RFCS RESEARCH PROJECT

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

847205-RECOVERY-RFCS-2018

Deliverable 3.1

Blueprint instrument/indicator

European Commission

Research Fund for Coal & Steel

Authors

Prof. Dr. Dagmar Haase, Humboldt-Universität zu Berlin
Dipl. Geogr. Peer von Döhren, Humboldt-Universität zu Berlin
Łukasz Pierzchała Ph.D, Central Mining Institute
Ewa Janson Ph.D Eng., Central Mining Institute
Adam Hamerla Ph. D, Central Mining Institute
Prof Dr. Eng. Alicja Krzemień, Central Mining Institute

Deliverable 3.1	
Due date of Deliverable	01.01.2021
Start - End Date of Project	01.07.2019 – 30.06.2023
Duration	4 years
Deliverable Lead Partner	UBER
Dissemination level	Public
Work Package	WP 3
Digital File Name	D3.1 Blueprint instrument/indicator
Keywords	Blueprint instrument/indicator, LC assessment, CLC, ES assessment, LC change, Scenarios

Table of contents

List of Figures

List of Tables

Executive Summary

The deliverable Report D3.1 informs about the objectives, methodological background and application of a blueprint instrument/indicator to assess of mining impact and the recovery of post mining areas. The blueprint instrument/ indicator presented in the following documentation uses a tiered approach, which is based on the assessment of land cover (LC), from which landscape metrics are assessed and based on the landscape metrics ecosystem services (ES) of the investigated mining and post-mining landscapes are derived.

The base for the blueprint instrument/indicators is an assessment of the LC, that aims to identify the composition of the landscape. The types of LC are determined by the mining activities. A set of very distinct LC types is typical for mining landscapes and continues to dominate the post mining landscapes. LC assessment can be based on a variety of data sources, such as remote sensing imagery, or maps. In both cases the application of the blueprint instrument/ indicator requires digitization of the data and classification of the land uses in order to be used in a Geographical Information System (GIS). The LC assessment is demonstrated, as baseline mapping, in the Deliverables 2.1-2.5 of the RECOVERY project.

The assessment of landscape metrics informs the assessment of ES about the amount of ES which can be expected from the landscape depending on the size of the area of each LC class. Despite the complexity associated with the topic of landscape metrics the blueprint instrument/indicator presented can sufficiently be based on the landscape composition, especially the sizes of the different LC classes identified in the baseline mapping. The calculation of the patch sizes of the respective polygons is done in the GIS. From this calculation a quick overview about the direct impact of the mining activities is possible, showing the difference of pit mining and underground mining.

The assessment of ES is the next step in the blueprint instruments/indicators procedure. ES are well-suited to demonstrate the dependency of the human society on natural systems. Within the blueprint instrument/indicator procedure the ES approach connects the evaluation of the LC and landscape metrics to the benefits for human society. The ES concept is very successful in science and politics and has strong influence on natural capital accounting and green infrastructure planning. It is therefore important to understand what ES represent.

Scenarios are important to set a framework for future projections for the post-mining development. Within the blueprint instruments/indicator procedure the scenarios provide the framework for the assessment of LC changes in the post mining period. There are a lot of different approaches to the development of scenarios, and as scenarios are assumptions of future developments they are to a certain degree fictional. It is therefore important to develop storylines, which are internally consistent and comprehensible. Even though this report will not go into detail as to how to develop storylines, it demonstrates a method to operationalize the developed storylines. Transition rules are one way to systemize the LC change based on the storylines.

The application of the blueprint instrument/indicator procedure is demonstrated by two case studies. The first case study builds on exploratory work in the post mining area south of Leipzig (the Mibrag Mines area). In this case study the LC change of the landscape before the mining activity, during the mining activity and the post-mining landscape was assessed using land surface data from historical maps and the EU CORINE LC dataset, validated using digital satellite images from the COPERNICUS programme and Google Earth Pro™. From this LC assessment the landscape metrics of the LC classes were calculated and based on this the relevant ES were assessed. The study then explores three possible scenarios to develop the post-mining region and projects the changes of ES generated by the different compositions of post-mining landscapes. The second case study explores the application of the blueprint instruments/indicators approach to an area with an active underground mining operation. The underground mining activity doesn't cause a wide range of spatial changes like open-cast mining and different approaches in this case is needed. Both case studies provide valuable information for the further development of the methods within the RECOVERY project.

1 Introduction

With ongoing efforts to keep climate change within an acceptable level, the EU set out a vision for the decarbonisation of the European economy (European Commission, 2018a). The efforts to fulfil this mission will eventually result in the abandonment of fossil energy-resource-extraction in the future. However, with the beginning of the industrial revolution the economy depended on the mining of coal and lignite for energy generation for processes especially in the heavy industry (European Commission 2018b; Wirth et al., 2012). Coal and lignite mining have transformed landscapes and degraded ecosystems resulting in the loss of natural capital and transformation of social and settlement structures (European Commission, 2018b; Kabisch, 2004; Mancini & Sala, 2018; Wirth et al., 2012). The need to, not only halt the deterioration of biodiversity (Target 1 of the EU biodiversity strategy to 2020) but also maintain and enhance ESs (Target 2) (European Commission, 2011) makes the rehabilitation of post-mining landscapes necessary for the future of the EU. The rehabilitation and ecological restoration of coal-mining affected landscapes faces major challenges, which require the development of tools, which are suitable to identify, assess and evaluate alternative rehabilitation strategies and future land-uses and their potentials to deliver sustainable ESs.

The EU RFCS research project recovery takes on the challenge to deliver a comprehensive approach to meet the challenges of returning the transformed and degraded (post-) mining landscapes to a condition, which is equivalent to the condition before mining. A key element of this objective is the development of a process, which enables scientists as well as practitioners to assess the transformation of the landscape under different development expectations. This assessment serves as base for the evaluation and selection of the best available pathways towards rehabilitation of post-mining landscapes.

The task T3.1 in Work Package Nº 3 focuses on the development of a blueprint instrument/ indicator, representing a feasible ex-ante impact assessment approach to support best practices in the assessment of mining activities and their impact on land-cover, land-use and ES provision. Specific objectives are:

1. Assessing the pre-mining, mining and post-mining landscapes with respect to function and sustainability, seeking a quantitative pragmatic assessment.
2. Applying the ESs approach to this assessment.
3. Evaluating the applicability of the ESs concept to mining impact assessment and post-mining landscape patterns.
4. Developing a blueprint instrument/indicator set for both mining impact assessment and post-mining landscape (e) valuation.

2 Methods

The specific objectives for the development of a blueprint instrument/ indicator for the assessment and evaluation of the recovery/rehabilitation of post mining landscapes uses a set of methods, which need to be on the one hand reliable and valid, on the other hand feasible and pragmatic. Reliability and validity means the blueprint instrument/indicator set should deliver comparable measures, where possible in biophysical or sociocultural dimensions. Feasibility and pragmatism means the blueprint instrument/indicator should work with readily available data and the methods used should be comprehensible and readily applicable for the people involved with planning, administrating and evaluating post-mining landscape rehabilitation.

The blueprint instrument/indicator presented here provides a general framework for the assessment of mining and post-mining landscapes. It serves as a toolkit designed to convert LC data as input into a feasible and pragmatic ex ante assessment of mining landscapes and conversion pathways. The blueprint instrument indicator was developed based on the baseline mapping and ecosystem assessment procedures applied earlier in the recovery project and extended to include guidance on the operationalization of scenarios of future development paths for the respective mining areas. The blueprint instrument/indicator comprises a LC change assessment coupled with an assessment of the affected landscape functions resulting in an assessment of the ESs which are based on the landscape functions. By applying different alternatives of LC change scenarios, future development paths for post mining landscapes are assessed. Transfer/transition matrices are used assess LC change and compare the development alternatives.

Blueprint instrument/indicator:

- LC assessment:
    - Definition of boundaries of the study area based on spatial connectivity and functional cohesion
    - Mapping and classification of LC
- Assessment of ES:
    - Calculation of landscape metrics (landscape composition):
    - ES quantification
- Scenario development:
    - Development of LC alternatives in the form of storylines
    - Operationalisation of scenarios with transition rules
    - Application of transition rules to LC and ES assessment

2.1 Land cover assessment – baseline mapping

- Landcover assessment:
    - Definition of boundaries of the study area based on spatial connectivity and functional cohesion
        - Procedures:
            - Direct impact of mining on the landscape (mining and dump sites) have to be within the boundaries
            - Indirect impact of mining (industrial sites using mining products, settlements build to house the workforce, other artificial LC with functional connection to mining, industry or settlements with connection to mining) should be within the study site.
            - Natural areas that are potentially affected by flows of material or energy from the mining and dump sites should be included based on geomorphological (valleys, ridges, watersheds) or if not applicable administrative (e.g. municipalities) criteria.
        - Resources:
            - Digital satellite images
            - Topographic maps (digitalization is needed)
            - Digital elevation models
            - Software with editing functionality of digital land surface data (Google Earth Pro™, GIS)
        - Pros:
            - Data availability
            - Access to data
            - Comprehensive criteria for delineation
        - Cons:
            - Delineation more complicated for large mining areas and homogenous geomorphological criteria
    - Mapping and classification of LC.
        - Procedures:
            - visual recognition of different textures
            - visual recognition of boundaries between textures
            - classification of LC based on CORINE LC classification
        - Resources:
            - Digital satellite images (required)
            - Software with editing functionality of digital land surface data (Google Earth Pro™, GIS) (required)
            - Digital topographic maps (supplementary)

        - Other digital geospatial datasets (e.g. digital elevation models, Copernicus Land Monitoring Service – High Resolution Layers, OpenStreetMap)(supplementary)
        - Reference works for CORINE LC classification (Kosztra et al., 2017)
    - Pros:
        - Data availability
        - Access to data
        - Established classification system
    - Cons:
        - differentiate similar natural areas (e.g. different forest covers) is challenging
        - Seasonal variation of agricultural areas.

The LC assessment uses the experiences gained from the baseline mapping procedure in WP 2 of the Recovery project. After defining the boundaries based on existing spatial connectivity and functional cohesion, the methods demonstrated in the deliverables 2.1-2.5 apply visual identification and delineation discrete LC patches of satellite images provided by Google Earth Pro™. The delineation is followed by a visual classification of the land uses based on reference works developed in the EU CORINE LC programme (Kosztra et al., 2017). The baseline mapping was further supplemented by the use of the following open sources of high-resolution LC data for refinement:

- Copernicus Land Monitoring Service – High Resolution Layers 2015 (Tree cover area, Grassland, Water and Wetness)
  Source: https://osmlanduse.org/#14/19.31215/50.08129/0)
- OpenStreetMap Landcover (plugin QuickOSM for QGIS)
  Source: https://osmlanduse.org/#14/19.31215/50.08129/0

The methods explored in the baseline mapping have the following advantages. The data is widely available and can easily be accessed. The delineation of land use polygons is comparably easy for landscapes that show a distinctive influence of human activity, as in the case of mining landscapes. The LC classification is feasible provided the person doing the classification is familiar with the usual types of land use of the study area. Application of the CORINE LC classification makes sense, because this classification system covers all LCs encountered in Europe and knowledge transfer is facilitated by using an established and broadly accepted classification system.

In the development of the blueprint instrument/ indicator procedures challenges have to be considered to make the method of baseline mapping applicable as part of the blueprint instrument/ indicator set. These will be addressed in the following paragraphs and recommendations to overcome these challenges are provided.

The identification of the boundaries for the study area shows a marked difference between surface and underground mining. Especially if the mining area is very large, and the landscape is not mountainous, the identification of natural boundaries for the study area becomes challenging. The solution to this is the use of administrative boundaries for the study area. For mining areas this is justified by the assumption, that with spatial connectivity not impeded by natural barriers the functional cohesion depends on the planning and administration of mining and post mining areas.

The use of satellite images, such as Google Earth Pro™ as demonstrated in the baseline mapping imposes some limitations. One is the availability of clear satellite images, which may only cover certain seasons, resulting in a confounding factor in case the vegetation cover changes drastically over the seasons.

The detailed third level of classification of the CORINE LC classification requires more experience when it comes to discerning agricultural land uses or types of natural or semi-natural vegetation cover. This drawback can be compensated by comparison to existing CLC datasets that are available freely in a 25 ha resolution for most of the European Union land surface.

2.2 Assessment of ecosystem services

- Assessment of ES:
    - Calculation of landscape metrics (landscape composition):
        - Procedures:
            - Calculation of the number of different LC classes
            - Calculation of the total area of each LC class
            - Calculation of the proportion of each LC class
        - Resources:
            - GIS
        - Pros:
            - simple, comprehensive landscape metrics
            - easy to understand and relate to decision makers
            - early estimation of mining impact possible
        - Cons:
            - Comparison between different mining sites not advised
            - Simple landscape metrics don´t capture landscape configuration
    - ES quantification
        - Procedures:
            - Identification of relevant ES depending on local demand
            - Identification on ES generated by LC class (indicators)

    - Consideration of amount of ES generated depending on landscape composition (indicators by spatial unit)
    - Consideration of ES which exclude each other
    - Standardisation of ES indicator values
  - Resources:
    - Reference for ES classification: Millennium Ecosystem Assessment (MEA, 2005), CICES v5.1 (Haines-Young & Potschin, 2018)
    - Reference works for ES based on LC: MAES (Maes et al., 2013; Maes et al., 2015; Maes et al., 2016), RUBICODE project (Burkhard et al., 2009)
  - Pros:
    - The key message is easy to understand
    - ES approach considers aspects of ecology and economics.
    - ES approach is compatible with administrative and economic planning.
    - ES quantification is targeted at local demand for ES.
    - Comparison of alternative ES based on value of benefits
  - Cons:
    - Anthropocentric perspective of ES approach is debatable
    - Overestimation of economic aspects of ES approach is a challenge

Landscape metrics/indices establish the connection between land use/LC mapping and ES accounting by relating landscape structure to ecosystem functions associated with the landscapes (Botequilha Leitão & Ahern, 2002; Uuemaa et al., 2009).

In the preliminary work that was done to prepare the blueprint instrument/indicator development, the calculation of landscape metrics was kept to the necessary minimum of assessing the most basic characteristics of the landscape composition. The basic characteristics of the landscape composition are the number of different LC types, representing the diversity of land uses in the study area and the area occupied by the respective land uses representing the proportion of the area being occupied by the respective LC. These basic landscape metrics are necessary to assess the potential of ecosystems services that can be generated by the respective LC (Maes et al., 2013). The basic landscape metrics can easily be assessed after the baseline mapping is done using freely available GIS software.

The advantage of only applying the most basic landscape metrics in the blueprint indicator are the simplicity and comprehensibility of the applied metrics. The calculation of the number of different LCs and size and proportion of the respective LC types is easy to understand and apply. Despite representing the most basic types of landscape metrics the diversity and proportion of the LC types provide information about the type and intensity of human influence the landscape is subjected to.

The disadvantage is that aspects of ES generation that are influenced by more complex landscape metrics representing the landscape configuration are not covered by the blueprint instrument/ indicator procedures. However, concerning the applicability of complex landscape metrics a review exploring the use of landscape metrics in ecological studies found out, that landscape metrics are mainly used for the assessment of general LC patterns rather than ecosystem functions (Uuemaa et al., 2013). Typical applications are very specialized on certain species for which the habitat specifications can be assessed by landscape metrics and generalization of these findings to general assumptions about landscape pattern and biodiversity are limited (Uuemaa et al., 2009; Walz, 2011; Walz & Syrbe, 2013).

The next step in the blueprint instrument/indicator for mining and post mining impact assessment is the assessment of the ecosystem functions associated with the identified LCs the respective ecosystem functions are quantified. The ecosystem functions used for this assessment are either relevant for economic processes or for the realisation of the EU´s strategic goals concerning the conversion of earth´s environment (European Commission, 2011).

To be able to consider overlapping of mutually excluding ES from the same LC classes, the blueprint instrument/indicator set uses multiple classification systems for ES. Alternative classification systems are applied, to meet the requirements of making the assessment comparable to the common classification systems and informing valuation and cost-benefit analysis as well as landscape planning. As additional classification systems, supplementing the CICES classification, which emphasizes the assessment of final ESs (Haines-Young & Potschin, 2018), the classifications based on excludability and rivalness (Costanza, 2008; Fisher et al., 2009) and spatial characteristics (Costanza, 2008, Fisher et al., 2009) have to be recorded for assessed ESs.

The selection of ES indicators, based on the LC uses the updated CLC classification (Büttner & Kosztra, 2017; Kosztra et al., 2017) in connection with the latest version (v5.1) of the CICES (Haines-Young & Potschin, 2018). Similar approaches for the assessment of ES have been suggested (Burkhardt et al., 2009; Maes et al., 2013) and tested for regional ES assessment studies (for example Burkhardt et al., 2009) national (for example Albert et al. 2016; for a review of National ES Assessments in Europe cf. Schröter et al., 2016) and the European level (Maes et al., 2015). Burkhard et al. (2009:6) introduce a lookup table, which displays a set of 29 ES for the 44 level 3 CLC classes representing expert assumptions on the relevance for each CLC class to provide the 29 ES (Figure 1). A comprehensive and current list of ES indicators including the data availability and uncertainties can be found in Maes et al. (2016: 20).

	Ecological Integrity Σ	Abiotic heterogeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy Capture (Radiation)	Reduction of Nutrient loss	Storage capacity (SOM)	Provisioning services Σ	Crops	Livestock	Fodder	Capture Fisheries	Acquaculture	Wild Foods	Timber	Wood Fuel	Energy (Biomass)	Biochemicals / Medicine	Freshwater	Regulating services Σ	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air Quality Regulation	Erosion Regulation	Nutrient regulation	Water purification	Pollination	Cultural services Σ	Recreation& Aesthetic Values	Intrinsic Value of Biodiversity
Continuous urban fabric	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Discontinuous urban fabric	7	1	1	1	1	1	1	1	3	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial or commercial units	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Road and rail networks	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port areas	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	1	1	0
Airports	7	1	1	1	1	1	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mineral extraction sites	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dump sites	8	2	1	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Construction sites	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Green urban areas	18	3	3	2	1	4	3	2	2	0	0	0	0	0	1	0	1	0	0	0	11	2	1	0	2	1	2	1	1	1	3	3	0
Sport and leasure facilities	16	2	2	2	1	4	3	2	0	0	0	0	0	0	0	0	0	0	0	0	9	1	1	0	2	1	1	1	1	1	5	5	0
Non-irrigated arable land	22	3	2	3	4	5	1	4	21	5	5	5	0	0	0	0	0	5	1	0	5	2	1	1	1	0	0	0	0	0	1	1	0
Permanently irrigated land	21	3	2	5	2	5	1	3	18	5	5	2	0	0	0	0	0	5	1	0	5	3	1	1	0	0	0	0	0	0	1	1	0
Ricefields	20	3	2	5	1	5	1	3	7	5	0	2	0	0	0	0	0	0	0	0	4	2	0	0	2	0	0	0	0	0	1	1	0
Vineyards	14	3	2	3	1	3	0	2	5	4	0	0	0	0	0	0	1	0	0	0	3	1	1	0	1	0	0	0	0	0	5	5	0
Fruit trees and berries	21	4	3	4	2	3	2	3	13	5	0	0	0	0	0	4	4	0	0	0	19	2	2	2	2	2	2	1	1	5	5	5	0
Olive groves	17	3	2	3	2	3	1	3	12	4	0	0	0	0	0	4	4	0	0	0	7	1	1	0	1	1	1	1	1	0	5	5	0
Pastures	24	2	2	4	5	5	2	4	10	0	5	5	0	0	0	0	0	0	0	0	8	1	1	1	1	0	4	0	0	0	3	3	0
Annual and permanent crops	18	2	2	3	2	4	2	3	20	5	5	5	0	0	0	0	0	5	1	0	7	2	1	1	1	1	1	0	0	0	1	1	0
Complex cultivation patterns	20	4	3	3	2	4	1	3	9	4	0	3	0	0	0	0	0	0	2	0	5	2	1	1	1	0	0	0	0	0	2	2	0
Agriculture& natural vegetation	19	3	3	3	2	3	2	3	21	3	3	2	0	0	3	3	3	3	1	0	13	3	2	1	2	1	3	0	1	0	5	2	3
Agro-forestry areas	27	4	4	4	3	4	4	4	14	3	3	2	0	0	0	3	3	0	0	0	13	2	1	1	1	1	2	1	1	3	3	3	0
Broad-leaved forest	31	3	4	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Coniferous forest	30	3	4	4	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Mixed forest	32	3	5	5	4	5	5	5	21	0	0	1	0	0	5	5	5	0	5	0	39	5	4	3	2	5	5	5	5	5	10	5	5
Natural grassland	30	3	5	4	4	4	5	5	5	0	3	0	0	0	2	0	0	0	0	0	22	2	3	1	1	0	5	5	5	0	6	3	3
Moors and heathland	30	3	4	4	5	4	5	5	10	0	2	0	0	0	1	0	2	5	0	0	20	4	3	2	2	0	0	3	4	2	10	5	5
Sclerophyllous vegetation	21	3	4	2	3	3	4	2	8	0	2	0	0	0	1	0	2	0	3	0	7	2	1	1	1	0	0	0	0	2	6	2	4
Transitional woodland shrub	21	3	4	2	3	3	4	2	5	0	2	0	0	0	1	0	2	0	0	0	3	1	0	0	0	0	0	0	0	2	4	2	2
Beaches, dunes and sand plains	10	3	3	1	1	1	0	1	2	0	0	0	0	0	0	0	0	2	0	0	6	0	0	5	1	0	0	0	0	0	7	5	2
Bare rock	6	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	1	0	0	0	1	0	4	4	0
Sparsely vegetated areas	9	2	3	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	1	1	0	0	0	0	0	0	0	0
Burnt areas	6	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
Glaciers and perpetual snow	3	2	1	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	5	10	3	3	0	4	0	0	0	0	0	5	5	0
Inland marshes	25	3	2	4	4	4	3	5	7	0	2	5	0	0	0	0	0	0	0	0	14	2	2	4	2	0	0	4	0	0	0	0	0
Peatbogs	29	3	4	4	4	4	5	5	5	0	0	0	0	0	0	0	0	5	0	0	24	4	5	3	3	0	0	3	4	2	8	4	4
Salt marshes	23	2	3	4	3	3	3	5	2	0	2	0	0	0	0	0	0	0	0	0	8	1	0	5	0	0	0	2	0	0	3	3	0
Salines	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	2	2	0
Intertidal flats	13	2	3	0	2	1	4	1	0	0	0	0	0	0	0	0	0	0	0	0	7	1	0	5	0	0	0	1	0	0	4	4	0
Water courses	18	4	4	0	3	3	3	1	12	0	0	0	3	0	4	0	0	0	0	5	10	1	0	2	1	0	0	3	3	0	10	5	5
Water bodies	23	4	4	0	4	4	3	4	12	0	0	0	3	0	4	0	0	0	0	5	7	2	1	1	2	0	0	1	0	0	9	5	4
Coastal lagoons	25	4	4	0	5	5	3	4	16	0	0	0	4	5	4	0	0	3	0	0	5	1	0	4	0	0	0	0	0	0	9	5	4
Estuaries	21	3	3	0	5	5	3	2	17	0	0	0	5	5	4	0	0	3	0	0	9	0	0	3	0	0	0	3	3	0	7	4	3
Sea and ocean	15	2	2	0	3	3	4	1	11	0	0	1	5	5	0	0	0	0	0	0	13	3	5	0	0	0	0	5	0	0	6	4	2

Legend: 0 = rosy colour = no relevant capacity of the land cover type to provide this particular ecosystem service, 1 = grey green = low relevant capacity, 2 = light green = relevant capacity, 3 = yellow green = medium relevant capacity, 4 = blue green = high relevant capacity and 5 = dark green = very high relevant capacity. In the rows between the assessments (yellow colour), sums for the individual ecosystem services groups were calculated.

Figure 1. Matrix for the assessment of the different LC types‘ capacities to provide selected ecosystem goods and services (from Burkhard et al., 2009: 6)

The following ES matrix (Table 1) is an example of how CLC, ES according to CICES classification and two alternative classifications can be documented. The Matrix also records suitable indicators as well as information about possible bundles of ES and if trade-offs or synergies exist between the bundles.

Table 1. Example of a CLC-ES-indicator matrix to record ES characteristics

No	CLC	ES	CICES Code	Rivalness/ Excludability	Spatial P/B relation	Indicator	Bundle with, trade-off/synergy
1	2.1.1. Non-irrigated arable land	Cultivated terrestrial plants for nutritional puroposes	1.1.1.1	Rival/ Excludable	In situ	Agricultural productivity of food crops	n/a
2	3.1.1. Broad-leaved forest	Regulation of chemical composition of atmosphere and oceans	2.2.6.1	Non-rival/ Non excludable	Omni-directinal	Above-ground carbon storage	No 3, trade-off
3	3.1.1. Broad-leaved forest	Fibres and other materials from wild plants for direct use or processing	1.1.5.2	Rival/ Excludable	In situ	Forest productivity	No 2, trade off
…	…	…	…	…	…	…	…

The proposed blueprint instrument/indicator delivers different units for different ES indicators. The measurements themselves can´t be compared to each other based on their measuring units, even for the two, which share a convertible unit, i.e. tons to kg comparison does not make sense. One way is to convert all the ES indicators measuring units to monetary values, following the TEEB approach (TEEB, 2010). Apart from the uncertainties involved in monetary valuation, it is too complicated for a feasible impact assessment. Comparability of ES indicator values is achieved by standardizing each indicator to scores from 0-1 by subtracting the minimum value of the respective indicators from the indicator value to be transformed and then dividing by the difference of maximum respective indicator value and minimum indicator value. With all indicator values transformed to values between 0 and 1 they can be added to compare total ES output between each ES. A comparable approach by standardization to values between 1 and 10 was used for ES comparison by Larondelle & Haase (2012: 570). The application of a weighting to the standardized indicator value facilitates inclusion of stakeholder participation (i.e. inclusion of non-monetary valuation approaches) as additional option in the application of the blueprint instrument/indicators for mining landscape assessment. Weighting can be done by multiplying the standardized indicator values per LC patch, with a number between 0 and 1. This represents a value assigned by different stakeholders to the ES output based on planning targets or demand for that ES. The weighting procedure is an interesting option to help decision procedures about ecosystem bundles, when trade-off decisions between ES are necessary (cf. Kubal et al., 2009; Meyer et al., 2009).

2.3 Scenarios of LC change

- Scenario development:
    - Development of LC alternatives in the form of storylines
        - Procedures:
            - Description of the planning goals or drivers of projected developments
            - Description of the actions, LC transformations connected to the projected developments
            - Documentation of the motivation/reason for choosing the respective storylines
        - Resources:
            - Development plans or policies which impact the regional development
            - Expert judgement on possible LC development
            - External economic drivers based on global developments
        - Pros:
            - Storylines can be selected based on the motivation of the scenario developers
            - Development of scenarios is an open process, which can serve several purposes (e.g. targeted action or “laisser-faire”, economic priorities or ecologic priorities, etc.)
        - Cons:
            - The open process of storyline development can lead to misunderstandings.
    - Operationalisation of scenarios with transition rules
        - Procedures:
            - Determine which original LC classes will be transformed

            - Determine which LC classes will not be transformed
            - Determine the resulting LC classes of the respective transformation
            - Development of LC transition matrices
        - Resources:
            - Statistical information of LC transformations in comparable post mining areas
            - Development plans and/ or policies which impact the regional development
            - Expert judgement on possible LC transition
        - Pros:
            - Easy applicability of LC transition determined by transition matrices
            - Procedure is easy to understand by decision makers and stake holders
        - Cons:
            - Transition matrix is limited to deterministic assumptions. Complex transitions are beyond the scope of the procedure
    - Application of transition rules to LC and ES assessment
        - Procedures:
            - Replace LC classes of the original LC assessment with the respective transformed LC class (cf. LC assessment)
            - Recalculate ES potentials based on transformed LC classes (cf. Assessment of ES)
        - Resources:
            - LC classes dataset from LC assessment (s.a.)
            - Transition matrix from operationalisation of scenarios (s.a)
            - GIS
        - Pros:
            - Easy implementation in GIS
            - Direct comparison of current landscape composition to projected landscape composition
            - Direct comparison of current ES supply to projected ES supply
        - Cons:
            - Complex changes in landscape configuration cannot be represented by the procedure
            - Changes in ES demand are not accounted for

Scenarios of LC change inform the future pathways of development of the post-mining landscapes. The development of scenarios is a projection of future developments. Scenarios are in use in several disciplines for forecasting and planning purposes and have a long history in land use planning (Xiang & Clarke, 2003). Scenarios are a tool to support decision making, by informing decision-makers and stakeholders of the possible outcomes of their choices (EEA, 2007). Though there is no generally accepted classification of scenario-types or requirements of how to design scenarios (Börjeson et al., 2006; EEA, 2007; Xiang & Clarke, 2003), there are some guidelines which help in developing scenarios which are useful in the blueprint instrument/indicator approach.

The blueprint instrument/ indicator approach uses scenarios of alternative land uses for the purpose of projecting possible outcomes of the reclamation process. They can therefore be described as explorative, strategic scenarios, meaning they project what can happen to the landscape if we act in a certain way, i.e. follow a certain development strategy (Börjeson et al., 2006: 728).

To project the LC changes from the scenario assumptions the LC classes assessed for the present day situation of ongoing or recently stopped mining activities are transformed into the projected land uses according to the scenario. The scenario storyline guides the decision which LC classes are transformed to which future LCs. The storylines can draw on different sources of information such as policy guidelines (Schwarz et al., 2011) assumptions based on past trends in land use change (Büttner & Kosztra, 2011), or different alternatives to explore the continuum of possible reclamation outcomes (Larondelle & Haase, 2012). The storylines for the development should be documented, to enable experts and stakeholders to understand the assumptions and judge the plausibility and efforts connected to the assumptions. Assumptions about the LC change may be “pessimistic” or “optimistic” in relation to the EUs ecological development goals projecting a worst case or best case scenario respectively. A business as usual scenario serves to balance the extreme scenario assumptions and provide a baseline for scenario comparison. If the time period of the landscape transformations plays a role for the assessment it should be guided by experience values of the processes assumed for the storylines.

Transition rules represent the change of LC classes from one class to another. Examples for the use of transition rules can be found in Schwarz et al. (2011: 101) or for explicit transition of mining landscapes in Larondelle & Haase (2012: 570).

The transition rules are implemented in the GIS with the current LC assessment by replacing the current land use with the projected land use according to the transition rules. The procedure is straight-forward and easy to understand and reproduce. The results for the landscape are recorded in LC transfer matrices and can be displayed with easy graphical solutions such as bar or pie charts, which are easy to understand for decision makers and stakeholders.

A drawback of the procedures used to operationalise the land use alternatives from the scenarios is the deterministic approach to the LC transition. The transition rules are limited in their capacity to account for complex mechanisms of LC changes, for example LC changes that influence each other once a tipping point is reached by either or all involved LC classes. These effects are considered to be of very low relevance, as the reclamation of artificially disturbed landscapes is a deterministic process, which limits unforeseen effects.

The ES potentials and landscape structure of the LC alternatives generated in the scenarios are assessed like the present state LC and landscape structures (see 2.2 Assessment of ES). To ensure a meaningful comparison it is necessary to use the same LC Indicators and landscape metrics in the calculations for the current and projected ES. For a visualization of the projected landscape change maps of the projected CLC are very useful as they offer a quick overview.

A constraint of the ES assessment based on replacing the current LC classes with the LC classes assumed in the different scenarios and operationalized by application of LC transfer rules leading to LC transition matrices and LC transition maps is the underestimation of changes in ecosystem demand by the local or global beneficiaries. The methods employed in the presented blueprint instrument/ indicator assume current demand for ES to determine relevance of the ES and therefore consideration in the assessment. The underestimation of ES supply should not be overrated. Most ES chosen for mining or post mining sites play a critical role during or as an objective of the reclamation. The demand for them can therefore be assumed to remain constant or increase in the future rather than decrease.

3 Application

This section of the report introduces two case studies, which provided valuable insights for the development of the blueprint instrument indicator. The first one demonstrates a pre-mining, mining and post-mining landscape assessment of an open cast lignite mining area south of Leipzig, Germany. This case study gives examples of the ES approach for impact assessment of mining and post mining landscapes as well as the guiding questions considered in the development of the blueprint instrument/indicator. The other example demonstrates the ES approach for mining impact assessment of an underground coal-mine – Libiąż area where Janina Coal Mine is still active. The two examples demonstrate the application of the ES concept to mining landscapes, piloting the blueprint instrument/indicator development and show the differences caused by the type of the mining operation, thereby highlighting the need for a flexible use of the blueprint instrument/indicator in mining landscape assessment.

3.1 The Mibrag Mines case study

3.1.1 Description of the Mibrag Mines study site

The Mibrag Mines case study introduced in the following section builds on the preliminary work done in the Recovery project and on the lessons learnt from a previous study done in the pit mining landscape south of Leipzig (Larondelle & Haase, 2012).

The study area is located in eastern central Germany, south of Leipzig in a region which belongs to the “Mitteldeutsches Braunkohlerevier” (Middle-German Lignite Fields). The study area covers roughly 200 km², making it, with almost twice the size of all other study areas together, the largest study area in the EU RFCS research project “Recovery of degraded and transformed ecosystems in coal mining –affected areas”. The study area is dominated by three large abandoned lignite mining pits giving testimony to almost a century of large scale lignite mining in the region (Larondelle & Haase, 2012). Small-scale mining operations in the area south of Leipzig started as early as 1672, when the rulers of the area, gave permission to the mining of sulphur and subsequently lignite, which was, at that time, not differentiated from hard coal (Berkner, 2004). However, the mining was very small scale. The large scale pit mining operations, which resulted in the characteristic landscape transformation of the area started in 1921 (Berkner, 2004). The landscape before the mining operations began in 1921, was a typical Pleistocene landscape in the catchment of the Pleiße and Weiße Elster rivers (Fig 2).

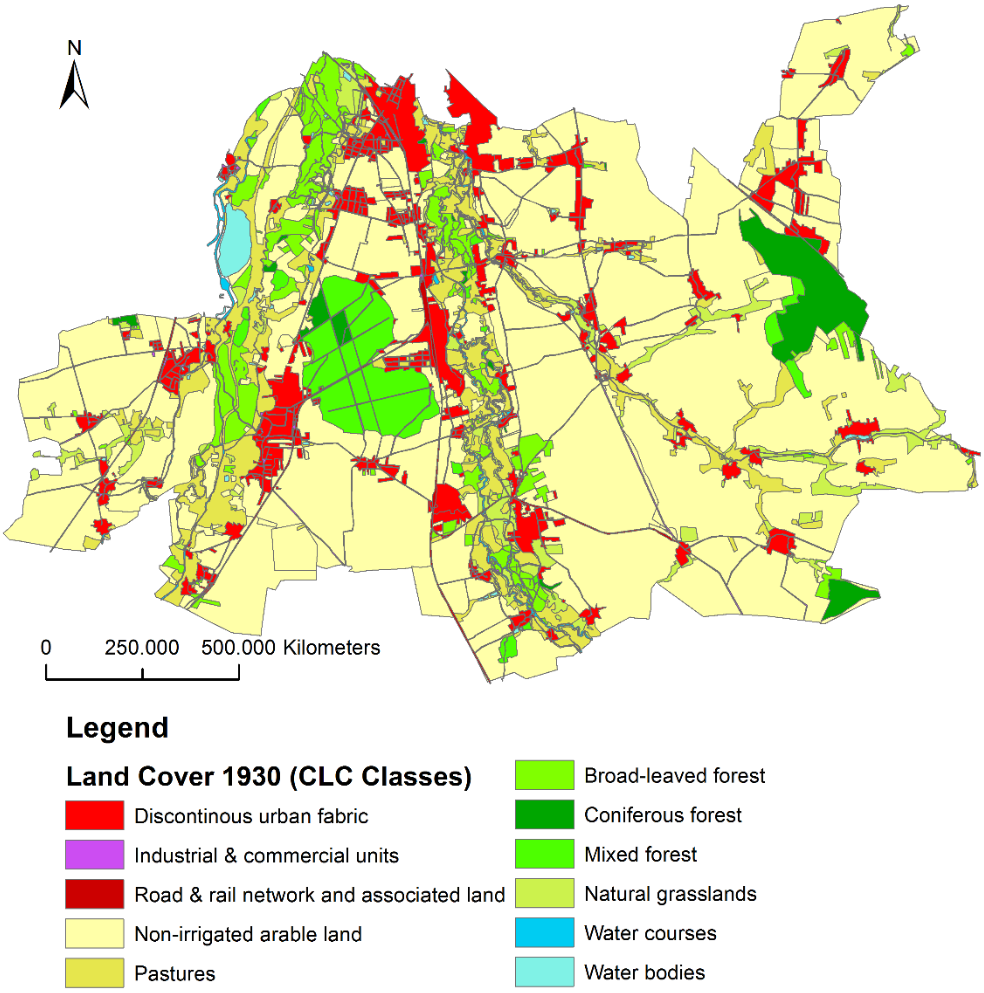


Figure 2. Mibrag Mines study area before large scale mining (1930)

The Assessment of LC and ES for the Mibrag Mines region was essentially done in the same way as demonstrated in the deliverables 2.5 and 2.10 of the RECOVERY Project. The reader is referred to the respective deliverable reports for detailed information on the procedures and data used. The impact assessment of the Mibrag Mine was used as a pilot study as it goes beyond the other case studies of the RECOVERY Project. The Mibrag Mines case study also uses data form digitized historical topographic maps from 1930 and allows a comparison of the projected post mining landscape composition to the one before the mining activities began.

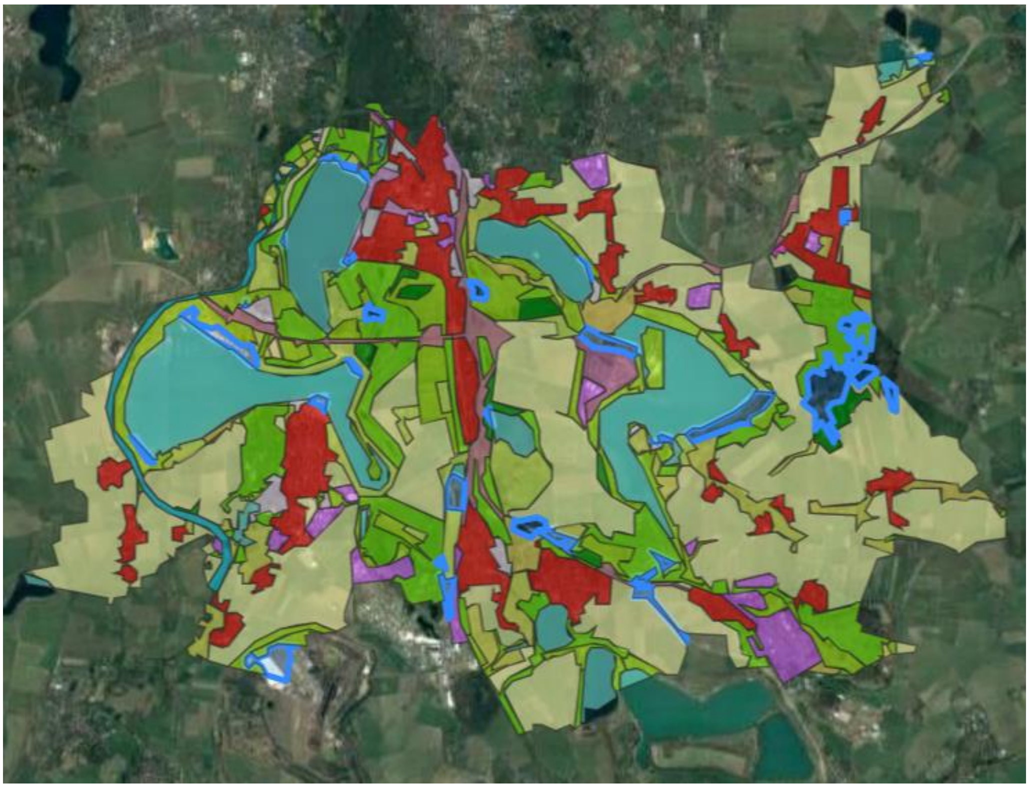


Figure 3. CLC classes in Mibrag Mines study area (2016) over the orthoimage of the area

3.1.2 Description of Mibrag Mines Scenarios

From the current landscape composition (Figure 3), three scenarios were developed to project three paths of development for the area after the end of mining. The endpoint for the scenarios was 2050. The scenarios were inspired by the previous work done in this study area (Larondelle & Haase, 2012).

- Scenario I – Recreational Priority:
    - Storyline: The completely filled pit mining lakes are used for a water sports and nature tourism based regional development. The storyline is plausible because lakes of comparable size don´t naturally occur in this kind of landscape and respective strategic and development planning documents are being realized (Larondelle & Haase, 2012; Wirtschaftsförderungsgesellschaft Anhalt-Bitterfeld & Stadt Leipzig, 2014).
    - Transition rules:
        - Increase in discontinuous urban fabric as recreational housing in appropriate shoreline locations (natural grasslands).
        - Moderate increase in broad-leaved forest at the expense of transitional woodland and grassland.

        - Mining sites and dump are reclaimed for broad leaved and mixed forest and partly agriculture (appropriate locations)
- Scenario II: Agricultural priority:
    - Storyline: Agriculture, especially non-irrigated arable land dominates the post-mining economy. Most reclaimed land is used for agricultural production. Forested areas remain in the peripheral parts of the study area.
    - Transition rules:
        - Mining and dump sites transformed to agricultural land (mainly non-irrigated arable land, remote parts pastures and agricultural land with significant proportions of natural vegetation, depending on site condition)
        - Pit lakes are flooded (not as highly as in scenario I)
        - No new residential settlements in the reclaimed areas
        - Forest remains in peripheral parts of the study area
- Scenario III: Forestry priority:
    - Storyline: forestry as economical resource for fibre production dominates the post-mining development of the study site.
    - Transition rules:
        - Mining and dump sites transformed to broadleaved forest
        - No new residential settlements in the reclaimed areas
        - Pit lakes are flooded (not as highly as in scenario I)
        - No transformation of existing non-irrigated arable land to other uses.

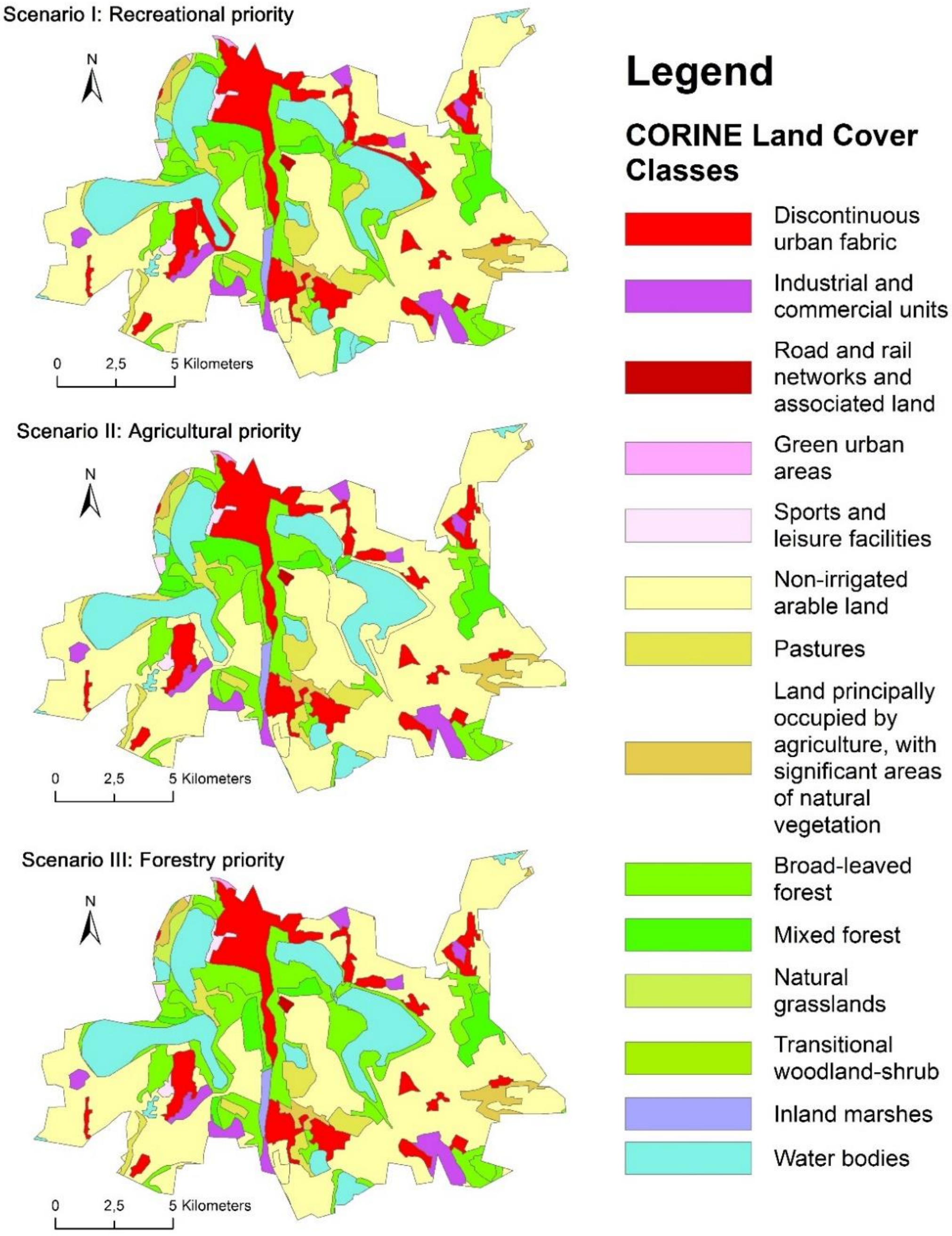


Figure 4. LC scenarios for Mibrag Mines study area

3.1.3 Results and conclusions of Mibrag Mines scenarios

The major changes from the pre to the mining state of the landscape are the changes of agricultural area to mining related uses including the increase in proportion of mining areas, waste disposal areas and industrial areas as well as the proportional increase in traffic areas. This does not show in the transfer matrix because the reclamation is already going. The changes from the present state to the different scenarios have one thing in common, the filling up of the pit mining lakes is finished and so the inactive mining pits are transformed to lakes. Another transformation of the scenarios is the transition of the dump sites and the successional state of transitional woodland/shrub to either forest in scenario 3, agricultural land in scenario 2 or grassland and discontinuous urban fabric (holiday accommodation) in scenario 1 (Table 2, Figures 4, 5).

Table 2. Proportions of relevant LC from pre- to post-mining period

CLC Code / Description	LC 1930	LC 2016	LC Scenario I	LC Scenario II	LC Scenario III
112: Discontinuous urban fabric	8.73%	10.81%	12.40%	11.60%	11.60%
121: Industrial or commercial units	1.95%	3.01%	3.24%	3.25%	3.25%
122: Road and rail networks and associated land	0.56%	2.24%	0.14%	0.14%	0.14%
131: Mineral extraction sites	0.00%	0.43%	0.00%	0.00%	0.00%
132: Dump sites	0.00%	0.63%	0.00%	0.00%	0.00%
211: Non-irrigated arable land	62.27%	36.74%	44.90%	50.73%	45.13%
231: Pastures	9.31%	3.59%	6.23%	6.35%	3.15%
243: Land principally occupied by agriculture, with significant areas of natural vegetation	0.00%	1.28%	2.16%	2.17%	2.17%
311: Broad-leaved forest	4.79%	11.01%	16.97%	11.62%	21.66%
312: Coniferous forest	2.77%	1.12%	0.00%	0.00%	0.00%
313: Mixed forest	3.94%	2.34%	3.87%	4.50%	3.26%

321: Natural grasslands	3.90%	3.76%	0.68%	0.68%	0.68%
324: Transitional woodland-shrub	0.00%	13.15%	0.32%	0.32%	0.32%
512: Water bodies	0.67%	6.30%	7.87%	7.40%	7.40%

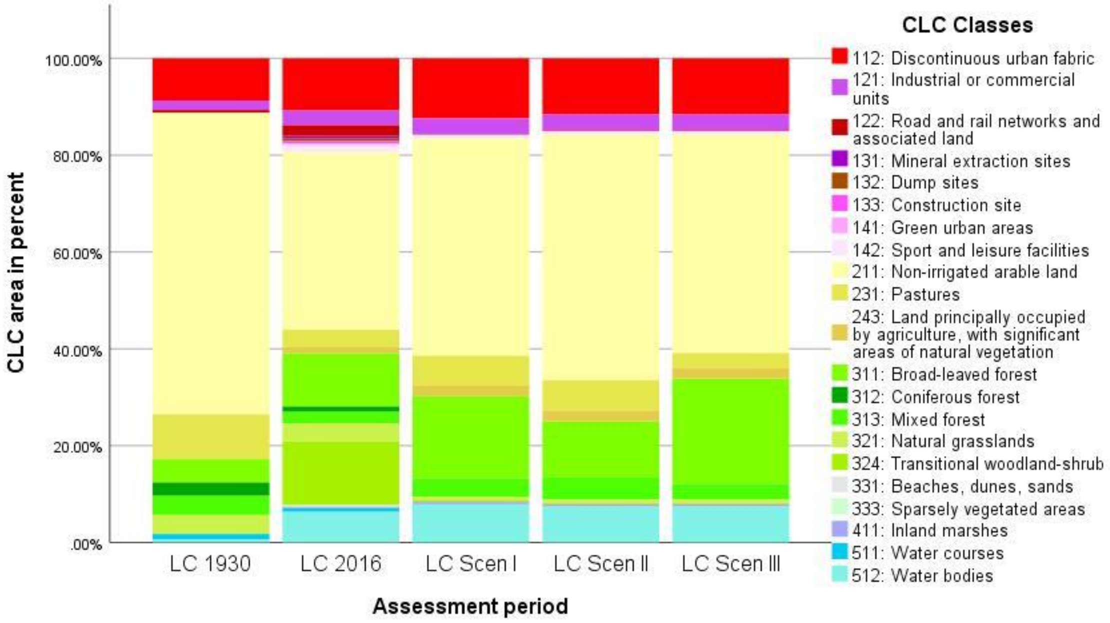


Figure 5. Proportions of CLC in the different assessment periods

The most drastic changes in LC and ES (Figure 6) occurred between 1930 and 2016. The artificial surfaces increased from 11.25% of the landscape in 1930 to 19.30% in 2016. This indicates the effects of mining activities, the increase of mining related LCs excluding traffic areas is 4.14 percent points. The following Scenarios I-III are not very different from each other, however it seems remarkable, that the scenario III, in which the forest cover is increased doesn´t perform much better concerning fibre production and carbon sequestration. The main explanation could be, that the increase in forest cover is not very high and the small effect on carbon sequestration by agricultural land, counts more in scenario II because its total area is disproportionately higher than forest. The inclusion of finer indicators for forest productivity could be helpful. The example also showed that the determinants of the reclamation for pit-mining areas are the artificial lakes.

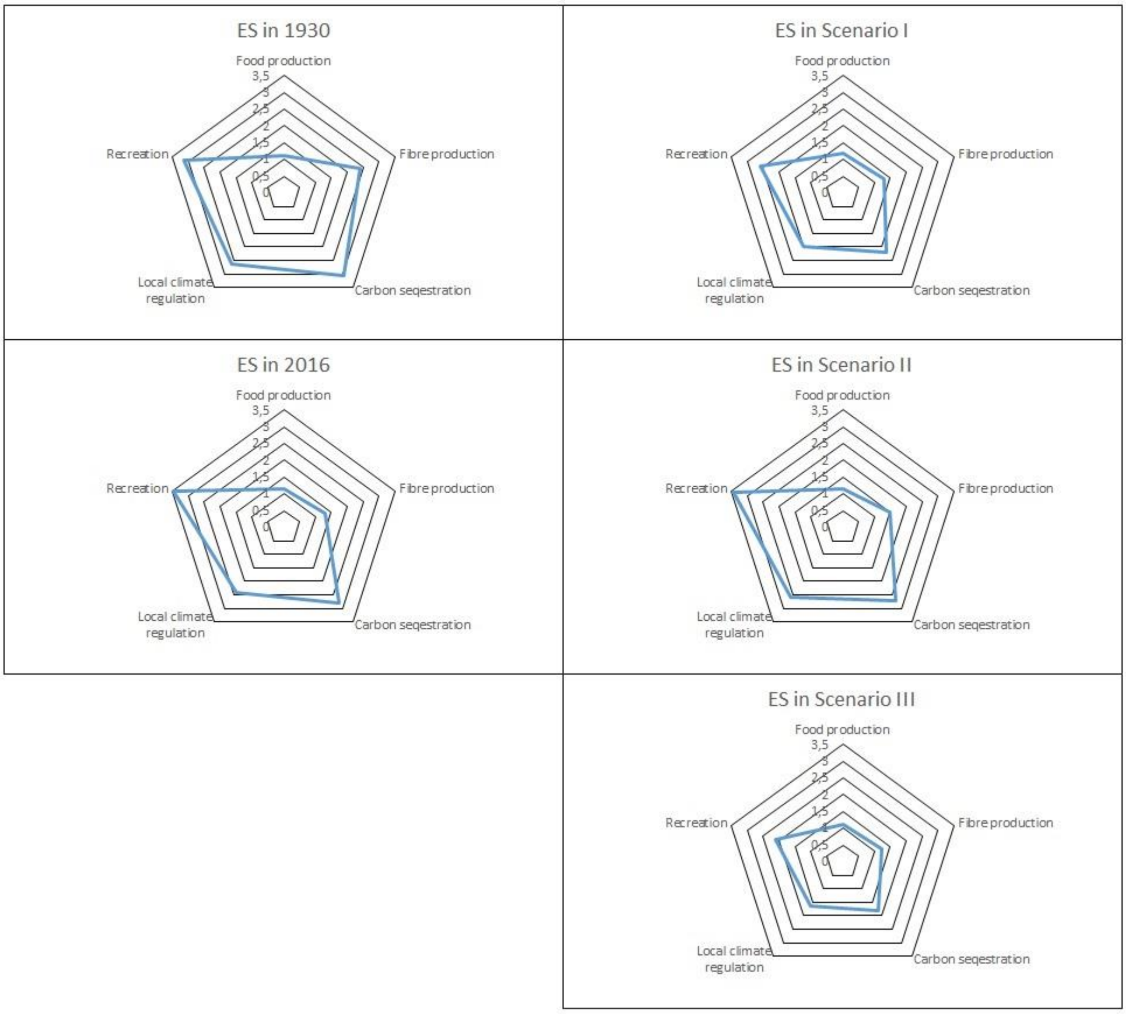


Figure 6. ES assessment for Mibrag Mines area (standardisation applied)

The scenario generation of the Mibrag Mines approach demonstrates one possible application of scenarios in the blueprint instrument/indicator for the Recovery project. It is important to understand, that scenarios are assumptions of development paths. The projection of the land use change depends on the considerations and the input used for the storylines and the transition rules. As a scientific planning tool the valuation and recommendation should not be done by the analysts performing the scenario based assessment of alternatives. It is ideally done by consultations with local and regional stakeholders, which can provide more local knowledge regarding the most desirable, feasible or probable development for the study area.

3.2 The Janina Mines approach

Within this task based on historical maps and spatial plans of Libiąż district the long term changes of landscape and land use were analysed. Four periods were taken into account:

the year 1902 as a pre-mining period; the year 1990 as a time of the highest mining activity in the region; actual situation (by the end of 2019) when underground coal mining has been fading; as well as future scenario where 100 years period is taken into consideration. In Libiąż area for periods mentioned above, evaluation of mining impacts and urbanisation processes on ecosystem services were assessed. The underground mining activity doesn't cause a wide range of spatial changes like open-cast mining. The applying of scenarios for future development is not possible. In the case of Libiąż the trend of future landscape changes was assumed based on applicable spatial plans. Former and future land cover maps were prepared according to CLC classification (see Deliverable 2.7). According to the assessment of ecosystem services such as air quality regulation and temperature regulation, long term changes of this services were evaluated. The methods of calculating these ecosystem indicators were described in deliverable D2.7 (*Assessment of ecosystem services of Janina Mine*).

For temperature regulating services in 1902 and 1990, as well as the future current values of temperature regulating ability for each CLC type were used. It is assumed that ability of each ecosystem type to deliver services have not been changed during the time, while changes of landscape features have significantly impacted the ecosystem services in Libiąż district. The methods of calculating these ecosystem indicators were described in deliverable D2.7 (*Assessment of ecosystem services of Janina Mine*).

Data sources: 1902 – based on topographic map – http://amzpbig.com/maps/025_TK25; 1990 – the database CLC 1900 for the European Union area, http://land.copernicus.eu/pan-european/corine-land-cover/clc-1990

Future map: Spatial Plan of Libiąż District: Municipality Spatial Decision Numbers: XXXVII/264/2018, XXXI.230.2017, XXI/147/2016, XVII/118/2016. https://libiaz.pl/dokumenty-planistyczne/miejscowe-plany-zagospodarowania-przestrzennego/

Both landscape and land use changes of the Libiąż district were mainly caused by urbanisation pressure, which is indirectly connected with mining activity and relates to land development due to industrial impacts. Long term increase of discontinuous urban fabric can be seen, and this trend will last in the future. The development of urban structures was realised mainly on rural and grassland area. Mining activity in Libiąż district impacted the area covered by industrial or commercial units and mainly appearance of area covered by waste heaps. Considering the scale of the whole district area, these changes were not very large in terms of coverage.

The areas covered by forests have not been changed in significant way, but in comparison with the past decades or even centuries the share of mixed and broad-leaved forests have increased. During the analysed periods (1900, 1990, 2019) the highest decrease of natural grassland and inland marshes were observed (Figure 7).

Indirect positive impact of underground mining activity on natural ecosystem is the appearance of new inland water ecosystems, namely water reservoirs formed in subsidence basins.

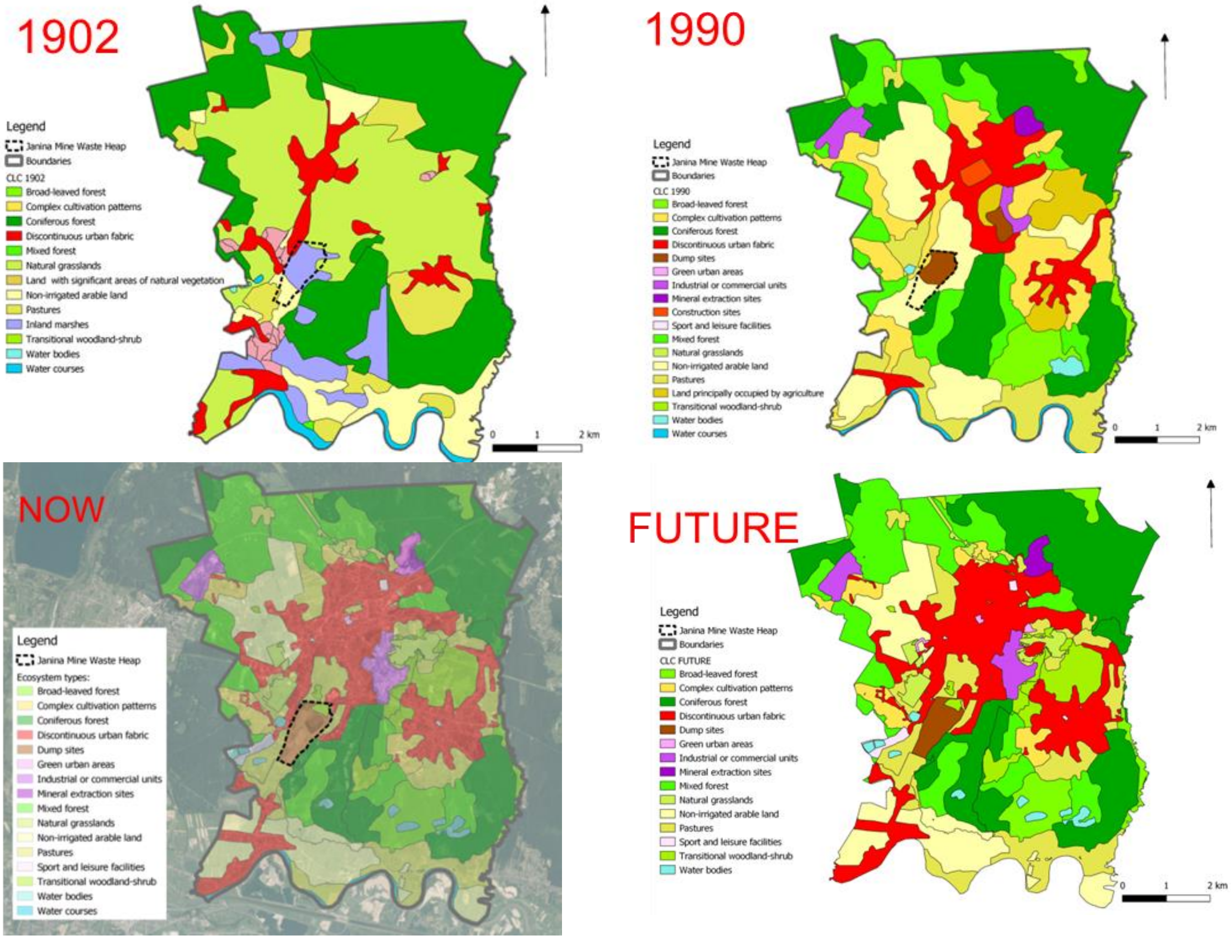


Figure 7. Long term landscape changes based on CLC classification.

Figure 8 shows landscape changes in the polish Libiąż district, one of the case studies of RECOVERY project, based on CLC classification provided by Google Earth Pro™.

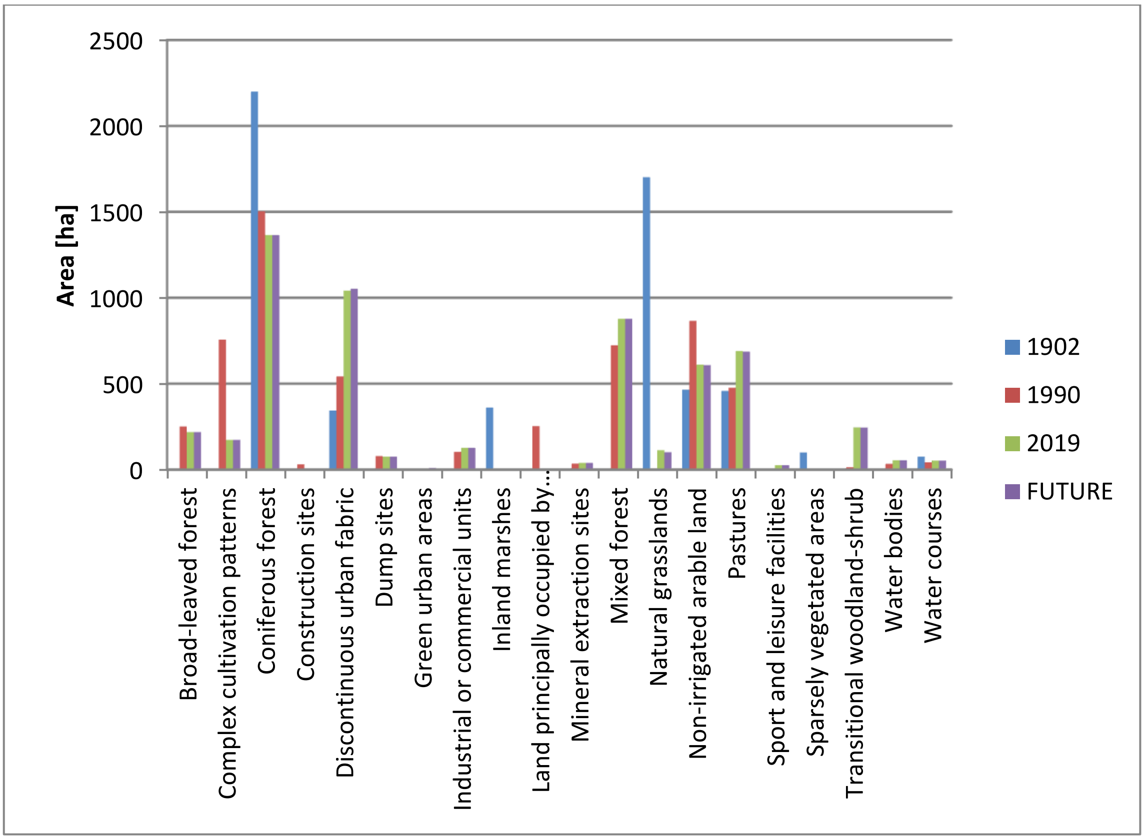


Figure 8. Landscape cover in 1902, 1990, 2019 and in the future.

AIR QUALITY REGULATION

Air quality regulation is provided in the Libiąż district mainly by Coniferous forest, Broad-leaved forest, Mix Forest and transitional woodland-shrubs. Ability of air pollution removal decreased (about 15.9%) since pre-mining up to now and this service will decrease in the future (Figure 9 and 10). It is mainly cause by decrease of natural ecosystem areas (especially natural grassland) and changes in forest structure. Due to the fact that Libiąż district is located very near to important communication routes and most buildings are heated by coal and wood, the decrease of ability to air pollution removal could negatively affect living standards. Exposure to dusty air impacts public and individual health due to increased morbidity and mortality (Manisalidis et al., 2020, Kończak et al., 2020). The decreasing of ecosystem ability to air pollution removal in the future is a consequence of the urbanization process. The spatial planning for the Libiąż district assumes the development of a discontinuous urban fabric in rural and grassland areas. Calculations of PM 10 absorbance and decrease of its value during related period is presented in figures below.

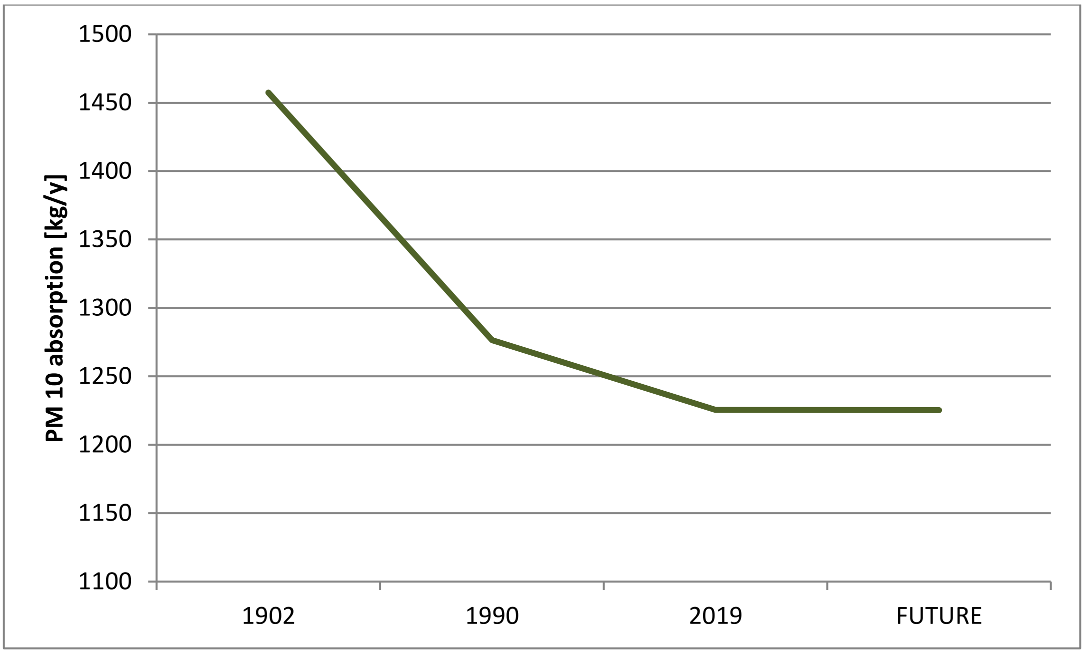


Figure 9. Libiąż district ecosystems ability to air pollution removal in 1902, 1990 2019 and in the future

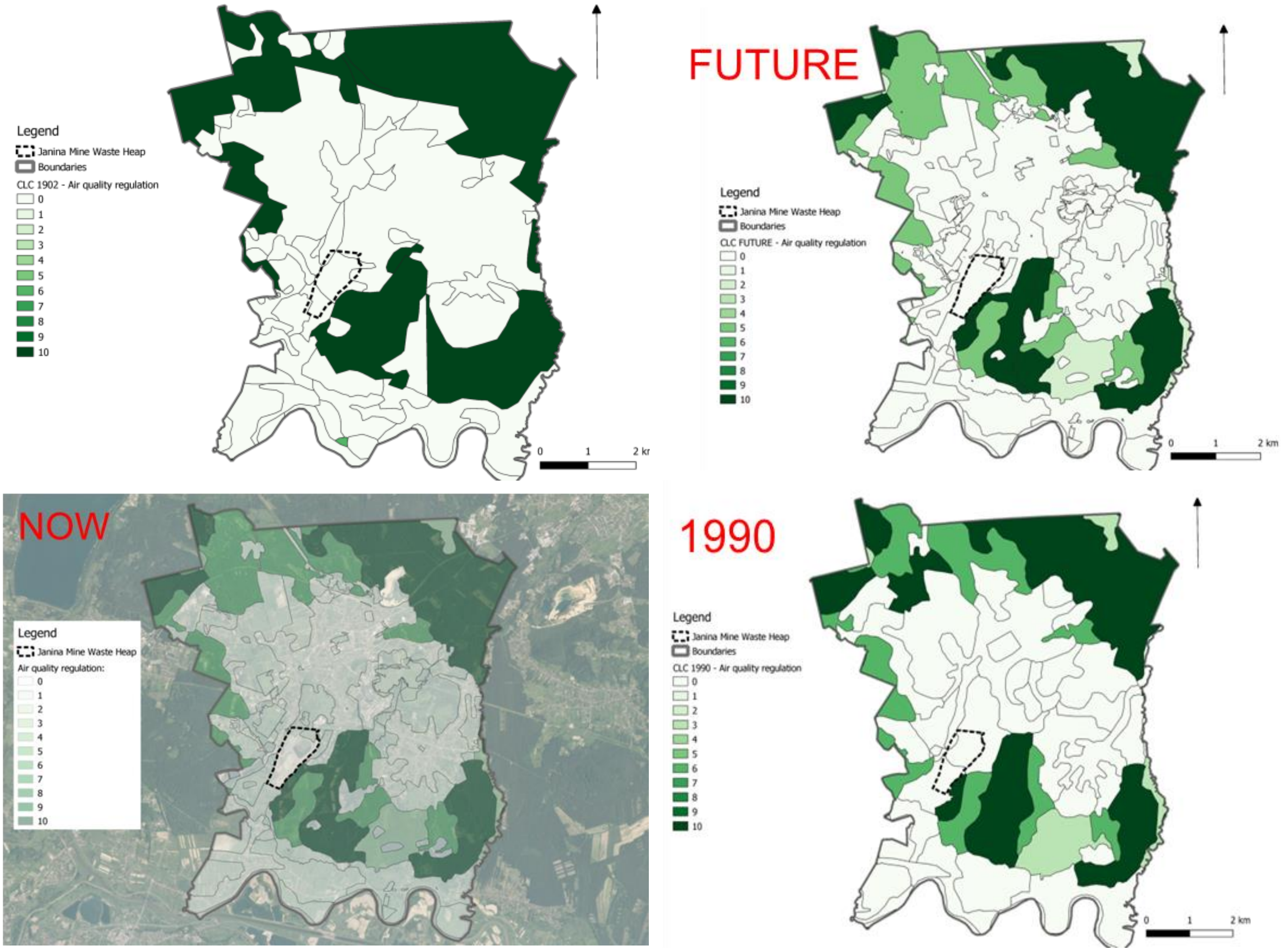
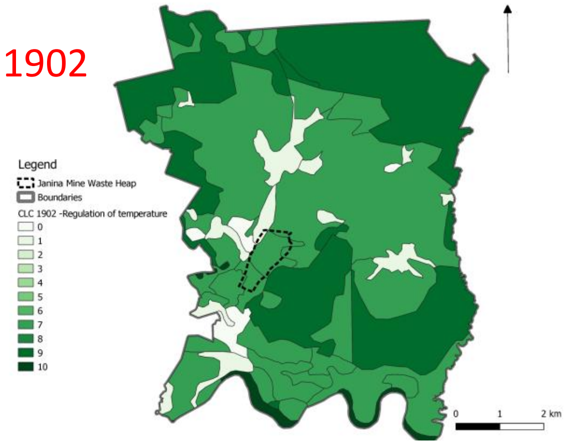
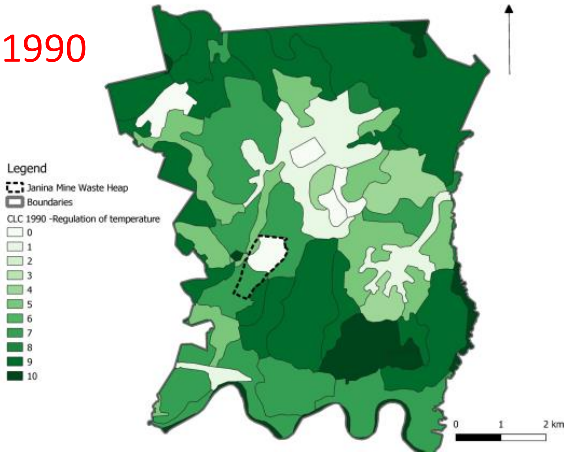


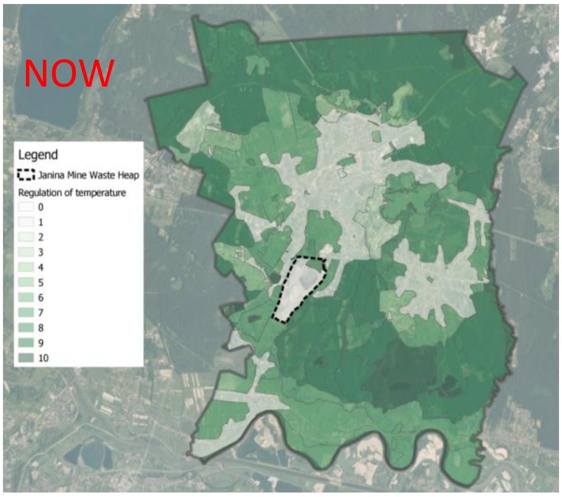
Figure 10. Spatial long term changes of ecosystems ability to air quality regulation

CLIMATE REGULATION

Taking into consideration the whole area of Libiąż district the changes of land cover cause the increase of mean thermal emissivity by 0.16% since pre-mining up to now and this trend will be observed in the future (Figure 11 and 12). These changes are related to increase of anthropogenic areas (urban, industrial and damps) and the decrease of natural ecosystems (marshes, grasslands). The increasing of the discontinuous urban fabric in rural and grassland areas will be also observed in the future (due to local spatial planning). The thermal emissivity of this anthropogenic land cover is about 2 % higher than rural and grassland areas (see table 3). In relation to sunny summer days to each 1m^2 of surface area reaches 1000W solar energy the changes of 2% thermal emissivity could have a significant influence on local thermal conditions and could cause the intensification of urban heat island processes. It means also that the urbanization process will decrease thermal regulation ability Libiąż district in the future.







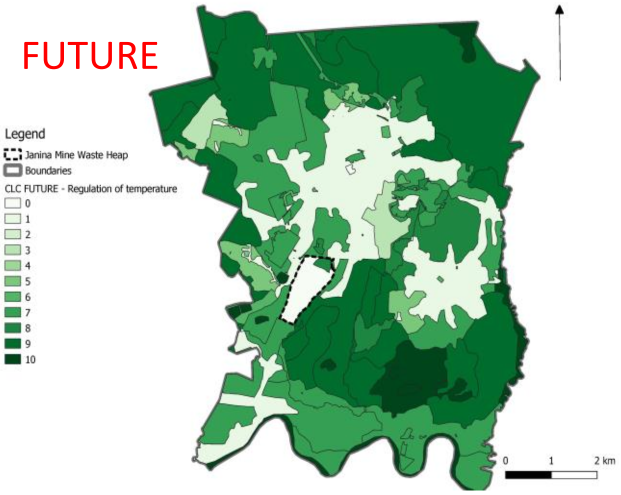


Figure 11. Spatial long term changes of ecosystems ability to temperature quality regulation

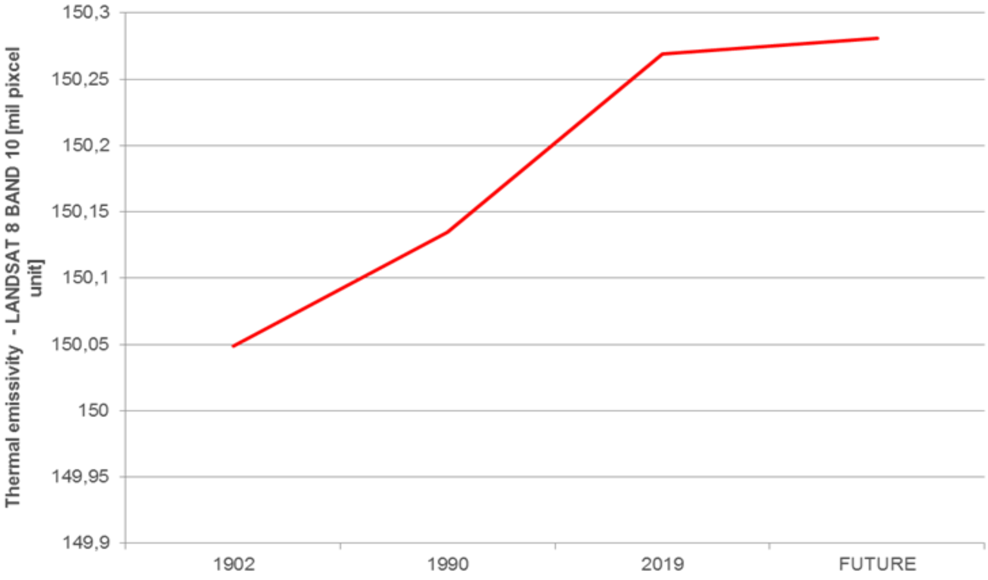


Figure 12. Thermal emissivity of Libiąż area in related period

Table 3 Statistic of thermal emissivity for each CLC class (DN - digital number of LANDSAT 8 BAND)

CLC	DN MEAN	DN	DN	STD_DE	DN
Broad-leaved forest	25910,2	26587,0	25705,	102,2	0,0
Water bodies	25990,2	26591,0	25750,	138,3	80,0
Water corses	26016,0	26508,0	25750,	142,2	105,8
Coniferous forest	26098,5	26804,0	25798,	145,0	188,3
Mixed forest	26107,4	26896,0	25855,	129,2	197,2
Mineral extraction sites	26148,0	26639,0	25752,	178,1	237,8
Transitional woodland-shrub	26162,3	27021,0	25830,	168,5	252,0
Inland marshes	26269,3	27252,0	25951	738,9	359,1
Land principally occupied by agriculture, with significant areas of natural vegetation	26322,3	269232,0	26031, 0	254,3	412,1
Pastures	26322,3	27167,0	25810,	212,1	412,1
Non-irrigated arable land	26340,3	27120,0	25822,	226,5	430,1
Natural grasslands	26362,5	27010,0	26005,	153,7	452,3
Sport and leisure facilities	26378,7	27427,0	25867,	369,9	468,5
Complex cultivation patterns	26486,6	27171,0	25972,	221,9	576,4
Industrial or commercial units	26820,9	27809,0	26020,	398,3	910,6
Discontinuous urban fabric	26861,7	27739,0	25993,	320,1	951,5
Dump sites	26870,0	27748,0	26120,	343,5	959,8
Construction sites	26938,7477	27277,0	26683,	131,5	1028,5
Sparsely vegetated areas	27001,0	27446,0	26362,	178,9	1090,8

Coal regions in transition are facing problems of sustainable land reclamation and the assessment of the potential to provide ecosystem services. Method of evaluation of this potential is a baseline for future best option of mine rehabilitation which is guided by the prior definition of an intended post-mining land use. A feasible ex-ante impact assessment planning instrument – blueprint indicator is one of the suitable tools to make recommendations for future planning and development of post mining landscapes. Moreover, if these recommendations are given with ecosystem services approach, future scenarios for post mining areas will assure sustainable development in relation to transition of coal regions. The landscape changes of Libiąż district are mainly caused by urbanization processes, which were indirectly related with mining activities. When mining affects natural or semi-natural ecosystems, a range of ecosystem services are lost or otherwise affected. Mining activities directly increased thermal emission of land surface and on a lower scale caused decrease in ability of ecosystems to air pollution removal. Including ecosystem services into planning and evaluation of environmental rehabilitation of mining is an opportunity to highlight the social benefits of rehabilitation efforts.

4 Conclusion and lessons learnt

The landscapes in Europe are highly transformed by human influence. Among the heaviest impacts on the geological, geomorphological and hydrological systems, which constitute the foundation of the landscape are mining operations. The extraction of minerals from the underground has been a prerequisite for the technological development of humanity for centuries. Mining is still a source of wealth and economic development for some regions in Europe leaving it´s marks in the landscape.

The blueprint instrument/indicator was conceived to provide a toolkit for a feasible ex ante assessment of mining impacts as well as assess the transformation of the landscape beyond simply recording the new landscape elements produced by the mining operations. By going further than the LC assessment the procedures used in the blueprint instrument/ indicators provide a comprehensible assessment of the beneficial output of ecosystems in the post mining landscape and can be used to take a broader, more educated perspective on the sustainable value of present and future mining operations. As additional options the framework allows to include the weighting of different values and beliefs, responding diversification of societies and the consequences for participatory approaches in planning and decision-making processes. Last but not least the blueprint instrument/indicators provides a method to project the future development of the post-mining landscape based on the transformation decisions for the post mining LC change, by using scenarios of post-mining landscape transformation.

Some important lessons were learned from the development of the blueprint instrument/ indicator. The subject of LC transformation is very complex and involves several complex measures, which are designed to provide additional in-depth information on landscape transformation. The landscape configuration is such a complex topic, however the use of the respective spatial statistics is not feasible compared to the information gained by interpretation of these statistics. In addition this would generally overburden the capacities of most stakeholder involvement, as very specialized knowledge is needed for comprehension. The blueprint instrument/indicator thus uses the most basic landscape metrics which are easy to apply and comprehend. Another lesson concerns the generation of scenarios. The storylines of scenarios are not instructions of how to reclaim the former mining sites. They are assumption based projections, with uncertainties regarding unexpected developments, external pressures or changes in ES demands. The scenarios are supposed to inform stakeholders of how reclamation can develop and agree on visions of the reclamation of former mining sites.

The two case study examples demonstrated, how the blueprint instrument/indicator can be applied to different types of mining operations. The examples showed similarities between above-ground and underground mining such as the development of industrial sites and mining related settlements and the demand for climate regulating ES to be met by reclamation. The case studies also showed differences between the two types of mining operations, such as the spatial extend of the landscape impacted by above-ground mining as compared to underground mining. Based on the experiences from the two examples it is recommended that the choice of ES should be open for the local experts applying the instruments/indicators to decide based on their local knowledge. Comparability of the results is limited so far, based on the standardization of indicator values an estimation of the expected ES supply is possible.

The presented and demonstrated blueprint instrument/indicator represents “a feasible ex-ante impact assessment approach to support best practices in the assessment of mining activities and their impact on land-cover, land-use and ES provision” and thus achieves the objectives of deliverable 3.1.

5 Glossary

CICES – Common International Classification of Ecosystem Services

CLC – CORINE Land Cover

CORINE – Coordination of information on the environment

ES – Ecosystem Service/ Services

GIS – Geographic information system

LC – Land cover

MAES – Mapping and Assessment of Ecosystems and their Services

MEA – Millennium Ecosystem Assessment

TEEB – The Economics of Ecosystems and Biodiversity

6 References

Albert, C., Bonn, A., Burkhard, B. Daube, S. Dietrich, K., Engels, B., Frommer, J., Götzl, M., Grêt-Regamey, A., Job-Hoben, B., Koellner, T., Marzelli, S., Moning, C., Müller, F., Rabe, S.-E., Ring, I., Schwaiger, E., Schweppe-Kraft, B. Wüstemann, H. (2016). Towards a national set of ecosystem service indicators: Insights from Germany. Ecological Indicators 61: 38-48. http://dx.doi.org/10.1016/j.ecolind.2015.08.050

Berkner, A. (2004). Der Braunkohletagebau im Südraum Leipzig. Bergbau in Sachsen Band 11. Sächsisches Landesamt für Umwelt und Geologie (LfUG). (German). Retrieved from: https://nbn-resolving.org/urn:nbn:de:bsz:14-qucosa-78896

Börjeson, L., Höjer, M., Dreborg, K.-H., Ekvall, T., Finnveden, G. (2006). Scenario types and techniques: towards a user´s guide. Futures 38: 723-739. DOI:10.1016/j.futures.2005.12.002

Botequilha Leitão, A., Ahern, J. (2002). Applying landscape ecological concepts and metrics in sustainable landscape planning. Landscape and Urban Planning 59: 65-93.

Büttner, G., Kosztra, B. (2011). Manual of CORINE Land Cover changes - EEA subvention 2011. *European Environment Agency 1-154.* Retrieved from: https://land.copernicus.eu/user-corner/technical-library/manual_of_changes_final_draft.pdf

Büttner, G., Kosztra, B. (2017). CLC2018 Technical Guidelines. *European Environment Agency*, (3436), 1-60. Retrieved from: https://land.copernicus.eu/user-corner/technical-library/clc2018technicalguidelines_final.pdf

Burkhard, B., Kroll, F., Müller, F.; Windhorst, W. (2009). Landscapes´ Capacities to Provide Ecosystem Services – a Concept for Land-Cover Based Assessments. Landscape Online 15: 1-22. DOI: 10.3097/LO.200915

Costanza, R. (2008). Ecosystem services: multiple classification systems are needed. Biological Conservation 141: 350-352. DOI: 10.1016/j.biocon.2007.12.020

European Commission (2011). COMMUNICATION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Our life insurance, our natural capital: an EU biodiversity strategy to 2020. COM/2011/244 final https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52011DC0244&from=EN

European Commission (2018a). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN

ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK. A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. COM/2018/773 final https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM%3A2018%3A773%3AFIN

European Commission (2018b). Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries, in accordance with Directive 2006/21/EC EUR 28963 EN; doi:10.2760/35297, JRC109657.

EEA (2007). Land-use scenarios for Europe: a qualitative and quantitative analysis on a European scale. EEA Technical report No 9/2007. Retrieved from: https://www.eea.europa.eu/publications/technical_report_2007_9

Fisher, B., Turner, R. K., Morling, P. (2009). Defining and classifying ecosystem services for decision making. Ecological Economics 68: 643-653. DOI: 10.1016/j.ecolecon.2008.09.14

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, Retrieved from www.cices.eu

Kabisch, S. (2004). Revitalization chances for communities in post-mining landscapes. Peckiana 3, 87–99.

Kończak, B., Cempa, M., Pierzchała, Ł., Deska, M. (2021). Assessment of the ability of roadside vegetation to remove particulate matter from the urban air. Environmental Pollution, 268, 115465.

Kosztra, B., Büttner, Hazeu, G., Arnold, S. (2017). Updated CLC illustrated nomenclature guidelines. *European Environment Agency*, (3436), 1–126. Retrieved from https://land.copernicus.eu/user-corner/technical-library/corine-land-cover-nomenclature-guidelines/docs/pdf/CLC2018_Nomenclature_illustrated_guide_20170930.pdf%0Ahttp://land.copernicus.eu/user-corner/technical-library/Addendum_finaldraft_v2_August_2014.pdf

Kubal, C., Haase, D., Meyer, V., Scheuer, S. (2009). Integrated urban flood risk assessment - adapting a multicriteria approach to a city. Natural Hazards and Earth System Sciences 9: 1881-1895.

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

Maes, J., Fabrega, N., Zulian, G., Barbosa, A., Vizcaino, P., Ivits, E., Polce, C., Vandecasteele, I., Rivero, I. M., Guerra, C., Perpiña Castillo, C., Vallecillo, S., Baranzelli, C., Barranco, R., Batista e Silva, F., Jacobs-Crisoni, C., Trombetti, M., Lavalle, C. (2015). Mapping and Assessment of Ecosystems and their Services: Trends in ecosystems and ecosystem services in the European Union between 2000 and 2010. Publications office of the European Union, Luxembourg. DOI: 10.2788/341839

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

Maes, J., Teller, A., Erhard, M., Liquete, C., Braat, L., Berry, P., Egoh, B., Puydarrieux, P., Fiorina, C., Santos, F., Paracchini, M. L., Keune, H., Wittmer, H., Hauck, J., Fiala, I., Verburg, P. H., Condé, S., Schägner, J. P., San Miguel, J., Estreguil, C., Ostermann, O., Barredo, J. I., Pereira, H. M., Stott, A., Laporte, V., Meiner, A., Olah, B., Royo Gelabert, E., Spyropoulou, R., Petersen, J. E., Maguire, C., Zal, N., Achilleos, E., Rubin, A., Ledoux, L., Brown, C., Raes, C., Jacobs, S., Vandewalle, M., Connor, D., Bidoglio, G. (2013). Mapping and Assessment of Ecosystems and their Services. An analytical framework for ecosystem assessments under action 5 of the EU biodiversity strategy to 2020. Publications office of the European Union, Luxembourg. https://doi.org/10.2779/12398

Mancini, L., Sala, S. (2018). Social impact assessment in the mining sector: Review and comparison of indicators frameworks. Resources Policy 57: 98-111. https://doi.org/10.1016/j.resourpol.2018.02.002

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: a review. Frontiers in public health, 8.

Meyer, V., Scheuer, S., Haase, D. (2009). A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. Natural Hazards 48: 17-39. DOI:10.1007/s11069-008-9244-4

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

Schröter, M., Albert, C., Marques, A., Tobon, W., Lavorel, S., Maes, J., Brown, C., Klotz, S., Bonn, A. (2016). National Ecosystem Assessments in Europe: A review. Bioscience 66: 813-828. DOI:10.1093/biosci/biw101

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

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

Uuemaa, E., Antrop, M., Roosaare, J., Marja, R., Mander, Ü. (2009). Landscape Metrics and Indices: An Overwiev of Their use in Lamdscape Research. Living Reviews in Landscape Research 3.

Uuemaa, E., Mander, Ü., Marja, R. (2013). Trends in the use of landscape spatial metrics as landscape indicators: A review. Ecological Indicators 28: 100-106. http://dx.doi.org/10.1016/j.ecolind.2012.07.018

Walz, U. (2011). Landscape Structure, landscape Metrics and Biodoversity. Living Reviews in Landscape Research 5 (3): 1-35.

Walz, U., Syrbe, R.-U. (2013) Linking landscape structure and biodiversity. Ecological Indicators 31: 1-5. http://dx.doi.org/10.1016/j.ecolind.2013.01.032

Wirth, P., Černič Mali, B., Fischer, W. (2012): Problems and Potentials of Post-Mining Regions. In: Wirth, P., Černič Mali, B., Fischer, W. (Eds.) (2012). Post-Mining Regions in Central Europe - Problems, Potentials, Possibilities. oekom verlag München.

Wirtschaftsförderungsgesellschaft Anhalt-Bitterfeld & Stadt Leipzig (2014). Gewässerlandschaft im mitteldeutschen Raum - Das Tourismuswirtschaftliche Gesamtkonzept im Überblick. (German) www.gruenerring-leipzig

Xiang, W.-N., Clarke, K. C. (2003). the use of scenarios in land-use planning. Environment and Planning B: Planning and Design 30: 885-990. DOI:10.1068/b2945