feasible valuation technique for every suitable indicator.
3. To select an adequate discount rate for each case study. The importance of using scenarios in ecosystem services assessments is beginning to be realised, as early assessments presented a static picture in a changing world.

First step of the selection of suitable indicators will be to select the suitable indicators that will allow a proper quantification of every ecosystem service involved in the coal-mining affected areas. This task will be leaded by UBER with the cooperation of all the partners, each one addressing its specific case study.

Indicators of ecosystem services are scientific constructs that use quantitative data to measure ecosystems condition and human well-being. Properly constituted, indicators can convey relevant information for the whole process.

With this purpose, indicators developed in other studies will be taken into account, as well as from the scientific literature, and developing new and specific indicators if appropriate.

The following criteria will be considered in order to select the most suitable indicators:

1. *Stakeholders-relevant and meaningful*: indicators should send a clear message and provide information at a level appropriate for management decision-making by assessing changes in the status of ecosystem services.
2. *Ecosystem services-relevant*: indicators should address key properties of ecosystem services or related issues as pressures, state, impacts and responses.
3. *Acceptance and intelligibility*: the power of an indicator depends on its broad acceptance. Involvement of all the partners of the project in the development of indicators is crucial.
4. *Cause-effect relationship*: information on cause-effect relationships should be achievable and quantifiable in order to link pressures, state and response indicators. These relationship models allow scenario analysis and represent the basis of the ecosystem approach.
5. *Spatial coverage*: indicators should ideally be relevant for coal mining affected landscapes.
6. *Country comparison*: as far as possible, it should be possible to make valid comparisons between countries using the indicators selected.

# 2 Methods

## 2.1 Criteria for suitable indicators

Environmental indicators are widely used in assessing and monitoring the state and development of the environment (Smeets and Weterings, 1999). The introduction of the conept of ecosystem services (ES) (MA, 2005) has resulted in a number of initiatives to classify ES and make the concept useful for illustrating and monitoring the benefits of ecosystems to societies (TEEB, 2010). With an increasing number of studies assessing ES in local, regional and national contexts the indicators used encompass a wide variety of different measures (Boerema et al., 2017). The approach of the Recovery project aims to demonstrate the application of ES assessment and valuation for coal mining affected landscapes and thus provide a showcase for further practical applications of ES-based methods to select the most promising restoration alternatives for post-mining landscapes. The challenges of mining-impacted landscapes and ecosystems for the generation of ES have to be specially considered, as they differ from the challenges arising from other land uses. The cause-effect relations between ecosystems structures, functions and mining impacts have to be included to establish the connections between the socio-economic developments, the impacts on land use and land cover and ultimately the consequences for the affected ecosystems to provide and maintain ES.

The key function of indicators is information and communication (Smeets and Weterings, 1999). Indicators inform scientists, decision makers and administrators about the condition of the environment and they are used to communicate the resulting challenges and options to stakeholders involved in, or affected by the decision making process. To meet the objective of the Recovery approach, to provide a scientific base, a clear communication tool and a pragmatic showcase, the indicators have to be clear, comprehensible, meaningful and comparable. The level of complexity should be as low as possible to ensure acceptance and communication of the indicators´ messages. To meet these challenges the selection of suitable indicators for ES from coal-mining affected landscapes follows an methodology which (i) illustrates the cause effect relation of the pressures, states and impacts leading to the generation of ES in the mining affected landscapes and (ii) reviews literature on existing ES indicators to identify suitable indicators, based on an established framework used for various environmental analyses, among them the development of ecological indicators (Troian et al., 2021).

The approach is based on reflecting the causal chain between the socio-economic system and the consequences for the ecosystems, which in turn results in impacts that lead to changes of the system to generate the functions, which are constitute the base for ecosystem services. This framework is extended to a causal network to include the interactions between the parallel causal chains (Niemeijer and de Groot, 2008a,b). The application of cause effect relationships for the development of suitable indicators ensures that the indicators reflect the specific impacts of mining, realizing the requirement of *ecosystem services relevance*, *cause-effect relationships* and *spatial coverage*. The remaining requirement for suitable ES indicators, as outlined in the introduction will be achieved by using references to existing ES assessments from scientific literature.

Several papers were published to assess the requirements of environmental indicators (Feld et al., 2010; Heink and Kowarik, 2010; Müller and Burkhard, 2012; Niemeijer and de Groot, 2008b; Seppelt et al., 2012; van Oudenhoven et al., 2018) and the thematic coverage and quality of ES indicators (Czúcz et al., 2018; Heink et al., 2016; Layke et al., 2012; Maes et al., 2016). The criteria demanded for ES indicators in scientific literature, credibility salience, legitimacy and feasibility (van Oudenhoven et al., 2018) are reflected by the criteria: *stakeholders-relevant and meaningful*, *acceptance and intelligibility* and *country comparison*, listed in Task 4.1 of the Recovery project.

## 2.2 The DPSIR Framework and the causal network approach

To ensure the suitability of the ES indicators used in the Recovery project, causal chains for each indicator are developed. The causal chains address key properties of ecosystem services and related issues as pressures, states impacts and responses; informing about cause-effect relationships as well as reflect the relevance for mining and post-mining landscapes,. An established and widely used causal chain approach is the Driving Forces-Pressures-State-Impact-Response (DPSIR) framework (Figure 1), that was developed by the European Environmental Agency (Smeets and Weterings, 1999) by expanding and specifying previously existing Stress-Response (Rapport and Friend, 1979) and Pressure-State-Impact (OECD, 1993) frameworks.

This framework is based on the understanding, that the human society exerts influence on the state of the environment. The changes in the state of the environment in turn results in impacts on the environments functions to generate the services which are utilised by human societies as benefits.

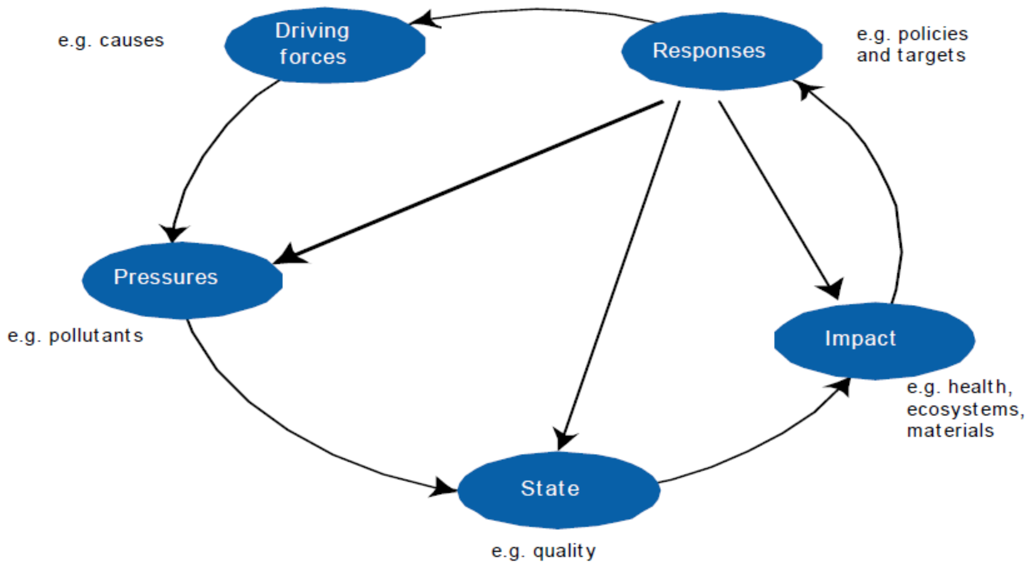


**Figure 1. The DPSIR framework (Gabrielsen and Bosch, 2003: 8)**

DPSIR components (from Gabrielsen and Bosch, 2003: 8,9):

1. Driving forces indicators: "[…] describe the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns." Driving forces originate mostly outside the study area (global/national scale).
2. Pressures indicators: "[…] describe developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land by human activities." Pressures originate within the study area. Pressures can be interpreted as the consequences of driving forces on regional or local scales.
3. State indicators: "[…] give a description of the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric $CO_2$-concentrations) in a certain area."
4. Impact indicators: describe the "[…] impacts on the functions of the environment, such as human and ecosystem health, resources availability, losses of manufactured capital, and biodiversity." "In the strict definition impacts are only those parameters that directly reflect changes in environmental use functions by humans." Accordingly ES are represented by Impact indicators.
5. Response indicators: "[…] refer to responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment."

The DPSIR framework is useful to reflect the causal chain from a driving force (economic growth, energy demand, labour demand), over a pressure (coal/lignite mining, emission of harmful substances, land use/land cover change, etc.) to a state (soil quality, vegetation, habitat suitability, etc.) to the impacts for local population (agricultural productivity, land based recreation, drinking water provision, etc.). The impacts reflect the changes in potential benefits which can be utilized from the ecosystems and can be interpreted as the changes in ES resulting from the influence of the driving forces being transmitted through the causal chain via local pressures inducing changes in the state of the ecosystems. Responses to the impacts close the causal chain to a “causal loop” by establishing the feedback as a reaction of society to the impacts.

The causal chain represented by the DPSIR framework does not adequately reflect the cause-effect relationships that are essential for detailed assessment of the situation and in turn for well-informed policy and planning interventions (cf. Niemeijer and de Groot, 2008 a,b). To solve this shortcoming of the DPSIR framework Niemeijer and de Groot (2008a) propose enhancing the DPSIR to a causal network approach.

The causal network approach provides a way to reflect the linkages between the driving forces, pressures, states, impacts and responses by showing the interactions between the several different components across each category of the DPSIR framework. The causal network thus improves the process of selecting indicators by providing decision support based on the cause-effect relation of each indicator in the causal network. The causal network approach also provides a better knowledge base for the planning of responses. The approach allows to consider the effects of changes in the driving forces, policy interventions, or behavioural changes in the causal network, taking possible positive and negative feedbacks between changes of the multiple driving forces, pressures, and states into account.

Niemeijer and de Groot (2008a,b) give examples for causal network designs. The example provided in Niemeijer and de Groot (2008b: 103) shows the orientation on the DPSIR frameworks categories.

The Recovery project´s causal network of coal mining landscapes is displayed in Figure 2.

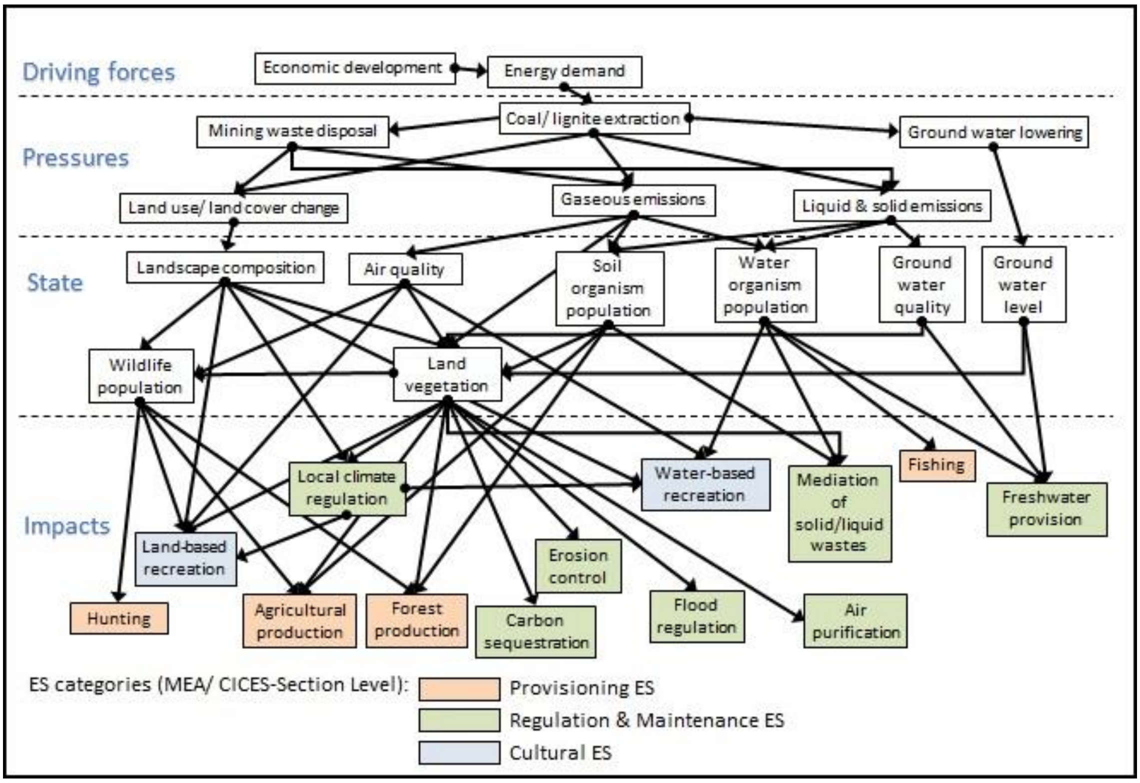


**Figure 2. Causal network of coal mining impacts**

The causal network of coal mining impacts was simplified to include the pressures, which are caused by coal mining. This reflects the focus on coal mining and the related effects for the state of the ecosystems and the resulting impacts. The text fields represent the relevant compartments of the network; arrows represent the functional links between the compartments. The driving forces are economic development and the resulting energy demand, these can be interpreted as originating mainly outside the mining areas, but drive the pressures in the mining areas. The pressure of coal/lignite extraction is the constituting pressure of mining areas. The initial pressure of coal/lignite extraction causes other pressures such as mining wastes, land cover change, ground water lowering and the emission of gaseous, solid and liquid emissions. The pressures influence the state of the affected landscape ecosystems. The state section of the causal network shows the affected ecosystem components. The complexity of connections in the state section of the network reflects the complexity of ecosystem structures and highlights the importance of biodiversity, represented by the land vegetation, wildlife population soil and water organism populations, for the generation of ES. The impacts section represents the changes in the generation of ecosystem services. The impact categories follow the cause-effect relations of the network, and can be translated into MEA/CICES categories making them comparable to other ES assessments. To illustrate this the ES categories from the MEA (2005), which correspond to the Section level of

CICES v5.1 (Haines-Young and Potschin, 2018), were colour coded in the impact section of the causal network. The impact categories are used as base for selecting indicators.

Acknowledging the differences in the different study areas, among them climatic conditions, different modes and scales of mining extraction, and different stages of re-cultivation of the mining landscape, the selection of suitable indicators requires the inclusion of local knowledge to identify the magnitude of impact on the ES in the respective local mining contexts, representing the supply of ES and the local demand for ES. For example the climatic conditions may result in the hydrological situation being more important in dryer areas, underground coal mining has less impact on the landscape composition than aboveground pit mining, re-cultivation of pit mines as lakes offers other recreation opportunities than recently re-cultivated mine dumps. The mining sites also differ in terms of demand for ES. Within the Recovery project each project partner identifies the relevant ES from the impact categories of the causal network based on the local situation and selects suitable indicators with reference to ES indicators established from previous scientific studies.

## 2.3 Indicator selection in Recovery

The causal network provides a general overview over the ES influenced by coal mining. The strength of the causal network is the ability to cover the different types of coal mining and address underground and aboveground mining alike. The next step of indicator selection has to acknowledge the differences in the different study areas, among them climatic conditions, different modes and scales of mining extraction and different stages of re-cultivation of the mining landscape. The selection of suitable indicators requires the inclusion of local knowledge to identify the magnitude of impact on the ES in the respective local mining contexts, representing the supply of ES and the local demand for ES. For example the climatic conditions may result in the hydrological situation being more important in dryer areas; underground coal mining has less impact on the landscape composition than aboveground pit mining; re-cultivation of pit mines as lakes offers other recreation opportunities than recently re-cultivated mine dumps. The mining sites also differ in terms of demand for ES. Within the Recovery project each project partner identifies the relevant ES from the impact categories of the causal network. Based on the local situation and ES indicators established from previous scientific studies, each partner selects suitable indicators. Table 1 shows the ES categories identified by the causal network and the corresponding CICES v5.1 classification.

**Table 1. Impact category and corresponding MEA and CICES v5.1 categories**

| Impact category | MEA category | CICES v5.1 group level (CICES code) |
|---|---|---|
| Agricultural production | Provisioning | Cultivated terrestrial plants for nutrition, materials or energy (1.1.1) & Reared animals for nutrition, materials or energy (1.1.3) |
| Forest production | Provisioning | Wild plants (terrestrial and aquatic) for nutrition, materials or energy (1.1.5) |
| Hunting | Provisioning | Wild animals (terrestrial and aquatic) for nutrition, materials or energy (1.1.6) |
| Fishing | Provisioning | Wild animals (terrestrial and aquatic) for nutrition, materials or energy (1.1.6) |
| Mediation of solid/liquid wastes | Regulation & Maintenance | Mediation of wastes or toxic substances of anthropogenic origin by living processes (2.1.1) |
| Erosion control | Regulation & Maintenance | Regulation of baseline flows and extreme events (2.2.1) |
| Flood regulation | Regulation & Maintenance | Regulation of baseline flows and extreme events (2.2.1) |
| Freshwater provision | Regulation & Maintenance | Water conditions (2.2.5) |
| Carbon sequestration | Regulation & Maintenance | Atmospheric composition and conditions (2.2.6) |
| Local cooling | Regulation & Maintenance | Atmospheric composition and conditions (2.2.6) |
| Air purification | Regulation & Maintenance | Mediation of wastes or toxic substances of anthropogenic origin by living processes (2.1.1) & Atmospheric composition and conditions (2.2.6) |

| | | |
|---|---|---|
| Land based recreation | Cultural | Physical and experiential interactions with natural environment (3.1.1) & Intellectual and representative interactions with natural environment (3.1.2) |
| Water based recreation | Cultural | Physical and experiential interactions with natural environment (3.1.1) & Intellectual and representative interactions with natural environment (3.1.2) |

The general impact categories are used to inform and guide the selection of suitable indicators for each specific coal-mining site. The table shows that the causal network and the MEA/ CICES categories don´t match completely, this is due to the fact, that the CICES classification system builds on the categories from the MEA but is not nested in cause-effect relationships of a given landscape/ecosystem context. However, the CICES classification is comparable to the impact categories derived from the causal network approach as can be seen in Table 1.

Several reviews to determine thematic coverage and quality of indicator sets for the assessment of ES based on CORINE Land Cover classes (Boerema et al., 2017; Czúcz et al., 2018; Maes et al., 2016, van Oudenhoven et al., 2018) can be found in the scientific literature. The reviews reveal which of the ES are more frequently assessed, the thematic coverage, and the reasons, why certain ES are more intensively assessed and measured than others. Some of the reviews also report the scale of measurement or quality of the indicators (Czúcz et al., 2018; Maes et al., 2016).

The reviews evaluate which ES categories form the MEA or CICES are supported by indicators of high quality in terms of data availability, data content and implementation (Maes er al., 2016). In terms of indicator quality approximately 20% of the indicators were considered to be of high quality (Maes et al., 2016). Differences between the ES categories and the studied ecosystems agro-ecosystems, forests freshwater and marine ecosystems are demonstrated in the review. While the proportion low quality indicators for provisioning services in the three mining relevant ecosystem types (agro-ecosystems, forest, freshwater), is overall low, this does not apply for the regulating services, where the forest ecosystems show a high proportion of low quality or unknown quality indicators. For cultural indicators the proportion of middle and low quality indicators is high in all mining-relevant ecosystem types (cf. Maes et al., 2016).

The findings of the review in terms of indicator quality has implications for the selection of suitable indicators for the Recovery project. Within the impacts categories identified by the network approach the importance of impacted ES varies between specific coal mining sites and for some sites the impact on specific ES may not be important as compared to other sites. Especially cultural ES are difficult to specify. In the selection of indicators, the local knowledge becomes especially important in specifying the cultural ES of each study site.

In the following section of the Deliverable Report the suitable indicators for each study area are introduced. Based on the causal network and the local context, the relevant ES for the respective study site are described and suitable indicators are selected based on relevant scientific studies using suitable indicators.

# 3 Suitable indicators for the RECOVERY case studies

## 3.1 Figaredo Mine (Spain)

In the case of Figaredo Mine, considering the casuistry of its area and the region in which it is located (Asturias, Spain), ninth ecosystem services were selected following the CICES V5.1 classes (Haines-Young and Potschin, 2018).

Regarding provisioning services, food and fibre production were considered, and abiotic freshwater supply was not considered. In Asturias, groundwater aquifers are not usually necessary for water supply, both drinking and industrial, as there are many rivers and water is abundant everywhere.

As for regulating services, climate regulation has been considered in the Figaredo mining area in two ways: through temperature and humidity. as Also, carbon sequestration, which is widely used in all ecosystem service assessments. Air quality regulation was considered in the Figaredo mine area under air purification, and flood regulation and storm-water retention were considered in water flow regulation. Erosion control was another ecosystem service considered.

As for cultural services, the biophysical characteristics or qualities of species or ecosystems were considered a good proxy for assessing biodiversity in general, also related to physical and mental recreation.

A detailed description of the selected indicators for each ecosystem services is presented hereafter.

### 3.1.1 Provisioning services: fibre production

Fibre production through pine plantations to produce wood as raw material is always one of the ecosystem service alternatives traditionally considered in Asturias, as well as one of the scenarios that will be further analysed. The relevant CICES V5.1 code is 1.1.1.2, and the class is 'Fibres and other materials from cultivated plants, fungi, algae and bacteria for direct use or processing (excluding genetic material)'. The ecosystem services indicator could be forest productivity as in Larondelle & Haase (2012).

### 3.1.2 Provisioning services: food production

Food production is another scenario that will be considered within the Figaredo mine area. Food supply through cows reared for feed at the Figaredo mine can only occur on pasture. However, horses are also reared for feed nowadays, although this is not as common as cows' case. The corresponding CICES V5.1 code is 1.1.3.1, and the class

"Animals reared for nutritional purposes". The ecosystem services indicator could be livestock production, as used by Baró et al. (2017).

### 3.1.3 Regulating services: climate regulation (temperature)

Air temperature is most apparent/suitable indicator to assess the climate impact of different planning policies, as trees and green regions moderate the climate. The corresponding CICES V5.1 code is 2.2.6.2 and the class 'Regulation of temperature and humidity, including ventilation and transpiration'. As air temperature is not easy to estimate spatially, thermal emissions from the earth's surface, which indicate the amount of energy emitted by bodies, could be used to measure temperature regulation. In this case, the ecosystem service indicator could be land surface thermal emissions as used by Schwarz et al. (2011).

### 3.1.4 Regulating services: climate regulation (humidity)

Humidity (evapotranspiration) was selected as a second indicator for estimating local climate regulation, as forests and green areas influence precipitation and water availability both locally and regionally. Evapotranspiration is the sum of the evaporation of water from the land surface and transpiration from vegetation. While CICES V5.0 shares in code 2.2.6.2 both temperature and humidity regulation, the old version V4.3 had different codes for them: 2.3.5.2 'Micro and regional climate regulation', and 2.2.3.2 'Ventilation and transpiration'. The reason is that the classification structure of provisioning services in V4.3 was changed in V5.1 to allow aggregation when the end-use is not known. The classification can be more easily used for accounting purposes. However, as temperature and humidity are not correlated, splitting the two services would facilitate the analysis. In this case, the ecosystem service indicator could be the evapotranspiration, as Schwarz et al. (2011) used.

### 3.1.5 Regulating services: water flow regulation

Water flow regulation is another regulating service to consider, as Asturias is a rainy region. The corresponding CICES V5.1 code is 2.2.1.3, and the class 'Hydrological cycle and water flow regulation'. The ecosystem services indicator could be the runoff, as in Nunes et al. (2011).

### 3.1.6 Regulating services: erosion control

Erosion control is also a regulating service to be considered, although its importance in the Asturias region is not very significant. The corresponding CICES V5.1 code is 2.2.1.1 and the class 'Control of erosion rates'. The ecosystem services indicator could be the soil loss potential as in Baró et al. (2017).

### 3.1.7 Regulating services: air purification

Air purification or removal of air pollution is provided by plants. They have large surfaces areas for particle deposition and adsorption of gases by the leaf or chemical reactions on the leaf surface. These processes are often referred to as ‘dry deposition’. The amount of pollution removed by plants depends on their leaves' size and surface area but can vary depending on climate, time of year, and other pollutants in the atmosphere. The CICES V5.1 code is 2.2.6.1. and the class is “Regulation of chemical composition of atmosphere and oceans”. The ecosystem service indicator selected was dry deposition of pollutants, as used by Jones et al. (2017).

### 3.1.8 Regulating services: carbon sequestration

Carbon sequestration was the last regulating service considered. In the case of pastures and coniferous forests, since they are considered provisioning services, this is incompatible with accounting for carbon sequestration as a regulating service. The CICES V5.1 code will be again 2.2.6.1 and the class “Regulation of chemical composition of atmosphere and oceans”. The ecosystem services indicator shall be above-ground carbon storage as in Larondelle & Haase (2012).

### 3.1.9 Cultural services: qualities of species or ecosystems (biodiversity)

The qualities of species or ecosystems (biodiversity) or biophysical features (landscapes) representing typical Asturian forests (Broad-leaved forests) in the Figaredo mine area was the last ecosystem service to be analysed. The CICES V5.1 code is 3.2.2.1, and the class ‘Characteristics or features of living systems that have an existence value’. An example of service should be ‘areas designated as wilderness’, and the ecosystem services indicator could be the types of living systems or environmental settings. Code 3.2.2.2 has the same ecosystem service class and the same indicator. The only difference is that while the simple descriptor of this code is ‘things in nature that we want future generations to enjoy or use’, the first code was ‘the things in nature that we think should be conserved’. In our view, the two are complementary and indissoluble, at least in this case.

Although there are different metrics to assess biodiversity considering aspects such as richness, evenness and identity of species, a study on the nexus between urban shrinkage and ecosystem services by Haase et al. (2014) was used as a reference for the specific biotope of Figaredo mine, to simplify the process. The indicator selected was the impact of shrinkage-related cover patterns.

Finally, Table 2 shows the ecosystem services and indicators that were selected for the Figaredo Mine area.

**Table 2. Ecosystem services and indicators for the Figaredo Mine area**

| Ecosystem Service | Indicator |
|---|---|
| Fibre production | Forest productivity |
| Food production | Livestock production |
| Climate regulation (temperature) | Land surface thermal emissions |
| Climate regulation (humidity) | Evapotranspiration |
| Water flow regulation | Runoff |
| Erosion control | Soil loss |
| Air purification | Dry deposition of pollutants |
| Carbon sequestration | Above-ground carbon storage |
| Qualities of species or ecosystems (Biodiversity) | Impact of shrinkage-related cover patterns |

## 3.2 Janina Mine (Poland)

The Janina Mine Waste Heap is an example of significant negative influence on the environment. In this area following impact categories should be considered:

- Air purification – zone contaminated by suspended dust (particulate matter – PM10, from site.
- Local cooling – decreasing the ability of ecosystems  to regulate temperature
- Flood regulation – increasing of surface water runoff
- Cultural services – decreasing of green area with recreation function for local community

Simultaneously mining activities create new ecosystem services which without mining impacts will never be served. In this area following impact categories could be identified:

- Mediation of solid/liquid wastes - increase storage capacity potential –
- Solar energy production - increase potential for deliver electric power from solar power

Base on assumption gathered in the Table 1, literature review and own experiences, for each impact categories following suitable indicators were defined:

### 3.2.1 Air quality regulation

The method for indication of the potential value of the role played by ecosystems is base on removal of atmospheric particulate pollution. It could be used to develop a range of decision support tools such as identifying optimal green area planting strategies for the removal  air pollution.  They used the amount of PM10 absorbed by different habitats as an indicator for this study (Tallis et al., 2011).

### 3.2.2 Hydrological cycle and water flow regulation

The water balance is directly connected with the water flow regulation of ecosystems in the urban area. The changing of relief and surface sealing impacts urban sprawl on water balance in an urban area and this process has caused both environmental problems and repercussions in society. The direct run-off was used as an indicator for water fluxes and the water balance assessment, as in Haase and Nuisl (2007).

### 3.2.3 Regulation of temperature

Urban heat island impacts on citizen’s general health status. Based on Land Surface Temperature higher and lower temperatures during sunny summer days could be delimited, as in study Mirzaei et al. (2020) Combining this information with the current land cover allow to access the role of ecosystems in local climate regulation.

### 3.2.4 Physical and experiential interactions with natural environment

The methods for biophysical assessment of cultural ecosystem service could be based on spatially explicit models for assessing different components of ecosystem services: potential, demand and actual flow. The number of inhabitants in distance buffers from the nature-based recreational site could be used as the indicator of physical and experiential interactions with natural environment (Vallecillo et al., 2019).

### 3.2.5 Solar power

Solar plants offer an opportunity to deliver ecosystem benefits but their development and operation may be detrimental to ecosystems (Casalegno et al., 2014). Solar power generation can be justified as ES in the post-mining landscape, because the landscape is already substantially impacted and solar energy generation can provide short term opportunities for compensating the economic decline and possible energy shortages in connection with the end of coal mining. Benefits from solar energy production is an important element of land-use planning and decision. The use of a photovoltaic geographical information system (Join Research Centre in the European Commission, 2018) as an input data source for estimation electric power production from solar energy plants was recommended in the study von Haaren et al. (2019).

### 3.2.6 Mediation of waste

Understanding the different functions that underpin the delivery of regulating ES is thus the first step in a mapping process. Mapping the mediation of waste and mass flows or the regulation of global and local climate is often based on the mapping of indicator substances or indicator species. Examples of these include carbon in case of climate regulation, nitrogen in case of wastewater regulation, or bees in case of pollination. There is insufficient mapping of, for example, how ecosystems clean up different pesticides or other pollutants, how it is in relation to waste storage and mediation, how they regulate other greenhouse gasses, or what is the combined role of all service providing species. So appropriate mapping methods and models are available but usually they are not applied on or extended to other material flows or other species. This requires more accurate spatial data of the stocks that are under regulation by ecosystems (e.g. pesticides, wastes) or the better inclusion of existing species trait information (for instance in case of pollination or pest control) (Burkhard and Maes, 2017). For Janina case study the estimation of available volume with waste mediation potential, with relation to density of stored wastes as an indicator of Mediation of waste potential were used.

Selected indicators allow a proper quantification of every ecosystem service involved in the Janina Mine coal mining-affected areas (Table 3).

**Table 3. Indicators for selected ecosystem services in Janina Mine case study**

| Ecosystem Service | Indicator |
|---|---|
| water flow regulation | The direct water run-off (QD) |
| air quality regulation | Air pollution absorption (PM10 & SO2) |
| temperature regulation | Thermal emissivity |
| Interactions with natural environment | biotopes values/<br>number of inhabitants in distance buffers from the nature-based recreational site |
| solar energy | electric power production |
| mediation of waste | Storage capacity |
| Carbon sequestration | Above-ground carbon storage |
| Qualities of species or ecosystems (Biodiversity) | Impact of shrinkage-related cover patterns |

## 3.3 Ema-Terezie Mine dumps complex (Czech Republic)

In the case of Ema – Terezie Mine dumps complex, considering the casuistry of its area and the region in which it is located (Upper Silesia/North Moravia, Czech Republic), six ecosystem services were selected following the CICES V5.1 classes (Haines-Young and Potschin, 2018).

Regarding provisioning services, food production was considered.

As for regulating services, Carbon sequestration and Climate regulation (temperature, according to Schwarz et al., 2011) has been considered. For Carbon sequestration (Larondelle and Haase, 2012) the indicator is above-ground carbon storage. In the CICES V5.1 framework is referred as carbon sequestration too, as in Kain et al. (2016), and is widely used in all ecosystem service assessments.

Due to significant occurrences of protected/rare species of plants and animals on Ema – Terezie Mine dump complex, next Regulating services, Regulation of physical, chemical, biological condition, were considered.

As for cultural services, cultural heritage and the biophysical characteristics or qualities of species or ecosystems were considered a good proxy for assessing biodiversity in general, also related to physical and mental recreation.

A most detailed description of the selected ecosystem services is presented hereafter.

### 3.3.1 Provisioning services: food production

Food provision is delivered in the Ema-Terezie mine dump case-study in Complex cultivation patterns and Land principally occupied by agriculture. Pastures are used only extensively; their livestock production is not known. The corresponding CICES V5.1 code is 1.1.1.1. and the class „Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes”. The ecosystem services indicator could be surface area of organic crops (ha), as used by Maes et al. (2016).

### 3.3.2 Regulating services: carbon sequestration

Carbon sequestration is delivered in the Ema-Terezie mine dump study-case by Broad-leaved forest, Dump sites, Green urban areas, Transitional woodland/shrubs and Natural grasslands. CLC Discontinuous urban fabric plays an important role due to large area. The corresponding CICES V5.1 code is 2.2.6.1 and the class “Regulation of chemical composition of atmosphere and oceans”. The ecosystem services indicator could be Above-ground carbon storage ($ha^{-1}$), The ecosystem service could be carbon sequestration as in Kain et al. (2016), and the ecosystem services indicator shall be above-ground carbon storage as in Larondelle & Haase (2012).

### 3.3.3 Regulating services: Climate regulation (temperature)

Climate regulation is delivered in the Ema-Terezie mine dump case-study by Broad-leaved forest (included mine dump sites), Green urban areas, Pastures, Transitional woodland/shrubs and Natural Grassland.
Air temperature was declared as the most apparent/suitable indicator when Schwarz et al. (2011) assessed the climate impact of different planning policies in the urban area of Leipzig in Germany, as trees and green regions moderate the climate. The corresponding CICES V5.1 code is 2.2.6.2 and the class 'Regulation of temperature and humidity, including ventilation and transpiration'. As air temperature is not easy to estimate spatially, thermal emissions from the earth's surface, which indicate the amount of energy emitted by bodies, could be used to measure temperature regulation. In this case, the ecosystem service indicator could be land surface thermal emissions as used by Schwarz et al. (2011).

### 3.3.4 Regulating services: regulation of physical, chemical, biological condition

Maintaining rare populations and habitats (including gene pool protection) in the Ema-Terezie mine dump case study due to protected and iconic plant species (for example *Quercus cerris, Pyrola minor, Hacquetia epipactis, Chenopodium botrys*) and animal species (for example *Bombina bombina, Bombina variegata, Anguis fragilis, Emberiza citrinella, Dendrocopos minor*). The corresponding CICES V5.1 code is 2.2.2.3 and the class "Maintaining nursery populations and habitats (Including gene pool protection)". In this case, the ecosystem service indicator could be Number of rare species (Liquete et al., 2016).

### 3.3.5 Cultural services: cultural heritage

The biophysical characteristics or qualities of species or ecosystems (landscapes) which people seek to preserve for future generations for whatever reason: in this case, the conservation and protection of typical ecosystems bound to thermally active black coal mine dumps with the occurrence of thermophilic fauna and flora species. The corresponding CICES V5.1 code is 3.2.2.1 and the class "Characteristics or features of living systems that have an existence value". In this case, the ecosystem service indicator could be number of visitors (Baró et al. 2016).

### 3.3.6 Cultural services: qualities of species or ecosystems (biodiversity)

The qualities of species or ecosystems (biodiversity) or biophysical features (landscapes) representing typical Broad-leaved forests in the Ema – Terezie mine dumps complex was the last ecosystem service could be analysed. The CICES V5.1 code is 3.2.2.1, and the class ‘Characteristics or features of living systems that have an existence value’. An example of service should be ‘areas designated as wilderness’, and the ecosystem services indicator could be the types of living systems or environmental settings. Code 3.2.2.2 has the same ecosystem service class and the same indicator. The only difference is that while the simple descriptor of this code is ‘things in nature that we want future generations to enjoy or use’, the first code was ‘the things in nature that we think should be conserved’. In our view, the two are complementary and indissoluble, at least in this case.

Although there are different metrics to assess biodiversity considering aspects such as richness, evenness and identity of species, a study on the nexus between urban shrinkage and ecosystem services by Haase et al. (2014) was used as a reference for the specific biotope of Figaredo mine, to simplify the process. The indicator selected was the impact of shrinkage-related cover patterns.

Finally, Table 4 shows the ecosystem services and indicators that were selected for the Ema – Terezie mine dumps complex.

**Table 4. Ecosystem services and indicators for the Ema – Terezie mine dump complex**

| Ecosystem Service | Indicator |
|---|---|
| Food production | Surface area of organic crops |
| Carbon sequestration | Above-ground carbon storage |
| Climate regulation (temperature) | Land surface thermal emissions |
| Regulation of physical, chemical, biological condition | Number of rare species |
| Cultural heritage | Number of visitors |
| Qualities of species or ecosystems (Biodiversity) | Impact of shrinkage-related cover patterns |

## 3.4 Most-Ležáky mine and Chabařovice mine (Czechia)

### 3.4.1 Provisioning services: food provision

Arable lands on both study cases are not that valuable according to farmland classification but these areas provide stable agricultural production. The CICES V5.1 code is 1.1.1.1 and class name is “Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes” Indicator could be productivity of food crops (Larondelle and Haase, 2012).

### 3.4.2 Regulating services: erosion rate regulation

Transitional woodland/shrubs has big impact on erosion rates on north and west part of the Lake Most and surroundings around Lake Milada. These areas are mainly for slope stability purposes but also for fauna habitats but also for recreation purposes. The CICES V5.1 code is 2.2.1.1 and class name is “Control of erosion rates” Indicator could be soil loss potential (Baró et al., 2017).

### 3.4.3 Regulating services: climate regulation

Lake Most and lake Milada and Broad-leaved forests, Transitional woodland/shrubs, Natural grasslands and Pastures has huge impact on microclimate. Especially when there are large differences in day and night temperatures. The lakes cumulate large amount of thermal energy and react with the ambient temperature, which results in evapotranspiration. The CICES V5.1 code is 2.2.6.2 and class name is “Regulation of temperature and humidity, including ventilation and transpiration” Indicator could be potential evapotranspiration (Schwarz et al., 2011).

### 3.4.4 Cultural services: environment for sport and recreation

The process of resocialization on the Chabařovice and Most-Ležáky study areas is in progress. There are many possibilities to do sports and relax. On both lakes there are new studies and plans how to increase and improve the process of resocialization for sports, relax and education. The CICES V5.1 code is 3.1.1.1 and class name is “Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions” Indicator could be recreational areas (Handley, J et al., 2003).

#### *3.4.4.1 Cultural services: using nature to destress*

Chabařovice and Most-Ležáky study areas offer numerous species of animals and plants. Thanks to combination of lakes, transitional woodland/shrubs and forests, there many species of waterfowls, fishes, birds, mammals and amphibians. And with the easy access to these areas for people, the is a great opportunity to observe fauna. The CICES V5.1 code is 3.1.1.2 and class name is "Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through passive or observational interactions". Indicator could be species diversity (Lindemann-Matthias et al., 2010).

### 3.4.5 Regulation services: atmosphere regulation

Study case areas are mainly covered by vegetation with high percentage of forestry type of land cover. Thanks to this composition of land cover. These ecosystems are regulating carbon and dust particles in atmosphere which is relevant issue in both localities and surroundings due to active mining and industry. The CICES V5.1 code is 2.2.6.1 and class name is "Regulation of chemical composition of atmosphere and oceans" Indicator could be above-ground carbon and dust particles storage (Larondelle and Haase, 2012).

### 3.4.6 Regulation services: landslide regulation

Spoil heaps are few years and at most dozens of years old. These new structures in landscape are vulnerable to landslides and similar extreme events due to erosion. Even with correct procedures in remediation process, there still can be danger of high erosion rates. For type of slopes where this was threatened was very helpful to prevent risks with amelioration plants. The CICES V5.1 code is 2.2.1.2 and class name is "Buffering and attenuation of mass movement" Indicator could be area in vulnerable exposition covered by vegetation (Baró et al., 2017).

Table 5 shows the ecosystem services and indicators that were selected for the Most-Ležáky mine and Chabařovice mine.

**Table 5. Ecosystem services and indicators for the Most-Ležáky mine and Chabařovice mine area**

| Ecosystem Service | Indicator |
|---|---|
| Food provision | Productivity of food crops |
| Erosion rates regulation | Soil loss potential |
| Climate regulation | Potential evapotranspiration |
| Environment for sport and recreation | Recreation areas |

| | |
|---|---|
| Using nature to de-stress | Species diversity |
| Atmosphere regulation | Above-ground carbon and dust particles storage |
| Landslide regulation | Area in vulnerable exposition covered by vegetation |

## 4 Conclusions and lessons learned

The selection of suitable indicators for coal mining affected landscapes and ecosystems represents a challenge for ecosystem service assessment. With the relevant factor for the predominant land use determined by geological potentials and not by land cover these landscapes have the coal mining activities as common feature, while the other landscape attributes, in particular the ecosystems that constitute the land cover and landscape functions may vary considerably between mining landscapes.

The relevance of coal mining for the landscape requires an approach to indicators selection which considers the specific driving forces and pressures from coal mining on the ecosystem state and the resulting impacts for the ability to generate the ecosystem functions which can bee utilized as ecosystem services. Within the first steps of indicators selection this is done by building on the DPSIR framework mainstreamed by the EEA for environmental impact assessment. To account for the complexity of interactions between pressures states and impacts the DPSIR framework was extended to a causal network. The causal network guides the process of indicator selection by providing clear representation of the coal mining impact and displaying the ES which have to be considered in the process of post-mining landscape recovery.

At this stage of the indicators selection process the list of ES is not study site specific, it rather represents a framework to be adopted for coal mining sites, regardless whether the mining action takes place aboveground or underground. With some minor adjustments the framework can also be used for ore mining and quarrying, adding additional value to the developed indicators selection approach.

In the application stage of the process of indicators selection the specific conditions of the respective study site is considered. Selection of suitable indicators for each ecosystem services in several case studies (Figaredo Mine in Spain, Janina Mine in Poland, Ema-Terezie Mine and Most-Ležáky mine and Chabařovice mine in Czech Republic) is leading to quantification of every ES related to coal mining-affected areas. Feasible valuation technique in general relates to indicators specifically selected for those areas, considering location, climate and mining impact, which cause land degradation and changes in water, soil and air conditions.

Indicators of ecosystem services selected for case studies in the project are scientific constructs and its quantification is possible with use data and existing measurements of ecosystem conditions (i.e. air pollution, water run-off, soil degradation and erosion etc.) and, indirectly, human well-being (cultural, habitants' interactions with natural environment).

Considering different stakeholders involved in the process of changing mine-impacted areas, ecosystem indicators provide information at a level appropriate for management decision-making by assessing changes in the status of ecosystem services. This ecosystem indicators are selected from main categories (cultural, provisioning) and relates to regulation and economical features of mine impacted areas (i.e. waste meditation, solar energy production etc.).

Comparison between case studies in the project will be possible taking into consideration ES indicators such as: water runoff, air pollution and thermal emissivity and other indicators related to the impact of coal mining. The comparison has to be reflected in the light of differences in the type (above/underground) and the scale of mining (large scale/small scale) and other landscape conditions, such as climate, geomorphology or hydrology.

However, in terms of recovery of landscape functions or replacement or creation of new landscape functions following the mining the different study sites are comparable. This comparison can be based on the benefits derived from the ES and uses the assessment of ES based on the suitable indicators for each study sites and a valuation of the benefits using feasible valuation techniques.

For example in the case of Figaredo Mine in Spain, Land based recreation & Hunting were considered altogether within an ecosystem serviced named “Qualities of species or ecosystems (Biodiversity)”. Fishing and Water based recreation were not considered as in the area there are no water flows or water lakes. Finally, Freshwater provision was also not considered as in the Asturian region there is enough water from rivers and reservoirs. All the rest of ecosystem services derived from the causal network allow to determine the influence of coal mining on ecosystem state and ES generation. Thus, water runoff, air pollution and thermal emissivity may be adequate indicators to establish comparison as they are common to all the case studies that are being studied within RECOVERY.

The presented approach results in a compilation of ES which is in good accordance with the ES categories mainstreamed by the MEA and the CICES, even though the latter two are not the based on a causal chain approach. The application of the indicator selection process on the specific study sites also shows, that some ES which are treated as separate ES in the common classification system are bundled in one impact category and should be considered together. The application also shows, that some Impact categories identified by the causal network are not relevant in the context of a specific study site.

Considering the local context plays a major role in considering suitability of indicators and is important in the selection of suitable indicators. This confirms the choice of the two-sided approach. One side being the causal network approach to identify the coal mining impacts and provide the systematic foundation of the selection of indicators and the other side being the involvement of the local context to determine the extent of the relevance of the impact in the local setting and the suitability of the indicator for the respective study site. The selection of suitable indicators as presented by the Recovery project provides a method to meet the common challenge of recovering mining affected landscapes, while at the same time respecting the diversity of local conditions in the EU.

## 5 Glossary

CICES: Common International Classification of Ecosystem Services

CLC: Corine Land Cover

DPSIR: Driving Forces-Pressures-State-Impact-Response

LC: Land Cover

EEA: European Environmental Agency

ES: Ecosystem Service

MEA: Millennium Ecosystem Assessment

## References

Baró, F., Gómez-Baggethun, E., & Haase, D. (2017). Ecosystem service bundles along the urban-rural gradient: Insights for landscape planning and management. *Ecosystem Services*, *24*, 147–159. https://doi.org/10.1016/j.ecoser.2017.02.021

Boerema, A., Rebelo, A. J., Bodi, M. B., Esler, K. J., Meire, P. (2017). Are ecosystem services adequately quantified? *Journal of Applied Ecology 54*, 358-370. https://doi.org/10.1111/1365-2664.12696

Burkhard, B., & Maes, J. (2017). Mapping ecosystem services. Advanced books, 1, e12837.

Casalegno, S., Bennie, J. J., Inger, R., & Gaston, K. J. (2014). Regional scale prioritisation for key ecosystem services, renewable energy production and urban development. *PloS ONE, 9(9)*. https://doi.org/10.1371/journal.pone.0107822

Czúcz, B., Arany, I., Potschin-Young, M., Bereczki, K., Kertész, M., Kiss, M., Aszalós, R., Haines-Young, R. (2018). Where concepts meet the real world: A systematic review of ecosystem service indicators and their classification using CICES. *Ecosystem Services 29*: 145-157. https://doi.org/10.1016/j.ecoser.2017.11.018

Feld, C. K., Sousa, J. P., da Silva, P. M., Dawson, T. P., (2010). Indicators for biodiversity and ecosystem services: towards an improved framework for ecosystems assessment. *Biodivers Convers 19*: 2895-2919. DOI 10.1007/s10531-010-9875-0

Gabrielsen, P., Bosch, P. (2003). Environmental Indicators: Typology and Use in Reporting. EEA internal working paper. *European Environment Agency*, Copenhagen. 20 pp.

Haase D. (2009) Effects of urbanisation on the water balance - A long-term trajectory. *Environ Impact Assess Rev 29*: 211–219. https://doi.org/10.1016/j.eiar.2009.01.002

Haase, D., Haase, A., Rink, D., (2014). Conceptualising the nexus between urban shrinkage and ecosystem services. *Landsc. Urban Plan. 132*: 159–169. https://doi.org/10.1016/j.landurbplan.2014.09.003

Haase, D., & Nuissl, H. (2007). Does urban sprawl drive changes in the water balance and policy?: The case of Leipzig (Germany) 1870–2003. *Landscape and Urban Planning* 80(1-2), 1-13.

Haines-Young, R., & Potschin, M. B. (2018). Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure. *European Environment Agency*, (January), 53. Retrieved from www.cices.eu

Handley, J., Pauleit, S., Slinn, P., Lindley, S., Baker, M., Barber, A., Jones, C., 2003. Providing Accessible Natural Green Space in Towns and Cities: A Practical Guide to Assessing the Resource and Implementing Local Standards for Provision. Retrieved from http://publications.naturalengland.org.uk/publication/65021

Heink, U., Hauck, J., Jax, K., Sukopp, U. (2016). Requirements for the selection of ecosystem service indicators – The case of MAES indicators. *Ecological Indicators 61*: 18-26. http://dx.doi.org/10.1016/j.ecolind.2015.09.031

Heink, U., Kowarik, I. (2010). What are indicators? On the definition of indicators in ecology and environmental planning. *Ecological Indicators 10*: 584-593. DOI: 10.1016/j.ecolind.2009.09.009

Join Research Centre in the European Commission, (2018). Photovoltaic geographic information system Europe. Available: http://re.jrc.ec.europa.eu/pvgis.

Jones, L., Vieno, M., Morton, D., Cryle, P., Holland, M., Carnell, E., Nemitz, E., Hall, J., Beck, R., Reis, S., Pritchard, N., Hayes, F., Mills, G., Koshy, A. & Dickie, I. (2017). Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts. Final report for the Office of National Statistics (ONS). *Centre for Ecology and Hydrology (CEH)*, United Kingdom, July 2017. http://nora.nerc.ac.uk/id/eprint/524081/7/N524081RE.pdf

Kain, J. H., Larondelle, N., Haase, D., & Kaczorowska, A. (2016). Exploring local consequences of two land-use alternatives for the supply of urban ecosystem services in Stockholm year 2050. *Ecological Indicators*, *70*, 615–629. https://doi.org/10.1016/j.ecolind.2016.02.062

Larondelle, N., & Haase, D. (2012). Valuing post-mining landscapes using an ecosystem services approach - An example from Germany. *Ecological Indicators*, *18*, 567–574. https://doi.org/10.1016/j.ecolind.2012.01.008

Lindemann-Matthias et al., 2010, The influence of plant diversity on people's perception and aesthetic appreciation of grassland vegetation. Retrieved from https://doi.org/10.1016/j.biocon.2009.10.003

Liquete, C., Cid, N., Lanzanova, D., Grizzetti, B. and Reynaud, A. (2016). Perspectives on the link between ecosystem services and biodiversity: The assessment of the nursery function. *Ecological Indicators*, 63, pp.249-257.

Maes, J., Liquete, C., Teller, A., Erhard, M., Paracchini, M. L., Barredo, J. I., Grizzetti, B., Cardoso, A., Somma, F., Petersen, J.-E., Meiner, A., Gelabert, E. R., Zal, N., Kristensen, P., Bastrup-Birk, A., Biala, K., Piroddi, C., Egoh, B., Degeorges, P., Fiorina, C., Santos-Martín, F., Naruševičius, V., Verboven, J., Pereira, E. M., Bengtsson, J., Gocheva, K., Marta-Pedroso, C., Snäll, T., Estreguil, C., San-Miguel-Ayanz, J., Pérez-Sobam, M., Grêt-Regamey, A., Lillebø, A. I., Abdul Malak, D., Condé, S., Moen, J., Czúcz, B., Drakou, E. G., Zulian, G., Lavalle, C. (2016). An indicator framework for assessing ecosystem services in support of the EU Biodiversity Strategy to 2020. *Ecosystem Servcies 17*: 14-23. http://dx.doi.org/10.1016/j.ecoser.2015.10.023

Millennium Ecosystem Assessment (MEA) (2005). Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. https://doi.org/10.5822/978-1-61091-484-0_1

Mirzaei, M., Verrelst, J., Arbabi, M., Shaklabadi, Z., & Lotfizadeh, M. (2020). Urban heat island monitoring and impacts on citizen's general health status in Isfahan metropolis: A remote sensing and field survey approach. *Remote Sensing, 12(8)*, 1350.

Müller, F., Burkhard, B., (2012). The indicator side of ecosystem services. *Ecosystem Services 1*: 26-30. http://dx.doi.org/10.1016/j.ecoser.2012.06.001

Niemeijer, D., de Groot, R. S., (2008a). A conceptual framework for selecting environmental indicator sets. *Ecological indicators 8*: 14-25. https://doi.org/10.1016/j.ecolind.2006.11.012

Niemeijer, D., de Groot, R. S., (2008b). Framing environmental indicators: moving from causal chains to causal networks. *Environ Dev Sustain 10*: 98-106. https://doi.org/10.1007/s10668-006-9040-9

Nowak, D.J., Crane, D.E., Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. *Urban For. Urban Green. 4*: 115–123. https://doi.org/10.1016/j.ufug.2006.01.007

Nunes, A. N., de Almeida, A. C., & Coelho, C. O. A. (2011). Impacts of land use and cover type on runoff and soil erosion in a marginal area of Portugal. *Applied Geography, 31*(2), 687–699. https://doi.org/10.1016/j.apgeog.2010.12.006

Organisation for Economic Co-operation and Development (OECD) (1993). Environemnt Monographs Nº 83: OECD Core Set of Indicators for Environmental Performance Reviews – A synthesis report by the Group on the State of the Environment. OCDE/GD(93)179, Paris 39 pp. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=OCDE/GD(93)179&docLanguage=En

Rapport, D., Friend, A. (1979). Towards a comprehensive framework for environmental statistics: a stress-response approach. Statistics Canada Catalogue 11-510. Minister of Supply and Services Canada, Ottawa.

Seják, J., Dejmal, I., Petricek, V., Cudlin, P., Michal, I.,Cerny, Cudlinova, E. (2010). Method of monetary valuation of territorial ecological functions. Mscr., JE Purkyne University, Ústí nad Labem

Seppelt, R., Fath, B., Burkhard, B., Fisher, J. L., Grêt-Regamey, A., Lautenbach, s., Pert, P., Hotes, S., Spagenberg, J., Verburg, P. H., van Oudenhoven, A. P. E., (2012). Form follows function? Proposing a blueprint for ecosystem servcies assessments based on reviews and case studies. *Ecological Indicators 21*: 145-154. DOI: 10.1016/j.ecolind.2011.09.003

Smeets, E., Weterings, R., 1999. Environmental Indicators: Typology and Overview. Report No. 25. *European Environment Agency*, Copenhagen. 19 pp. https://www.eea.europa.eu/publications/TEC25 (Downloaded:01.11.2021).

Schwarz, N., Bauer, A., & Haase, D. (2011). Assessing climate impacts of planning policies - An estimation for the urban region of Leipzig (Germany). *Environmental Impact Assessment Review*, *31*(2), 97–111. https://doi.org/10.1016/j.eiar.2010.02.002

Tallis, M., Taylor, G., Sinnett, D., & Freer-Smith, P. (2011). Estimating the removal of atmospheric particulate pollution by the urban tree canopy of London, under current and future environments. *Landscape and Urban Planning, 103(2)*: 129-138.

TEEB (2010). The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Edited by Pushpam Kumar. *Earthscan*, London and Washington. http://www.teebweb.org/our-publications/teeb-study-reports/ecological-and-economic-foundations/#.Ujr1xH9mOG8

Troian, A., Gomes, M.C., Tiecher, T., Berbel, J., Gutiérrez-Martín, C. (2021). The Drivers-Pressures-State-Impact-Response Model to Structure Cause-Effect Relationships between Agriculture and Aquatic Ecosystems. *Sustainability 13*: 9365. https://doi.org/10.3390/su13169365

Vallecillo, S., La Notte, A., Zulian, G., Ferrini, S., & Maes, J. (2019). Ecosystem services accounts: Valuing the actual flow of nature-based recreation from ecosystems to people. *Ecological Modelling 392*: 196-211.

van Oudenhoven, A. P. E., Schröter, M., Drakou, E. G., Geijzendorffer, I. R., Jacobs, S., van Bodegom, P. M., Chazee, L., Czúcz, B., Grunewald, K., Lillebø, A. I., Mononen, L., Nogueira, A. J. A., Pacheco-Romero, M., Perennou, C., Remme, R. P., Rova, S., Syrbe, R.-U., Tratalos, J.A., Vallejos, M., Albert, C. (2018). Key criteria for developing ecosystem servcie indicators to inform decision making. *Ecological Indicators 95*: 417-426. https://doi.org/10.1016/j.ecolind.2018.06.020

von Haaren, C., Lovett, A. A., & Albert, C. (2019). Landscape planning with ecosystem services. *Springer Netherlands*.