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

847205-RECOVERY-RFCS-2018

Deliverable 5.3

Best scenario selection

Authors

Dr. Alicja Krzemień, GIG Research Institute (Poland)
Dr. Pedro Riesgo Fernández, University of Oviedo (Spain)
Dr. Kateřina Růžičková, VŠB-TU Ostrava (Czech Republic)
Dana Prokešová, Palivový kombinát Ústí, s.p. (Czech Republic)
Dr Robert Frączek, Tauron Wydobycie (Poland)
Dr. Angelika Więckol-Ryk, GIG Research Institute (Poland)
Dr. Lukasz Pierzchała, GIG Research Institute (Poland)
Dr. Arkadiusz Bauerek, GIG Research Institute (Poland)
Dr. Gregorio Fidalgo Valverde, University of Oviedo (Spain)
Juan José Álvarez Fernández, University of Oviedo (Spain)
Dr. Silverio García Cortés, University of Oviedo (Spain)
Dr. Bárbara Stalmachová, VŠB – TU Ostrava (Czech Republic)
Dr. Jana Nováková, VŠB-TU Ostrava (Czech Republic)
Dr. Simona Matušková, VŠB-TU Ostrava (Czech Republic)
Dr. Hana Švehláková, VŠB-TU Ostrava (Czech Republic)
Robert Šimůnek, Palivový kombinát Ústí, s.p. (Czech Republic)

Deliverable 5.3	
Due date of Deliverable	31.03.2023
Start - End Date of Project	01.07.2019 – 30.06.2023
Duration	4 years
Deliverable Lead Partner	GIG
Dissemination level	Public
Work Package	WP 5
Digital File Name	D5.3 Best scenario selection
Keywords	Scenario, selection, maintenance, restoration, Emission allowances, ecosystem services, biodiversity

Disclaimer

Part of the content of this Deliverable has been published in:

Krzemień, A., Álvarez Fernández, J.J., Riesgo Fernández, P., Fidalgo Valverde, G., & Garcia-Cortes, S. (2023). Valuation of Ecosystem Services Based on EU Carbon Allowances—Optimal Recovery for a Coal Mining Area. *International Journal of Environmental Research and Public Health* 20(1), 381. https://doi.org/10.3390/ijerph20010381

Table of contents

List of Figures

List of Tables

Executive summary

In this Deliverable, the net present value for every generated scenario was calculated to establish net economic consequences in the ecosystem services provision and select the most interesting scenario for each case study.

First, the CLC classes involved in the assessment of scenarios and the changing rules of CLC classes for the different scenarios were presented. Also, the ecosystem services and their indicators were summarised.

Second, the quantification of non-provisioning ecosystem services was developed, selecting the quantification method and normalising the values in an index between 1 and 10.

Third, non-provisioning ecosystem services were evaluated by comparing ecosystem services with the reference attribute that, in most cases, was biodiversity. Then, to monetise the set of ecosystem services, the one for which valuation is most feasible was first selected: carbon sequestration through the EU Emissions Trading System is the most viable.

Fourth, and after valuing the non-provisioning ecosystem services for each scenario, the valuation of provisioning ecosystem services was estimated by calculating the net present value of their investment and maintenance costs and their market price data, if any.

Fifth, the total value of the different scenarios was obtained by adding the non-provisioning ecosystem service values to the net present value calculated for the provisioning ecosystem services and the investment and maintenance costs of the non-provisioning ecosystem services.

Finally, an exercise was carried out for Figaredo mine to estimate what the price of EU allowances would have to be for the scenario that prioritises biodiversity to be chosen, as a sensitivity and uncertainty analysis of the results obtained.

1 Introduction

Work Package 5 was to develop the cost-benefit assessment of the different scenarios by quantifying the costs of the alternative actions and the economic value of the ecosystem services provision to determine which options will deliver the most significant benefits concerning their costs.

Specific objectives of this work package were:

- To collect all the relevant market price data and determine when prices are distorted to correct distortions.
- To collect detailed costs of the restoration processes and maintenance costs.
- To estimate the net present value for every scenario with a sensitivity and uncertainty analysis.
- To determine which options will deliver the most significant benefits concerning their investment and maintenance costs.

Once relevant market price data was collected and detailed costs of the investment processes and the maintenance costs for the analysed case studies, the last task was to evaluate each scenario to determine the best scenario selection possible in each case study.

2 Best scenario selection for Figaredo Mine

2.1 Land cover types involved in the assessment of scenarios

Figures 2-1 present the state of Figaredo Mine with all the Corine Land Cover (CLC) classes that were identified at the beginning of the RECOVERY Project.

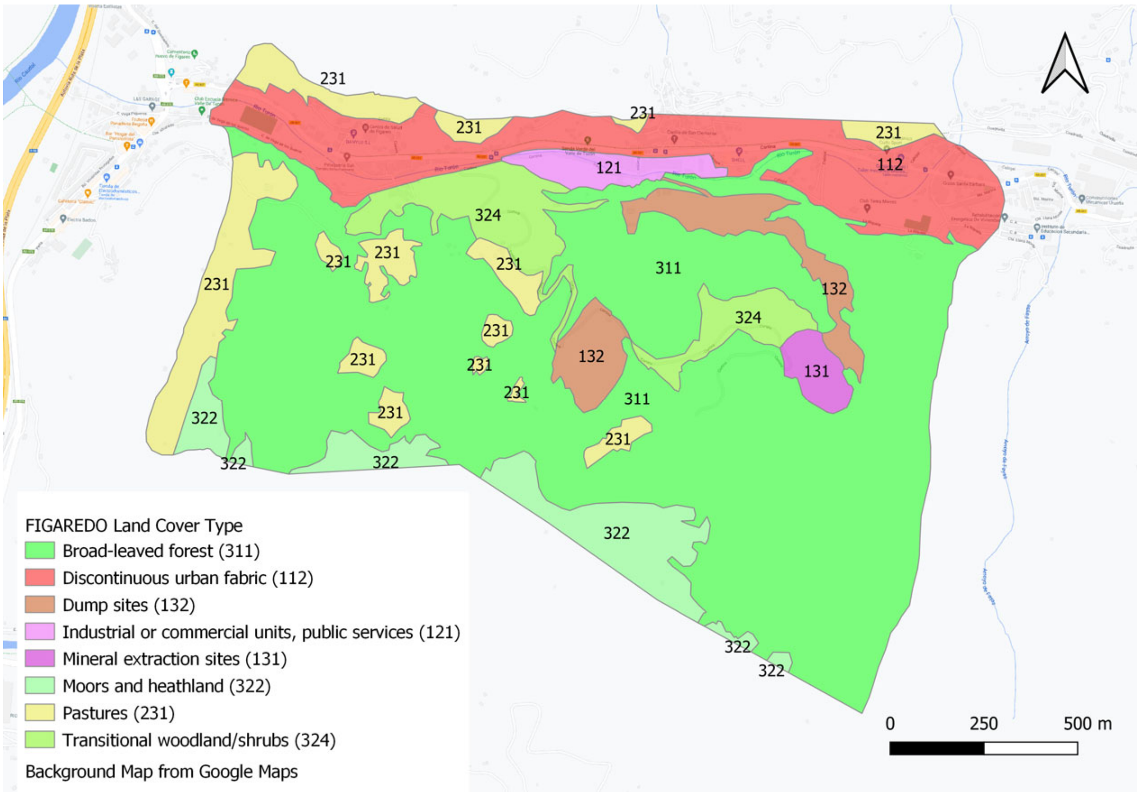


Figure 2-1. Presentation of the GIS of the CLC classes at the Figaredo mine

The CLC classes identified were: Broad-leaved forest (311), Discontinuous urban fabric (112), Dump sites (132), Industrial or commercial units (121), Mineral extraction sites (131), Moors and heathland (322), Pastures (231) and Transitional woodland/shrubs (324).

After, three scenarios were considered feasible to undergo the ecosystem restoration of the area:

1. Pine plantations for the production of wood as raw material (Fibre).
2. Feeding of cows for beef production (Food).
3. Reconstruction of a broad-leaved forest similar to those already present in the landscape of the region (Landscape).

The Fibre scenario is characterised by a focus on pine tree plantations for producing wood as raw material. Thus, the CLC class Coniferous forest (312) has to be also considered.

The food scenario is characterised by a focus on feeding cows to produce meat. The correspondent CLC class to develop this scenario, Pastures (231), was already considered.

The landscape scenario is characterised by reconstructing a Broad-leaved forest similar to the ones already present in the region. The corresponding CLC class to develop this scenario is Broad-leaved forest (311) which was already considered.

Table 2-1 presents the CLC classes that must be considered to undergo the scenario selection of Figaredo Mine.

Table 2-1. CLC classes involved in the assessment of scenarios

CLC classes
Discontinuous urban fabric (112)
Industry or commercial units (121)
Mineral extraction sites (131)
Dump sites (132)
Pastures (231)
Broad-leaved forest (311)
Coniferous forest (312)
Moors and heathland (322)
Transitional woodland/shrub (324)

Finally, the change rules in percentages of CLC land use areas for the three scenarios are presented in Table 2-2.

Table 2-2. Change rules of CLC classes for the three scenarios

Land use	Initial state	Scenario I Fibre (%)	Scenario II Food (%)	Scenario III Landscape (%)
Dump sites (132)	100	0	0	0
Coniferous forest (312)	0	100	0	0
Pastures (231)	0	0	100	0
Broad-leaved forest (311)	0	0	0	100

2.2 Representative ecosystem services

In the case of Figaredo Mine, considering the casuistry of its area and the region in which it is located (Asturias, Spain), ninth ecosystem services were selected following the CICES V5.1 classes (Haines-Young and Potschin, 2018) and the causal network of coal mining impacts that was developed in Deliverable 4.1 Suitable indicators.

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

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

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

Table 2-3 shows a summary of the ecosystem services selected as well as their indicators that were first presented in Deliverable 4.1 Suitable indicators.

Table 2-3. Summary of ecosystem services and their indicators

Ecosystem service	Indicator
Fibre production	Forest productivity
Food production	Livestock production
Climate regulation (Temperature)	Land surface thermal emissions
Climate regulation (Humidity)	Evapotranspiration
Water flow regulation	Runoff
Erosion control	Soil loss
Air purification	Pollutant capture
Carbon sequestration	Carbon storage
Qualities of species or ecosystems (Biodiversity)	Impact of shrinkage-related cover patterns

2.3 Quantification of non-provisioning ecosystem services

Although only three CLC classes are necessary for evaluating the different scenarios, the quantification of non-provisioning ecosystem services was made for all the CLC classes that are present in the Figaredo Mine area, that were shown in Table 2-1.

2.3.1 Regulating services: climate regulation (temperature)

The air temperature was declared as the most apparent/suitable indicator when Schwarz et al. (2011) assessed the climate impact of different planning policies in the urban area of Leipzig in Germany, as trees and green regions moderate the climate. The corresponding CICES V5.1 code is 2.2.6.2, and the class 'Regulation of temperature and humidity, including ventilation and transpiration'. As air temperature is not easy to estimate spatially, thermal emissions from the earth's surface, which indicate the amount of energy emitted by bodies, could be used to measure temperature regulation.

In this case, the ecosystem service indicator could be land surface thermal emissions from the Landsat 7 ETM+ satellite (band 6) and the quantification method, the emission index, as used by Schwarz et al. (2011) but with the broad-leaved forest as the reference because its emission value is the lowest. Values (v) were normalised in an index between 1 (highest emission) and 10 (lowest emission), according to equation (1), similar to that used by Larondelle & Haase (2012).

$$Index[i] = (max_{norm} + min_{norm}) - \left[(v - min) \times \frac{max_{norm} - min_{norm}}{max - min} + min_{norm}\right] \quad (1)$$

The thermal emissivities of the land cover and the respective normalised emission indexes adapted from Schwarz et al. (2011) are presented in Table 2-4.

Table 2-4. Thermal emissivities of CLC classes and normalized emission indexes

CLC classes	Thermal emissivity	
	Emission	Index
Discontinuous urban fabric (112)	139.4	3.5
Industry or commercial units (121)	141.5	1.0
Mineral extraction sites (131)	137.0	6.4
Dump sites (132)	139.0	4.0
Pastures (231)	135.4	8.3
Broad-leaved forest (311)	134.0	10.0
Coniferous forest (312)	137.4	5.9
Moors and heathland (322)	137.0	6.4
Transitional woodland/shrub (324)	136.0	7.6

2.3.2 Regulating services: climate regulation (humidity)

Humidity (evapotranspiration) was selected by Schwarz et al. (2011) as a second indicator for estimating local climate regulation, as forests and green areas influence precipitation and water availability both locally and regionally. Evapotranspiration is the sum of the evaporation of water from the land surface and transpiration from vegetation.

While CICES V5.0 shares in code 2.2.6.2 both temperature and humidity regulation, the old version V4.3 had different codes for them: 2.3.5.2 ‘Micro and regional climate regulation’, and 2.2.3.2 ‘Ventilation and transpiration’. The reason is that the classification structure of provisioning services in V4.3 was changed in V5.1 to allow aggregation when the end-use is unknown. The classification can be more easily used for accounting purposes.

Although there is a linear relationship between evapotranspiration and latent heat of vaporisation (the higher the evapotranspiration, the lower the energy available as sensible heat), this correlation disappears when analysing the total thermal emissivity. Thus, splitting the two services would facilitate the analysis. In this case, the ecosystem service indicator could be the evapotranspiration potential, as Schwarz et al. (2011) used.

The quantification method will approximate the evapotranspiration potential of the different land cover classes. Schwarz et al. (2011) used equations based on empirical estimates and considered soil types and climatic conditions. The evapotranspiration potential f[i] was calculated according to equation (2).

$$f[i] = (max\ evapotranspiration\ [i] \div ET_0) \tag{2}$$

where ET_0 is the reference evapotranspiration potential of the 12 cm tall grass.

Values (v) were again normalised between 1 (lowest evapotranspiration potential) and 10 (highest evapotranspiration potential). Equation (3) was used, as it was unnecessary to reverse the ranking to reflect the lowest evapotranspiration as the highest index.

$$Index[i] = \left[(v - min) \times \frac{max_{norm} - min_{norm}}{max - min} + min_{norm}\right] \tag{3}$$

The evapotranspiration potentials, adapted from Schwarz et al. (2011), and the respective normalised evapotranspiration indexes are presented in Table 2-5. Sources of uncertainty in this assessment are again differences in soil types and values under different climatic conditions, as these values were obtained for the urban region of Leipzig.

Table 2-5. Evapotranspiration potentials of CLC classes and evapotranspiration indexes

CLC classes	Evapotranspiration potential	
	f	Index
Discontinuous urban fabric (112)	0.9	2.8
Industry or commercial units (121)	0.8	1
Mineral extraction sites (131)	1.0	4.6
Dump sites (132)	1.0	4.6
Pastures (231)	1.1	6.4
Broad-leaved forest (311)	1.1	6.4
Coniferous forest (312)	1.3	10
Moors and heathland (322)	1.1	6.4
Transitional woodland/shrub (324)	1.1	6.4

2.3.3 Regulating services: water flow regulation

Water flow regulation is another regulating service, as Asturias is a region with high rainfall. The corresponding CICES V5.1 code is 2.2.1.3, and the class 'Hydrological cycle and water flow regulation'.

The ecosystem services indicator could be the volume of water retained by vegetation per ha, and the quantification method is the statistical runoff estimated by Nunes et al. (2011).

Some approximations had to be considered, as not all CLC classes of Figaredo mines were presented in Nunes et al. (2011). The values of the rainiest year between the two years analysed (2006) were selected, and the mineral extraction sites and dump sites were assimilated to afforested land. The value chosen for coniferous forests was the mean between broad-leaved forests, moors, and heathland.

According to Tanouchi et al. (2019), the range of the impervious surface ratio of the discontinuous urban fabric is between 50% and 80%, so a mean runoff value of 65% of the total rainfall was assigned to both the discontinuous urban fabric and industry or commercial units. The quantification results are presented in Table 2-6, and a water flow regulation index is calculated according to equation (1).

The assessment's sources of uncertainty will be the different values in different climatic environments/conditions and assumptions based only on one year's rainfall.

Table 2-6. Runoff as a percentage of rainfall of CLC classes and runoff indexes

CLC classes	Runoff	
	% rainfall	Index
Discontinuous urban fabric (112)	65.0	1.0
Industry or commercial units (121)	65.0	1.0
Mineral extraction sites (131)	12.3	8.3
Dump sites (132)	12.3	8.3
Pastures (231)	0.6	9.9
Broad-leaved forest (311)	0.1	10.0
Coniferous forest (312)	6.2	9.2
Moors and heathland (322)	12.3	8.3
Transitional woodland/shrub (324)	0.2	10.0

2.3.4 Regulating services: erosion control

Erosion control is also a regulating service to be considered, although its importance in the Asturias region is not very significant. The corresponding CICES V5.1 code is 2.2.1.1 and the class 'Control of erosion rates'. The ecosystem services indicator could be the soil erosion in g/m^2, and the quantification method is the statistical runoff as estimated by Nunes et al. (2011).

Using the same assumptions as with water flow regulation and values from the same year (2016), Table 2-7 presents soil erosion in g/m^2 and erosion control indexes calculated according to equation (1). In the case of the discontinuous urban fabric and industry or commercial units, as the non-impervious surface, according to Tanouchi et al. (2019), was 35%, this percentage was used to calculate their soil erosion based on that of mineral extraction sites and dump sites.

Table 2-7. Soil erosion of CLC classes and erosion indexes

CLC classes	Soil erosion	
	g/m^2	Index
Discontinuous urban fabric (112)	193.0	6.9
Industry or commercial units (121)	193.0	6.9
Mineral extraction sites (131)	551.3	1.0
Dump sites (132)	551.3	1.0
Pastures (231)	2.4	10.0
Broad-leaved forest (311)	1.4	10.0
Coniferous forest (312)	15.6	9.6
Moors and heathland (322)	29.8	9.1
Transitional woodland/shrub (324)	1.2	10.0

The assessment's sources of uncertainty will be the different values in different climatic environments/conditions and assumptions based only on one year's rainfall.

2.3.5 Regulating services: air purification

Plants provide air purification or removal of air pollution. They have large surface areas for particle deposition and adsorption of gases by the leaf or chemical reactions on the leaf surface. These processes are often referred to as 'dry deposition'. The amount of pollution removed by plants depends on their leaves' size and surface area but can vary depending on climate, time of year, and other atmospheric pollutants.

The CICES V5.1 code is 2.2.6.1. The class is "Regulation of chemical composition of atmosphere and oceans". The ecosystem service indicator could be pollutant capture. The quantification method could be dry deposition of the following pollutants, as used by Jones et al. (2017): Sulphur dioxide (SO2), coarse particulate matter (PM10), fine particulate matter (PM2.5), ammonia (NH3), nitrogen dioxide (NO2) and ozone (O3). Other interesting studies consider CO (Nowak et al., 2006), but the variations should not be significant as the pollutants will be considered together.

Table 2-8 presents the dry deposition of pollutants by land cover classes adapted from Jones et al. (2017) and a pollutant dry deposition index calculated according to equation (3).

Table 2-8. Dry deposition of pollutants of CLC classes and corresponding indexes

	Dry deposition of pollutants	
CLC classes	**k /year**	**Index**
Discontinuous urban fabric (112)	2.02	1.0
Industry or commercial units (121)	2.02	1.0
Mineral extraction sites (131)	2.02	1.0
Dump sites (132)	2.02	1.0
Pastures (231)	149.4	6.2
Broad-leaved forest (311)	258.9	10.0
Coniferous forest (312)	258.9	10.0
Moors and heathland (322)	120.2	5.1
Transitional woodland/shrub (324)	189.6	7.6

2.3.6 Regulating services: carbon sequestration

Carbon sequestration was the last regulating service considered. In the case of pastures and coniferous forests, since they are considered provisioning services, this is incompatible with accounting for carbon sequestration as a regulating service. The CICES

V5.1 code will be again 2.2.6.1, and the class "Regulation of chemical composition of atmosphere and oceans".

The ecosystem services indicator shall be above-ground carbon storage/ha. The above-ground carbon storage quantification method will be linked to land use in t C/ha, as Strohbach and Haase (2012) estimated in a study on above-ground carbon storage in Leipzig (Germany).

Table 2-9 presents the above-ground carbon storage per land cover to be considered, adapted from Strohbach & Haase (2012), and a carbon storage index calculated according to equation (3).

In this case, an indirect monetary valuation of the ecosystem service is possible using the EU Emissions Trading System (2015). Sources of uncertainty in the assessment are the values at different locations, as these values were obtained for Leipzig.

Table 2-9. Above-ground carbon storage of CLC classes and corresponding indexes

CLC classes	Above-ground carbon storage	
	t C/ha	Index
Discontinuous urban fabric (112)	20.0	3.6
Industry or commercial units (121)	8.52	2.1
Mineral extraction sites (131)	≈ 0	1.0
Dump sites (132)	≈ 0	1.0
Pastures (231)	≈ 0	1.0
Broad-leaved forest (311)	68.31	10.0
Coniferous forest (312)	≈ 0	1.0
Moors and heathland (322)	4.0	1.5
Transitional woodland/shrub (324)	10.12	2.3

2.3.7 Cultural services: qualities of species or ecosystems (biodiversity)

The qualities of species or ecosystems (biodiversity) or biophysical features (landscapes) representing typical Asturian forests (Broad-leaved forests) in the Figaredo mine area was the last ecosystem service to be analysed.

The CICES V5.1 code is 3.2.2.1, and the class 'Characteristics or features of living systems that have an existence value'. An example of service should be 'areas designated as wilderness, and the ecosystem services indicator could be the type of living systems or environmental settings.

The quantification method could be the number of endemic or quasi-endemic species observations. This particular ecosystem service represents an excellent proxy for quantifying biodiversity. Code 3.2.2.2 has the same ecosystem service class and the same indicator. The only difference is that while the simple descriptor of this code is 'things in nature that we want future generations to enjoy or use', the first code was 'the things in nature that we think should be conserved'. In our view, the two are complementary and indissoluble, at least in this case.

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

Table 2-10 presents the impact on the biodiversity of the different land cover cases in the Figaredo mine area, adapted from Haase et al. (2014) and the biodiversity index calculated with equation (3).

Table 2-10. Impact of shrinkage-related cover patterns of CLC classes and corresponding indexes

CLC classes	Impact	Index
Discontinuous urban fabric (112)	0	1
Industry or commercial units (121)	0	1
Mineral extraction sites (131)	1	4
Dump sites (132)	1	4
Pastures (231)	2	7
Broad-leaved forest (311)	3	10
Coniferous forest (312)	2	7
Moors and heathland (322)	2.5	8.5
Transitional woodland/shrub (324)	2.5	8.5

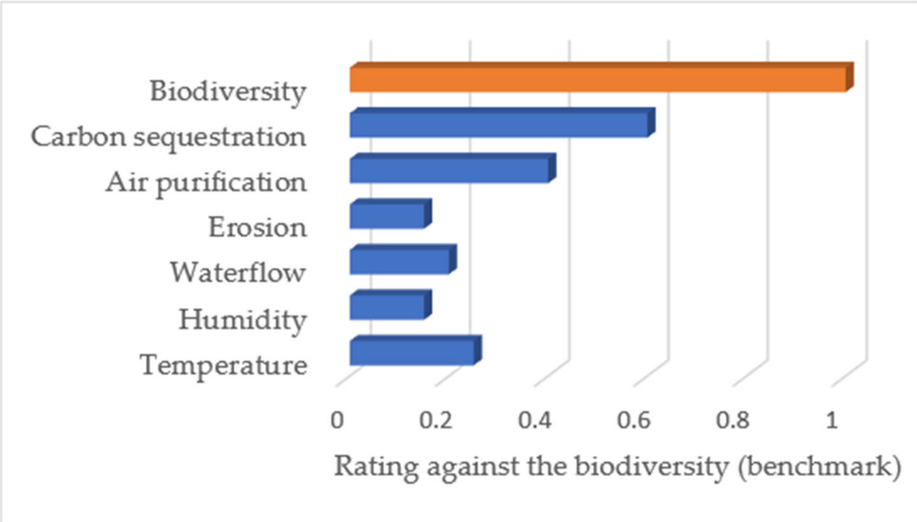
2.4 Valuation of non-provisioning ecosystem services

2.4.1 Comparing ecosystem services with the reference

To estimate the ecosystem services provision of each proposed scenario, it was first necessary to select a reference attribute. Biodiversity was chosen as the reference attribute because, of all the attributes, it was the one that allowed comparisons to be made with the others in the most obvious way, which facilitated the development of the process. The rest of the attributes were then compared with the reference attribute.

Rank orderings should not change with a different anchor, as they are bi-univocal among the various ecosystem services. What may change is only the difficulty of establishing these rank orderings. That is why biodiversity was the anchor selected, as it is the most intuitive among them. Table 2-11 presents the results of the comparison carried out using the Delphi method and the WINPRE program, developed by experts from Hulleras del Norte, S.A. (Spain), the School of Mining, Energy and Materials Engineering of Oviedo (Spain), and the Central Institute of Mining in Katowice (Poland).

Table 2-11. Rating of ecosystem services against the benchmark (biodiversity)



2.4.2 Most direct and market-related valuation possible: carbon sequestration

The ecosystem service for which valuation is most feasible must first be selected to monetise the set of ecosystem services. In this case, the indirect monetary valuation of carbon sequestration through the EU Emissions Trading System (2015) is the most feasible.

According to the EU Emissions Trading System (2015), during 2019 and 2020, the average value of EU Allowances, which allows for the emission of 1 tonne of carbon dioxide equivalent, was about 25 €/t (EMBER, 2021), as presented in Figure 2-2. As 3.67 t CO_2 contain 1 t C, the average value of sequestration of 1 t C can be estimated at 91.75 €/t. Therefore, an above-ground carbon storage rate of 10.0, equivalent to 68.31 t C/ha (Table 3), should be valued at 6,267 €/ha. This value will be used as the reference value for 100% weighted ecosystem services. We assume that all non-provisioning ecosystem services weighted at 100% are worth the same, given that the specific values for each ecosystem service will come from the relative comparison between them.

The revised EU Emissions Trading System Directive, which will apply from 2021–2030, generated a price escalation of carbon allowances, making it necessary to adjust or rethink the proposed framework. To achieve this goal, we have proposed in Krzemień, A., Álvarez Fernández, J.J., Riesgo Fernández, P., Fidalgo Valverde, G., & Garcia-Cortes, S. (2022) the introduction of new vectors or "missing ecosystem services" to counterbalance efforts to eliminate carbon dioxide emissions without necessarily removing humans from the equation: welfare and human health. 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 with the ones obtained before the price escalation of carbon allowances that started in 2021. However, this new ecosystem service will not be used within the present valuation.

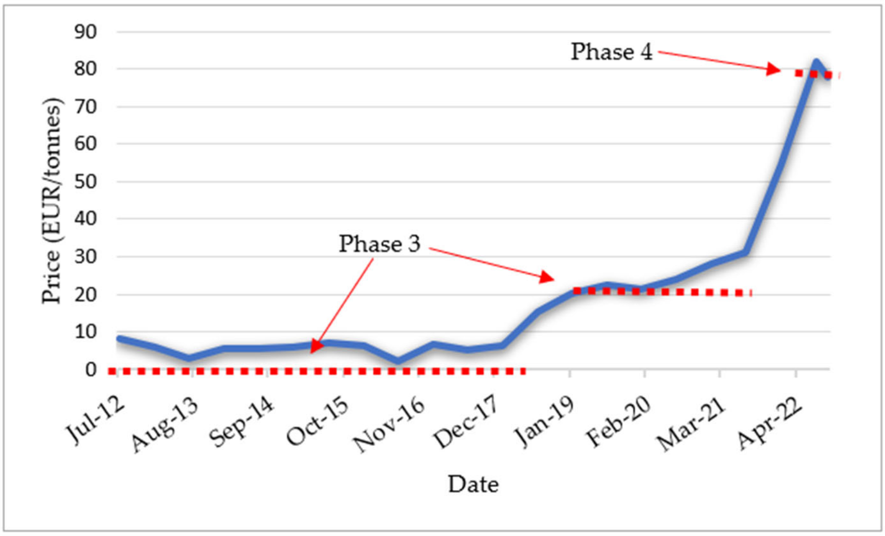


Figure 2-2. Prices of EU carbon permits from July 2012 (adapted from EMBER, 2021. and www.tradingeconomics.com)

2.4.3 Maximum contribution of non-provisioning ecosystem services per ha

According to the previous value of above-ground carbon storage of 6,267 €/ha when rated at index 10, and the rating of ecosystem services against the benchmark (biodiversity), Table 2-12 presents the maximum contribution of non-provisioning ecosystem services per ha corresponding, which is valued at 17,216 €/ha.

Table 2-12. Maximum contribution of ecosystem services per ha

Ecosystem service	Weight	Value
Temperature	25%	1,567 €
Waterflow	20%	1,235 €
Erosion	15%	940 €
Air purification	40%	2,507 €
Carbon sequestration	60%	3,760 €
Humidity	15%	940 €
Biodiversity	100%	6,267 €
Total		17,216 €

2.4.4 Valuing scenarios

Scenario 1: Fibre

The Fibre scenario has only one CLC class: Coniferous forest (312). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 2-12. These values are presented in Table 2-13.

Table 2-13. Non-provisioning ecosystem service values for Fibre

Indicator	Index	Value	Index x Value / 10
Thermal emissivity	5.9	1,567 €	925 €
Runoff	9.2	1,235 €	1,136 €
Soil erosion	9.6	940 €	902 €
Dry deposition pollutants	10.0	2,507 €	2,507 €
Above-ground C storage	1.0	3,760 €	376 €
Evapotranspiration potential	10.0	940 €	940 €
Biodiversity	7.0	6,267 €	4,387 €
TOTAL		**17,216 €**	**11,173 €**

Scenario 2: Food

The Food scenario has only one CLC class: Pastures (231). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 2-12. These values are presented in Table 2-14.

Table 2-14. Non-provisioning ecosystem service values for Pastures

Indicator	Index	Value	Index x Value / 10
Thermal emissivity	8.3	1,567 €	1,301 €
Runoff	9.9	1,235 €	1,223 €
Soil erosion	10.0	940 €	940 €
Dry deposition pollutants	6.2	2,507 €	1,554 €
Above-ground C storage	1.0	3,760 €	376 €
Evapotranspiration potential	6.4	940 €	602 €
Biodiversity	7.0	6,267 €	4,387 €
TOTAL		**17,216 €**	**10,382 €**

Scenario 3: Landscape

The Landscape scenario has only one CLC class: Broad-leaved forest (311). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 2-12. These values are presented in Table 2-15.

Table 2-15. Non-provisioning ecosystem service values for Broad-leaved forest

Indicator	Index	Value	Index x Value / 10
Thermal emissivity	10.0	1,567 €	1,567 €
Runoff	10.0	1,235 €	1,235 €
Soil erosion	10.0	940 €	940 €
Dry deposition pollutants	10.0	2,507 €	2,507 €
Above-ground C storage	10.0	3,760 €	3,760 €
Evapotranspiration potential	6.4	940 €	602 €
Biodiversity	10.0	6,267 €	6,267 €
TOTAL		**17,216 €**	**16,878 €**

2.5 Valuation of provisioning ecosystem services

To determine the revenues/costs of the three scenarios considered feasible: pine plantations for the production of wood as raw material (Fibre), feeding of cows for beef production (Food), and reconstruction of a broad-leaved forest similar to those already present in the landscape of the region (Landscape), firstly and according to the costs and payments previously analysed in Deliverable 5.1 Relevant market price data and Deliverable 5.2 Investment and maintenance costs, the net present value (NPV) of the provisioning ecosystem services will be calculated.

Real/constant discount rates as well as real/constant values in Euros from 2022 were used in the calculations, as it will be challenging to consider adequate variations of the inflation rate over long periods.

The discount rates to be used were presented in Deliverable 4.3:

- Non-intensive natural goods production, such as familiar animal exploitation, familiar tree plantations, familiar agriculture, etc., are proposed to be valued at a real/ constant rate of 1%, which is considered a moderate rate of growth.
- Intensive natural goods production, such as intensive animal farms, intensive forest exploitation, intensive agriculture, etc., are proposed to be valued at a real/constant discount rate of 3%-3.5%.
- 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.

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

2.5.1 Scenario 1: Fibre

Within the Fibre scenario, the provisioning ecosystem service of Fibre production occurs in the Coniferous forest (312) CLC. The indicator used is Forest productivity.

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 quantification method was m^3/ha/year.

In Asturias, pine plantations have on average four trees per 10 m^2, which is equivalent to 300 trees/ha. After 30-40 years, each pine will produce 2 tonnes of wood.

At a current price of 17 €/tonne, pine production can have a net income over 35 years of about 10,200 €/ha.

The cost of tree planting (300 trees/ha) was estimated at 2,040 €/ha, and the costs of clearing and cleaning, slow-release fertiliser and watering at 780 €/ha/year, which should take place over the first five years. The residual value in year 70 is assumed to be zero.

Using the 1% real discount rate for non-intensive natural goods production, the net present value of the Fibre scenario is 2,386 EUR:

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

2.5.1 Scenario 2: Food

Within the Food scenario, the provisioning ecosystem service of Food production occurs in the Pastures (231) CLC. The indicator used is Livestock production.

The corresponding CICES V5.1 code is 1.1.3.1, and the class "Animals reared for nutritional purposes". The Food scenario has only one CLC: 100% Pastures (231). The quantification method could be livestock units/ha/year.

Feeding cows for meat production in pastures can generate around one calf every two years valuated at 900 €, with additional feed needed such as dry grass of 300 €/year. The cost of buying a cow ready for insemination is about 1,000 euros, plus an insemination cost of 60 euros. A cow will be productive for around 14 years.

Using the 1% real discount rate for non-intensive natural goods production, the net present value of the Food scenario is 3,323 EUR:

$$NPV_{Food} = -\,1{,}060 - \frac{300}{(1+0.01)} + \frac{(900-300)}{(1+0.01)^2} + \ldots - \frac{(900-300-1060)}{(1+0.01)^{14}} - \frac{300}{(1+0.01)^{15}} + \ldots - \frac{(900-300)}{(1+0.01)^{70}} = 3{,}323\ €$$

2.5.1 Scenario 3: Landscape

Within the Landscape scenario, no provisioning ecosystem services are occurring in the Broad-leaved forest (311) CLC. Thus, no incomes are foreseen in this scenario but the investment and maintenance cost of planting the broad-leaved forest have to be considered in the calculations.

The cost of tree planting (250 trees/ha) was estimated at 1,700 €/ha, and the costs of clearing and cleaning, slow-release fertiliser and watering at 780 €/ha/year, which should take place over the first five years.

Using again the 1% real discount rate for non-intensive natural goods production, the net present value of the Landscape scenario is -5,486 EUR:

$$NPV_{Landscape} = -\,1{,}700 - \frac{780}{(1+0.01)} - \frac{780}{(1+0.01)^2} - \ldots - \frac{780}{(1+0.01)^5} = -\,5{,}486\ €$$

2.6 The total value of the different scenarios

Table 2-16 presents the total values of the different scenarios per ha, obtained by adding the non-provisioning ecosystem service values to the NPV calculated for the provisioning ecosystem services, as well as for the investment and maintenance costs of the non-provisioning ecosystem services.

Table 2-16. Total values of the different scenarios

Scenarios	Highest E.S. contribution	Ecosystem services values	NPVs	**Total values**
Landscape	17,216 €	16,878 €	– 5,486 €	**11,392 €**
Fibre	17,216 €	11,173 €	2,386 €	**13,559 €**
Food	17,216 €	10,382 €	3,323 €	**13,705 €**

As the difference between the fibre and food production scenarios is negligible (only 1%), both can be considered to bring similar value to society in the case of the Figaredo mine.

Therefore, the selection between them should be based on the ease of undertaking, measured in the lower investment needed to develop the scenario.

Food production should then be selected for the specific case of the Figaredo mine.

3 Best scenario selection for Ema-Terezie Mine dumps complex

3.1 Land cover types involved in the assessment of scenarios

Figure 3-1 presents the state of Ema-Terezie Mine dumps complex with all the Corine Land Cover (CLC) classes that were identified at the beginning of the RECOVERY Project.

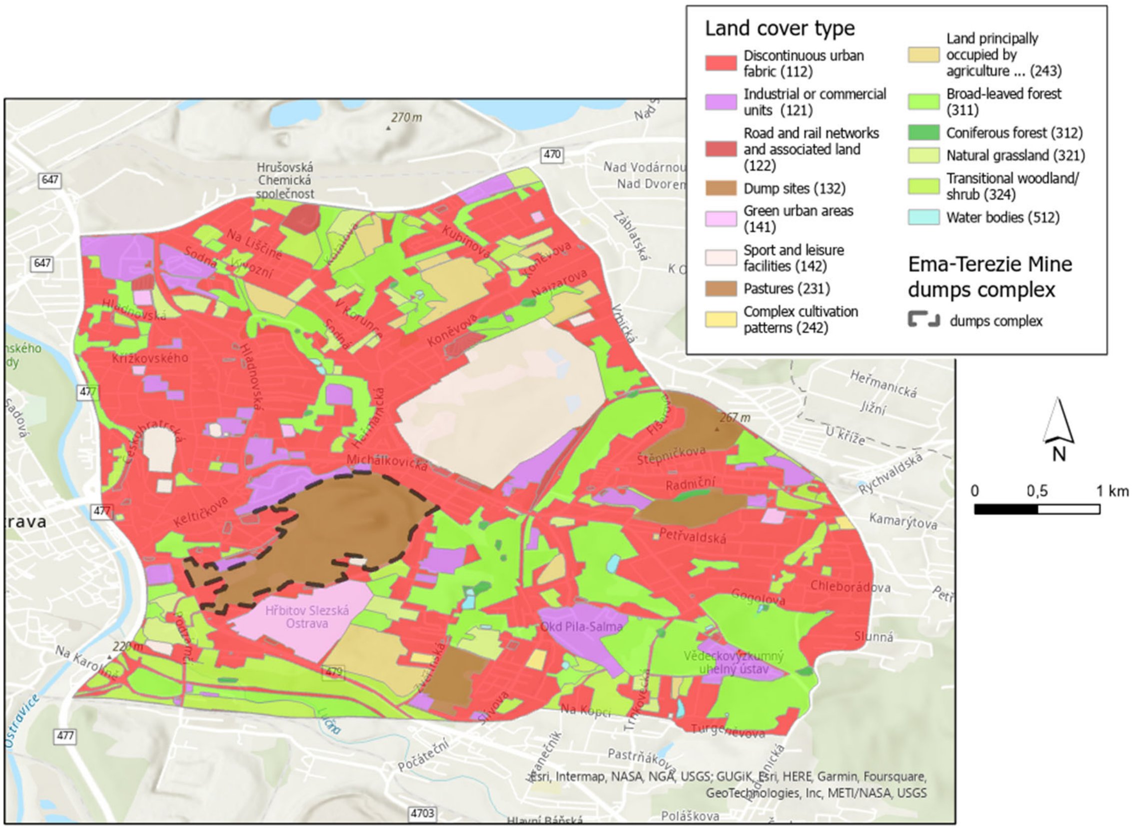


Figure 3-1. GIS presentation of the CLC classes at the Ema-Terezie Mine dumps complex

CLC classes identified were: Discontinuous urban fabric (112), Industrial or commercial units (121), Road and rail networks and associated land (122), Dump sites (132), Green urban areas (141), Sport and leisure facilities (142), Pastures (231), Complex cultivation patterns (242), Land principally occupied by agriculture, with significant areas of natural vegetation (243), Broad-leaved forest (311), Coniferous forest (312), Natural grassland (321), Transitional woodland/shrub (324) and Water bodies (512).

After, three scenarios were considered feasible to undergo the ecosystem restoration of the area:

1. Urban wildness (non-intervention) - mixed scenario of a forest and a physical recreation area (**Recreation**).
2. Combination of the ForestPark, Pastures, HorseTrails and Buildings (**Combination**)
3. Forest with predominant recreational function (**ForestPark**).

The **Recreation scenario** merging forest area for wild animal and “without any interventions” land-use, which assumed only slight interventions in the area with a preference for extensive use. The mine dump complex is located almost in the center of the city of Ostrava, so it has significant potential for recreation and leisure – time activities. Except these recreational activities, also support of ecological functions is suitable and desirable for use in the area (establishment and management of flower meadows, support of entomofauna, etc.). Nevertheless, this can be considered a scenario of a Broad-leaved forest (311) with a physical recreation area.

The **scenario Combination** links the Broad-leaved forest (311) for wild animal and forestpark for Sport and leisure activities (142) with horsetrails, Pastures (231), and Discontinuous urban fabric (112) land-use. It assumes ecological, hippo - tourist and partly agricultural use of the area, especially regard to horse breeding and riding school, which currently exists here.

Scenario ForestPark is characterized in terms of the predominant recreational function when a forest park with equipment for outdoor sports and outdoor furniture is built on the territory of the mine dump complex. Support for ecological functions is not as important as in Scenario Recreation. This scenario includes reconstructing a Broad-leaved forest similar to the ones already present in the region. The corresponding CLC class to develop this scenario is Broad-leaved forest (311) and natural Pastures (231) for wild animals.

Table 3-1 presents the CLC classes that must be considered to undergo the scenario selection of Ema-Terezie Mine dumps complex.

Table 3-1. CLC classes involved in the assessment of scenarios

CLC classes
Discontinuous urban fabric (112)
Industry or commercial units (121)
Road and rail networks and associated land (122)
Dump sites (132)
Green urban areas (141)
Sport and leisure facilities (142)
Pastures (231)
Complex cultivation patterns (242)
Land principally occupied by agriculture, with significant areas of natural vegetation (243)
Broad-leaved forest (311)
Coniferous forest (312)
Natural grassland (321)
Transitional woodland/shrubs (324)
Water bodies (512)

Finally, the change rules in percentages of CLC land use areas for the three scenarios are presented in Table 3-2 Table.

Table 3-2. Change rules of CLC classes for the three scenarios

Land use	**Initial state**	**Scenario I Recreation (%)**	**Scenario II Combination (%)**	**Scenario III ForestPark (%)**
Dump sites (132)	100	0	0	0
Broad-leaved forest (311)	0	100	63.42	98.93
Pastures (231)	0	0	1.07	1.07
Discontinuous urban fabric (112)	0	0	10.32	0
Sport and leisure facilities (142)	0	0	25.19	0

3.2 Representative ecosystem services

After analyzing CLC classes of the study area, field study, as well as the topography, the following ecosystem services (at the level of classes) were selected as important/representative for Ema-Terezie Mine dumps complex, with indication of the CICES V5.1 (Haines-Young and Potschin, 2018) and the causal network of coal mining impacts that was developed in Deliverable 4.1 Suitable indicators.

Regarding **provisioning services**, food production was considered.

As for **regulating services**, climate regulation – temperature has been considered in the Ema-Terezie Mine Dumps complex. Also, carbon sequestration is widely used in all ecosystem service assessments. The quantities of rare species or ecosystems (biodiversity) or biophysical features (landscapes) representing rare occurrence for Czech Republic at the Ema-Terezie Mine dump complex area was analyzed as ecosystem service.

As for **cultural services**, the biophysical characteristics or qualities of species or ecosystems were considered a good proxy for assessing biodiversity in general, also related to physical and mental recreation. The last selected service is cultural heritage, which is based on cultural values.

Table 3-3 shows a summary of the ecosystem services selected as well as their indicators that were first presented in Deliverable 4.1 Suitable indicators.

Table 3-3. Summary of ecosystem services and their indicators

Ecosystem service	**Indicator**
Food production	Surface area of organic crops
Climate regulation (Temperature)	Land surface thermal emissions
Carbon sequestration	Carbon storage
Qualities of species or ecosystems (Biodiversity)	Impact of shrinkage-related cover patterns
Quantity of rare species or ecosystems	Number of rare species
Cultural heritage	Number of visitants

3.3 Quantification of non-provisioning ecosystem services

Although only four CLC classes are necessary for evaluating the different scenarios, the quantification of non-provisioning ecosystem services was made for all the CLC classes that are present in the Ema-Terezie Mine dump complex, that were shown in Table 3-1.

3.3.1 Regulating services: climate regulation (temperature)

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

In this case, the ecosystem service indicator could be land surface thermal emissions from the Landsat 8 satellite (band 10) and the quantification method, the emission index, as used by Schwarz et al. (2011) was used. The broad-leaved forest as the reference because its emission value is the lowest. Values (v) were normalised in an index between 1 (highest emission) and 10 (lowest emission).

The thermal emissivity of the land cover and the respective normalised emission indexes adapted from Schwarz et al. (2011) are presented in Table 3-4.

Table 3-4. Thermal emissivity of CLC classes and normalized emission indexes

CLC classes	Thermal emissivity	
	Emission	**Index**
Discontinuous urban fabric (112)	27393.8	3.7
Industry or commercial units (121)	27768.6	1.0
Road and rail networks and associated land (122)	27565.4	2.5
Dump sites (132)	26540.0	10.0
Green urban areas (141)	26623.2	9.4
Sport and leisure facilities (142)	26989.4	6.1
Pastures (231)	26881.1	7.5
Complex cultivation patterns (242)	27300.9	4.4
Land principally occupied by agriculture, with significant areas of natural vegetation (243)	27508.4	2.9
Broad-leaved forest (311)	26540.6	10.0
Coniferous forest (312)	26576.9	9.7
Natural grassland (321)	27085.2	6.0
Transitional woodland/shrubs (324)	26914.9	7.3
Water bodies (512)	26540.6	10.0

3.3.2 Regulating services: carbon sequestration

Carbon sequestration was the second regulating service considered. Carbon sequestration is delivered in the Ema-Terezie Mine dump complex study-case by Broad-leaved forest, Dump sites, Green urban areas, Transitional woodland/shrubs and Natural grasslands. The CICES V5.1 code will be 2.2.6.1, and the class “Regulation of chemical composition of atmosphere and oceans”.

The ecosystem services indicator shall be above-ground carbon storage/ha. The above-ground carbon storage quantification method will be linked to land use in MgC/ha, as

Strohbach and Haase (2012) estimated in a study on above-ground carbon storage in Leipzig (Germany).

Table 3-5 presents the above-ground carbon storage per land cover to be considered, adapted from Strohbach & Haase (2012), and a carbon storage index.

Table 3-5. Above-ground carbon storage of CLC classes and corresponding indexes

CLC classes	Carbon sequestration	
	Mg C /ha	Index
Discontinuous urban fabric (112)	20,0±9,4*	3.5
Industry or commercial units (121)	8,52±7,78	2.1
Road and rail networks and associated land (122)	8,52±7,78	2.1
Dump sites (132)	68,31±12,63**	9.4
Green urban areas (141)	29.38±11,41***	4.6
Sport and leisure facilities (142)	20,0±9,4***	3.5
Pastures (231)	20,0±9,4*	3.5
Complex cultivation patterns (242)	8,52±7,78***	2.1
Land principally occupied by agriculture, with significant areas of natural vegetation (243)	10,12±2,93***	2.2
Broad-leaved forest (311)	68,31±12,63	9.4
Coniferous forest (312)	72.91±3,26	10.0
Natural grassland (321)	13,48 ±4,49	2.7
Transitional woodland/shrubs (324)	10,12±2,93	2.2
Water bodies (512)	≈ 0	1.0

*Discontinuous urban fabric=mixed urban fabric in M.W. Strohbach, D. Haase, 2012
**Dump sites = Broad-leaved forest, M.W. Strohbach, D. Haase, 2012 do not describe this category, most similar in terms of biotope
*** Determined approximately by physiognomically or ecologically similar CLC level

3.3.3 Regulating services: quantities of rare species or ecosystems (biodiversity)

The quantities of rare species or ecosystems (biodiversity) or biophysical features (landscapes) representing rare occurrence for Czech Republic at the Ema-Terezie Mine dump complex area was analyzed as ecosystem service. Analyzing due to protected and iconic plant species (for example *Quercus cerris, Pyrola minor, Hacquetia epipactis, Chenopodium botrys*) and animal species (for example *Bombina bombina, Bombina variegata, Anguis fragilis, Corvus monedula, Accipiter nisus, Accipiter gentilis, Muscicapa striata, Emberiza citrinella, Hirundo rustica, Oriolus oriolus, Dendrocopos minor*) was examined.

The corresponding CICES V5.1 code is 2.2.2.3 and the class “Maintaining nursery populations and habitats (Including gene pool protection)”. In this case, the ecosystem service indicator could be Number of rare species (Liquete et al., 2016).

The number of rare species of Sport and leisure facilities (in ZOO) was used as a maximum indicator reference value.

The table 3-6 shows the number of rare species found (qualifiedly estimated) for individual CLC classes. Method of converting the number of species to index:

Nr. of rare species	0	1-2 (1,5)	3	4	5	6	7	8	9	10
Index	1	2	3	4	5	6	7	8	9	10

Table 3-6. Impact of shrinkage-related cover patterns of CLC classes and corresponding indexes

CLC classes	Number of rare species	
	Nr. of species	**Index**
Discontinuous urban fabric (112)	3	3
Industry or commercial units (121)	0	1
Road and rail networks and associated land (122)	0	1
Dump sites (132)	7	7
Green urban areas (141)	1,5	2
Sport and leisure facilities (142)	10	10
Pastures (231)	1,5	2
Complex cultivation patterns (242)	0	1
Land principally occupied by agriculture, with significant areas of natural vegetation (243)	1,5	2
Broad-leaved forest (311)	7	7
Coniferous forest (312)	4	4
Natural grassland (321)	3	3
Transitional woodland/shrubs (324)	3	3
Water bodies (512)	1,5	2

3.3.4 Cultural services: qualities of species or ecosystems (biodiversity)

The qualities of species or ecosystems (biodiversity) or biophysical features (landscapes) in the Ema-Terezie Mine dump complex area was the last ecosystem service to be analyzed.

The CICES V5.1 code is 3.2.2.1, and the class ‘Characteristics or features of living systems that have an existence value’. An example of service should be ‘areas designated as wilderness, and the ecosystem services indicator could be the type of living systems or environmental settings.

The quantification method could be the number of endemic or quasi-endemic species observations. However, better information about species diversity is provided by diversity indexes, of which we chose the Shannon Wiener index (H´), which is widely used in Europe.

The Shannon - Wiener diversity index (H') for individual CLCs is shown in the table 3-7. These indexes are taken as impact on ecosystems. The method of transferring the impact to the index corresponds to the species diversity of the vegetation of the Czech Republic, communities with H'> 2.5 are rated as moderately rich and H'> 4 as rich.

Impact	0	(0;1)	(1;1,5)	(1,5;2)	(2;2,5)	2,5	(2,5;3)	(3;3,5)	(3,5;4)	4
Index	1	2	3	4	5	6	7	8	9	10

Table 3-7. Impact of shrinkage-related cover patterns of CLC classes and corresponding indexes

CLC classes	Impact	Index
Discontinuous urban fabric (112)	1,5	3
Industry or commercial units (121)	0	1
Road and rail networks and associated land (122)	0	1
Dump sites (132)	3,5	8
Green urban areas (141)	2	5
Sport and leisure facilities (142)	4	10
Pastures (231)	1,5	3
Complex cultivation patterns (242)	1	2
Land principally occupied by agriculture, with significant areas of natural vegetation (243)	0	1
Broad-leaved forest (311)	2	5
Coniferous forest (312)	1	2
Natural grassland (321)	2	5
Transitional woodland/shrubs (324)	2,5	6
Water bodies (512)	1	2

3.3.5 Cultural services: cultural heritage

The biophysical characteristics or qualities of species or ecosystems (landscapes) which people seek to preserve for future generations for whatever reason: in this case, the conservation and protection of ecosystems bound to thermally active black coal mine dumps with the occurrence of thermophilic fauna and flora species.

Valuation is based on cultural values. The corresponding CICES V5.1 code is 3.2.2.1 and the class “Characteristics or features of living systems that have an existence value”. In this case, the ecosystem service indicator could be number of visitors (Baró et al. 2016).

The number of visitors of Sport and leisure facilities (number of ZOO visitors) was used as a maximum indicator reference value.

Table 3-8 presents a number of visitors and the corresponding index.

Table 3-8. Number of visitors of CLC classes and corresponding indexes

CLC classes	Number of visitors	
	Nr. people 2018	**Index**
Dump sites (132) – recultivated a reused area	100 000	2.7
Green urban areas (141)	10 000	1.2
Sport and leisure facilities (142)	537 412	10
Broad-leaved forest (311)	90 000	9.1
Coniferous forest (312)	5 000	1.1
Other CLC	≈ 0	1

3.4 Valuation of non-provisioning ecosystem services

3.4.1 Comparing ecosystem services with the reference

To estimate the ecosystem services provision of each proposed scenario, it was first necessary to select a reference attribute. Biodiversity was chosen as the reference attribute because, of all the attributes, it was the one that allowed comparisons to be made with the others in the most obvious way, which facilitated the development of the process. The rest of the attributes were then compared with the reference attribute.

Rank orderings should not change with a different anchor, as they are bi-univocal among the various ecosystem services. What may change is only the difficulty of establishing these rank orderings. That is why biodiversity was the anchor selected, as it is the most intuitive among them. Figure 3-2 presents the results of the comparison carried out using the AHP method (Saaty, 1980).

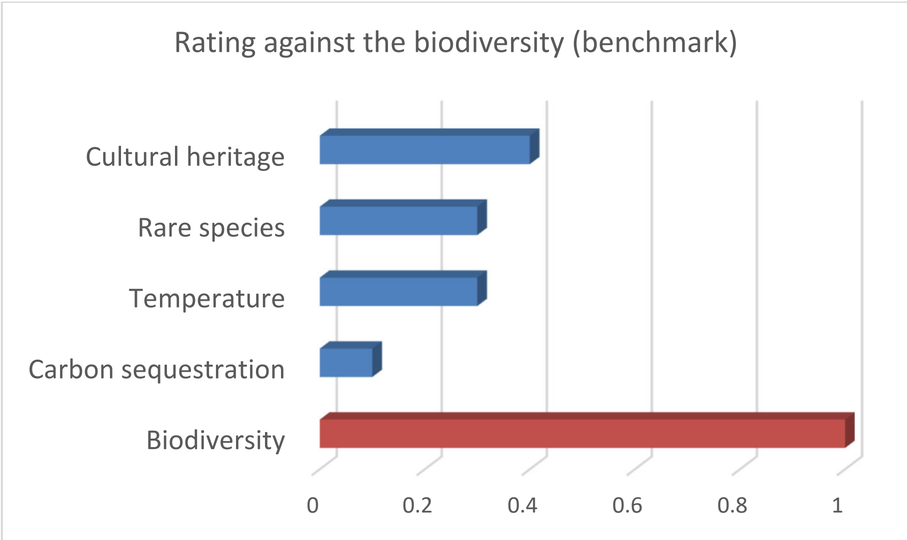


Figure 3-2. Rating of ecosystem services against the benchmark (biodiversity)

3.4.2 Most direct and market-related valuation possible: carbon sequestration

The ecosystem service for which valuation is most feasible must first be selected to monetize the set of ecosystem services. In this case, the indirect monetary valuation of carbon sequestration through the EU Emissions Trading System (2015) is the most feasible.

According to the EU Emissions Trading System (2015), during 2019 and 2020, the average value of EU Allowances, which allows for the emission of 1 tons of carbon dioxide equivalent, was about 25 €/t (EMBER, 2021), as presented in Figure 3-3. As 3.67 t CO_2 contain 1 t C, the average value of sequestration of 1 t C can be estimated at 91.75 €/t. Therefore, an above-ground carbon storage rate of 10.0, equivalent to 68.31 t C/ha (Table 3), should be valued at 6,267 €/ha. This value will be used as the reference value for 100% weighted ecosystem services. We assume that all non-provisioning ecosystem services weighted at 100% are worth the same, given that the specific values for each ecosystem service will come from the relative comparison between them.

3.4.3 Maximum contribution of non-provisioning ecosystem services per ha

According to the previous value of above-ground carbon storage of 6,267 €/ha when rated at index 10, and the rating of ecosystem services against the benchmark (biodiversity), Table 3-9 presents the maximum contribution of non-provisioning ecosystem services per ha corresponding, which is valued at 13,161 €/ha.

Table 3-9. Maximum contribution of ecosystem services per ha

Ecosystem service	Weight	Value
Temperature	30%	1,880 €
Carbon sequestration	10%	0,627 €
Rare species	30%	1,880 €
Cultural heritage	40%	2,507 €
Biodiversity	100%	6,267 €
Total		13,161 €

3.4.4 Valuing scenarios

Scenario 1: Recreation

The Recreation scenario has only one CLC class: Broad-leaved forest (311). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 3-9. These values are presented in Table 3-10.

Table 3-10. Non-provisioning ecosystem service values for Recreation (CLC Broad-leaved forest (311))

Indicator	Index	Value	Index x Value / 10
Temperature	10	1,880 €	1,880 €
Carbon sequestration	9.4	0,627 €	0,589 €
Rare species	7	1,880 €	1,316 €
Cultural heritage	9.1	2,507 €	2,281 €
Biodiversity	5	6,267 €	3,134 €
TOTAL		**13,161 €**	**9,200 €**

Scenario 2: Combination

The Combination scenario has four CLC classes: Broad-leaved forest (311), Sport and leisure activities (142), Pastures (231), and Discontinuous urban fabric (112). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 3-9. These values for Broad-leaved forest (311) are presented in Table 3-10, for Sport and leisure activities (142) are presented in Table 3-11, for Pastures (231) are presented in Table 3-12, and for Building (112) are presented in Table 3-13.

Table 3-11. Non-provisioning ecosystem service values for Combination for CLC class Sport and leisure activities (142)

Indicator	Index	Value	Index x Value / 10
Temperature	6.1	1,880 €	1,147 €
Carbon sequestration	3.5	0,627 €	0,219 €
Rare species	10	1,880 €	1,880 €
Cultural heritage	10	2,507 €	2,507 €
Biodiversity	10	6,267 €	6,267 €
TOTAL		**13,161 €**	**12,020 €**

Table 3-12. Non-provisioning ecosystem service values for Combination for CLC class Pastures (231)

Indicator	Index	Value	Index x Value / 10
Temperature	7.5	1,880 €	1,140 €
Carbon sequestration	3.5	0,627 €	0,219 €
Rare species	2	1,880 €	0,376 €
Cultural heritage	1	2,507 €	0,251 €
Biodiversity	3	6,267 €	1,880 €
TOTAL		**13,161 €**	**3,866 €**

Table 3-13. Non-provisioning ecosystem service values for Combination for CLC class Discontinuous urban fabric (112)

Indicator	Index	Value	Index x Value / 10
Temperature	3.7	1,880 €	0,696 €
Carbon sequestration	3.5	0,627 €	0,219 €
Rare species	3	1,880 €	0,564 €
Cultural heritage	1	2,507 €	0,251 €
Biodiversity	3	6,267 €	1,880 €
TOTAL		**13,161 €**	**3,610 €**

Final value of service value was calculated as weighted average total values for all four services. It is present in Table 3-14. The weights were done by percentage of each suggested CLC area, which are mentioned in Table 3-2.

Table 3-14. Non-provisioning ecosystem service values for Combination

Land use	Service value	Weight	Service value x Weight
Broad-leaved forest (311)	7,220	63.42 %	4,579 €
Pastures (231)	3,866	1.07 %	0,041 €
Discontinuous urban fabric (112)	3,610	10.32 %	0,371 €
Sport and leisure facilities (142)	12,020	25.19 %	3,028 €
TOTAL		100 %	**8,019 €**

Scenario 3: ForestPark

The ForestPark scenario has two CLC class: Broad-leaved forest (311) and Pastures (231). The values of the different ecosystem services for this land cover are available in Table 2-11 for Broad-leaved forest (311) and in Table 2-13 Pastures (231).

Final value of service value was calculated as weighted average total values for two services. It is present in Table 3-15. The weights were done by percentage of each suggested CLC area, which are mentioned in Table 3-2.

Table 3-15. Non-provisioning ecosystem service values for ForestPark

Land use	Service value	Weight	Service value x Weight
Broad-leaved forest (311)	9,200	98.93 %	9,102 €
Pastures (231)	3,866	1.07 %	0,041 €
TOTAL		100 %	**9,143 €**

3.5 Valuation of provisioning ecosystem services

To determine the revenues/costs of the three scenarios considered feasible: reconstruction of natural Broad-leaved forest with features for physical recreation installation (Recreation), extending firstly mentioned costs with establishing natural pastures, installation of equipment for outdoor sports and outdoor furniture and building the houses (Combination), or first version of Recreation with the predominant recreational function (ForestPark), firstly and according to the costs and payments previously analysed in Deliverable 5.1 Relevant market price data and Deliverable 5.2 Investment and maintenance costs, the net present value (NPV) of the provisioning ecosystem services will be calculated.

Real/constant discount rates as well as real/constant values in Euros from 2022 were used in the calculations, as it will be challenging to consider adequate variations of the inflation rate over long periods.

The discount rates to be used were presented in Deliverable 4.3:

- Non-intensive natural goods production, such as familiar animal exploitation, familiar tree plantations, familiar agriculture, etc., are proposed to be valued at a real/ constant rate of 1%, which is considered a moderate rate of growth.
- Intensive natural goods production, such as intensive animal farms, intensive forest exploitation, intensive agriculture, etc., are proposed to be valued at a real/constant discount rate of 3%-3.5%.
- 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.

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

3.5.1 Scenario 1: Recreation

Within the Recreation scenario there is not expected any financial benefits. The prices for planned activities were quantified according to the market prices and its overview present Table 3-16.

Table 3-16. Mean cost for Broad-leved Forest (CLC=311) per hectare, Scenario Recreation

Item	Cost (EUR/ha)	Applied on % of the designed CLC (CLC=313)
Clearing (illegal waste sites)	31.80 €	100%
Construction of unpaved trails	7920.00 €	1.65%
Revitalization of the water course	360.00 €	0.09%
Random logging	2130.00 €	2.13%
Removal of removed trees	27.00 €	3.35%
Planting deciduous trees (300 trees/ha)	7.66 €	2.13%
Planting deciduous trees (75 trees/ha)	88.08 €	97.87%
Installation of park furniture	217.00 €	100%

These activities will not cover all solved area. The area was divided into smaller places, where some or all activities should be realized (the portion percentage is in third column of Table 3-16). The final cost per hectare was calculated according to the area-ratio (costs were spreading to whole solved area). It is described in Deliverable 5-2 in detail. Final **mean investment is 10,782 €/ha**.

For the first five years maintenance in form of weeding the trees and replenishment of dead plants in planting (30 trees/ha) should be done. The clearing (garbage) and waste collection from trash cans will be necessary each year. The maitanence price are present in Table 3-17. The also this cost was calculated according to the area-ratio (costs were spreading to whole solved area).

Table 3-17. Mean maitanence for Broad-leved Forest (CLC=311) per hectare, Scenario Recreation

Item	Maintenance cost (EUR/ha)	Applied on % of the designed CLC (CLC=311)
Planting maintenance by weeding in areas planted 300 trees/ha	260.00 €	2.13%
Replenishment of dead plants in planting 30 trees/	36.00 €	2.13%
Clearing (garbage), waste collection from trash cans	198.38 €	100%

According to area dividing were expressed **maintenance per** hectare (representative for all solved area) in numbers per first five years as **0,205 €/ha**.

Using the 1% real discount rate for non-intensive natural goods production, the **net present value of the Recreation scenario is -12,689 €/ha**:

$$NPV_{Recreation} = -\ 10{,}782 - \frac{0{,}205}{(1+0.01)} - \cdots - \frac{0{,}205}{(1+0.01)^5} = -\ 12{,}689\ €/ha$$

3.5.2 Scenario 2: Combination

Within the Combination scenario, the gainful employment of family living occurs in the Discontinuous urban fabric (112) CLC. The indicator used is rent of house. At other Recreation scenario land-use there is not expected any financial benefits. It means at Broad-leaved forest (311), Sport and leisure facilities (142) and at Pastures (231) too, because it is intended as natural pastures for wild animals.

The prices for planned activities were quantified according to the market prices and its overview present Table 3-18.

Table 3-18. Costs per hectare and proportions of areas, where the item should be applied, Scenario Combination

Item	**Cost (EUR/ha)**	Applied on % of the designed CLC
Clearing (illegal waste sites)	31.80 €	100% for all CLC
Demolition of reinforced concrete structures	572.25 €	100% for CLC=112 3% for CLC=142
Landscaping with heavy mechanization	280 000.00 €	100% for CLC=112 10% for CLC=142 10% for CLC=313
Construction of unpaved trails	480 000.00 €	1.65% for CLC=142 1.65% for CLC=311
Revitalization of the water course	400 000.00 €	0.14% of CLC=311
Random logging	100 000.00 €	3.35% of CLC=311
Removal of removed trees	805.97 €	3.35% of CLC=311
Removal invasive plants	1200.00 €	100% for CLC=112 100% for CLC=231
Planting deciduous trees (300 trees/ha)	360.00 €	3.35% for CLC=311
Planting deciduous trees (75 trees/ha)	90.00 €	100% for CLC=142 96.65% for CLC=311
Restoration of the grass cover (including the price of the seed)	280.00 €	100% for CLC=231 10% for CLC=142
Installation of park furniture	241.05€	100% for CLC=142 100% for CLC=311
Fitness trail (set of 8 elements)	18 000.00 €	6.31% for CLC=142
Construction of family houses	1 200 000.00 €	100% for CLC=112

These activities will not cover all solved area. The area was divided into smaller places, where some or all activities should be realized. The percentage portion of designed land-use category is in third column of Table 3-18. The percentage portions of each designed land-use are in Table 2-2 (column Scenario2, Combination). The mean investment cost for each designed land-use were calculated as the area-ratio (costs were spreading to whole solved area) and final values are present in Table 3-19. It is described in Deliverable 5-2 in detail.

Table 3-19. Mean investment costs for suggested CLC per hectare, Scenario Combination

Land use	Mean investment cost (EUR/ha)
Discontinuous urban fabric (112)	1 481,804 €
Sport and leisure facilities (142)	9,743 €
Pastures (231)	1,511 €
Broad-leaved forest (311)	40,228 €

As a necessary maintenance basic care about new planted area and established pastures were specified. It is present in Table 3-20. Also, these costs were recalculated for each land-use category as the area-ratio (costs were spreading to whole solved area). It is described in Deliverable 5-2 in detail. Final values are in Table 3-21.

Table 3-20. Maintenance costs per hectare and proportions of areas, where the item should be applied, Scenario Combination

Item	Maintenance cost (EUR/ha)	Applied on % of the designed CLC
Planting maintenance by weeding in areas planted 300 trees/ha	260.00 €	3.35% for CLC=311
Replenishment of dead plants in planting 30 trees/	36.00 €	3.35% for CLC=311
Clearing (garbage), waste collection from trash cans	223.00 €	100% for CLC=142 100% for CLC=311
Grass cutting including removal (grazing and mowing)	260.00 €	30% for CLC=142 100% for CLC=231

Table 3-21. Mean maintenance costs for suggested CLC per hectare (for each of 5 years after investment), Scenario Combination

Land use	Mean investment cost (EUR/ha)
Discontinuous urban fabric (112)	0,00 €
Sport and leisure facilities (142)	0,301 €
Pastures (231)	0,260 €
Broad-leaved forest (311)	0,233 €

The financial income arises from renting of family houses was set according to market price as 144 EUR per hectare per year from the second year after investment.

Using the 1% real discount rate for non-intensive natural goods production, the net present value of each designed land-use of Combination scenario were calculated:

$$NPV_{Broad-leaved\ forest} = -\,40{,}229 - \frac{0{,}233}{(1+0.01)} - \cdots - \frac{0{,}233}{(1+0.01)^5} = -41{,}360\ €/ha$$

$$NPV_{Pstures} = -1{,}512 - \frac{0{,}260}{(1+0.01)} - \cdots - \frac{0{,}260}{(1+0.01)^5} = -\,2{,}774\ €/ha$$

$$NPV_{Sport\ and\ leisure\ activities} = -\,9{,}744 - \frac{0{,}301}{(1+0.01)} - \cdots - \frac{0{,}301}{(1+0.01)^5} = -\,11{,}205\ €/ha$$

$$NPV_{Housing} = -\,1\,481{,}804 + \frac{0}{(1+0.01)} - \cdots + \frac{144{,}000}{(1+0.01)^2} + \cdots + \frac{144{,}0}{(1+0.01)^5} = -\,925{,}484\ €/ha$$

Finally, the weighted average of these four land-use was calculated. The weights were set according to area proportional, which is present in Table 3-2 (column Scenario2, Combination). The result is present in Table 3-22.

Table 3-22. Non-provisioning ecosystem service values for Combination – for next 5 years

Land use (CLC)	**NPV**	**Weight**	**NPV x Weight**
Broad-leaved forest (311)	-41,360	63.42 %	-26,231 €
Pastures (231)	-2,774	1.07 %	-0,030 €
Discontinuous urban fabric (112)	-925,484	10.32 %	-95,510 €
Sport and leisure facilities (142)	-11,205	25.19 %	-2,823 €
TOTAL		100 %	**-124,594** €

The calculation for next 20 years was done in this case too. The maintenance for Broad-leaves forest, Pastures and Sport and leisure facilities should finish in fifth year, so the maintenance costs are the same. But the income from house renting follows up. So final NPV (in Table 3-23) become positive.

Table 3-23. Non-provisioning ecosystem service values for Combination – for next 20 years

Land use (CLC)	NPV	Weight	NPV x Weight
Broad-leaved forest (311)	-41,360	63.42 %	-26,231 €
Pastures (231)	-2,774	1.07 %	-0,030 €
Discontinuous urban fabric (112)	974,181	10.32 %	100,535 €
Sport and leisure facilities (142)	-11,205	25.19 %	-2,823 €
TOTAL		100 %	**71,451 €**

3.5.3 Scenario 3: ForestPark

Within the ForestPark scenario, no provisioning ecosystem services are occurring in the Broad-leaved forest (311) or Pastures (231) for wild animal. Thus, no incomes are foreseen in this scenario but the investment and maintenance cost of planting the broad-leaved forest and establishing of pastures must be considered in the calculations.

The prices for planned activities were quantified according to the market prices and its overview present Table 3-24.

Table 3-24. Costs per hectare and proportions of areas, where the item should be applied, Scenario ForestPark

Item	Cost (EUR/ha)	Applied on % of the designed CLC
Clearing (illegal waste sites)	31.80 €	100% for all CLC
Demolition of reinforced concrete structures	572.25 €	3% for CLC=311
Landscaping with heavy mechanization	280 000.00 €	10% for CLC=311
Construction of unpaved trails	480 000.00 €	1.65% for CLC=231 1.65% for CLC=311
Revitalization of the water course	400 000.00 €	0.09% of CLC=311
Random logging	100 000.00€	2.15% of CLC=311
Removal of removed trees	805.97 €	2.15% of CLC=311
Removal of air raid above 1m	1200.00 €	100% for CLC=231
Planting deciduous trees (300 trees/ha)	360.00 €	2.15% for CLC=311
Planting deciduous trees (75 trees/ha)	90.00 €	97.85% for CLC=311
Restoration of the grass cover including the price of the seed	280.00 €	100% for CLC=231
Installation of park furniture	216.18 €	100% for CLC=231 100% for CLC=311
Fitness trail (set of 8 elements)	18 000.00 €	1.61% for CLC=311

These activities will not cover all solved area. The area was divided into smaller places, where some or all activities should be realized. The percentage portion of designed land-use category is in third column of Table 3-24. The percentage portions of each designed land-use is in Table 3-2 (column Scenario3, ForestPark). The mean investment cost for each designed land-use were calculated as the area-ratio (costs were spreading to whole solved area) and final values are present in Table 3-25.

Table 3-25. Mean investment costs for suggested CLC per hectare, Scenario ForestPark

Land use (CLC)	Mean investment cost (EUR/ha)
Pastures (231)	9,908 €
Broad-leved Forest (311)	39,098 €

As a necessary maintenance basic care about new planted area and established pastures were specified. It is present in Table 3-26. Also, these costs were recalculated for each land-use category as the area-ratio (costs were spreading to whole solved area). It is described in Deliverable 5-2 in detail. Final values are in Table 3-27.

Table 3-26. Maintenance costs per hectare and proportions of areas, where the item should be applied, Scenario ForestPark

Item	Maintenance cost (EUR/ha)	Applied on % of the designed CLC
Planting maintenance by weeding in areas planted 300 trees/ha	260.00 €	2.15% for CLC=311
Replenishment of dead plants in planting 30 trees/	36.00 €	2.15% for CLC=311
Clearing (garbage), waste collection from trash cans	200.00 €	100% for CLC=311
Grass cutting including removal (grazing and mowing)	260.00 €	100% for CLC=231

Table 3-27. Mean maintenance costs for suggested CLC per hectare (for each of 5 years after investment), Scenario ForestPark

Land use (CLC)	Mean maintenance cost (EUR/ha)
Pastures (231)	0,260 €
Broad-leved Forest (311)	0,206 €

Using the 1% real discount rate for non-intensive natural goods production, the net present value of each designed land-use of ForestPark scenario were calculated:

$$NPV_{Broad-leaved\ forest} = -\ 39{,}098 - \frac{0{,}206}{(1+0.01)} - \cdots - \frac{0{,}206}{(1+0.01)^5}$$
$$= -40{,}097\ €/ha$$

$$NPV_{Pstures} = -9{,}908 - \frac{0{,}260}{(1+0.01)} - \cdots - \frac{0{,}260}{(1+0.01)^5} = -\ 11{,}170\ €/ha$$

Finally, the weighted average of these two land-use was calculated. The weights were set according to area proportional, which is present in Table 2-2 (column Scenario3, ForestPark). The result is present in Table 3-28.

Table 3-28. Non-provisioning ecosystem service values for ForestPark

Land use	Service value	Weight	Service value x Weight
Broad-leaved forest (311)	-40,097	98.93 %	-39,668 €
Pastures (231)	-11,170	1.07 %	-0,120 €
TOTAL		100 %	**-39,788 €**

3.6 The total value of the different scenarios

Table 3-29 presents the total values of the different scenarios per ha, obtained by adding the non-provisioning ecosystem service values to the NPV calculated for the provisioning ecosystem services, as well as for the investment and maintenance costs of the non-provisioning ecosystem services.

Table 3-29. Total values of the different scenarios with NPV in next 5 years

Scenarios	Highest E,S. contribution	Ecosystem services values	NPVs	Total values
Recreation	13,161 €	9,200 €	-12,689	**-5,469 €**
Combination	13,161 €	8,019 €	-124,594	**-117,634 €**
ForestPark	13,161 €	9,143 €	-39,788	**-32,604 €**

The calculation of NPV for next 20 years was done too. Because the maintenance in scenarios Recreation and ForestPark should finish in fifth year, the NPVs are the same as NPV in fifth year. And there is not any income. So Total values are identical. But the income from house renting follows up in scenario Combination. Final NPV and Total value become positive in this scenario (Combination) (Table3-30).

Table 3-30. Total values of the different scenarios with NPV in next 20 years

Scenarios	Highest E,S. contribution	Ecosystem services values	NPVs	**Total values**
Recreation	13,161 €	9,200 €	-12,689	**-5,469 €**
Combination	13,161 €	8,019 €	71,451	**64,311 €**
ForestPark	13,161 €	9,143 €	-39,788	**-32,604 €**

Stakeholders prefer Scenario 1 Recreation (non-intervention, natural conservation, and recreation land-use) and Scenario 2 Combination (they count with investment return in approximately 20 years) (it was mentioned in D3.6. Assessment of scenarios for Ema – Terezie Mine dump complex).

The Ecosystem values are similar for all three scenarios. The higher values occur within scenario, where is higher ratio of Broad-leaved forest. The highest one is for scenario Recreation, which is with non-intervention. Evaluation of Total values shows considerable differences. Scenario Recreation has the lowest investments, similar the scenario ForestPark. Scenario Combination needs highest investments because of houses development. On the other hand, only this scenario, which can product some income. Analyzing costs within the period of 20 years shows, that the Total values can change into positive numbers.

The selection between scenarios should be based on the ease of undertaking, measured in the lower investment needed to develop the scenario and can be considered to bring the best value to society. Recreation scenario should then be selected for the specific case of the Ema-Terezie Mine dumps complex. It is taking into consideration nature conservation and recreation potential of solved area.

4 Best scenario selection for Chabařovice and Most-Ležáky Mine

4.1 Land cover types involved in the assessment of scenarios of Chabařovice Mine

Figures 4-1 present the state of Chabařovice Mine with all the Corine Land Cover (CLC) classes that were identified at the beginning of the RECOVERY Project.

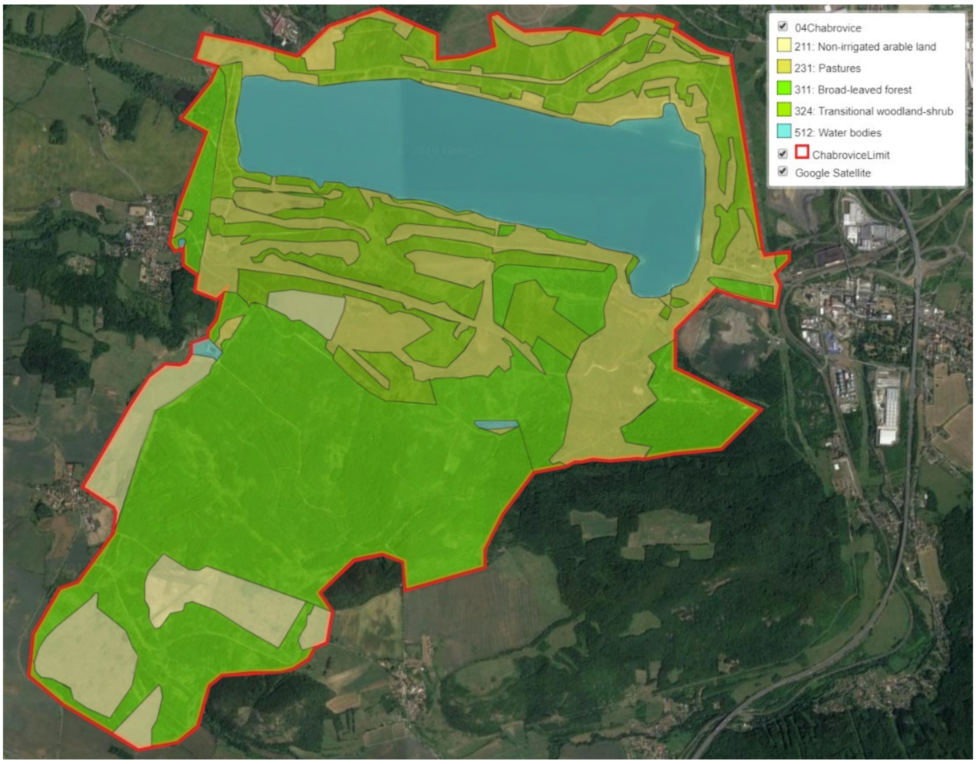


Figure 4-1 Presentation of the GIS of the CLC classes at the Chabařovice Mine

The CLC classes identified were: Non-irrigated arable land (211), Pastures (231), Broad-leaved forest (311), Transitional woodland/shrubs (324) and Water bodies (512).

After, three scenarios were considered feasible to undergo the ecosystem restoration of the area:

1. **Recreation**: Physical recreation, free time activity and leisure areas.
2. **Combination of scenarios**: Physical recreation, free time activity, leisure areas and biking trails.
3. **Sport**: Physical recreation and free time activity and biking trails.

The **Recreation scenario** is characterised by focus mainly on a passive recreation, which takes full advantage of the beauty of the surrounding environment and offers places for a quiet observation of the landscape. For these needs, will be created the objects co-create public spaces in the landscape. The objects provide views, facilities, new activities, and a quiet and peaceful place to relax in the landscape. The objects can serve as rest areas, lookout towers or shelters in bad weather. The corresponding CLC class to develop this scenario is Sport and leisure facilities (142), Pastures (231), Broad-leaved forest (311), Transitional woodland-shrub (324).

The **Combination of scenarios** is characterised by a combination of the physical recreation, freetime activity and biking trails, thus providing to visitors more diversity of activities. Therefore, this scenario includes both the realization of the objects mentioned in Recreation scenario and the realization of biking trails mentioned in Sport scenario. The corresponding CLC class to develop this scenario is Sport and leisure facilities (142), Pastures (231), Broad-leaved forest (311), Transitional woodland-shrub (324).

The **Sport scenario** is characterised by the construction of the Milada Bikecenter sports ground. Downhill and uphill trails with technical elements are designed for the area of the slope facing south above the water surface of Lake Milada. A pumptrack and a skillcenter for improving riding skills are proposed under the trails. The Bikecenter will serve as a public sports ground for leisure activities and a recreation area. The corresponding CLC class to develop this scenario is Sport and leisure facilities (142).

Table 4-1 presents the CLC classes that must be considered to undergo the scenario selection of Chabařovice Mine.

Table 4-1 CLC classes involved in the assessment of scenarios

CLC classes
Sport and leisure facilities (142)
Non-irrigated arable land (211)
Pastures (231)
Broad-leaved forest (311)
Transitional woodland-shrub (324)
Beaches, dunes, sands (331)
Water bodies (512)

Finally, the change rules in percentages of CLC land use areas for the three scenarios are presented in Table 4-2.

Table 4-2 Change rules of CLC classes for the three scenarios

Land use	Initial state	Scenario I Recreation (%)	Scenario II Combination (%)	Scenario III Sport (%)
Sport and leisure facilities	0	5	8	100
Non-irrigated arable land	8	0	0	0
Pastures	19	23	20	0
Broad-leaved forest	38	54	54	0
Transitional woodland-shrub	16	18	19	0
Beaches, dunes, sands	0	0	0	0
Water bodies	18	0	0	0
TOTAL	**100**	**100**	**100**	**100**

4.2 Land cover types involved in the assessment of scenarios of Most-Ležáky Mine

Figures 4-2 present the state of Most-Ležáky Mine with all the Corine Land Cover (CLC) classes that were identified at the beginning of the RECOVERY Project.

The CLC classes identified were: Industry or commercial units (121), Green urban areas (141), Non-irrigated arable land (211), Broad-leaved forest (311), Natural grassland (321), Transitional woodland/shrubs (324), Sparsely vegetated areas (333), Water courses (511), Water bodies (512).

After, three scenarios were considered feasible to undergo the ecosystem restoration of the area:

1. **Recreation**: Physical recreation and freetime activity with biking and hiking trails.
2. **Combination of scenarios**: Physical recreation and freetime activity, biking and hiking trails, transitional woodland shrub, and natural grassland.
3. **Nature**: transitional woodland shrub and natural grassland - leaving the area to more natural development without major interventions in the landscape.

Considering that the location of Lake Most is currently being developed for recreational, sports and adventure activities, the **Recreation scenario** is characterised by building a lookout on the northern slope of Lake Most, including parking spaces. The lookout will be visited by tourists, but also by cyclists who can relax here. The corresponding CLC class to develop this scenario is Transitional woodland-shrub (324).

Figure 4-2 Presentation of the GIS of the CLC classes at the Most-Ležáky mine

The **Combination of scenarios** will aim to create an environment close to nature, in which, however, the needs of visitors from the wider area will be considered in the form of basic recreation and leisure activities. The corresponding CLC class to develop this scenario is Non-Irrigated arable land (211), Broad-leaved forest (311), Natural grassland (321), Transitional woodland-shrub (324), Sparsely vegetated areas (333) and Water bodies (512).

The **Nature scenario** is based on the fact that human interventions in this location will be limited to an absolute minimum. The initial state is the remediation of the slopes and surrounding areas, the subsequent agricultural and forestry reclamation of the dumps and the controlled hydraulic reclamation of the residual pit, resulting in the creation of Lake Most. The corresponding CLC class to develop this scenario is Non-Irrigated arable land (211), Broad-leaved forest (311), Natural grassland (321), Transitional woodland-shrub (324), Sparsely vegetated areas (333), Water bodies (512).

Table 4-3 presents the CLC classes that must be considered to undergo the scenario selection of Most-Ležáky Mine.

Table 4-3 CLC classes involved in the assessment of scenarios

CLC classes
Industrial or commercial units (121)
Green urban areas (141)
Sport and leisure facilities (142)
Non-irrigated arable land (211)
Broad-leaved forest (311)
Natural grassland (321)
Transitional woodland-shrub (324)
Beaches, dunes, sands (331)
Sparsely vegetated areas (333)
Water courses (511)
Water bodies (512)

Finally, the change rules in percentages of CLC land use areas for the three scenarios are presented in Table 4-4.

Table 4-4 Change rules of CLC classes for the three scenarios

Land use	Initial state	Scenario I Recreation (%)	Scenario II Combination (%)	Scenario III Nature (%)
Industrial or commercial units	1	0	0	0
Green urban areas	3	0	0	0
Sport and leisure facilities	0	0	0	0
Non-irrigated arable land	5	0	5	5
Broad-leaved forest	22	0	22	24
Natural grassland	17	0	14	15
Transitional woodland-shrub	23	100	28	27
Beaches, dunes, sands	0	0	0	0
Sparsely vegetated areas	2	0	2	2
Water courses	0	0	0	0
Water bodies	26	0	27	26
TOTAL	**100**	**100**	**100**	**100**

4.3 Representative ecosystem services

After analyzing CLC classes of the study area, field study, as well as the topography, the following ecosystem services (at the level of classes) were selected as important/representative for Chabařovice and Most-Ležáky Mine, with indication of the CICES V5.1 (Haines-Young and Potschin, 2018) and the causal network of coal mining impacts that was developed in Deliverable 4.1 Suitable indicators.

Regarding **provisioning** services, food production was considered.

As for **regulating** services, erosion rate regulation, climate regulation, atmosphere regulation and landslide regulation have been considered in the Chabařovice and Most-Ležáky mine areas.

As for **cultural** services, environment for sport and recreation and using nature to destress were considered.

Table 4-5 shows a summary of the ecosystem services selected as well as their indicators that were first presented in Deliverable 4.1 Suitable indicators.

Table 4-5 Summary of ecosystem services and their indicators

Ecosystem Service	Indicator
Food provision	Productivity of food crops
Erosion rates regulation	Soil loss potential
Climate regulation	Potential evapotranspiration
Environment for sport and recreation	Recreation areas
Using nature to de-stress	Species diversity
Atmosphere regulation	Above-ground carbon and dust particles storage
Landslide regulation	Area in vulnerable exposition covered by vegetation

4.4 Quantification of non-provisioning ecosystem services

Although only four CLC classes for Chabařovice Mine and six for Most-Ležáky Mine are necessary for evaluating the different scenarios, the quantification of non-provisioning ecosystem services was made for all the CLC classes that are present in the Chabařovice Mine, that were shown in Table 2-1 and Most-Ležáky Mine area, that were shown in Table 2-3.

4.4.1 Regulating services: erosion control

Transitional woodland/shrubs has big impact on erosion rates on north and west part of the Lake Most and surroundings around Lake Milada. These areas are mainly for slope stability purposes but also for fauna habitats but also for recreation purposes. The CICES V5.1 code is 2.2.1.1 and class name is "Control of erosion rates". The ecosystem services Indicator could be the soil erosion in g/m^2, and the quantification method is the statistical runoff as estimated by Nunes et al. (2011).

Table 4-6 presents soil erosion in g/m^2 and erosion control indexes for Chabařovice mine and Table 4-7 for Most-Ležáky mine.

Table 4-6 Soil erosion of CLC classes and erosion indexes for Chabařovice mine

CLC classes	Soil erosion	
	g/m^2	Index
Sport and leasure facilities (142)	2,4	9,89
Non-irrigated arable land (211)	193	1
Pastures (231)	2,4	9,89
Broad-leaved forest (311)	1,4	9,93
Transitional woodland-shrub (324)	1,2	9,94
Beaches, dunes, sands (331)	1,2	9,94
Water bodies (512)	0	10

Table 4-7 Soil erosion of CLC classes and erosion indexes for Most-Ležáky mine

CLC classes	Soil erosion	
	g/m^2	Index
Industrial or commercial units (121)	193	1
Green urban areas (141)	2,4	9,89
Sport and leisure facilities (142)	2,4	9,89
Non-irrigated arable land (211)	193	1
Broad-leaved forest (311)	1,4	9,93
Natural grassland (321)	2,4	9,89
Transitional woodland-shrub (324)	1,2	9,94
Beaches, dunes, sands (331)	1,2	9,94
Sparsely vegetated areas (333)	29,8	8,61
Water courses (511)	0	10
Water bodies (512)	0	10

4.4.2 Regulating services: climate regulation (humidity)

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

The quantification method will approximate the evapotranspiration potential of the different land cover classes. Schwarz et al. (2011) used equations based on empirical estimates and considered soil types and climatic conditions.

The evapotranspiration potentials, adapted from Schwarz et al. (2011), and the respective normalised evapotranspiration indexes are presented in Table 4-8 for Chabařovice mine and in Table 4-9 for Most-Ležáky mine. Sources of uncertainty in this assessment are differences in soil types and values under different climatic conditions, as these values were obtained for the urban region of Leipzig.

Table 4-8 Evapotranspiration potentials of CLC classes and evapotranspiration indexes for Chabařovice Mine

CLC classes	Potencial evapotranspiration	
	f	Index
Sport and leasure facilities (142)	1	1
Non-irrigated arable land (211)	1,1	3,25
Pastures (231)	1,1	3,25
Broad-leaved forest (311)	1,1	3,25
Transitional woodland-shrub (324)	1,1	3,25
Beaches, dunes, sands (331)	1	1
Water bodies (512)	1,4	10

Table 4-9 Evapotranspiration potentials of CLC classes and evapotranspiration indexes for Most-Ležáky Mine

CLC classes	Potencial evapotranspiration	
	f	Index
Industrial or commercial units (121)	0,9	1
Green urban areas (141)	1,1	6,4
Sport and leisure facilities (142)	1	2,8
Non-irrigated arable land (211)	1,1	6,4
Broad-leaved forest (311)	1,1	6,4
Natural grassland (321)	1,1	6,4
Transitional woodland-shrub (324)	1,1	4,6
Beaches, dunes, sands (331)	1	2,8
Sparsely vegetated areas (333)	1	2,8
Water courses (511)	1,4	10
Water bodies (512)	1,4	10

4.4.3 Cultural services: Environment for sport and recreation

The process of resocialization on the Chabařovice and Most-Ležáky study areas is in progress. There are many possibilities to do sports and relax. On both lakes there are new studies and plans how to increase and improve the process of resocialization for sports, relax and education. The CICES V5.1 code is 3.1.1.1 and class name is "Characteristics of living systems that enable activities promoting health, recuperation or enjoyment through active or immersive interactions" Indicator could be recreational areas (Handley, J et al., 2003). Table 4-10 presents recreational areas in ha and corresponding indexes for Chabařovice mine and Table 4-11 for Most-Ležáky mine.

Table 4-10 Recreational areas of CLC classes and indexes for Chabařovice Mine

CLC classes	Recreational areas	
	ha	Index
Sport and leasure facilities (142)	51,39	2,82
Non-irrigated arable land (211)	0	1
Pastures (231)	147,85	6,24
Broad-leaved forest (311)	44,85	2,59
Transitional woodland-shrub (324)	169,7	7,01
Beaches, dunes, sands (331)	2,83	1,10
Water bodies (512)	254	10

Table 4-11 Recreational areas of CLC classes and indexes for Most-Ležáky Mine

CLC classes	Recreational areas	
	ha	**Index**
Industrial or commercial units (121)	0	1
Green urban areas (141)	0	1
Sport and leisure facilities (142)	22,1	1,65
Non-irrigated arable land (211)	0	1
Broad-leaved forest (311)	53,3	2,56
Natural grassland (321)	71	3,08
Transitional woodland-shrub (324)	244,1	8,13
Beaches, dunes, sands (331)	0,9	1,03
Sparsely vegetated areas (333)	22,3	1,65
Water courses (511)	0	1
Water bodies (512)	308	10

4.4.4 Cultural services: using nature to destress

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

Table 4-12 presents species diversity and species diversity indexes for Chabařovice mine and Table 4-13 for Most-Ležáky mine.

Table 4-12 Number of species of CLC classes and Species diversity indexes for Chabařovice Mine

CLC classes	Species Diversity	
	number of species	**Index**
Sport and leisure facilities (142)	38	1
Non-irrigated arable land (211)	62	2,1
Pastures (231)	134	5,2
Broad-leaved forest (311)	242	10
Transitional woodland-shrub (324)	210	8,6
Beaches, dunes, sands (331)	69	2,4
Water bodies (512)	71	2,5

Table 4-13 Number of species of CLC classes and Species diversity indexes for Most-Ležáky Mine

CLC classes	Species Diversity	
	number of species	Index
Industrial or commercial units (121)	12	1
Green urban areas (141)	35	1,8
Sport and leisure facilities (142)	50	2,3
Non-irrigated arable land (211)	71	3,0
Broad-leaved forest (311)	281	10
Natural grassland (321)	195	7,1
Transitional woodland-shrub (324)	254	9,1
Beaches, dunes, sands (331)	83	3,4
Sparsely vegetated areas (333)	77	3,2
Water courses (511)	78	3,2
Water bodies (512)	86	3,5

4.4.5 Regulating services: atmosphere regulation

Study case areas are mainly covered by vegetation with high percentage of forestry type of land cover. Thanks to this composition of land cover. These ecosystems are regulating carbon and dust particles in atmosphere which is relevant issue in both localities and surroundings due to active mining and industry. The CICES V5.1 code is 2.2.6.1 and class name is “Regulation of chemical composition of atmosphere and oceans”. The ecosystem services indicator shall be above-ground carbon storage/ha. The above-ground carbon storage quantification method will be linked to land use in t C/ha, as Strohbach and Haase (2012) estimated in a study on above-ground carbon storage in Leipzig (Germany).

Table 4-14 and Table 4-15 present the above-ground carbon storage per land cover to be considered, adapted from Strohbach & Haase (2012), and the carbon storage index.

In this case, an indirect monetary valuation of the ecosystem service is possible using the EU Emissions Trading System (2015). Sources of uncertainty in the assessment are the values at different locations, as these values were obtained for Leipzig.

Table 4-14 Above-ground carbon storage of CLC classes and corresponding indexes for Chabařovice mine

CLC classes	Above-ground carbon storage	
	t C/ha	Index
Sport and leasure facilities (142)	20	3,64
Non-irrigated arable land (211)	0	1
Pastures (231)	0	1
Broad-leaved forest (311)	68,31	10
Transitional woodland-shrub (324)	10,12	2,33
Beaches, dunes, sands (331)	0	1
Water bodies (512)	0	1

Table 4-15 Above-ground carbon storage of CLC classes and corresponding indexes Most-Ležáky mine

CLC classes	Above-ground carbon storage	
	t C/ha	Index
Industrial or commercial units (121)	8,52	2,12
Green urban areas (141)	29,38	4,87
Sport and leisure facilities (142)	20	3,64
Non-irrigated arable land (211)	0	1
Broad-leaved forest (311)	68,31	10
Natural grassland (321)	10,12	2,33
Transitional woodland-shrub (324)	10,12	2,33
Beaches, dunes, sands (331)	0	1
Sparsely vegetated areas (333)	4,02	1,53
Water courses (511)	0	1
Water bodies (512)	0	1

4.4.6 Regulating services: landslide regulation

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

Table 4-16 presents the area in vulnerable exposition covered by vegetation and corresponding indexes for Chabařovice mine and Table 4-17 for Most-Ležáky mine

Table 4-16 area in vulnerable exposition covered by vegetation of CLC classes and corresponding indexes for Chabařovice mine

CLC classes	area in vulnerable exposition covered by vegetation	
	ha	Index
Sport and leasure facilities (142)	0	10
Non-irrigated arable land (211)	0	10
Pastures (231)	249,85	5,6
Broad-leaved forest (311)	511,9	1
Transitional woodland-shrub (324)	218,5	6,2
Beaches, dunes, sands (331)	0	10
Water bodies (512)	0	10

Table 4-17 area in vulnerable exposition covered by vegetation of CLC classes and corresponding indexes for Most-Ležáky mine

CLC classes	area in vulnerable exposition covered by vegetation	
	ha	Index
Industrial or commercial units (121)	0	10
Green urban areas (141)	0	10
Sport and leisure facilities (142)	0	10
Non-irrigated arable land (211)	0	10
Broad-leaved forest (311)	0	10
Natural grassland (321)	54	8,0
Transitional woodland-shrub (324)	244,1	1
Beaches, dunes, sands (331)	0	10
Sparsely vegetated areas (333)	22,3	9,2
Water courses (511)	0	10
Water bodies (512)	0	10

4.5 Valuation of non-provisioning ecosystem services

4.5.1 Comparing ecosystem services with the reference

To estimate the ecosystem services provision of each proposed scenario, it was first necessary to select a reference attribute. Species diversity (Using nature to de-stress) was chosen as the reference attribute because, of all the attributes, it was the one that allowed comparisons to be made with the others in the most obvious way, which facilitated the development of the process. The rest of the attributes were then compared with the reference attribute.

Rank orderings should not change with a different anchor, as they are bi-univocal among the various ecosystem services. What may change is only the difficulty of establishing these rank orderings. That is why species diversity was the anchor selected, as it is the most intuitive among them. Figure 4-3 presents the results of the comparison for Chabařovice mine carried out using the AHP method (Saaty, 1980) and Figure 4-4 for Most-Ležáky mine.

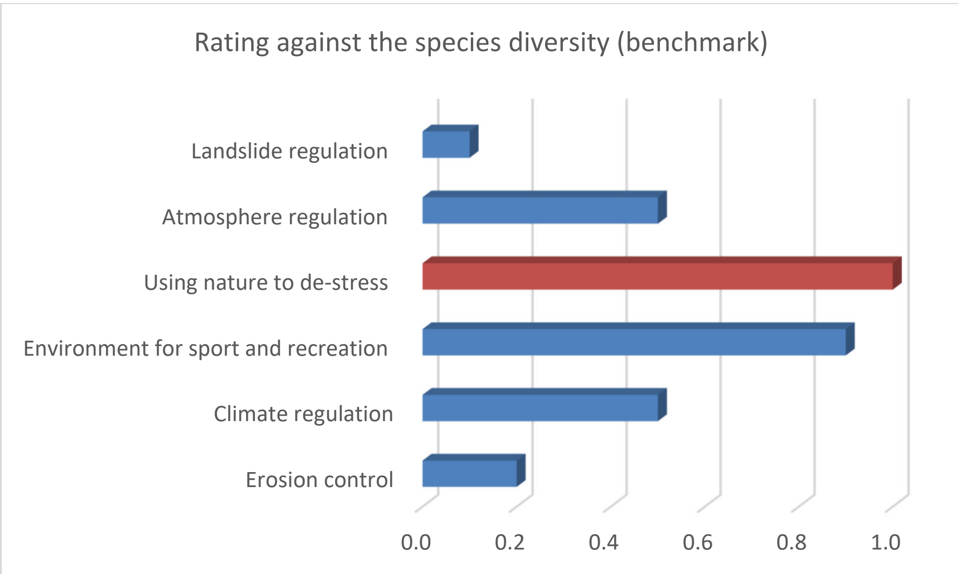


Figure 4-3 Rating of ecosystem services against the benchmark on Chabařovice mine (species diversity)

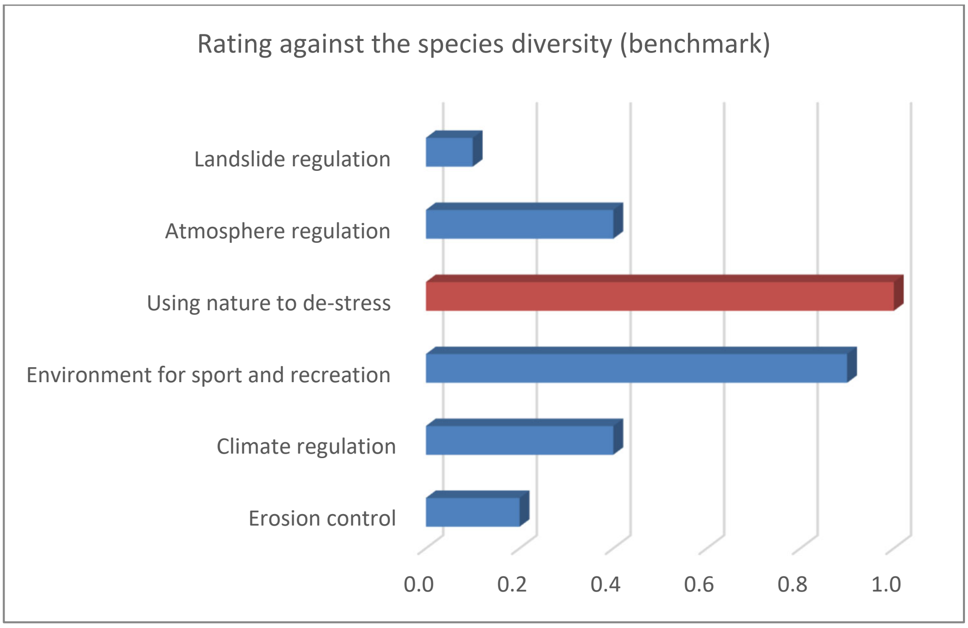


Figure 4-4 Rating of ecosystem services against the benchmark on Most-Ležáky mine (species diversity)

4.5.2 Most direct and market-related valuation possible: carbon sequestration

The ecosystem service for which valuation is most feasible must first be selected to monetise the set of ecosystem services. In this case, the indirect monetary valuation of carbon sequestration through the EU Emissions Trading System (2015) is the most feasible.

According to the EU Emissions Trading System (2015), during 2019 and 2020, the average value of EU Allowances, which allows for the emission of 1 tonne of carbon dioxide equivalent, was about 25 €/t (EMBER, 2021). As 3.67 t CO_2 contain 1 t C, the average value of sequestration of 1 t C can be estimated at 91.75 €/t. Therefore, an above-ground carbon storage rate of 10.0, equivalent to 68.31 t C/ha (Table 3), should be valued at 6,267 €/ha. This value will be used as the reference value for 100% weighted ecosystem services. We assume that all non-provisioning ecosystem services weighted at 100% are worth the same, given that the specific values for each ecosystem service will come from the relative comparison between them.

The revised EU Emissions Trading System Directive, which will apply from 2021–2030, generated a price escalation of carbon allowances, making it necessary to adjust or rethink the proposed framework. To achieve this goal, we have proposed in Krzemień, A., Álvarez Fernández, J.J., Riesgo Fernández, P., Fidalgo Valverde, G., & Garcia-Cortes, S. (2022) the introduction of new vectors or "missing ecosystem services" to counterbalance efforts to eliminate carbon dioxide emissions without necessarily removing humans from the equation: welfare and human health. 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 with the ones obtained before the price escalation of carbon allowances that started in 2021. However, this new ecosystem service will not be used within the present valuation.

4.5.3 Maximum contribution of non-provisioning ecosystem services per ha

According to the previous value of above-ground carbon storage of 6,267 €/ha when rated at index 10, and the rating of ecosystem services against the benchmark (biodiversity), Table 4-18 presents the maximum contribution of non-provisioning ecosystem services per ha corresponding, which is valued at 20,054 €/ha at the Chabařovice mine and at the Most-Ležáky mine is valued at 18,801 €/ha which presents Table 4-19.

Table 4-18 Maximum contribution of ecosystem services per ha at Chabařovice mine

Ecosystem Service	Weight	Value
Erosion control	20 %	1 253 €
Climate regulation	50 %	3 134 €
Environment for sport and recreation	90 %	5 640 €
Using nature to de-stress	100 %	6 267 €
Atmosphere regulation	50 %	3 134 €
Landslide regulation	10 %	627 €
Total		20 054 €

Table 4-19 Maximum contribution of ecosystem services per ha at Most-Ležáky mine

Ecosystem Service	Weight	Value
Erosion control	20 %	1 253 €
Climate regulation	40 %	2 507 €
Environment for sport and recreation	90 %	5 640 €
Using nature to de-stress	100 %	6 267 €
Atmosphere regulation	40 %	2 507 €
Landslide regulation	10 %	627 €
Total		18 801 €

4.5.4 Valuing scenarios Chabařovice mine

Scenario 1: Recreation

The Recreation scenario has four CLC classes: Sport and leisure facilities (142), Pastures (231), Broad-leaved forest (311), Transitional woodland-shrub (324). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 4-18. These values for Sport and leisure facilities (142) are presented in Table 4-20, Pastures (231) are presented in Table 4-21, for Broad-leaved forest (311) are presented in Table 4-22, for Transitional woodland-shrub (324) are presented in Table 4-23.

Table 4-20 Non-provisioning ecosystem service values for Recreation for CLC class Sport and leisure facilities

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 239 €
Evapotranspiraton potencial	1	3 134 €	313 €
Recreational areas	2,8	5 640 €	1 591 €
Species diversity	1	6 267 €	627 €
Above-ground C storage	3,6	3 134 €	1 139 €
Area in vulnerable exposition	10	627 €	627 €
Total		20 054 €	5 536 €

Table 4-21 Non-provisioning ecosystem service values for Recreation for CLC class Pastures

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 239 €
Evapotranspiraton potencial	1,1	3 134 €	345 €
Recreational areas	6,2	5 640 €	3 520 €
Species diversity	5,2	6 267 €	3 259 €
Above-ground C storage	1	3 134 €	313 €
Area in vulnerable exposition	5,6	627 €	351 €
Total		20 054 €	9 027 €

Table 4-22 Non-provisioning ecosystem service values for Recreation for CLC class Broad-leaved forest

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 245 €
Evapotranspiraton potencial	3,3	3 134 €	1 018 €
Recreational areas	2,6	5 640 €	1 461 €
Species diversity	10	6 267 €	6 267 €
Above-ground C storage	10	3 134 €	3 134 €
Area in vulnerable exposition	1	627 €	63 €
Total		20 054 €	13 188 €

Table 4-23 Non-provisioning ecosystem service values for Recreation for CLC class Transitional woodland-shrub

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 246 €
Evapotranspiraton potencial	3,3	3 134 €	1 018 €
Recreational areas	7	5 640 €	3 954 €
Species diversity	8,6	6 267 €	5 390 €
Above-ground C storage	2,3	3 134 €	731 €
Area in vulnerable exposition	6,2	627 €	389 €
Total		20 054 €	12 728 €

Final value of service value was calculated as weighted average total values for all four services. It is present in Table 4-24. The weights were done by percentage of each suggested CLC area, which were mentioned previously.

Table 4-24 Non-provisioning ecosystem service values for Recreation

Land use	Service value	Weight (%)	Service value x Weight
Sport and leisure facilities (142)	5 536 €	5	277 €
Pastures (231)	9 027 €	23	2 076 €
Broad-leaved forest (311)	13 188 €	54	7 121 €
Transitional woodland-shrub (324)	12 728 €	18	2 291 €
Total		100	**11 765 €**

Scenario 2: Combination of scenarios

The Combination of scenarios has four CLC classes: Sport and leisure facilities (142), Pastures (231), Broad-leaved forest (311), Transitional woodland-shrub (324). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from from Table 2-18. These values for Sport and leisure facilities (142) are presented in Table 2-20, Pastures (231) are presented in Table 2-21, for Broad-leaved forest (311) are presented in Table 2-22, for Transitional woodland-shrub (324) are presented in Table 2-23. Final value of service value was calculated as weighted average total values for all four services. It is present in Table 4-25. The weights were done by percentage of each suggested CLC area, poreviously mentioned.

Table 4-25 Non-provisioning ecosystem service values for Combination

Land use	Service value	Weight (%)	Service value x Weight
Sport and leisure facilities (142)	1 065 €	8	85 €
Pastures (231)	13 017 €	19	2 473 €
Broad-leaved forest (311)	19 600 €	54	10 584 €
Transitional woodland-shrub (324)	16 316 €	19	3 100 €
Total		100	**16 242 €**

Scenario 3: Sport

The Sport scenario has only one CLC class: Sport and leisure facilities (142). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 4-18. These values are presented in Table 4-26.

Table 4-26 Non-provisioning ecosystem service values for Sport and leisure facilities

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	3 134 €	3 098 €
Evapotranspiraton potencial	1	5 640 €	564 €
Recreational areas	2,8	6 267 €	1 767 €
Species diversity	1	3 134 €	313 €
Above-ground C storage	3,6	627 €	228 €
Area in vulnerable exposition	10	20 054 €	20 054 €
Total		38 855 €	26 025 €

4.5.5 Valuing scenarios Most-Ležáky mine

Scenario 1: Recreation

The Recreation scenario has only one CLC class: Transitional woodland-shrub (324). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 4-19. These values are presented in Table 4-27.

Table 4-27 Non-provisioning ecosystem service values for Transitional woodland-shrub

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 246 €
Evapotranspiraton potencial	4,6	2 507 €	1 153 €
Recreational areas	8,1	5 640 €	4 586 €
Species diversity	9,1	6 267 €	5 703 €
Above-ground C storage	2,3	2 507 €	585 €
Area in vulnerable exposition	1,0	627 €	63 €
Total		18 801 €	13 336 €

Scenario 2: Combination of scenarios

The Combination of scenarios has six CLC classes: Non-Irrigated arable land (211), Broad-leaved forest (311), Natural grassland (321), Transitional woodland-shrub (324), Sparsely vegetated areas (333), Water bodies (512). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 4-19. These values for Non-Irrigated arable land (211) are presented in Table 4-28, for Broad-leaved forest (311) are presented in Table 4-29, for Natural grassland (321) are presented in Table 4-30, for Transitional woodland-shrub (324) are presented in Table 4-31, for Sparsely vegetated areas (333) are presented in Table 4-32, Water bodies (512) are presented in Table 4-33.

Table 4-28 Non-provisioning ecosystem service values for Combination of scenarios for CLC class Non-Irrigated arable land (211)

Indicator	**Index**	**Value**	**Index x Value / 10**
Soil erosion	1	1 253 €	125 €
Evapotranspiraton potencial	6,4	2 507 €	1 604 €
Recreational areas	1	5 640 €	564 €
Species diversity	3	6 267 €	1 880 €
Above-ground C storage	1	2 507 €	251 €
Area in vulnerable exposition	10	627 €	627 €
Total		18 801 €	5 051 €

Table 4-29 Non-provisioning ecosystem service values for Combination of scenarios for CLC class Broad-leaved forest (311)

Indicator	**Index**	**Value**	**Index x Value / 10**
Soil erosion	9,9	1 253 €	1 245 €
Evapotranspiraton potencial	6,4	2 507 €	1 604 €
Recreational areas	2,6	5 640 €	1 444 €
Species diversity	10	6 267 €	6 267 €
Above-ground C storage	10	2 507 €	2 507 €
Area in vulnerable exposition	10	627 €	627 €
Total		18 801 €	13 694 €

Table 4-30 Non-provisioning ecosystem service values for Combination of scenarios for CLC class Natural grassland (321)

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 239 €
Evapotranspiraton potencial	6,4	2 507 €	1 604 €
Recreational areas	3,1	5 640 €	1 737 €
Species diversity	7,1	6 267 €	4 450 €
Above-ground C storage	2,3	2 507 €	585 €
Area in vulnerable exposition	8	627 €	501 €
Total		18 801 €	10 117 €

Table 4-31 Non-provisioning ecosystem service values for Combination of scenarios for CLC class Transitional woodland-shrub (324)

Indicator	Index	Value	Index x Value / 10
Soil erosion	9,9	1 253 €	1 246 €
Evapotranspiraton potencial	4,6	2 507 €	1 153 €
Recreational areas	8,1	5 640 €	4 586 €
Species diversity	9,1	6 267 €	5 703 €
Above-ground C storage	2,3	2 507 €	585 €
Area in vulnerable exposition	1	627 €	63 €
Total		18 801 €	13 336 €

Table 4-32 Non-provisioning ecosystem service values for Combination of scenarios for CLC class Sparsely vegetated areas (333)

Indicator	Index	Value	Index x Value / 10
Soil erosion	8,6	1 253 €	1 079 €
Evapotranspiraton potencial	2,8	2 507 €	702 €
Recreational areas	1,7	5 640 €	931 €
Species diversity	3,2	6 267 €	2 005 €
Above-ground C storage	1,5	2 507 €	383 €
Area in vulnerable exposition	9,2	627 €	577 €
Total		18 801 €	5 677 €

Table 4-33 Non-provisioning ecosystem service values for Combination of scenarios for CLC class Water bodies (512)

Indicator	Index	Value	Index x Value / 10
Soil erosion	10	1 253 €	1 253 €
Evapotranspiraton potencial	10	2 507 €	2 507 €
Recreational areas	10	5 640 €	5 640 €
Species diversity	3,5	6 267 €	2 193 €
Above-ground C storage	1	2 507 €	251 €
Area in vulnerable exposition	10	627 €	627 €
Total		18 801 €	12 471 €

Final value of service value was calculated as weighted average total values for all six services. It is present in Table 4-34. The weights were done by percentage of each suggested CLC area, which are mentioned in Table 4-4.

Table 4-34 Non-provisioning ecosystem service values for Combination

Land use	Service value	Weight (%)	Service value x Weight
Non-Irrigated arable land (211)	10 366 €	5	518 €
Broad-leaved forest (311)	18 600 €	23	4 278 €
Natural grassland (321)	6 856 €	14	960 €
Transitional woodland-shrub (324)	15 780 €	29	4 576 €
Sparsely vegetated areas (333)	3 058 €	2	61 €
Water bodies (512)	6 975 €	27	1 883 €
Total		100	**12 277 €**

Scenario 3: Nature

The Nature scenario has six CLC classes: Non-Irrigated arable land (211), Broad-leaved forest (311), Natural grassland (321), Transitional woodland-shrub (324), Sparsely vegetated areas (333), Water bodies (512). The values of the different ecosystem services for this land cover were calculated by multiplying the different indexes for this land cover, expressed as a percentage, by the ecosystem services values from Table 4-19. These values for Non-Irrigated arable land (211) are presented in Table 4-28, for Broad-leaved forest (311) are presented in Table 4-29, for Natural grassland (321) are presented in Table 4-30, for Transitional woodland-shrub (324) are presented in Table 4-31, for Sparsely vegetated areas (333) are presented in Table 4-32, Water bodies (512) are presented in Table 4-33.

Final value of service value was calculated as weighted average total values for all six services. It is present in Table 4-35. The weights were done by percentage of each suggested CLC area, which are mentioned in Table 2-4.

Table 4-35 Non-provisioning ecosystem service values for Nature

Land use	Service value	Weight (%)	Service value x Weight
Non-Irrigated arable land (211)	5 051 €	5	253 €
Broad-leaved forest (311)	13 694 €	24	3 287 €
Natural grassland (321)	10 117 €	15	1 518 €
Transitional woodland-shrub (324)	13 336 €	28	3 734 €
Sparsely vegetated areas (333)	5 677 €	2	114 €
Water bodies (512)	12 471 €	26	3 243 €
Total		100	**12 147 €**

4.6 Valuation of provisioning ecosystem services

To determine the revenues/costs of the three scenarios of Chabařovice mine considered feasible: creation of the objects provide views, facilities, new activities, and a quiet and peaceful place to relax in the landscape (Recreation), realization of the objects mentioned in Recreation scenario and biking trails mentioned in Sport scenario, thus providing to visitors more diversity of activities (Combination), and construction of the Milada Bikecenter sports ground with a pumptrack and a skillcenter for improving riding skills and biking trails with technical elements (Sport), and also for Most-Ležáky mine: building a lookout on the northern slope of Lake Most, including parking spaces (Recreation), creation of an environment close to nature, in which, however, the needs of visitors from the wider area will be considered in the form of basic recreation and leisure activities (Combination), and leave most of the territory to natural development without significant human interventions (Nature). The net present value (NPV) of investment and maintenance costs will be calculated as no provisioning ecosystem services are occurring in any of scenarios.

Real/constant discount rates as well as real/constant values in Euros from 2022 were used in the calculations, as it will be challenging to consider adequate variations of the inflation rate over long periods.

The discount rates to be used were presented in Deliverable 4.3:

- Non-intensive natural goods production, such as familiar animal exploitation, familiar tree plantations, familiar agriculture, etc., are proposed to be valued at a real/ constant rate of 1%, which is considered a moderate rate of growth.

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

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

4.6.1 Scenario 1 on Chabařovice mine: Recreation

Within the Recreation scenario, no provisioning ecosystem services are occurring, thus no incomes are foreseen in this scenario or any of remaining scenarios but investment and maintenance costs of construction of 23 recreational objects have to be considered in the calculations. NPV is calculated over 30 years, because recreational objects and buildings will be included in depreciation group no. 5. This rule will be used in all scenarios for both mines to ensure appropriate results.

The most important item are investment costs 4,381.849 €/ha as maintenance costs are lowest among all three scenarios at 54.65 €/ha.

Using the 1% real discount rate as we don't have any production is very conservative during current turbulent time, the net present value of the Recreation scenario is -5,841 EUR:

$$NPV_{Recreation} = -4381{,}849 - \frac{54{,}65}{(1+0.01)} - \cdots - \frac{54{,}65}{(1+0.01)^{30}} = -5841{,}22\ €/ha$$

4.6.2 Scenario 2 on Chabařovice mine: Combination of scenarios

Within the Combination of scenarios, no provisioning ecosystem services are occurring, thus no incomes are foreseen in this scenario as stated earlier but investment and maintenance costs of construction of 23 recreational objects and Milada Bikecenter sports ground and biking trails have to be considered in the calculations.

The investment costs are 4,616.019 €/ha and maintenance costs are at 113.79 €/ha.

Using the 1% real discount rate as we don't have any production is very conservative during current turbulent time, the net present value of the Combination of scenarios is -7,655 EUR:

$$NPV_{Combination\ of\ scenarios} = -\,4616{,}019 - \frac{113{,}79}{(1+0.01)} - \cdots - \frac{113{,}79}{(1+0.01)^{30}} = -\,7654{,}67\ €/ha$$

4.6.3 Scenario 3 on Chabařovice mine: Sport

Within the Sport scenario, no provisioning ecosystem services are occurring in the is Sport and leisure facilities (142) CLC. Thus, no incomes are foreseen in this scenario but the investment and maintenance cost of construction of the Milada Bikecenter sports ground and biking trails have to be considered in the calculations.

Sport scenario investment costs 13,851.989 €/ha and maintenance costs 378.41 €/ha are highest among all three scenarios.

Using again the 1% real discount rate as we don't have any production is very conservative during current turbulent time, the net present value of the Sport scenario is -23,957 EUR:

$$NPV_{Sport} = -\,13851{,}989 - \frac{378{,}41}{(1+0.01)} - \cdots - \frac{378{,}41}{(1+0.01)^{30}} = -\,23957{,}06\ €/ha$$

4.6.4 Scenario 1 on Most-Ležáky mine: Recreation

Within the Recreation scenario, no provisioning ecosystem services are occurring, thus no incomes are foreseen in this scenario but investment and maintenance costs of building a lookout on the northern slope of Lake Most with parking spaces have to be considered in the calculations.

Investment costs 1,560.976 €/ha are the same as in second scenario but maintenance costs are lowest among all three scenarios at 134.33 €/ha.

Using again the 1% real discount rate as we don't have any production is very conservative during current turbulent time, the net present value of the Recreation scenario is -5,148 EUR:

$$NPV_{Recreation} = -\,1560{,}974 - \frac{134{,}33}{(1+0.01)} - \cdots - \frac{134{,}33}{(1+0.01)^{30}} = -\,5148{,}13\ €/ha$$

4.6.5 Scenario 2 on Most-Ležáky mine: Combination of scenarios

Within the Combination of scenarios, no provisioning ecosystem services are occurring, thus no incomes are foreseen in this scenario but investment and maintenance costs of of nature without significant human interventions, as well as the construction of a lookout on the northern slope of Lake Most with parking spaces have to be considered in the calculations.

Investment costs 1,560.976 €/ha are the same as in Recreation scenario but maintenance costs are higher at 216.75 €/ha.

Using again the 1% real discount rate as we don't have any production is very conservative during current turbulent time, the net present value of the Combination of scenarios is -7,349 EUR:

$$NPV_{Combination\ of\ scenarios} = -1560{,}974 - \frac{216{,}75}{(1+0.01)} - \cdots - \frac{216{,}75}{(1+0.01)^{30}} = -7349{,}07\ €/ha$$

4.6.6 Scenario 3 on Most-Ležáky mine: Nature

Within the Nature scenario, no provisioning ecosystem services are occurring, thus no incomes are foreseen in this scenario but maintenance costs of nature without significant human interventions have to be considered in the calculations.

No investment cost are planned in Nature scenario but maintenance costs 308.24 €/ha are highest among all three scenarios.

Using again the 1% real discount rate as we don't have any production is very conservative during current turbulent time, the net present value of the Nature scenario is -23,957 EUR:

$$NPV_{Nature} = 0 - \frac{308{,}24}{(1+0.01)} - \cdots - \frac{308{,}24}{(1+0.01)^{30}} = -8231{,}25\ €/ha$$

4.7 The total value of the different scenarios

Table 4-36 presents the total values of the different scenarios of Chabařovice mine per ha and Table 4-37 of Most-Ležáky mine, obtained by adding the non-provisioning ecosystem service values to the NPV calculated for the investment and maintenance costs of the non-provisioning ecosystem services.

Table 4-36 Total values of the different scenarios of Chabařovice mine

Scenarios	Highest E.S. contribution	Ecosystem services values	NPVs	Total values
Recreation	20 054 €	11 765 €	-5 841 €	**5 924 €**
Combination of scenarios	20 054 €	11 698 €	-7 655 €	**4 043 €**

Sport	20 054 €	26 025 €	-23 957 €	**2 068 €**

Table 4-37 Total values of the different scenarios of Most-Ležáky mine

Scenarios	**Highest E.S. contribution**	**Ecosystem services values**	**NPVs**	**Total values**
Recreation	18 801 €	13 336 €	-5 148 €	**8 188 €**
Combination of scenarios	18 801 €	12 167 €	-7 349 €	**4 818 €**
Nature	18 801 €	12 147 €	-8 231 €	**3 915 €**

The conclusion in both case of studies is that the best scenario is Recreation. This scenario is also preferred by all stakeholders and at the same time it is consistent with the studies for both lakes.

5 Janina Mine Waste Heap

Figure 5-1 presents current land use of Libiąż district Janina Mine Waste Heap – the area of concern in RECOVERY project is located.

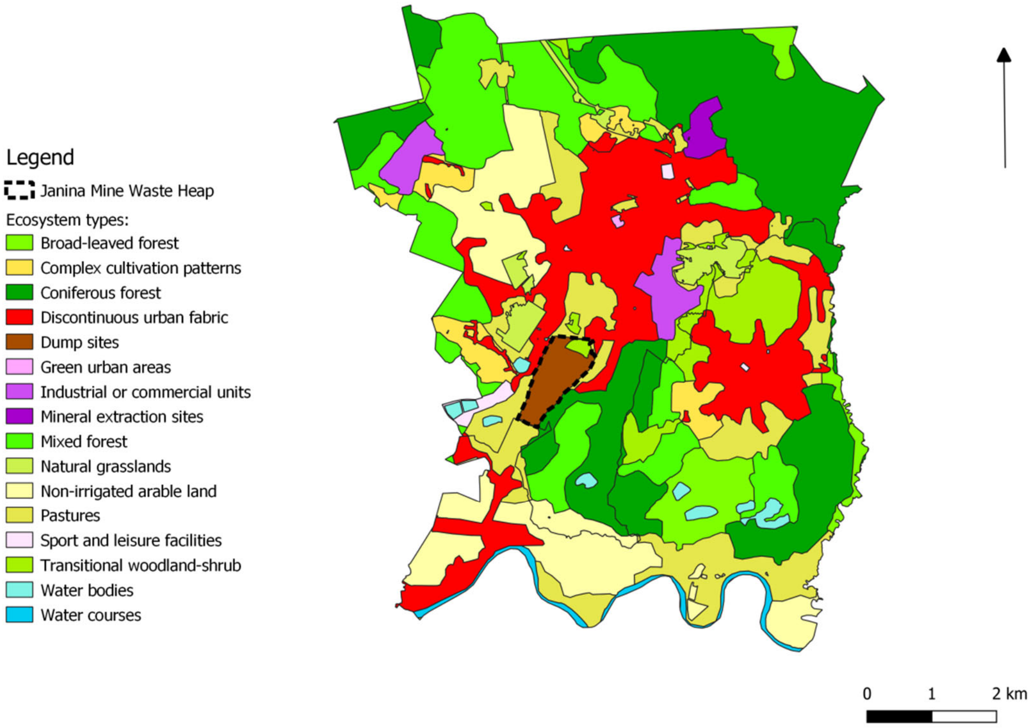


Figure 5-1. Presentation of CLC classes in Libiąż district

The identified CLC classes were: Discontinuous urban fabric (112), Industrial or commercial units (121), Green urban areas (141), Mineral extraction sites (131), Dump sites (132), Sport and leisure facilities (142), Non-irrigated arable land (211), Pastures (231), Complex cultivation patterns (242), Broad-leaved forest (311), Coniferous forest (312), Mixed forest (313), Natural grassland (321), Transitional woodland/shrub (324), Water courses (511), Water bodies (512).

After, three scenarios were considered feasible to undergo the ecosystem restoration of the area:

- Scenario I. Increasing the natural and recreational potential,
- Scenario II. Increasing the economic potential,
- Scenario III. Increasing the natural, recreational and economic potential.

Table 5-1. CLC classes involved in the assessment of scenariospresents the CLC classes considered under scenario selection of Janina Mine Waste Heap.

Table 5-1. CLC classes involved in the assessment of scenarios

CLC classes
Natural grasslands (321)
Transitional woodland/shrub (324)
Sport and leisure facilities (142)
Green urban areas (141)
Industrial or commercial units and public facilities (solar panels) (121)
Industrial or commercial units and public facilities (commercial buildings) (121)
Water bodies (512)

The change share in percentages of CLC land use areas for the three scenarios of Janina Mine Waste Heap are presented in Table 5-2.

Table 5-2. Share of CLC types on each scenario

Scenario I	**Initial state [%]**	**Scenario I [%]**	**Scenario II [%]**	**Scenario III [%]**
Dump sites	100	0	17,5	0
Construction sites	0	0	73,1	6,7
Green urban areas	0	8,2	0	10,7
Industrial or commercial units	0	0	9,4	6,5
Natural grassland	0	29,1	0	24,9
Sport and leisure facilities	0	10,7	0	9
Transitional woodland-shrub	0	29,1	0	27,7
Water bodies	0	22,9	0	14,5

5.1 Representative ecosystem services

In the case of Janina Mine Heap six ecosystem services indicators were selected to the detailed exploring of consequences of each scenario taking into consideration benefits that could be generated by ecosystem. Three regulating (water flow regulation, air quality regulation, temperature regulation), one cultural (interactions with the natural environment) and two provisioning (solar energy, mediation of waste) were selected as representative for ecosystem services assessment. The selection of suitable indicators were described in Deliverable 4.1. Table 5-3 presents a summary of the ecosystem services selected as well as their indicators.

Table 5-3. Summary of ecosystem services and their indicators

Ecosystem service	ES indicator
air quality regulation	Air pollution absorption (PM10 & SO_2)
water flow regulation	The direct water run-off (QD)
temperature regulation	Thermal emissivity
Interactions with natural environment	To biotopes values for recreation and contact with nature
solar energy	electric power production

5.2 Quantification of non-provisioning ecosystem services

For evaluating the different scenarios, the quantification of non-provisioning ecosystem services was made for all the CLC classes that are present in Libiąż district (that was set as study area) and CLC classes included in scenarios of Janina Mine Waste Heap revitalization.

5.2.1 Regulating services: air quality regulation

The CICES V5.1 code are 2.1.1 and 2.2.6. The amount of PM10 absorbed by different habitats shows the potential of ecosystems for removal of atmospheric particulate pollution. For Libiąż district the quantification of air quality regulation in accordance with the methodology proposed by Tallis et al. (2011) is presented in Table 5-4.

Table 5-4. Quantification of CLC classes for air quality regulation

CLC classes	kg/ha/year	Index
Broad-leaved forest (311)	158	3.2
Complex cultivation patterns (242)	16	1.2
Coniferous forest (312)	640	10.0
Construction sites (133)	0	1,0
Discontinuous urban fabric (112)	0	1.0
Dump sites (132)	0	1.0
Green urban areas (141)	16	1.2
Industrial or commercial units (121)	0	1.0
Mineral extraction sites (131)	0	1.0
Mixed forest (313)	328	5.6
Natural grasslands (321)	16	1.2
Non-irrigated arable land (211)	16	1.2
Pastures (231)	16	1.2
Sport and leisure facilities (142)	16	1.2
Transitional woodland-shrub (324)	16	1.2
Water bodies (512)	0	1.0
Water courses (511)	0	1.0

5.2.2 Regulating services: water flow regulation

The CICES V5.1 code of Regulation of baseline flows is 2.2.1.2. The water balance is directly connected with the water flow regulation of ecosystems in the urban area. The changing of relief and surface sealing impacts urban sprawl on water balance in an urban area and this process has caused both environmental problems and repercussions in society. The direct run-off was used as an indicator for water fluxes and the water balance assessment. The values were calculated for Libiąż district according methodology presented in paper Haase and Nuissl (2007). The quantification results are presented in Table 5-5.

Table 5-5. Direct runoff of CLC classes and direct runoff indexes

CLC classes	Direct run-off (mm)	Index
Broad-leaved forest (311)	47.5	9.3
Complex cultivation patterns (242)	116.2	7.3
Coniferous forest (312)	24.0	10.0
Construction sites (133)	135.3	6.8
Discontinuous urban fabric (112)	263.5	3.0
Dump sites (132)	332.3	1.0
Green urban areas (141)	122.2	7.1
Industrial or commercial units (121)	313.3	1.6
Mineral extraction sites (131)	185.6	5.3
Mixed forest (313)	80.0	8.4
Natural grasslands (321)	90.2	8.1
Non-irrigated arable land (211)	59.0	9.0
Pastures (231)	95.0	7.9
Sport and leisure facilities (142)	154.0	6.2
Transitional woodland-shrub (324)	58.1	9.0
Water bodies (512)	72.7	8.6
Water courses (511)	27.3	9.9

5.2.3 Regulating services: temperature regulation

The CICES V5.1 code of Regulation of temperature and humidity including ventilation and transpiration is 2.2.6.2. Urban heat island impacts on citizen's general health status. Based on Land Surface Temperature higher and lower temperatures during sunny summer days could be delimited. Combining this information with the current land cover allow to access the role of ecosystems in local climate regulation. The LST accounted base on Landsat 8 Thermal Band data were used for quantification potential of different CLC classes for temperature regulating.

Values (v) were normalised in an index between 1 (highest emission) and 10 (lowest emission), according to equation (1), similar to that used by Larondelle & Haase (2012).

The values LST and the normalised indexes for each CLC classes are presented in Table 5-6.

Table 5-6. LST of CLC classes and normalized emission indexes

CLC classes	LST	Index
Broad-leaved forest (311)	20.8	10.0
Complex cultivation patterns (242)	22.2	4.8
Coniferous forest (312)	21.3	8.3
Construction sites (133)	23.3	1.0
Discontinuous urban fabric (112)	23.1	1.4
Dump sites (132)	23.2	1.3
Green urban areas (141)	22.0	5.7
Industrial or commercial units (121)	23.1	1.7
Inland marshes (411)	21.7	6.7
Land principally occupied by agriculture, with significant areas of natural vegetation (243)	21.8	6.2
Mineral extraction sites (131)	21.4	7.8
Mixed forest (313)	21.3	8.2
Natural grasslands (321)	21.9	5.9
Non-irrigated arable land (211)	21.9	6.1
Pastures (231)	21.8	6.2
Sport and leisure facilities (142)	22.8	2.8
Sparsely vegetated areas (333)	22.0	5.7
Transitional woodland-shrub (324)	21.4	7.7
Water bodies (512)	21.0	9.3
Water courses (511)	21.1	9.0

5.2.4 Regulating services: interactions with natural environment

The CICES V5.1 code of Physical and experiential interactions with natural environment is 3.1.1. The biophysical characteristics or qualities ecosystems (landscapes) that enable activities promoting health, de-stressing and nature-based recreation in Janina Mine case study were evaluated in accordance with the methodology by Seják et all (2010).

The ecosystems that deliver the services connected with nature-based recreation in Janina case study is mostly connected with forest ecosystems, water bodies, water courses and natural grasslands (Table 5-7).

Table 5-7. Quantification of CLC classes for deliver interactions with natural environment

CLC classes	Ecosytem quality	Index
Broad-leaved forest (311)	34	10.0
Complex cultivation patterns (242)	15	4.9
Coniferous forest (312)	33	9.6
Construction sites (133)	1	1.3
Discontinuous urban fabric (112)	7	2.8
Dump sites (132)	0	1.0
Green urban areas (141)	20	6.3
Industrial or commercial units (121)	0	1.0
Mineral extraction sites (131)	16	5.3
Mixed forest (313)	22	6.9
Natural grasslands (321)	32	9.5
Non-irrigated arable land (211)	16	5.2
Pastures (231)	16	5.3
Sport and leisure facilities (142)	3	1.8
Transitional woodland-shrub (324)	20	6.3
Water bodies (512)	28	8.4
Water courses (511)	23	7.1

5.3 Valuation of non-provisioning ecosystem services

5.3.1 Comparing ecosystem services with the reference

In the case of Janina Waste Heap, the comparison of the importance of non-provisioning ecosystem services, was done based on the number of citizens that are the potential beneficiaries of each ES. For that estimation the range of negative impact of analysed post-mining area and the spatial distribution of residential areas were taken into consideration. In the case of ES related to the qualities of ecosystems that enable nature-based recreation (cultural services) the impact on increase of accessibility to green spaces (green infrastructure) was also accounted (Figure 5-2).

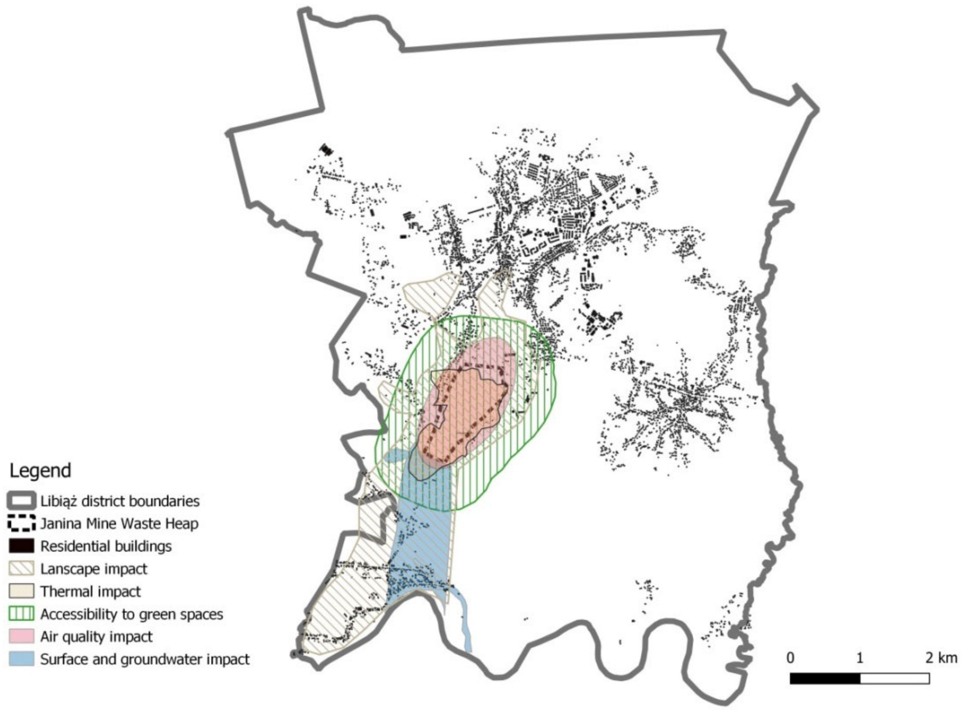


Figure 5-2. The estimation of potential beneficiaries of each ES

Base on the results of the interactions with natural environment as the ES with wider impact on local communities was chosen as reference ecosystem services. The number of people influenced by each ES allowed also to set the rating of other ES against the reference ES. The results are presented in Figure 5-3.

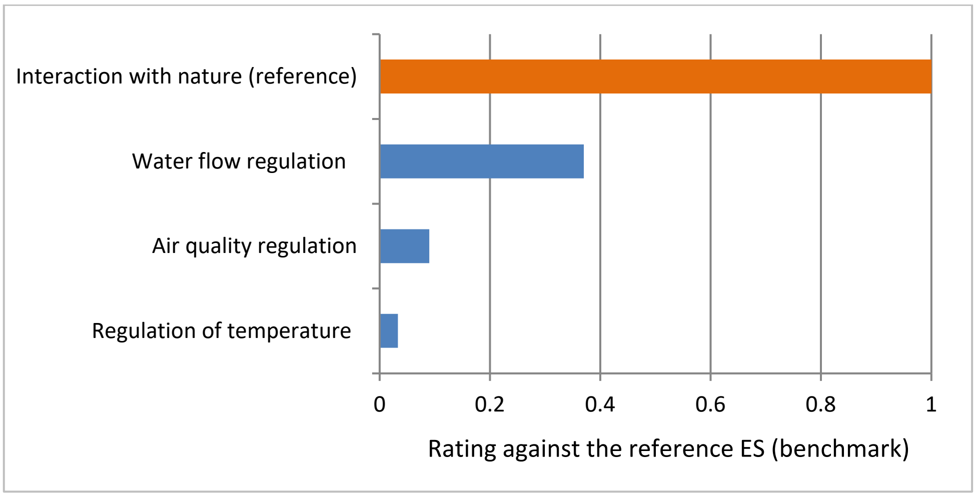


Figure 5-3. Rating of ecosystem services against the benchmark on Janina Mine waste heap

5.3.2 Most direct and market-related valuation

The values of some ecosystem goods or services can be measured using market prices. Some ecosystem products, such as fish or wood, are traded in markets. Thus, their values can be estimated by estimating consumer and producer surplus, as with any other market good. Other ecosystem services, such as clean water, are used as inputs in production, and their value may be measured by their contribution to the profits made from the final good.

Some ecosystem or environmental services, like aesthetic views or many recreational experiences, may not be directly bought and sold in markets. However, the prices people are willing to pay in markets for related goods can be used to estimate their values. For example, people often pay a higher price for a home with a view of the ocean, or will take the time to travel to a special spot for fishing or bird watching. These kinds of expenditures can be used to place a lower bound on the value of the view or the recreational experience. In conventional economics it is generally accepted that measures of economic value should be based on what people want; and that individuals, not the government, should be the judges of what they want. Using this notion of value, the maximum amount of one thing a person is willing to give up to get more of something else is considered a fair measure of the relative "value" of the two things to that person. Monetary values (currencies) are a universally accepted measure of economic value because the amount that people are "willing to pay" for something reflects how much of all other for-sale goods and services they are willing to give up to get it.

The local circumstances of Janina Waste Heap causes that introduction the ecosystem with potential to above-ground carbon storage was not possible (no opportunity to forest ecosystems developing). Due to the negative impact on the surface and underground waters, the most direct and market-related valuation of ES, was based on the relation water flow regulation.

For purposes of assessing the economic value of ecosystem services such as water flow regulation it is important to note that measuring the value of something using currency does not require that it be bought and sold in markets. It only requires estimating how much purchasing power (monetary value) people would be willing to give up to get it (or would need to be paid to give it up), if they were forced to make a choice.

In the case of ecosystem service related to Water Flow Regulation it is important to note that water runoff from the case study – Janina Waste Heap should be recognized as water loss (in current land management scenario). However, the scenario of mine waste heap recovery and change of its coverage (i.e. Coniferous forest) would increase the value of this ecosystem service, thus maximum water runoff from 332.3 mm will be decreased to 24.0 mm (according to direct runoff of CLC classes and direct runoff indexes). Therefore, calculation of the monetary value of Water Flow Regulation is directly related to area of concern and its coverage. For Janina Waste Heap maximum water runoff from total area of the heap is in actual coverage is: 227 625.5 m^3, while for coniferous forest 16 440 m^3, which means that total amount of water runoff will decrease its loose on 211 181,5 m^3.

Considering water services value in this case the price of water service related to rainwater discharge (according to Polish Water Act) value is: 0.75 PLN/m^3 (0.16 €), which directly gives Water Flow Regulation ecosystem service value: 35 193.6 €/year. This may be given as unit value per ha: 513.7 €/ha/year.

5.3.3 Maximum contribution of non-provisioning ecosystem services per ha

According to the previous value of Water Flow Regulation (513.7 €/ha) when rated at index 10, and the rating of ecosystem services against the benchmark (biodiversity or biotops values), Table 5-8 presents the maximum contribution of non-provisioning ecosystem services per ha corresponding, which is valued at 2097,6 €/ha/year. Taking into consider 25 year range of time, the maximum contribution of non-provisioning ecosystem services was estimated on **52 425 €/ha/year.**

Table 5-8 Maximum contribution of ecosystem services per ha/year

Ecosystem service	Weight (%)	Value (€/ha/year)
Interaction with nature	100	1400,2
Water flow regulation	37	513,7
Air quality regulation	10	136,7
Regulation of temperature	3	47,0
Total		**2097,6**

5.3.4 Valuing scenarios

At the first step the value of non-provision services for each CLC classes included in redevelopment scenarios was accounted. The values of non-provision services of each CLC type were calculated taking into consideration potential the different land cover type (indexes from Table 5-4 to Table 5-7) and ecosystem services values from Table 5-8. The results are presented in Tables 5-9 to 5-16.

Table 5-9. Non-provisioning ecosystem service values for Dump sites

Indicator	Index	Value	Value (€/ha/year)
Water flow regulation	1	514	51
Air quality regulation	1	137	14
Regulation of temperature	1,3	47	6
Interactions with natural environment	1	1400	140
Total values (€/ha/year)			**211**

Table 5-10. Non-provisioning ecosystem service values for Construction sites

Indicator	Index	Value	Value (€/ha/year)
Water flow regulation	6,8	514	349
Air quality regulation	1	137	14
Regulation of temperature	1	47	5
Interactions with natural environment	1,3	1400	182
Total values (€/ha/year)			**550**

Table 5-11. Non-provisioning ecosystem service values for Green urban areas

Indicator	Index	Value	Value (€/ha/year)
Water flow regulation	7,1	514	365
Air quality regulation	1,2	137	16
Regulation of temperature	5,7	47	27
Interactions with natural environment	6,3	1400	882
Total values (€/ha/year)			**1290**

Table 5-12. Non-provisioning ecosystem service values for Industrial or commercial units

Indicator	Index	Value (€)	Value (€/ha/year)
Water flow regulation	1,6	514	82
Air quality regulation	1	137	14
Regulation of temperature	1,7	47	8
Interactions with natural environment	1	1400	140
Total values (€/ha/year)			**244**

Table 5-13. Non-provisioning ecosystem service values for Natural grassland

Indicator	Index	Value (€)	Value (€/ha/year)
Water flow regulation	8,1	514	416
Air quality regulation	1,2	137	16
Regulation of temperature	5,6	47	26
Interactions with natural environment	9,5	1400	1330
Total values (€/ha/year)			**1789**

Table 5-14. Non-provisioning ecosystem service values for Sport and leisure facilities

Indicator	Index	Value (€)	Value (€/ha/year)
Water flow regulation	6,2	514	318
Air quality regulation	1	137	14
Regulation of temperature	2,8	47	13
Interactions with natural environment	1,8	1400	252
Total values (€/ha/year)			**597**

Table 5-15. Non-provisioning ecosystem service values for Transitional woodland-shrub

Indicator	Index	Value (€)	Value (€/ha/year)
Water flow regulation	9	514	462
Air quality regulation	1,2	137	16
Regulation of temperature	7,7	47	36
Interactions with natural environment	6,3	1400	882
Total values (€/ha/year)			**1397**

Table 5-16. Non-provisioning ecosystem service values for Water bodies

Indicator	Index	Value (€)	Value (€/ha/year)
Water flow regulation	8,6	514	442
Air quality regulation	1	137	14
Regulation of temperature	9,3	47	44
Interactions with natural environment	8,4	1400	1176
Total values (€/ha/year)			**1675**

The values ES for each CLC type was used to estimate non-provisioning ecosystem values of each redevelopment scenarios.

5.3.5 Scenario I Increasing the natural and recreational potential

The Scenario I has five CLC classes: Sport and leisure activities (142), Green urban areas (141), Natural grassland (321), Transitional woodland-shrub (324), Water bodies (511). Taking into consideration values ES for each CLC and them percentage share in Scenario I the average total values of ES deliver by each hectare/year was estimated (Table 5-17). Taking into consideration a 25 year range of time the non-provisioning ecosystem services for scenario I is estimated on **36 975 Euro/ha** (1479€/ha/year x 25 year).

Table 5-17. Non-provisioning ecosystem service values for Scenario I

CLC type	ES values (€/ha/year)	Share (%)	ES values × share (€/ha/year)
Green urban areas (141)	1290	8,1	104
Sport and leisure facilities (142)	597	10,7	64
Natural grassland (321)	1789	29,1	521
Transitional woodland-shrub (324)	1397	29,1	407
Water bodies (511)	1675	22,9	384
Total values (€/ha/year)			**1479**

5.3.6 Scenario II Increasing the economic potential

The Scenario II has three CLC classes: Industrial or commercial units (121), Dump sites (132), Construction sites (133). The average total values of ES deliver by each hectare of terrain redevelopment according this scenarios is presented in Table 5-18. The ES values that will be deliver by each hectare in 25 years is estimated on **11 550 Euro**.

Table 5-18. Non-provisioning ecosystem service values for Scenario II

CLC type	ES values (€/ha/year)	Share (%)	ES values × share (€/ha/year)
Industrial or commercial units (121)	244	9,4	23
Dump sites (132)	211	17,5	37
Construction sites (133)	550	73,1	402
Total values (€/ha/year)			**462**

5.3.7 Scenario III increasing the natural, recreational potential and the economic potential

The Scenario III has eight CLC classes: Industrial or commercial units (121), Dump sites (132), Construction sites (133), Sport and leisure activities (142), Green urban areas

(141), Natural grassland (321), Transitional woodland-shrub (324), Water bodies (511). The average total values of ES deliver by each hectare of terrain redevelopment according this scenarios is presented in Table 5-18. The ES values that will be deliver by each hectare in 25 years is estimated on **32 975 Euro.**

Table 5-19. Non-provisioning ecosystem service values for Scenario III

CLC type	ES values (€/ha/year)	Share (%)	ES values × share (€/ha/year)
Industrial or commercial units (121)	244	6,5	16
Construction sites (133)	550	6,6	36
Green urban areas (141)	1290	10,7	138
Sport and leisure facilities (142)	597	9	54
Natural grasslands (321)	1789	24,9	445
Transitional woodland-shrub (324)	1397	27,7	387
Water bodies (512)	1675	14,5	243
Total values (€/ha/year)			**1319**

5.4 Valuation of provisioning ecosystem services

To determine the revenues/costs of the three considered scenarios in Janina Mine case study: (I) Increasing the natural and recreational potential, (II) Increasing the economic potential, and (III) Increasing the natural, recreational and economic potential, according to the costs and payments of market price, investment and maintenance costs previously analysed in Deliverable 5.1 data and Deliverable 5.2, the net present value (NPV) of the provisioning ecosystem services were calculated. The costs and incomes (if occurs) were analysed within the period of 25 years.

The discount rates to be used in calculation were presented in Deliverable 4.3, as follows:

- Non-intensive natural goods production, such as green area plantations, are proposed to be valued at a real/ constant rate of 1%, which is considered a moderate rate of growth.

- Industrial goods production, such as renewable energy production 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.

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

5.4.1 Scenario I: increasing the natural and recreational potential

The provisioning ecosystem service of Scenario I in Janina Mine case study occurs in the five CLC: 8.2% Green urban areas, 29.1% Natural grassland, 10.7% Sport and leisure facilities, 29.1% Transitional woodland-shrub, 22.9% Water bodies.

Based on the Deliverable 5.1 and 5.2 study, the total cost of Scenario I in Janina Mine case study are presented in Table 5-20.

Table 5-20. The total cost of Scenario I in Janina Mine waste heap

CLC classes	Area (ha)	Investment cost (€/ha)	Maintenance cost (€/ha)	Market price cost (€/ha)
Green urban areas (141)	5.52	118 250	1955	0
Transitional woodland-shrub (324)	19.96	106 400	2000	0
Natural grasslands (321)	19.97	52 500	200	0
Sport and leisure facilities (142)	7.34	539 980	17140	0
Water bodies (512)	15.72	6 470	100	0

According to the scenario I there is not expected financial benefits. The maintenance cost of transitional woodland-shrub was calculated for the first 3 years and the period of 25 years was assumed for the for the other lands, comparable to the Scenario II and III.

The maintenance costs of green urban areas and natural grassland were involved in mowing the meadow and lawn (twice a year). The cost of small infrastructure maintenance was estimated at 2.5% of the initial investment. The maintenance costs of transitional woodland-shrub area were associated with clearing the shrubs whereas of water bodies with harvesting wetland vegetation (ones a year on 25% area cover by vegetation).

Using the 1% real discount rate for non-intensive natural goods production, the net present value of the Scenario I were calculated, as follows:

$$\mathrm{NPV}_{(141)} = -118\,250 - \frac{1955}{1+0.01} - \frac{1955}{(1+0.01)^2} - \ldots - \frac{1955}{(1+0.01)^{25}} = -161305€/\mathrm{ha}$$

$$\mathrm{NPV}_{(324)} = -106\,400 - \frac{2000}{1+0.01} - \frac{2000}{(1+0.01)^2} - \frac{2000}{(1+0.01)^3} = -112\,282€/\mathrm{ha}$$

$$\mathrm{NPV}_{(321)} = -52\,500 - \frac{200}{1+0.01} - \frac{200}{(1+0.01)^2} - \cdots - \frac{200}{(1+0.01)^{25}} = -56\,905€/\mathrm{ha}$$

$$\mathrm{NPV}_{(142)} = -539\,980 - \frac{17140}{1+0.01} - \frac{17140}{(1+0.01)^2} - \cdots - \frac{17140}{(1+0.01)^{25}} = -917\,457€/\mathrm{ha}$$

$$\mathrm{NPV}_{(512)} = -6\,470 - \frac{100}{1+0.01} - \frac{100}{(1+0.01)^2} - \ldots - \frac{100}{(1+0.01)^{25}} = -8\,672€/\mathrm{ha}$$

Finally, the weighted average of these five land-use was calculated. The weights were set according to area proportional, which is present in Table 5-2. The net present value calculated of the scenario I is -162 614 €/ha. The results are presented in Table 5-21.

Table 5-21. Non-provisioning ecosystem service values for Scenario I – for next 25 years

Land use (CLC)	$\mathrm{NPV}_{(CLC)}$	Weight (%)	$\mathrm{NPV}_{(CLC)}$ × Weight
Green urban areas (141)	-161 305	8.2	-13 227
Transitional woodland-shrub (324)	-112 282	29.1	-32 674
Natural grasslands (321)	-56 905	29.1	-16 559
Sport and leisure facilities (142)	-917 457	10.7	-98 168
Water bodies (512)	-8 672	22.9	-1 986
Total NPV			**-162 614**

5.4.2 Scenario II: increasing the economic potential

The provisioning ecosystem service of Scenario II in Janina Mine case study occurs in the three CLC: 17.5% Dump sites, 73.1% Construction sites including solar energy panels and meadow vegetation (anti-erosion functions), 9.4% Industrial or commercial units including road construction and meadow vegetation.

Based on the Deliverable 5.1 and 5.2 study, the total cost of Scenario II in Janina Mine case study are presented in Table 5-22.

Table 5-22. The total cost of Scenario II in Janina Mine waste heap

CLC classes	Area (ha)	Investment cost (€/ha)	Maintenance cost (€/ha)	Market price cost (€/ha)
Construction sites (133)	50.1	694 340	6 889	57 885
Industrial or commercial units (121)	6.42	68 040	0	255 000
Dump sites (132)	11.99	0	0	71 309

According to the scenario II the financial benefits from energy production, sale of real estate and depositing mining waste are expected.

Scenario II is based on the lowest efficiency of installation on the plateau and slopes of the Janina Mine Heap and the calculated electricity yield from solar panels per hectare was estimated at 0.85 GWh/year.

As it was previously analysed, in Deliverable 5.1, the electrical energy market price in the 2022 year was 68 085 Euro/GWh. It was assumed that the operational lifetime of a solar panel before degradation (or reduced energy production) is 25 year.

The costs of solar panel maintenance and mowing the meadow (twice a year) were estimated at 1.0% of the investment cost of construction sites.

In scenario II there are no maintenance cost in the industrial or commercial units and dump sites. It was assumed that in the first year of investment, the sale of the properties and the land for mining waste disposal was purchased. The capacity of coal mining settlement for waste management is approximately 380 000 m^3 and the cost of storage of mine wastes on landfill is 2.25 €/m^3.

Using the 6% real discount rate for renewable energy production, and industrial facilities, the net present value of the Scenario II were calculated, as follows:

$$\mathrm{NPV}_{(133)} = -694\,340 - \frac{6\,889 + 57\,885}{1 + 0.06} - \frac{6\,889 + 57\,885}{(1 + 0.06)^2} - \ldots - \frac{6\,889 + 57\,885}{(1 + 0.06)^{25}} = -42\,440€/\mathrm{ha}$$

$$\mathrm{NPV}_{(121)} = -68\,040 + \frac{255\,000}{1 + 0.06} = 172\,526€/\mathrm{ha}$$

$$\mathrm{NPV}_{(132)} = \frac{71\,309}{1 + 0.01} = -70\,603€/\mathrm{ha}$$

Finally, the weighted average of these three land-use was calculated. The weights were set according to area proportional, which is present in in Table 5-2. The net present value calculated of the scenario II is -2 450 €/ha. The results are presented in Table 5-23.

Table 5-23. Non-provisioning ecosystem service values for Scenario II – for next 25 years

Land use (CLC)	$\mathrm{NPV}_{(CLC)}$	Weight (%)	$\mathrm{NPV}_{(CLC)}$ × Weight
Construction sites (133)	-42 440	73.1	-31 023
Industrial or commercial units (121)	172 526	9.4	16 217
Dump sites (132)	70 603	17.5	12 356
Total NPV			**-2 450**

5.4.3 Scenario III: increasing the natural, recreational potential and the economic potential

The provisioning ecosystem service of Scenario III in Janina Mine case study occurs in the CLC: 10.7% Green urban areas, 24.9% Natural grassland, 9.0% Sport and leisure facilities, 27.7% Transitional woodland-shrub, 14.5% Water bodies, 6.6% Construction sites including solar energy panels and meadow vegetation (anti-erosion functions), 6.5% Industrial or commercial units including road construction and meadow vegetation.

Based on the Deliverable 5.1 and 5.2 study, the total cost of Scenario III in Janina Mine case study are presented in Table 5-24.

Table 5-24. The total cost of Scenario III in Janina Mine waste heap

CLC classes	Area (ha)	Investment cost (€/ha)	Maintenance cost (€/ha)	Market price cost (€/ha)
Green urban areas (141)	7.36	118 250	1955	0
Transitional woodland-shrub (324)	18.97	106 400	2000	0
Natural grasslands (321)	17.09	52 500	200	0
Sport and leisure facilities (142)	6.14	539 980	16960	0
Water bodies (512)	9.96	6 470	100	0
Construction sites (133)	4.55	694 340	6889	68 100
Industrial or commercial units (121)	4.45	68 040	508	255 000

Scenario III assumes the use of southern slopes for energy production from photovoltaic panels. The solution is based on the highest efficiency of installation and the calculated electricity yield of solar panels per hectare was estimated at 1 GWh/year. It was assumed that the operational lifetime of a solar panel is 25 year and the electrical energy market price is 68 085 Euro/GWh.

The costs of solar panel maintenance and mowing the meadow (twice a year) were estimated at 1.0% of the investment cost of construction sites. Furthermore, there are no maintenance cost in the industrial or commercial units if the properties are sold in the first year of investment.

Using the 1% real discount rate for non-intensive natural goods production and 6% real discount rate for renewable energy production, and industrial facilities, the net present value of the Scenario III were calculated, as follows:

$$\mathrm{NPV}_{(141)} = -118\,250 - \frac{1955}{1+0.01} - \frac{1955}{(1+0.01)^2} - \ldots - \frac{1955}{(1+0.01)^{25}} = -161305€/\mathrm{ha}$$

$$\mathrm{NPV}_{(324)} = -106\,400 - \frac{2000}{1+0.01} - \frac{2000}{(1+0.01)^2} - \frac{2000}{(1+0.01)^3} = -112\,282€/\mathrm{ha}$$

$$\mathrm{NPV}_{(321)} = -52\,500 - \frac{200}{1+0.01} - \frac{200}{(1+0.01)^2} - \cdots - \frac{200}{(1+0.01)^{25}} = -56\,905€/\mathrm{ha}$$

$$\mathrm{NPV}_{(142)} = -539\,980 - \frac{17140}{1+0.01} - \frac{17140}{(1+0.01)^2} - \cdots - \frac{17140}{(1+0.01)^{25}} = -917\,457€/\mathrm{ha}$$

$$\mathrm{NPV}_{(512)} = -6\,470 - \frac{100}{1+0.01} - \frac{100}{(1+0.01)^2} - \ldots - \frac{100}{(1+0.01)^{25}} = -8\,672€/\mathrm{ha}$$

$$\mathrm{NPV}_{(133)} = -694\ 340 - \frac{6\ 889 + 69\ 100}{1 + 0.06} - \frac{6\ 889 + 69\ 100}{(1 + 0.06)^2} - \ldots - \frac{6\ 889 + 69\ 100}{(1 + 0.06)^{25}} = 88\ 142€/\mathrm{ha}$$

$$\mathrm{NPV}_{(121)} = -68\ 040 + \frac{255\ 000}{1 + 0.06} = 172\ 526€/\mathrm{ha}$$

Finally, the weighted average of these seven land-use was calculated. The weights were set according to area proportional, which is present in Table 5-2. The net present value calculated of the scenario III is -129 240 €/ha. The results are presented in Table 5-25.

Table 5-25. Non-provisioning ecosystem service values for Scenario III – for next 25 years

Land use (CLC)	$NPV_{(CLC)}$	Weight (%)	$NPV_{(CLC)}$ × Weight
Green urban areas (141)	-161 303	10.7	-17 259
Transitional woodland-shrub (324)	-112 282	27.7	-31 102
Natural grasslands (321)	-56 905	24.9	-14 169
Sport and leisure facilities (142)	-917 457	9	-82 571
Water bodies (512)	-8 672	14.5	-1 257
Construction sites (133)	88 142	6.7	5 906
Industrial or commercial units (121)	172 526	6.5	11 214
Total NPV			**-129 240**

5.5 The total value of the different scenarios

Table 5-26 presents the total values of the different scenarios per ha, obtained by adding the non-provisioning ecosystem service values to the NPV calculated for the provisioning ecosystem services in the period of 25 years.

Table 5-26. Total values of the different scenarios with NPV in next 25 years

Scenarios	Highest E,S. contribution	Ecosystem services values	NPVs	Total values
I natural potential	52 425 €	36 975 €	-162 614 €	**-125 639 €**
II economic potential	52 425 €	11 550 €	-2 450 €	**9 100 €**
III natural potential + economic potential	52 425 €	32 975 €	-129 240 €	**-96 265 €**

The results revealed that the lowest ecosystem services will be delivered in the scenario aimed on increasing economic potential of redevelopment area. This scenario has also negative value of NPV indicator. In means that long term income generated by industrial using of post-mining area will be non-profitable. The total value of this scenario is high (sum of NPV and ES value) but low effectiveness of solar farm (located in that scenario also on the west and east slopes exposition) causes that this solution is not attractive from business point of view (negative NPV). This factor causes that the Scenario II is not recommended for implementation.

The highest ecosystem services will be delivered by scenario I which aims on increasing the natural and recreational potential. This redevelopment action has also the lowest values of NPV indicator. It is caused by high investment and maintenance cost and no direct incomes.

Scenario III which is a combination of the two previous approaches, will deliver relatively high value of ecosystem services and has higher NPV indicator than scenario I. The higher positive cash flows of the investment is generating directly by incomes from sales real estate for industrial propose and incomes generating by photovoltaic farm that is located on slope with south exposition. To improve the effectiveness of that scenarios the land covers with high investment and maintenance cost (e.g Sport and leisure facilities) in the target land redevelopment project should be decrease. Taking into consideration the high values of ES services and lower that scenario I NPV and the stakeholders expectations this combined approaches is recommended for redevelopment of Janina Mine Waste Heap.

6 Sensitivity and uncertainty analysis

Finally, an exercise was carried out to estimate what the price of EU allowances would have to be for the Landscape scenario to be chosen in the Figaredo mine case study.

In Figaredo mine case study, the Landscape scenario is the one that prioritises biodiversity (Table 2-10). This is tantamount to allowing nature (biodiversity) to set the price of EU allowances in the Figaredo Mine environment.

For this purpose, and so that there can be no doubt about the preponderance between the different scenarios, it will be assumed that the value of the Landscape scenario should be at least 25% above the highest value of the other two scenarios, using the same percentage that Harmsworth and Jacoby (2015) proposed as the minimum improvement when considering the benefits from change initiatives related with the success of new products.

To achieve this goal, the total value of the Landscape scenario should be EUR 38,754/ha, as presented in Table 6-1.

Table 6-1. The updated total value of the different scenarios per ha

Scenarios	Highest Ecosystem Service Contribution	Interval Means	Ecosystem Services Values	NPVs	Total Values
Landscape	EUR 47,570	0.93	EUR 44,240	EUR –5486	EUR 38,754
Fibre	EUR 47,570	0.60	EUR 28,542	EUR 2386	EUR 30,928
Food	EUR 47,570	0.57	EUR 27,115	EUR 3323	EUR 30,438

By dividing the value of ecosystem services in the Landscape scenario by 0.93, it is possible to obtain the updated total value of the highest potential contribution of ecosystem services in the Figaredo Mine area: EUR 47,570/ha. To achieve this result, it is necessary to value 68.31 t C/ha (equivalent to an above-ground carbon storage rate of 10.0) at EUR 17,298. This would mean that the average sequestration value of 1 t C should be estimated at EUR 253.23, divided by the 3.67 t CO_2 contained in 1 t C, resulting in 1 tonne of carbon dioxide emission equivalent valued at about EUR 69 instead of EUR 25.

This value of EUR 69 is very similar to the price of EU carbon permits on 17 December 2021, EUR 73.5 (Figure 2-2), after the price escalation that coincides with phase 4 of the allocation of allowances under the EU Emissions Trading System (2015).

7 Conclusions and lessons learned

This Deliverable presents a new way of valuing ecosystem services based on the price of EU carbon dioxide emission allowances. Its main advantage is that it facilitates monetising non-provisioning ecosystem services, which is the Achilles heel of current frameworks.

The research approach is built on the notion that land rehabilitation and ecological restoration involve trade-offs between ecosystem services. A quantitative assessment (valuation) of these trade-offs is necessary to make sound decisions. However, using different valuation methods to estimate monetary values creates a non-comparability in the valuation process that is difficult to correct.

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

1. Local scaling was the method selected to transform non-provisioning ecosystem service values into a common metric, an index between one and ten in this particular case. 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. To estimate the ecosystem services provision (or weight) for each proposed scenario, selecting a reference ecosystem service was necessary. Biodiversity was chosen as the reference ecosystem service because of all the ecosystem services. 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 ecosystem services were then compared with biodiversity.

3. To achieve consistency, monetisation of all non-provisioning ecosystem services 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 ecosystem services valuation process developed. To achieve this goal, the introduction of new vectors or “missing ecosystem services” 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 ecosystem services and the costs incurred for non-provisioning ecosystem services 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.

8 Glossary

CAPM: Capital asset pricing model

CICES: Common International Classification of Ecosystem Services

CLC: Corine Land Cover

EIA: Environmental Impact Assessment

ES: Ecosystem services

EU: European Union

EURIBOR: Euro Interbank Offered Rate

GCD: Global credit data

HUNOSA: Hulleras del Norte, S.A.

TEEB: The Economics of Ecosystems and Biodiversity

NPV: Net present value

PKÚ: Palivový Kombinát Ústí

PV: Photovoltaic

References

Krzemień, A., Álvarez Fernández, J.J., Riesgo Fernández, P., Fidalgo Valverde, G., & Garcia-Cortes, S. (2022). Restoring Coal Mining-Affected Areas: The Missing Ecosystem Services. International Journal of Environmental Research and Public Health 19(21), 14200. https://doi.org/10.3390/ijerph192114200

Krzemień, A., Álvarez Fernández, J.J., Riesgo Fernández, P., Fidalgo Valverde, G., & Garcia-Cortes, S. (2023). Valuation of Ecosystem Services Based on EU Carbon Allowances—Optimal Recovery for a Coal Mining Area. International Journal of Environmental Research and Public Health 20(1), 381. https://doi.org/10.3390/ijerph20010381

Bagstad, K.J., Semmens, D.J., Waage, S., Winthrop, R. (2013). A comparative assessment of decision-support tools for ecosystem services quantification and valuation. Ecosyst. Serv. 5, 27–39. https://doi.org/10.1016/j.ecoser.2013.07.004

Cavard, X., Macdonald, S.E., Bergeron, Y., Chen, H.Y.H. (2011). Importance of mixed woods for biodiversity conservation: Evidence for understory plants, songbirds, soil fauna, and ectomycorrhizae in northern forests. Environmental Review 19, 142–161. https://doi.org/10.1139/A11-004

De Groot, R.S., Wilson, M.A., Boumans, R.M.J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. Ecological Economics 41, 393–408. https://doi.org/10.1016/S0921-8009(02)00089-7

EMBER, 2021. Daily EU ETS carbon market price (Euros). Retrieved from https://ember-climate.org/data/carbon-price-viewer/

EU Emissions Trading System (2015). EU ETS Handbook. Retrieved from https://ec.europa.eu/clima/sites/clima/files/docs/ets_handbook_en.pdf

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

Hämäläinen, R.P., Helenius, J. (1998). WIMPRE: Workbench for Interactive Preference Programming. Retrieved from https://sal.aalto.fi/en/resources/downloadables/winpre

Harmsworth, C., Jacoby, J. (2015). Managing Change Initiatives: Real and Simple; Trafford Publishing: Bloomington, IN, USA.

Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C. (2006). Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57, 209–228. https://doi.org/10.1016/j.ecolecon.2005.04.005

Jones, L., Vieno, M., Morton, D., Cryle, P., Holland, M., Carnell, E., Nemitz, E., Hall, J., Beck, R., Reis, S., Pritchard, N., Hayes, F., Mills, G., Koshy, A., Dickie, I. (2017). Developing Estimates for the Valuation of Air Pollution Removal in Ecosystem Accounts. Final report for the Office of National Statistics (ONS). Centre for Ecology and Hydrology (CEH), United Kingdom, July 2017.

Kang, N., Hou, L., Huang, J., Liu, H. (2022). Ecosystem services valuation in China: A meta-analysis. Science of the Total Environment 809, 151122. https://doi.org/10.1016/j.scitotenv.2021.151122

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

Martin, D.M., Mazzota, M. (2018). Non-monetary valuation using Multi-Criteria Decision Analysis: Sensitivity of additive aggregation methods to scaling and compensation assumptions. Ecosystem Services 29, 13-22. https://doi.org/10.1016/j.ecoser.2017.10.022

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

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

Saarikoski, H., Mustajoki, J., Barton, D.N., Geneletti, D., Langemeyer, J., Gomez-Baggethun, E., Marttunen, M., Antunes, P., Keune, H., Santos, R. (2016). Multi-Criteria Decision Analysis and Cost-Benefit Analysis: Comparing alternative frameworks for integrated valuation of ecosystem services. Ecosystem Services 22, 238-249. http://dx.doi.org/10.1016/j.ecoser.2016.10.014

Saaty, T.L. (1980). The Analytic Hierarchy Process. McGraw Hill: New York.

Salo, A.A., Hämäläinen, R.P. (1995). Preference programming through approximate ratio comparisons. European Journal of Operational Research 82, 458–475. https://doi.org/10.1016/0377-2217(93)E0224-L

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, 97–111. https://doi.org/10.1016/j.eiar.2010.02.002

Sijtsma, F.J., van der Heide, C.M., van Hinsberg, A. (2013). Beyond monetary measurement: How to evaluate projects and policies using the ecosystem services framework. Environmental Science & Policy 32, 14-25.

http://dx.doi.org/10.1016/j.envsci.2012.06.016

Spangenberg, J.H., Settele, J. (2016). Value pluralism and economic valuation – defendable if well done. Ecosystem Services 18, 100-109. http://dx.doi.org/10.1016/j.ecoser.2016.02.008

Strohbach, M.W., Haase, D. (2012). Above-ground carbon storage by urban trees in Leipzig, Germany: Analysis of patterns in a European city. Landscape and Urban Planning 104, 95–104. https://doi.org/10.1016/j.landurbplan.2011.10.001

Tanouchi, H., Olsson, J., Lindström, G., Kawamura, A., Amaguchi, H. (2019). Improving Urban Runoff in Multi-Basin Hydrological Simulation by the HYPE Model Using EEA Urban Atlas: A Case Study in the Sege River Basin, Sweden. Hydrology 6, 28. https://doi.org/10.3390/hydrology6010028

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

Vigerstol, K.L., Aukema, J.E. (2011). A comparison of tools for modeling freshwater ecosystem services. Journal of Environmental Management 92(10), 2403-2409. https://doi.org/10.1016/j.jenvman.2011.06.040

Wam, H.K., Bunnefeld, N., Clarke, N. Hofstad, O. (2016). Conflicting interests of ecosystem services: Multi-criteria modelling and indirect evaluation of trade-offs between monetary and non-monetary measures. Ecosystem Services 22, 280-288. http://dx.doi.org/10.1016/j.ecoser.2016.10.003

Xie, G., Zhang, C., Zhen, L., Zhang, L. (2017). Dynamic changes in the value of China's ecosystem services. Ecosystem Services 26, 146-154. http://dx.doi.org/10.1016/j.ecoser.2017.06.010

Zhang, X., Lu, X. (2010). Multiple criteria evaluation of ecosystem services for the Ruoergai Plateau Marshes in southwest China. Ecological Economics 69, 1463-1470. https://doi.org/10.1016/j.ecolecon.2009.05.017