Recovery
RFCS RESEARCH PROJECT

RECOVERY OF DEGRADED AND TRANSFORMED ECOSYSTEMS IN COAL MINING-AFFECTED AREAS

BEST PRACTICE GUIDELINES

An innovative framework for land rehabilitation and ecological restoration of coal mining-affected areas during or after mine operations

Co-funded by the European Union

Research Fund for Coal & Steel

ACKNOWLEDGEMENTS

This work was carried out by the RECOVERY project, co-funded by the European Union via the Research Fund for Coal and Steel, under Grant Agreement No 847205.

The document was developed under the supervision of Dipl Geogr Peer von Döhren, Humboldt-Universität zu Berlin, Germany.

The study was reviewed and edited by the Coordinator of the project, Prof Dr Eng Alicja Krzemień, from the Central Mining Institute in Katowice, Poland, and Prof Dr Eng Pedro Riesgo Fernández, from the School of Mining, Energy and Materials Engineering of Oviedo, Spain.

Contents

1. Introduction: The legacy of coal mining in the EU

1.1. The challenges of reclaiming coal mining landscapes

Coal mining fuelled industrial development and provided job opportunities for ten thousand workers during the 19th and early 20th centuries. The local economy has benefitted from coal mining which offered job opportunities and generated tax revenues and welfare. Coal mining also resulted in several ecologic impacts. Among these ecological impacts are the disturbance of the soil structure and the groundwater system; destruction of the landscape, for example, deforestation, mining pits and dump heaps; disturbance of the local ecosystems, for instance, by emission of harmful materials; and unbalanced economic development, with a concentration on mining and related energy refining and generating industries, which are additional sources of negative ecologic impact.

While coal production in most parts of Europe lost competitiveness in the second half of the 20th century, the international communities´ decision to limit global temperature rise by reducing CO2 emissions worldwide was the final signal for phasing out coal extraction for energy generation.

As already indicated by the impacts coal mining has on the landscape and the socio-economic structure of the affected regions, the challenges of reclamation are substantial: landscapes must be reclaimed based on new soil and hydro-geological conditions; vegetation has to be recovered, if necessary, by planting and fertilising; ecological functions need to develop to provide ecosystem services (ES) to the local population. The change of the socio-economic structures, which were determined by the mining economy, into new sustainable livelihoods in the post-mining landscapes, requires the participation of local stakeholders to ensure the acceptance of the post-mining landscape transition.

What needs to be understood is that the reclamation cannot fully restore the landscape changes caused by the mining extraction. However, this does not mean that reclamation is not worth the effort. On the contrary, reclamation provides the opportunity to create landscapes with features, which are uncommon for landscapes in the respective regions. The reclamation can thus offer unique selling points for the regions to tackle the challenges of the post-mining transition. The potentials of the different mining regions must be assessed, and possible pathways and outcomes of reclamation have to be projected to find the best possible ways to approach the reclamation of regions structured by coal mining for many decades.

1.2. How these best practice guidelines should be used

The presented guidelines are based on the ES concept widely accepted in ecological economics, environmental science and planning. The ES concept integrates environmental, sociocultural, and economic conditions into a concept that accounts for value aspects not directly recognised by classical economic theories. Therefore, the guidelines can incorporate different elements of value into a more comprehensive approach to post-mining reclamation.

This best practice guidelines report covers aspects of mining reclamation, which are generalisable to different coal mining contexts, for example, underground or above-ground mining and hard coal or lignite mining. This means that the guidelines advise on procedures suitable to the project and assess the processes following the mine closure, identify alternatives for post-mining development and compare these alternatives to find an appropriate pathway to acceptable post-mining landscapes.

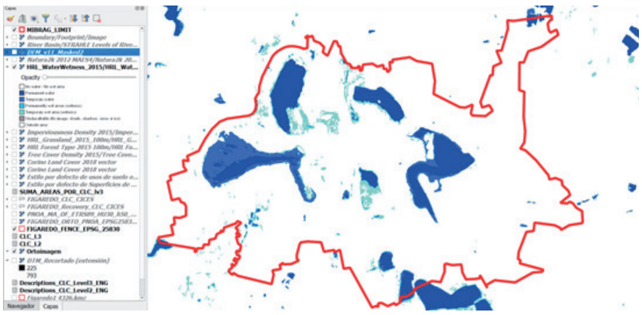
For the terminology in this report, the term coal generally refers to all types of mineral coal used to generate energy for power or heating purposes. This includes (listed by increasing carbon content): lignite, sub-bituminous coal, bituminous coal and anthracite.

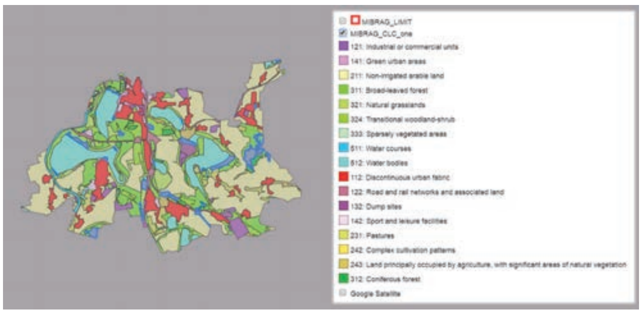
The guidelines build on the Ecosystem Services (ES) concept, modelled in the ES cascade and operationalised in the Common International Classification of Ecosystem Services (CICES) v5.1. The ES concept puts the ecosystems' benefits for the (local) population in the focus of the valuation of the mining and post-mining landscapes. The mining itself is not considered in the valuation, as it is considered to be ended and thus cannot be considered a land-use option.

The guidelines do not aim for the precise restoration of the pre-mining landscape and its ecological conditions, as this is most often not feasible given that the transformative situation already stresses local communities and the financial and personal resources are generally unavailable. Post-mining landscapes offer opportunities to create/ shape landscapes that are untypical for the respective regions and therefore offer potential for extraordinary, even unique settings for economic, cultural and ecological development.

With this objective, the guidelines provide the tools to assess and compare the landscape potentials and provide examples from the RECOVERY project that demonstrate the application in different European mining landscapes and settings.

2. Baseline mapping of relevant ecosystems





In the first place, and after a detailed description of each case study, the adequate boundaries for the study areas were defined based on the existing spatial connectivity and functional cohesion.

In the second place, a revision of the available online geospatial data was developed. It was obtained mainly from CORINE Land Cover, COPERNICUS Land monitoring System and COPERNICUS imagery and reference data.

In the third place, CORINE Land Cover (CLC) classes (level 3) were used to delineate, categorise and map the different ecosystem types of land cover in the study areas, ensuring the comparability of the land use classes, although doing detailed field mapping at a higher resolution.

Finally, the information was introduced in the QGIS 3.8 Zanzibar (QGIS was previously known as Quantum GIS). The result for each case study can be accessed in the WebGIS area of the webpage.

FOR MORE INFORMATION ON THE BASELINE MAPPING OF RELEVANT ECOSYSTEMS, PLEASE SEE THE FOLLOWING DETAILED REPORTS:

- Baseline mapping of relevant ecosystems of Figaredo Mine
- Baseline mapping of relevant ecosystems of Janina Mine Waste Heap
- Baseline mapping of relevant ecosystems of Ema-Terezie Mine dumps complex Publish Date
- Baseline mapping of relevant ecosystems of Chabařovice Mine and Most-Ležáky Mine
- Baseline mapping of relevant ecosystems of Mibrag Mines

click

The lessons relevant to RECOVERY from the baseline mapping of relevant ecosystems of the case studies can be summarised as follows:

1

Identifying the adequate boundaries of the case-study area can be challenging work. Selecting a considerable size within limits will end in much mapping-related work. Choosing a small site may risk not selecting representative land covers and potential ES. Using administrative boundaries, socio-economic areas or spatial ranges on environmental pressure can help set the appropriate limits.

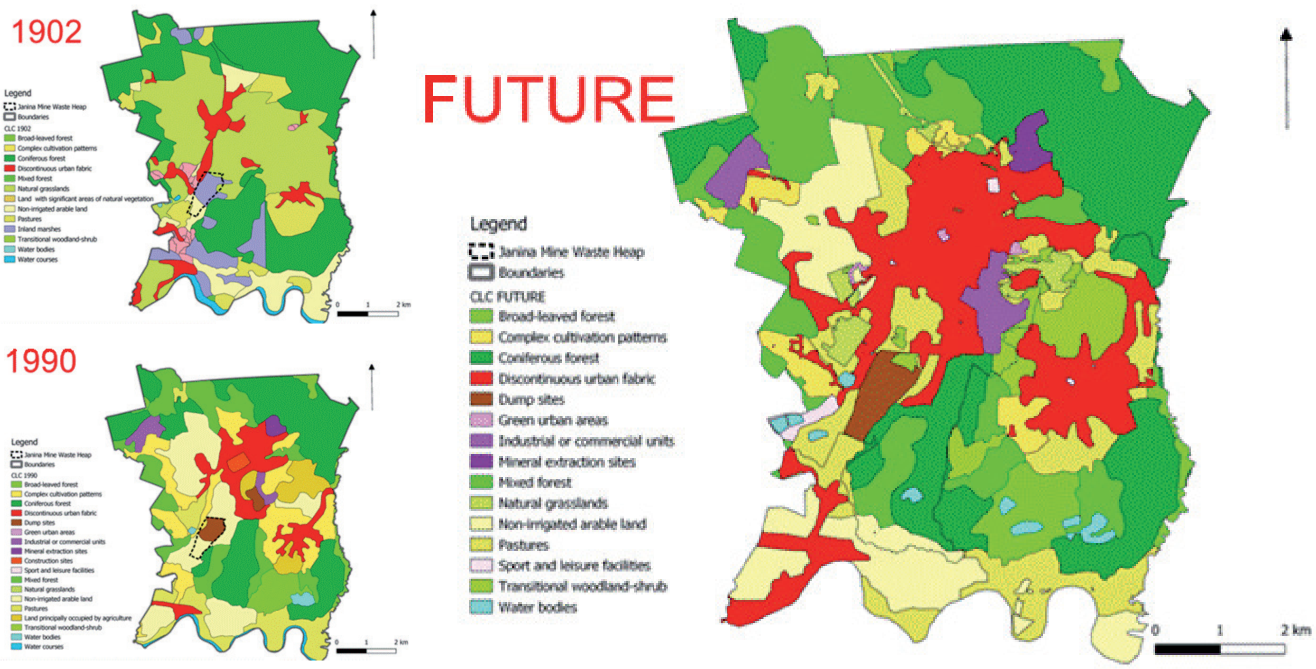
2

Much geospatial data is available, mainly from CLC, COPERNICUS Land Monitoring System, COPERNICUS imagery and reference data, and national repositories. In combination with information provided by Google Earth, all of these facilitate categorising and mapping the relevant ecosystems, although at a higher resolution than in the CORINE programme.

3

The mapping of a study area can be quickly done even by people without experience with GIS. Google Earth polygons are easy to build and export to almost any GIS.

3. Blueprint instrument/indicator.
Identification of ecosystems in (pre) and (post) mining landscapes



The blueprint instrument/indicator provides a method to project the future development of the post-mining landscape based on the transformation decisions for the post-mining land cover (LC) change by using scenarios of post-mining landscape transformation. The one presented here uses a tiered approach based on the assessment of LC, from which simple landscape metrics are assessed. The ES of the investigated mining and post-mining landscapes are identified based on the landscape metrics.

The assessment of the LC aims to identify the composition of the landscape. 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. From the calculation of the patch sizes, a quick overview of the direct impact of mining activities on the landscape is possible. The assessment of ES is the next step in the blueprint instruments/indicators procedure. Within the blueprint instrument/indicator procedure, the ES approach connects the evaluation of the LC and landscape metrics to the benefits for human society.

Within the blueprint instruments/indicator procedure, the scenarios provide the framework for assessing 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 results, they are, to a certain degree, fictional. It is, therefore, essential to develop internally consistent and comprehensible storylines. This report demonstrates a method to operationalise the developed storylines. Transition rules are one way to systemise the LC change based on the storylines.

Two case studies demonstrate the application of the blueprint instrument/indicator procedure. The first case study builds on exploratory work in the post-mining area south of Leipzig (the Mibrag Mines area). The second case study explores applying the blueprint instruments/indicators approach to an area with an active underground mining operation in Poland.

The lessons relevant to RECOVERY from the development of the Blueprint instrument/ indicator can be summarised as follows:

1

The subject of LC transformation is very complex and involves several complex measures designed to provide additional in-depth information on landscape transformation. The necessary information can be obtained by analysing the basic landscape composition, such as the proportion of different LC classes within the landscape. However, calculating and interpreting complex landscape configuration metrics requires specialised expert skills. Therefore, the comparably low level of additional information gained by analysing these statistics is unjustified. In addition, this would generally overburden the capacities of most stakeholder involvement, as very specialised knowledge is needed for comprehension. The blueprint instrument/indicator thus uses the most basic landscape metrics, which are easy to apply and comprehend.

2

A second lesson concerns the generation of scenarios. The storylines of scenarios are not instructions on 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.

3

Based on the experiences from the two case studies, 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. Estimating the expected ES supply is possible based on the standardisation of indicator values.

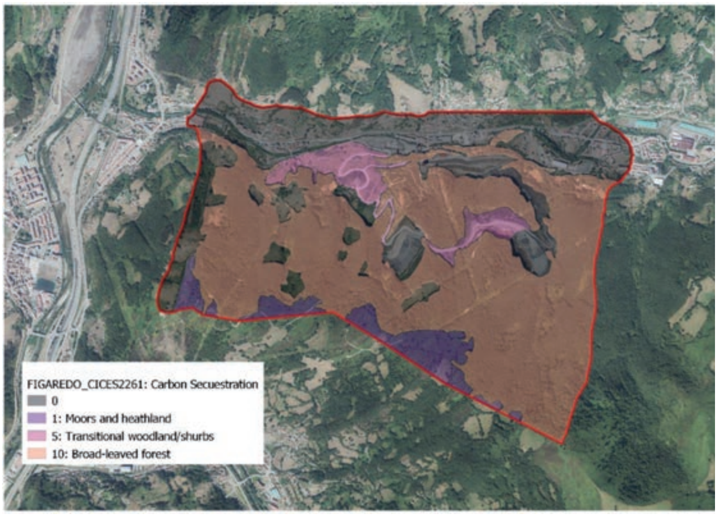
4. Assessment of Ecosystem Services

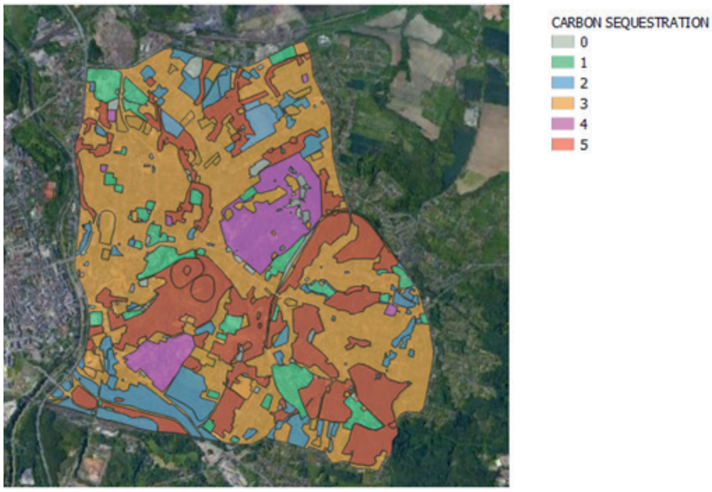
The assessment method is based on the Common International Classification of Ecosystem Services (CICES) V5.1.

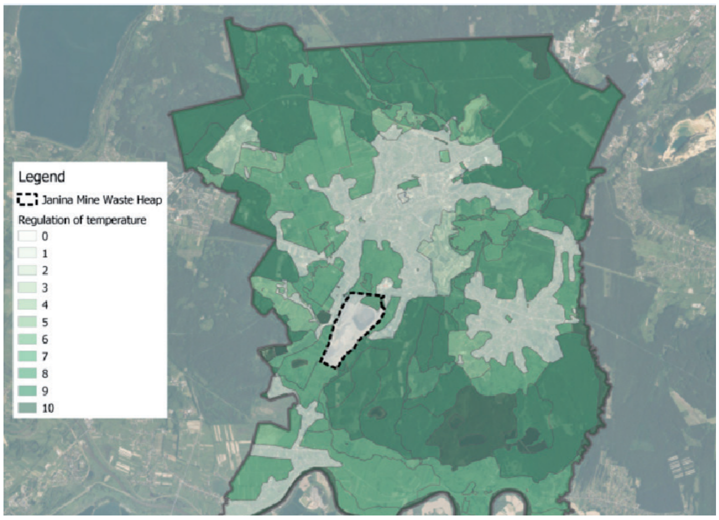
The relevance of the ES is guided by the importance of the respective ES for the post-mining development of the landscape. The relevant ES must provide economical alternatives for the mining-based economy and support the transformation process's economic viability. The relevance of the regulating services is guided by the environmental conditions from the transformed mining landscape, which have to be regulated to support the living conditions in the post-mining area. The cultural services relevant to the study area contribute to the aesthetic restoration of the post-mining landscape. They can also provide economic opportunities based on the touristic attractiveness of the reclaimed post-mining landscape. Finally, the provisioning services in the assessment represent the base for economic alternatives to the mining-related economy.

The ES were selected from CICES V5.1 according to the CLC classes of the study areas, the topography, the environment and the specific climate. Other two criteria were also used for the selection: representing significant ES in urban ecosystems and representing different sections of the list of ES developed by the Economics of Ecosystems and Biodiversity Ecological and Economic Foundations.

From each ES, the following information was collected: CICES V5.1 class level, ES indicator, measuring methods, scientific references, primary data sources, type of valuation and sources of uncertainty.







FOR MORE INFORMATION ON THE ASSESSMENT OF ES, PLEASE SEE THE FOLLOWING DETAILED REPORTS:

- Assessment of ecosystem services of Figaredo Mine
- Assessment of ecosystem services of Janina Mine
- Assessment of ecosystem services of Ema-Terezie Mine dumps complex
- Assessment of ecosystem services of Chabařovice Mine and Most-Ležáky Mine
- Assessment of ecosystem services of Mibrag Mine

click

The lessons relevant to RECOVERY from the assessment of ES of the case studies can be summarised as follows:

1

The CICES is designed to capture as many ES as possible. In the case of provisioning services, the division between the classes is comprehensible. The categories of regulating services are less clear, and the types of cultural ES are least clear.

2

Another challenge of applying the CICES is alternative ES from the same land cover. Some ES can be achieved in the same area and only at the expense of the other respective service. Other ES can both be performed without interference.

3

The challenges mentioned above can be met by considering the local context of the ES. The local demand for ES provides an excellent guideline to identify the relevant ES in the local context. The issue of rivalling ES should be considered in selecting ES for the assessment.

4

The challenges as mentioned above can be met by considering the ES's local context (local demand). Which benefit that will be derived from the land cover finally depends on a variety of factors depending on local, regional, and even global socio-economic conditions.

5. Assessment of scenarios.

Deciding on desired reclamation pathway – consider the sustainability of the resulting reclamation landscape

Taking into account the recommendations for future planning and development of the post-mining landscape from the blueprint instrument/indicator, as well as the need to improve socio-economic outcomes and to catalyse the development of new jobs, different types of land rehabilitation and ecosystem restoration actions were considered to generate various scenarios:

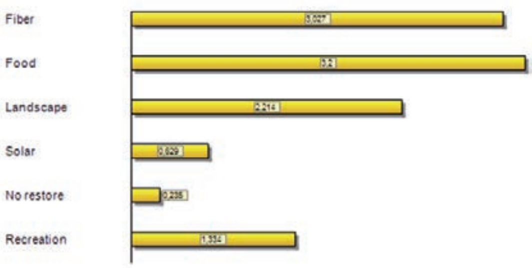
1. Recolonisation of the site by local vegetation.
2. Commercial forestry plantations.
3. Secondary forests using local plant species.
4. Development for agriculture: arable land and pastures.
5. Leisure and recreational purposes: museums and recreation areas.
6. Areas for physical recreation.
7. Space for wildlife and nature conservation.
8. Development of artificial water bodies, e.g., lakes, reservoirs, and streams.
9. Renewable energy generation: photovoltaic and wind power.
10. Industrial areas and business facilities
11. Residential areas.

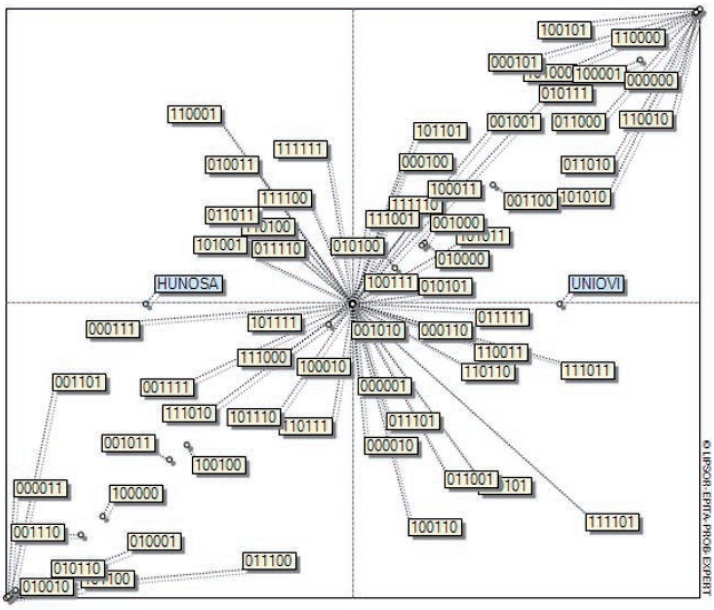
Particular emphasis was given to consultation of scenarios with stakeholders (local authorities, neighbourhood associations, the coal mining industry, trade unions, and environmental NGOs) to guarantee the success of the whole process. The consultation took place via the Project's webpage Consultation area or the development of specific surveys.

In some cases, the Smic Prob-Expert tool facilitated the scenario selection. The Smic Prob-Expert tool is a cross-impact probability method that aims to define simple and conditional probabilities of hypotheses and events and the probabilities of combinations of the latter, considering interactions between events or hypotheses. This method seeks to tease out the most plausible scenarios for decision-makers and examine combinations of hypotheses one would have initially excluded.

#	Long label	Short label
1	Pine tree plantation	Fiber
2	Cows reared for nutritional purpose	Food
3	Broad-leaved forest	Landscap
4	Photovoltaic energy	Solar
5	Recolonisation by local vegetation	No restore
6	Physical recreation	Recreation

© LIPSOR-EPITA-PROB-EXPERT

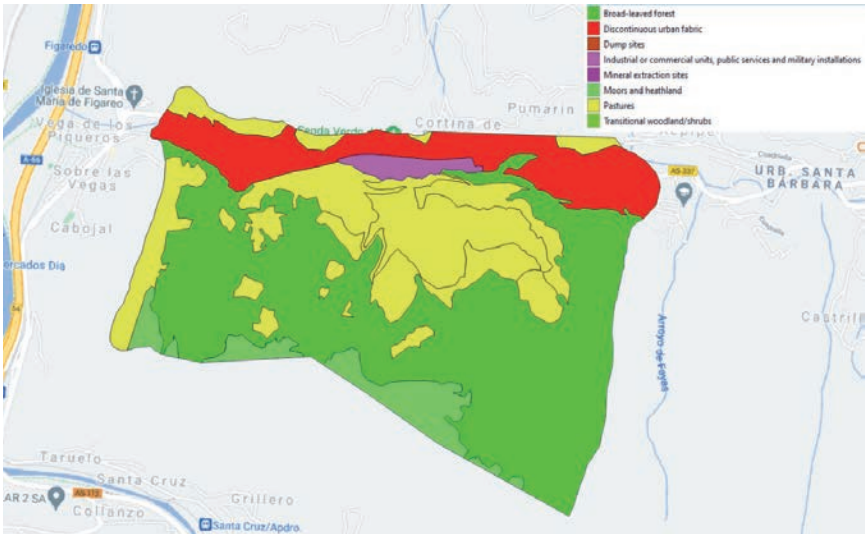


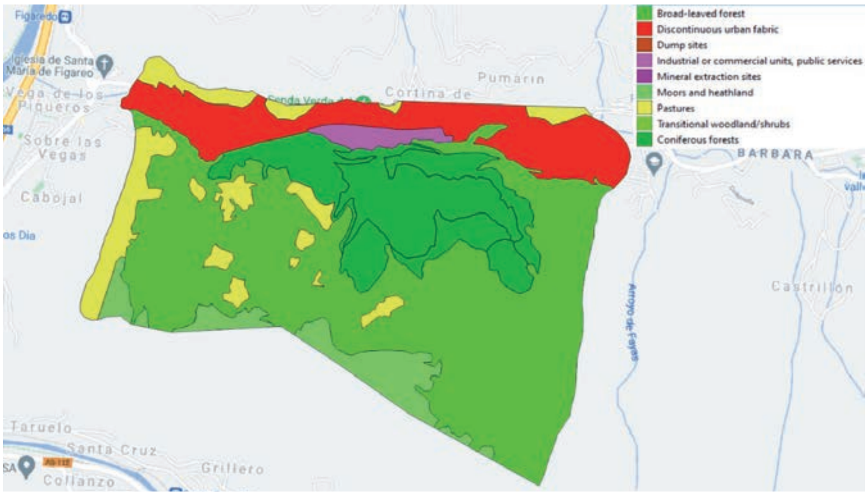


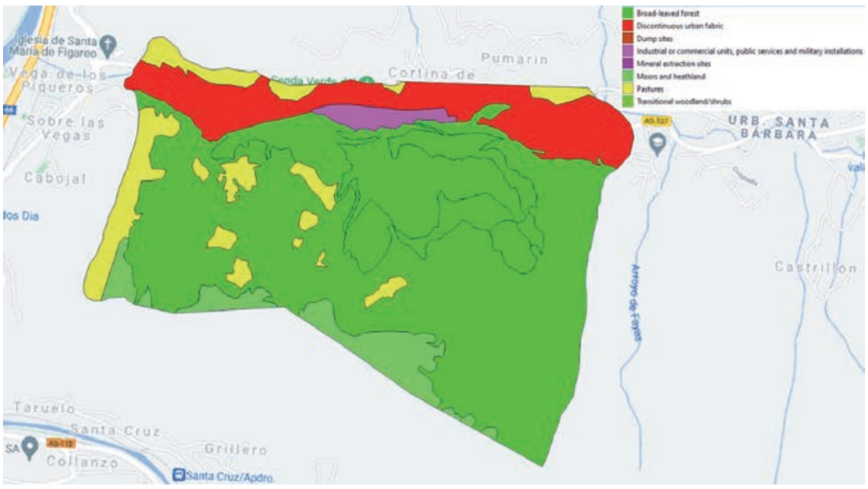
In other cases, local circumstances and long-term development of the considered landscape were used to facilitate the scenario selection.

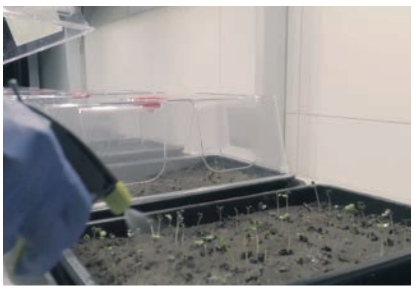
Once the scenarios to be analysed were selected, a narrative for each of them was developed according to stakeholders' opinions, including an overall vision for the new post-mining region and some clear targets: km² of a recreation area, water protection area, or km² of new forest planted, or nature conservation goals.

After, narratives were translated into change rules, procedures and conditions for CLC land use classes using the if-then-else mode. Finally, after running the change algorithms, a map per scenario was developed to expand the GIS web interface.









FOR MORE INFORMATION ON THE ASSESSMENT OF SCENARIOS, PLEASE SEE THE FOLLOWING DETAILED REPORTS:

- Assessment of scenarios for Figaredo Mine
- Assessment of scenarios for Janina Mine
- Assessment of scenarios for Ema Terezie complex
- Assessment of scenarios for Chabařovice and Most-Ležáky Mine

click

The lessons relevant to RECOVERY from the assessment of scenarios can be summarised as follows:

1

Although a particular emphasis was given to consultation with stakeholders (local authorities, neighbourhood associations, coal mining industry, trade unions, and environmental NGOs) to guarantee the success of the whole process, in some cases, it was not easy to achieve significant involvement of the stakeholders despite the efforts made by the partners.

2

Introducing the opinion of stakeholders in the Smic Prob-Expert tool was not feasible in most cases due to the statistical knowledge needed to feed the software. In one case, supporting them within all the processes was feasible. Nevertheless, stakeholders' opinions were always considered to select the different alternatives or hypotheses for analysis.

3

The results of the stakeholder survey questionnaire showed that knowledge of the ES concept is not widespread and that the assessment of revitalisation actions to deliver ES based on expert opinion might yield different results than the assessment based on stakeholders' views.

4

Finally, as it is probable that non-assessed ES will arise from the assessment of scenarios, they should complement the previous assessment of ES.

6. Choose appropriate technology, considering the ecologic disturbance, the needed ES, the desired reclaimed landscape, cost and regulatory requirements

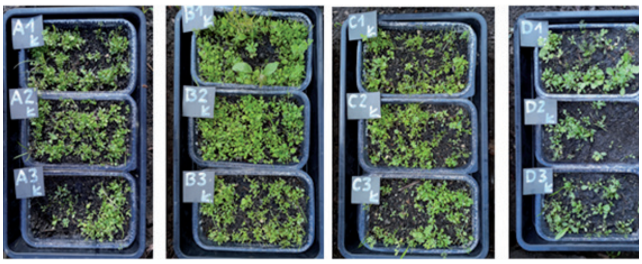
6.1. Artificial substitutes for soils in difficult terrains

The research tries to develop soil substitutes for land rehabilitation of coal mine-affected areas (waste heaps), outlining a novel approach to using wastes generated in coal mines and coal-fired power plants. The following coal combustion by-products were included: fly ashes from coal and biomass combustion, aggregate from mine waste processing, sealing material and energetic slag. Additionally, sewage sludge and spent mushroom compost were incorporated into the elaboration of soil substitutes as substrates enriching with organic matter and valuable nutrients. The selected wastes are generated in coal mines, coal-fired power plants, agriculture industries, and residues from wastewater plants.

Based on the physical and chemical characteristics of the investigated wastes, soil substitutes were prepared by appropriate blending of wastes. Soil substitutes differed in terms of waste type and percentage share. Two tests were carried out to assess each soil substitute's suitability for vegetation development. First, white mustard (Sinapis alba) was used as the typical plant for the seed germination test. In the second place, seeds of semi-natural meadow communities were additionally used. They were represented by plant species-specific for meadow communities in Central Europe. Considering habitat conditions on waste heaps slopes, the species with low (dry meadow) and middle soil moisture requirements (mesic meadow) were used.

1

2



The evaluation of semi-natural meadow communities, such as types of reclaimed coal-mine affected areas, has already started at Libiąż waste heap. The mining waste heaps offer a suitable location for these semi-natural communities' development.

The following photographs show the state of the reclaimed area in April 2022.

The following photographs show the development of meadow vegetation using soil covers at the Janina Mine waste heap: mesic and dry meadow vegetation.

The following photographs show examples of fauna observed on the experimental polygon after reclamation.






FOR MORE INFORMATION ON THE DEVELOPMENT OF ARTIFICIAL SUBSTITUTES FOR SOILS IN DIFFICULT TERRAINS, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Artificial substitutes for soils in difficult terrains

The lessons relevant to RECOVERY from the development of artificial substitutes for soils in difficult terrains regarding the laboratory tests can be summarised as follows:

1

Exploring the local market for suppliers of by-products from coal combustions, coal mines, and organic matter-rich material is essential before developing soil substitute mixtures.

2

The first stage of laboratory testing of components can be limited to testing the aqueous extracts prepared for waste according to EN 12457-4:2002 Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 4: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction).

3

The parameters for the aqueous extract tested in the first stage can be limited to pH, electrolytic conductivity, primary ions and main heavy metals.

4

Waste with the lowest possible pH and electrolytic conductivity should be qualified for further testing and analysis. Power plant slags, which contact process waters during manufacturing, usually meet this condition.

5

When preparing substitute mixtures, it is crucial to limit the number of components providing the ones that ensure: (1) proper soil structure – skeleton-building components (energy slags, fine aggregate); (2) fine-fraction components that retain water – decarbonisation lime and sealing material (from coal dressing plants); (3) organic carbon-rich and structure-enhancing ingredients (spent mushrooms compost).

6

Due to its smear-like consistency and high nitrogen content, sewage sludge is unnecessary and may even be inadvisable. A disproportionate share hinders soil homogenisation and can cause excessive growth of inoculated plant biomass.

7

Fly ashes from coal and biomass combustion should also be avoided in the composition of soil substitutes. This component causes high pH and salinity in the soil substrate mixture. The soil substrate's high pH and conductivity indicate unfavourable conditions for plant growth.

Regarding the polygon test construction phase as well as the plant introduction, the main lessons learnt were as follows:

1

Constructing a reclamation layer using the 2-layer technology is logistically easier but requires precise homogenisation of soil substitutes with mine waste in a 1:1 ratio.

2

In areas in the temperate transitional climate zone (cold winter, warm summer), the testing ground and plant sowing should be constructed in late autumn, avoiding the negative impact of extreme summer weather events (drought, heavy rainfall) on an unplanted reclaimed area with young germinating vegetation.

3

Agrotechnical treatments should be carried out perpendicular to the slope to reduce erosion.

4

In the case of planting shrub seedlings, the use of fencing against animals is necessary.

5

Agro-fibre should be spread around planted young shrubs to separate them from overly expansive herbaceous plants.

6

Meadow communities in the first years of vegetation should be mowed once a year, in autumn, before the sowing period of undesirable plants. After the first and the second mowing, the biomass can be left on the reclaimed area to reduce water erosion.

7

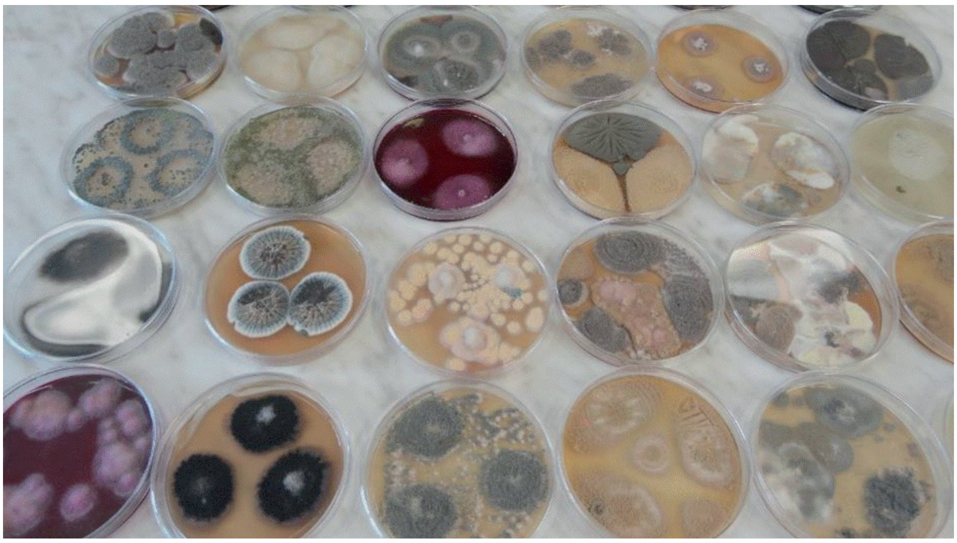
Botanical studies have not shown a significant difference in the conditions of vegetation introduced on a polygon built using the 2-layer technology (cheaper technology) and the multi-layer technology (more expensive technology). Thus, the 2-layer method could successfully reclaim post-mining waste heaps as a more affordable and equally effective.

Multi-layer technology is recommended on the part of the heap where an intensive process of rainwater infiltration occurs, and the risk of acid drainage appearance is high (e.g. flat top of the heap).

6.2. Assessment of rehabilitation techniques for waste heaps

An assessment of rehabilitation techniques for waste heaps in Figaredo Mine and the Ema-Terezie mine dumps complex was developed.
Regarding Figaredo Mines, water analyses were collected above the waste dump, in the waste dump and below the waste heaps. Soil analysis was also developed at a place that was already restored. Also, an above-ground vegetation comparative assessment at Figaredo Mine was developed to determine the degree of vegetal development of the restored waste heaps.

Regarding the Ema-Terezie mine spoils dump, research has been focused on evaluating individual environmental factors that affect the reclamation methods used and the subsequent development of vegetation, fauna and soils in dumps after mining activities. The following aspects were analysed: hydrological properties of the area, development of soils, character, development of vegetation including phytocenological evaluation, the occurrence of rare and endangered plant species, the occurrence of invasive plant species; zoological evaluation, and microbiological evaluation focusing on soil development.



FOR MORE INFORMATION ON THE ASSESSMENT OF REHABILITATION TECHNIQUES FOR WASTE HEAPS, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Assessment of rehabilitation techniques for waste heaps

The lessons relevant to RECOVERY from the assessment of rehabilitation techniques for waste heaps can be summarised as follows:

1

Water and soil analyses allow estimating the contribution of the waste heaps to water and soil characteristics to design remediation measures, if necessary in the case of water, and to determine the predominant soil types (soil forming substrate) together with the anomalous metal concentrations.

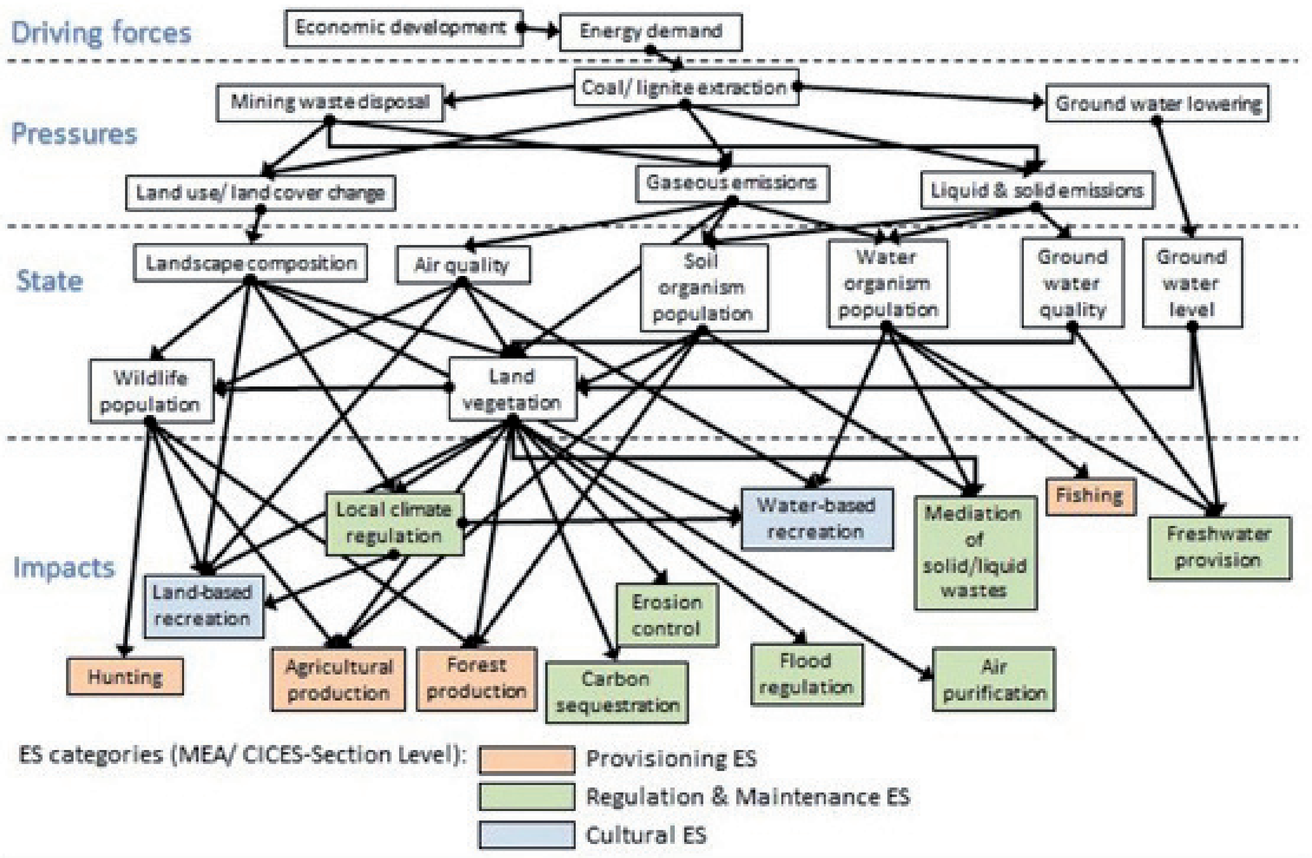
2

Above-ground vegetation comparative assessments, including, when necessary phytocenological evaluation, evaluation of the occurrence of rare and endangered plant species, and occurrence of invasive plant species, according to the different reclamation techniques, allow evaluating the individual ecological factors that affect both the reclamation methods used and the subsequent development of vegetation.

3

Finally, the evaluation of a zoological evaluation (species composition, focusing mainly on invertebrate species, rare and endangered species) and a microbiological evaluation focusing on soil development can help complement the understanding of the biological characteristics of the area, as well as understanding the response to the environmental stress, more precisely disturbance, which leads to a dislocation of ecological balances.

7. Suitable indicators



Suitable indicators that properly quantify every ES involved in the coal-mining affected areas were selected at this stage. Indicators of ES are scientific constructs that use quantitative data to measure ecosystems condition and human well-being. Adequately constituted indicators can convey relevant information for the whole process.

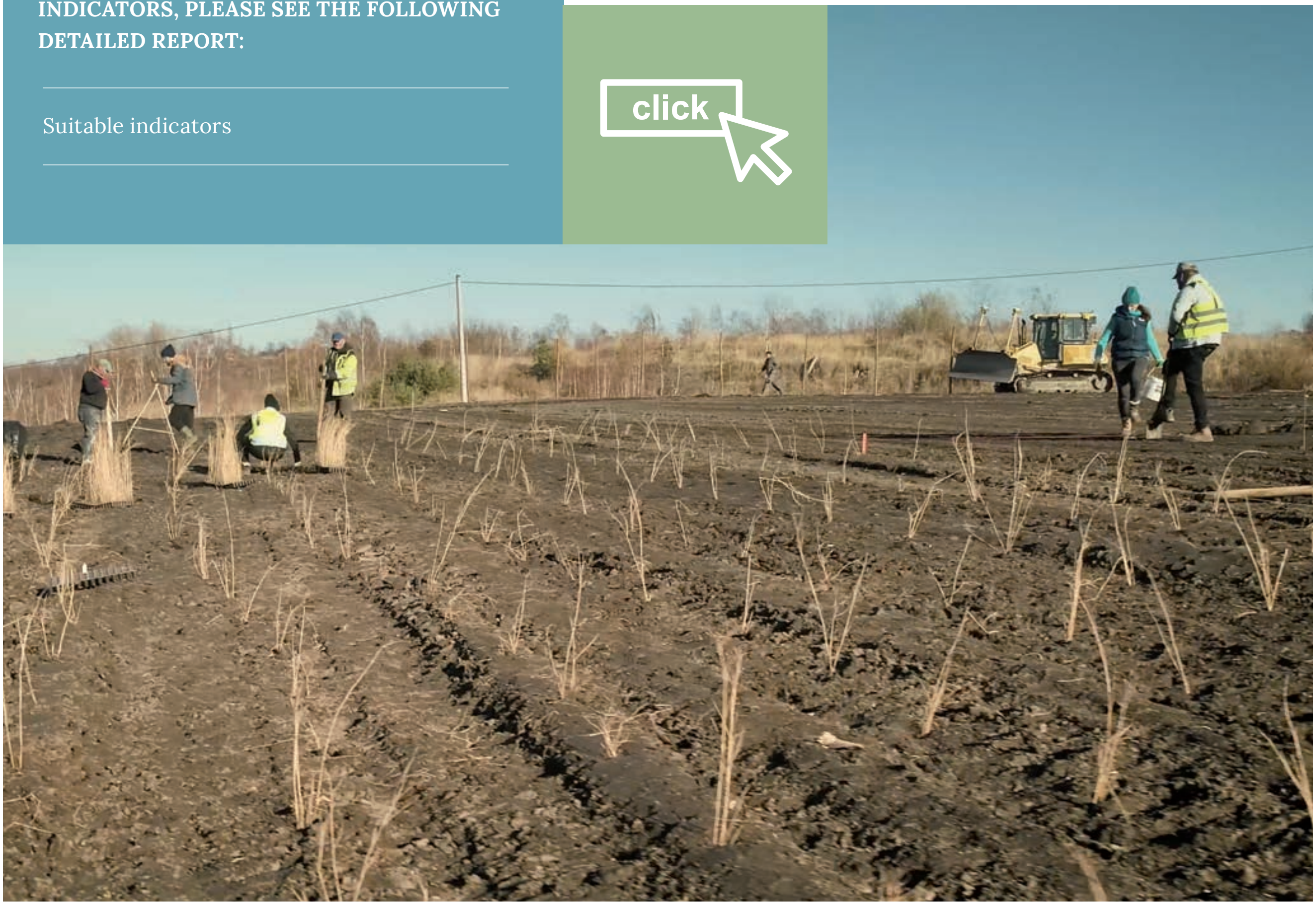
To ensure the suitability of the ES indicators used in the Recovery project, causal chains for each indicator were developed. The causal chains address critical properties of ES and related issues such as pressures, state impacts and responses, informing about cause-effect relationships and reflecting the relevance for mining and post-mining landscapes. An established and widely used approach, the Driving Forces-Pressures-State-Impact-Response (DPSIR) framework, developed by the European Environmental Agency (EEA), was enhanced to a causal chain framework.

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 planning responses. The approach allows considering the effects of changes in the driving forces, policy interventions, or behavioural changes in the causal network, taking possible positive and negative feedback between changes of the multiple driving forces, pressures, and states into account.

FOR MORE INFORMATION ON SUITABLE INDICATORS, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Suitable indicators

click



The lessons relevant to RECOVERY from the selection of suitable indicators can be summarised as follows:

1

ES indicators should allow to carry out the assessment of mining impact and reveal the potential of mine-affected areas for the provisioning of ecosystem services.

2

During the indicators´ selection process, the list of ES is not study site-specific. It represents a framework to be adopted for coal mining sites, regardless of whether the mining action occurs above-ground 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.

3

Comparison between case studies in the project will be possible, considering ES indicators such as water runoff, air pollution, 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, the different study sites are comparable in terms of recovering landscape functions or replacing or creating new landscape functions following the mining. 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 site and a valuation of the benefits using feasible valuation techniques.

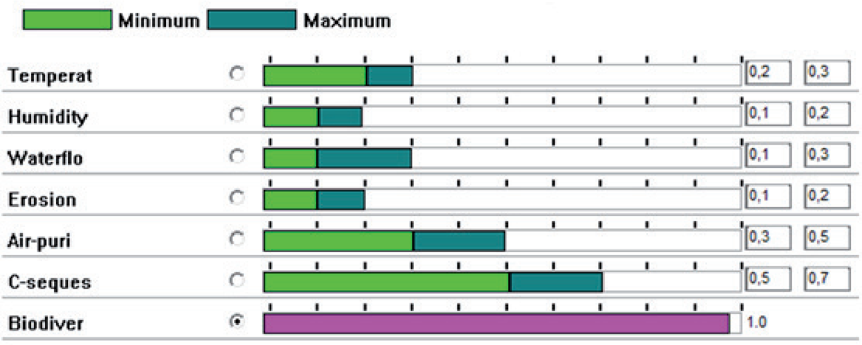
8. New valuation methodology

A new valuation methodology for non-provisioning ES is developed, as evidence was found regarding the lack of homogeneity caused by the existing approaches. Using different valuation methods for non-provisioning ES generates a lack of uniformity in the valuation process that Multi-criteria decision analysis can hardly correct.

First, non-provisioning ES were quantified before monetisation using tables of coefficients for each land cover type derived from field experiments. Then, they were transformed into a standard metric, an index between one and ten, through local scaling. Local scaling sets upper and lower bounds using locally measured performance values instead of global scales that may cause irrelevance of differences between local measures.

	Soil erosion		Dry deposition of pollutants		Above-ground carbon storage	
CLC classes	g/m^2	Index	k /year	Index	t C/ha	Index
Discontinuous urban fabric (112)	193.0	6.9	2.02	1.0	20.0	3.6
Industry or commercial units (121)	193.0	6.9	2.02	1.0	8.52	2.1
Mineral extraction sites (131)	551.3	1.0	2.02	1.0	≈ 0	1.0
Dump sites (132)	551.3	1.0	2.02	1.0	≈ 0	1.0
Pastures (231)	2.4	10.0	149.4	6.2	≈ 0	1.0
Broad-leaved forest (311)	1.4	10.0	258.9	10.0	68.31	10.0
Coniferous forest (312)	15.6	9.6	258.9	10.0	≈ 0	1.0
Moors and Heathland (322)	29.8	9.1	120.2	5.1	4.0	1.5
Transitional woodland/shrub (324)	1.2	10.0	189.6	7.6	10.12	2.3

In the second place, to monetise non-provisioning ES, the implementation of techniques based on the propagation of imprecise preference statements in hierarchical weighting was used. Once a reference attribute has been selected, the remaining attributes are compared to the reference, considering the specific environment and the local scale used.



To achieve consistency, monetisation of all non-provisioning ES will build on the above comparison and the monetary valuation of the attribute with the most direct and market-related valuation possible: carbon sequestration, which was valuated using the EU Emissions Trading System.

Considering the non-provisioning ecosystem services value of the different scenarios per ha calculated, the upper and lower bounds for the alternative scenarios and the ecosystem service obtained per ha for the three scenarios considered.

Attribute	Comparative average weight	Ecosystem service value per ha
Temperature	25%	1,567 €
Waterflow	20%	1,235 €
Erosion	15%	940 €
Air purification	40%	2.507 €
Carbon sequestration	60%	3,760 €
Biodiversity	100%	6,267 €
Total		16,294 €

Scenarios	Lower bound	Mean	Upper bound	ES value
Landscape	0.87	0.93	0.99	15,154 €
Fibre	0.49	0.60	0.71	9,777 €
Food	0.47	0.57	0.67	9,288 €

FOR MORE INFORMATION ON FEASIBLE VALUATION TECHNIQUES, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Feasible valuation techniques

click

The lessons relevant to RECOVERY from the valuation of non-provisioning ES can be summarised as follows:

1

Multi-criteria decision analysis was developed to determine the best choice based on the scores of different criteria and the relative weights given to those criteria. However, assigning relative weights to criteria evaluated with varying assessment methods is complicated.

2

Non-provisioning ES have to be quantified in the first place using tables of coefficients for each land cover type derived from field experiments. Then, they will be transformed into a standard metric employing local scaling instead of global scales that may cause irrelevance differences between local measures.

3

The source of uncertainty in these valuations will be the different values in different climatic environments/conditions and assumptions based on specific areas or circumstances.

4

Then, the implementation of techniques based on the propagation of imprecise preference statements in hierarchical weighting may be used, with a reference attribute having to be selected to compare the remaining attributes. Biodiversity was chosen as, of all the attributes, it was the one that allowed comparisons to be made with the others in the most obvious way.

5

Finally, monetisation of all non-provisioning ES should be built on the above comparison and the monetary valuation of the attribute with the most direct and market-related valuation possible: carbon sequestration using the EU Emissions Trading System.

6

As the average value of EU Allowances during 2019 and 2020 was used, variation in the value may change the results. This question will be discussed later.

8.1. Investment and maintenance costs

The investment and maintenance costs for the different scenarios considered for the five case studies (Figaredo Mine in Spain, Janina Mine in Poland, and Ema-Terezie, Most-Ležáky Mine and Chabařovice Mine in the Czech Republic) were specified, collected and calculated.

Special attention was also given to the sunk costs, which are necessary regardless of the scenario selected. These costs were collected to inform the different stakeholders about all the costs involved in the restoration process, not only the ones related to the specific development of foreseen scenarios.

Both investment and maintenance costs are presented in EUR/m2 and EUR/ha to facilitate their comprehension. When necessary, the areas involved in the costs (in ha) and the total costs are also presented, together with the shares of Corinne Land Cover (CLC) classes in each scenario.

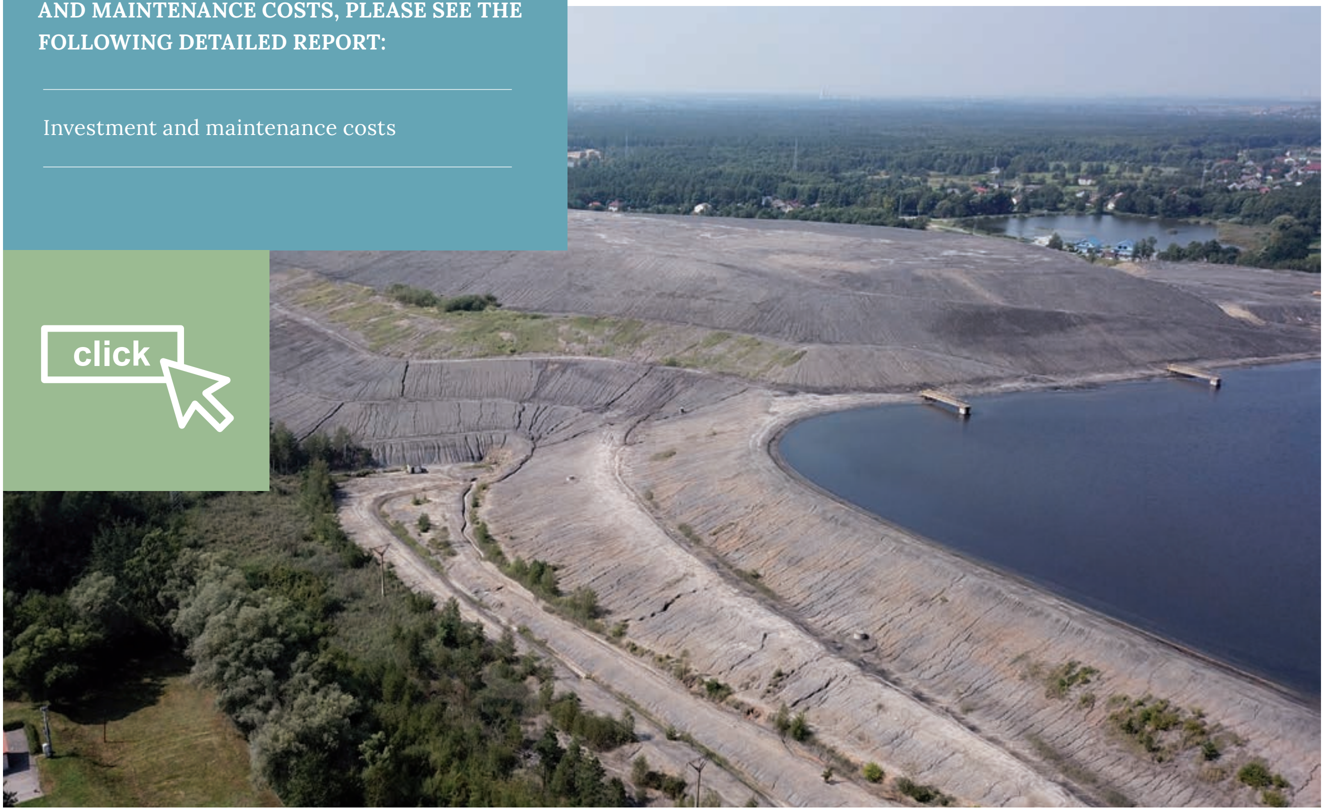
For example, the investment and maintenance costs of pine tree planting in Figaredo mine (300 trees/ha) are presented in Table. The planting holes have to be sanitised, and topsoil must be added. Then, during the first months after planting, maintenance and watering must be carried out, followed by annual maintenance for at least five years, which includes the following tasks: weeding around each plant for a perimeter of about one metre, hand weeding around the tree, weeding, breaking up large clumps, fertilising with slow-release fertiliser, giving each tree a minimum of 150 g of fertiliser, and checking the condition of the stakes. Trees should be planted with a tutor and protective netting. In addition, it is advisable to rinse once a week in the warmer season, with a water supply of about 35 litres per watering plant.

Item	€/m²	€/ha
Tree plantation (300 trees/ha)	0.204	2,040
Clearing and cleaning/year	0.045	450
Slow-release fertiliser/year	0.020	200
Watering/year	0.013	130

FOR MORE INFORMATION ON INVESTMENT AND MAINTENANCE COSTS, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Investment and maintenance costs

click



The lessons relevant to RECOVERY from the collection of investment and maintenance costs can be summarised as follows:

1

Although it is interesting to present costs in EUR/m^2 and EUR/ha, in some cases, such as constructions, roads, and shelters, costs in EUR/m^2 do not have a physical significance.

2

Sunk costs are unnecessary when deciding which options (scenarios) will provide the most significant benefits. However, the stakeholders need to know the exact costs they will incur during the restoration process.

3

It is essential to specify the precise area involved in the cost or the percentage that applies in the designed CLC to facilitate subsequent NPV calculations.

8.2. Relevant market price data

The relevant market prices for the scenarios considered for Figaredo Mine in Spain, Janina Mine in Poland, and Ema-Terezie in the Czech Republic, were specified and collected. Most-Ležáky Mine and Chabařovice Mine in the Czech Republic do not expect benefits in their foreseen scenarios.

When necessary, the areas involved in the market prices (in ha) and the total market prices are also presented in the Deliverable, together with the shares of Corinne Land Cover (CLC) classes in each scenario.

In the Figaredo mine, fibre production through pine plantations to produce wood as raw material is always one of the ecosystem service alternatives traditionally considered in the region. 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 and the quantification method, m^3/ha/year.

It has not been possible to find a data source to quantify the ecosystem service as the development of pines depends on the specific climate. However, in Asturias, pine plantations have, on average, four trees per 10 m^2, equivalent to 300 trees/ha. After 30–40 years, each pine will produce 2 tonnes of wood at 17 EUR/tonne.

The source of uncertainty in this valuation will mainly derive from developing market prices for pine timber as a function of demand/supply and elasticity.

FOR MORE INFORMATION ON RELEVANT MARKET PRICE DATA, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Relevant market price data

The lessons relevant to RECOVERY from the collection of market prices can be summarised as follows:

1. In several cases, finding a data source to quantify the ES was impossible, so specific research had to be developed in the region to estimate market prices.

2. The sources of uncertainty in many valuations are derived from the changing market prices as a function of demand/supply and their elasticity.

3. For estimating the solar energy generated by photovoltaic panels, the Photovoltaic Geographical Information System from the European Commission (https://re.jrc.ec.europa.eu/pvg_tools/en/tools.html) is a perfect tool.

8.3. Adequate discount rates

The appropriate discount rates are proposed to evaluate provisioning ES, including the costs incurred for developing them and the expenses needed to create non-provisioning ES.

For this purpose, three different categories of goods were distinguished: (1) non-intensive natural goods production, such as familiar animal exploitation, familiar tree plantations, and familiar agriculture; (2) intensive natural goods production, such as intensive animal farms, intensive forest exploitation, and intensive agriculture; and (3) industrial goods production such as renewable energy production, and industrial facilities.

The proposed discount rate was then used in the Figaredo mining area case study and applied to calculate the value of fibre production (1% for non-intensive natural goods production, which refers to pine plantations producing wood as raw material). The following equation represents the NPV per ha of a pine plantation:

$$NPV_{Pine\ tress} = -2{,}040 - \frac{780}{(1+0.01)} - \ldots - \frac{780}{(1+0.01)^{5}} + \frac{10{,}200}{(1+0.01)^{35}} - \frac{2{,}040}{(1+0.01)^{36}} - \ldots + \frac{10{,}200}{(1+0.01)^{70}} = 2{,}386\ €$$

FOR MORE INFORMATION ON ADEQUATE DISCOUNT RATES, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Adequate discount rates

click

The lessons relevant to RECOVERY from the selection of the adequate discount rates can be summarised as follows:

1

Real/constant discount rates should be used in the calculations, as it will be challenging to consider adequate variations of the inflation rate over 70 years or more. Moreover, real/constant rates will allow using a common language despite the usual economic differences among European countries.

2

Non-intensive natural goods production, such as familiar animal exploitation, familiar tree plantations, and familiar agriculture, are proposed to be valued at a real/ constant rate of 1%, which is equivalent to the average reference rate of the European mortgage market in 2020.

3

Intensive natural goods production, such as intensive animal farms, intensive forest exploitation, and intensive agriculture, are proposed to be valued at a real/constant discount rate of 3%-3.5%.

4

Industrial goods production, such as renewable energy production and industrial facilities, are proposed to be valued at a real/constant discount rate of around 6.0%-7.0% as there is usually an external investment trying to achieve capital returns.

5

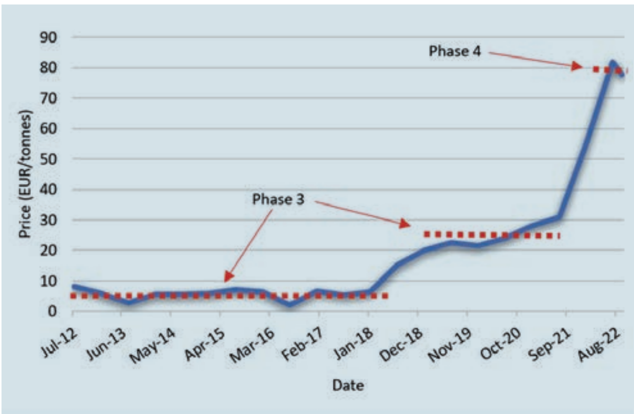
The values proposed for discounting industrial goods production should be accepted only when the industrial goods production risk can be considered average. If the risk is over average, the discount rate should increase in the same proportion.

6

When the difference in the valuation between several scenarios is negligible, the selection between them should be based on the ease of undertaking, measured in the lower investment needed to realise the scenario.

7

The price of EU carbon permits varies over time, so in the valuation, the average value was used during 2019 and 2020, which was relatively stable and coincident with phase 3 of the allocation of allowances. After the price escalation that coincides with phase 4 of the allocation of allowances under the EU Emissions Trading System that takes place from 1 January 2021, the consideration changed and, although not stable yet, it allowed to estimate this carbon price by prioritising biodiversity over the rest of scenarios, something that was never done before.



9. Best scenario selection

The net present value (NPV) for every generated scenario was calculated to establish the net economic consequences in the ES provision and select the most exciting scenario for each case study.

The total value of the different scenarios was obtained by adding the non-provisioning ES values to the net present value calculated for the provisioning ES and the investment and maintenance costs of the non-provisioning ES.

Scenarios	Mean	ES value	NPV	Total value
Landscape	0.93	15,154 €	– 5,486 €	9,668 €
Fibre	0.60	9,777 €	2,386 €	12,163 €
Food	0.57	9,288 €	3,323 €	12,611 €

FOR MORE INFORMATION ON THE BEST SCENARIO SELECTION, PLEASE SEE THE FOLLOWING DETAILED REPORT:

Best scenario selection

click

The lessons relevant to RECOVERY from the best scenario selection can be summarised as follows:

1

In this case, local scaling was selected to transform non-provisioning ES values into a common metric, an index between one and ten. Local scaling sets upper and lower bounds using locally measured performance values instead of global scales that may cause irrelevance of differences between local measures. Thus, all criteria performance values will have the same influence on the final scores of the alternatives if they are weighted equally.

2

Selecting a reference ES was necessary to estimate each proposed scenario's ES provision (or weight). Biodiversity was chosen as the reference ES because of all the ES. It was the one that allowed comparisons to be made with the others in the most obvious or intuitive way, which facilitated the development of the process. The rest of the ES were then compared with biodiversity.

3

To achieve consistency, monetisation of all non-provisioning ES was carried on the above comparison and the monetary valuation of the attribute with the most direct and market-related valuation possible: carbon sequestration, using the EU Emissions Trading System.

4

The price escalation coinciding with phase 4 of the allocation of allowances under the EU ETS (2015), which took place on 1 January 2021, made it necessary to adjust or rethink the ES valuation process developed. To achieve this goal, introducing new vectors or "missing ES" was proposed to counterbalance efforts to eliminate carbon dioxide emissions without necessarily removing humans from the equation: welfare and human health.

5

As the linkages regarding ecosystem health, ecological restoration and human health are not well known, only welfare was incorporated into the framework. The results were highly satisfactory, in line with what was expected for the study region and those obtained before the price escalation of carbon allowances started in 2021.

6

The valuation of the provisioning ES and the costs incurred for non-provisioning ES were done by calculating their net present value (NPV) over a sufficiently long period.

7

Finally, it was possible to estimate the price of EU allowances after the price escalation that coincides with phase 4 of allowances allocation by prioritising the Landscape scenario. It is tantamount to allowing nature (biodiversity) to set the price of EU allowances in the study area to become the scenario to be chosen.

10. Conclusion/Outlook

Coal mining has played a significant role in providing energy for economic activities such as manufacturing, transport, and household consumption in the so-called industrialised countries. While coal mining in Europe is declining, mining continues in other parts of the world. There is a common understanding that energy generation from fossil fuels, including hard and brown coal, causes greenhouse gas emissions responsible for global warming and climate change. The global community has therefore pledged to reduce greenhouse gas emissions. Terminating coal extraction is necessary but not easy, as numerous challenges for developing the post-mining landscapes arise.

While the transformation from coal mining landscapes to post-mining landscapes was done on a case-to-case basis in past decades, a need for a broader perspective to post coal mining transition became apparent. The EU RFCS project “RECOVERY of degraded and transformed ecosystems in coal mining-affected areas” investigated the perspectives of post-mining landscapes for several different European coal mining sites in Poland, Czech Republic, Spain and Germany, including both above-ground and underground, as well as hard coal and lignite mining.

The project methodology is based on the ES concept, established in ecological economics to account for the benefits and values of different reclamation approaches and relate them to the needs of local communities and stakeholders. Based on the experiences gained from the more advanced transformations, the ES approach provides information on the benefits of different land uses. Mining pits can be transformed into lakes, adding new landscape elements to landscapes where lakes don´t naturally occur. The new landscape features benefit the local population and the resettlement of wildlife by providing diverse ecological niches. The new ES potentials were used to generate scenarios to project the future values of different reclamation options. The ES projected in the different scenarios can be compared based on marked-based and non-market-based valuation methods to provide directions for the planned or ongoing transformations. Connected to the approach of ES assessment, the most promising practices of regeneration soils and replanting vegetation were investigated to advise on the most effective ways to reconcile and revegetate the mining dump heaps, transforming them from harmful waste sites to green hills providing valuable ES, such as immobilising and reducing soil pollutants or providing recreational vista points.

Due to the structured methods and the established concept of ES, the knowledge generated in the project can be applied to other coal mining sites and even other mining sites. Most above-ground and below-ground mining has similar impacts on ES and thus faces similar reclamation challenges as assessed for the coal mines in the recovery project. The project guidelines provide a good framework for assessing the current and projection of future ES in different scenarios. The guidelines also allow adaptation to specific site conditions based on different minerals extracted, climatic conditions or others.

Recovery

PARTNERS IN THE PROJECT

Główny Instytut Górnictwa
Poland

Universidad de Oviedo
Spain

Humboldt - Universität zu Berlin
Germany

Univerzita Ostrava
Czech Republic

Hulleras del Norte S.A.
Spain

TAURON Wydobycie S.A.
Poland

DIAMO, státní podnik
Czech Republic