RESTORATION OF ECOSYSTEM SERVICES IN POST-MINING AREAS: A RECOVERY PROJECT APPROACH

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ABSTRACT

Ecological restoration of post-mining areas aims to accelerate the recovery of degraded and transformed ecosystems to a good ecosystem status. Ecosystems impacted by mining are challenging to restore, further diminishing their capacity to generate benefits for society. Therefore, they provide an excellent framework for multidimensional analysing of the links between people and the environment. Links between ecosystems and the economy are often described using "ecosystem services". Ecosystem services represent the flow of value to human societies due to the state and quantity of natural capital. The ecosystem services concept involves an essential dimension in land rehabilitation and ecological restoration. A valuation of the ecosystem services provided by different land rehabilitation and ecological restoration scenarios must be undertaken to assess their contribution to society and evaluate the consequences of alternative actions. The research is premised on land rehabilitation and ecological restoration management decisions involving trade-offs among ecosystem services. A quantitative-based assessment of these trade-offs is the necessary ingredient for sound decision-making. This paper presents the research undertaken within the RECOVERY Project (Recovery of degraded and transformed ecosystems in coal mining-affected areas). It aims to guide policy and decision-makers in identifying optimal alternatives while solving environmental problems in post-mining areas through adequate and implementable strategies.

KEYWORDS

Ecological restoration, ecosystem services, coal, post-mining areas, RECOVERY Project

1. INTRODUCTION

The study of ecosystems provides a valuable framework for analysing and acting on the linkages between people and the environment. Ecosystems impacted by mining in general and coal mining, particularly, are challenging to restore, being possible to a particular structural and functional level, but compared to their original or natural state.

Ultimately, a loss of capacity to provide benefits to society such as supply, regulation and purification of water, fresh air, floodwater retention, habitat function, biodiversity etc., may happen.

Links between ecosystems and the economy are often described using the innovative concept of "ecosystem services", or flows of value to human societies due to the state and quantity of natural capital (Larondelle & Haase, 2012; Baró et al., 2017).

Ecosystem services can be defined as the benefits people obtain from ecosystems and are usually classified into three groups: provisioning services, regulating and maintenance services, and cultural services, according to the Common international classification of ecosystem services (CICES) (European Environment Agency, 2018).

The RECOVERY project's approach is premised on the notion that management decisions about land rehabilitation and ecological restoration of coal mining-affected areas involve trade-offs among ecosystem services. A quantitative assessment of these trade-offs is the necessary ingredient for sound decision-making (Figure 1). By quantifying the costs of the alternative land rehabilitation and ecological restoration actions, as well as the economic value of the ecosystem services provision, it will be possible to determine which options will deliver the most significant benefits in relation to their investment and maintenance costs.

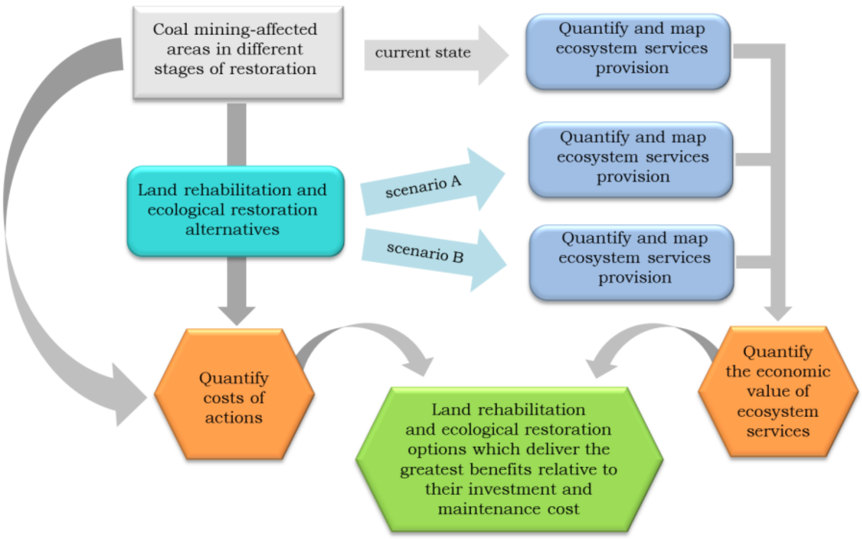


Figure 1 – RECOVERY Project's methodology

The ecosystem services concept involves an essential dimension to current best practices in the land rehabilitation and ecological restoration of coal mining-affected areas. Ecosystem services provide relevant indicators to assess the level of restoration, especially from a holistic and societal perspective, considering the ability of ecosystems to deliver multiple ecosystem services, improve socio-economic outcomes, and catalyse the development of new jobs. Thus, a valuation of the ecosystem services provided by different land rehabilitation and ecological restoration scenarios must be undertaken. The objective is to assess their contribution to human well-being, understand individual decision-makers incentives in managing ecosystems in different ways, and evaluate the consequences of alternative courses of action.

The importance of using scenarios in ecosystem services assessments is beginning to be realised, as early estimates presented a static picture in a changing world. Generating different con- and diverging scenarios is significant for monetary valuation since scenarios enable an analysis of service delivery changes required for quantifying trade-offs among them.

Six case studies were used for mapping, quantifying and valuating the ecosystem services provision to appraise coal mining-affected areas, their ecosystems and ecosystem services. Two underground coal mines (Poland and Spain), an underground coal mine dumps complex with a thermally active mine dump (Czech Republic) and three opencast lignite mines (two in the Czech Republic and one in Germany), all of them in different stages of restoration.

First, Janina Mine (Silesia, Poland), an active underground coal mine property of Tauron Wydobycie S.A., operated from the beginning of the twentieth century. Restoration has already started in the Libiąż waste heap, being one of the most prominent objects of this kind in the eastern part of the Silesian Coal Basin; Second, Figaredo Mine (Asturias, Spain), a closed underground coal mine property of Hulleras del Norte S.A. that is undertaking its partial restoration nowadays; Third, The Terezie – Ema mine dumps complex (Silesia, Czech Republic): The complex includes dumps of Ema, Terezie and Bezruč coal mines in Ostrava city, which spoil deposition was started in the middle of 19th century and ended in the 1980s (Terezie, Bezruč) or 1976 (Ema); Fourth and fifth, Chabařovice and Most-Ležáky mines, two restoration projects that Palivový kombinát Ústí developed in opencast lignite mines; and sixth, Mibrag Mines (South of Leipzig, Germany), one of the most prominent former open cut lignite mining areas in Europe that were subject to rehabilitation and revitalisation efforts by both the mining company and the regional planning authority.

A feasible ex-ante impact assessment planning instrument was also developed using the Mibrag Mines case study: an integrated and functional assessment of landscape and land-use changes caused by coal mining, as there is no state-of-the-art or blueprint instrument/indicator (a way to support best practices in assessments by delivering control of pre-operative planning and guiding the creation of items) set for both mining impact assessment and post-mining landscape (e)valuation.

Finally, the RECOVERY Project also developed soil substitutes for evaluating land rehabilitation of coal mine-affected areas (waste heaps), outlining a novel approach to the use of wastes generated in coal mines and coal-fired power plants. Bauerek et al. (2022) described this research in the open access paper entitled “Development of Soil Substitutes for the Sustainable Land Reclamation of Coal Mine-Affected Areas”.

The following coal combustion by-products were included (Figure 2): fly ashes from coal and biomass combustion, aggregate from mine waste processing, sealing material from coal processing and decarbonisation lime. Additionally, sewage sludge and spent mushroom compost were incorporated into the elaboration of soil substitutes as substrates enriching with organic matter and valuable nutrients. The selected wastes are generated in coal mines, coal-fired power plants, agriculture industries, and residues from wastewater plants.

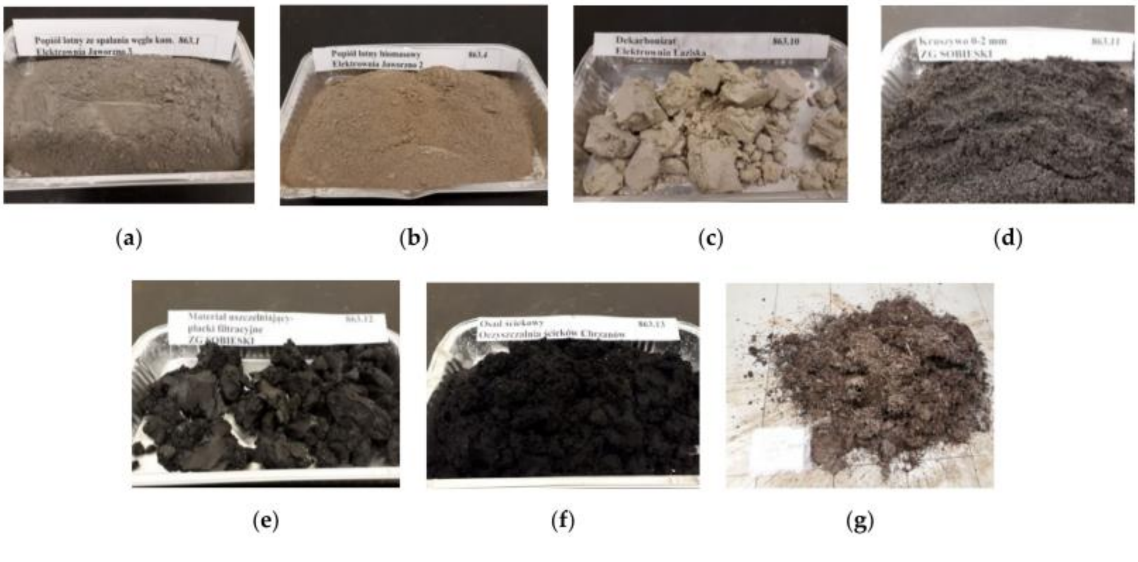


Figure 2 – Wastes used for soil substitutes: (a) fly ash from coal combustion; (b) fly ash from biomass combustion; (c) decarbonisation lime; (d) aggregate from mine waste processing; (e) sealing material from coal processing; (f) sewage sludge; and (g) spent mushroom compost. Source: Bauerek et al. (2022)

2. ASSESSMENT OF ECOSYSTEM SERVICES

In the first place, and after a detailed description of each case study, the adequate boundaries for the study areas were defined based on the existing spatial connectivity and functional cohesion. Identifying the proper limits of a case-study area can be challenging, and selecting a considerable size within the boundaries will end in much work related to mapping. Choosing a small site may risk not selecting representative land covers and potential ecosystem services. Using administrative boundaries, socio-economic areas, or spatial ranges on environmental pressure can help set the appropriate boundaries and establish an adequate ecosystem services context.

In the second place, a revision of the available online geospatial data was developed. Land cover and land use maps were obtained mainly from CORINE Land Cover (European Environment Agency, 2000). The land monitoring system, imagery, and reference data were obtained from the COPERNICUS Program (European Union, 2014).

The land monitoring system provided information about the level of sealed soil (imperviousness), tree cover density and forest type, grasslands, wetness and water, and small woody features. Figure 3 presents the boundaries of the Figaredo case study and the imperviousness density in 2015, capturing the percentage and change of soil sealing. Built-up areas are characterised by substituting the original (semi-) natural land cover or water surface with an artificial, often impervious cover.

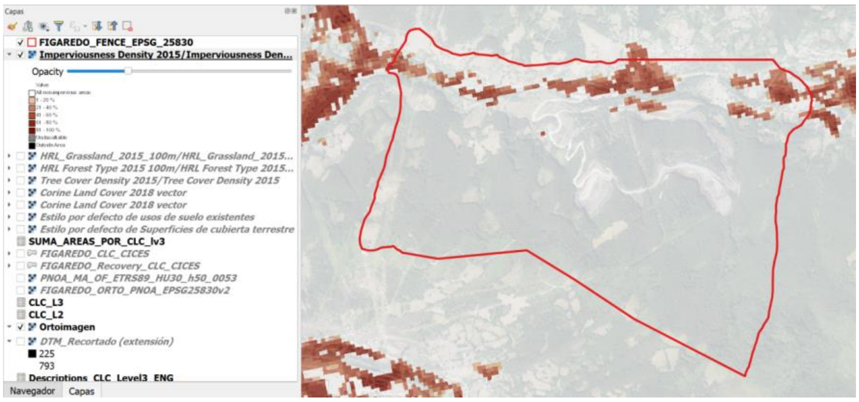


Figure 3 – Imperviousness density of the Figaredo case study in 2015

In the third place, CORINE Land Cover (European Environment Agency, 2000) classes were used to delineate, categorise and map the different ecosystem types of land cover in the study areas. It ensures the comparability of the land use classes, although doing detailed field mapping at a higher resolution. Finally, the information was introduced in the QGIS 3.8 Zanzibar (previously known as Quantum GIS). The result for each case study can be accessed in the WebGIS area of the RECOVERY's webpage (www.recoveryproject.eu).

Finally, and after mapping the different ecosystem types of land cover in the study areas, the hierarchical structure of the Common International Classification of Ecosystem Services (CICES) V5.1 (Haines-Young and Potschin, 2018) was used. CICES allows for assessing the ecosystem services provision to achieve standardisation and to avoid any overlapping or redundancy within the different categories.

The selection of ecosystem services and suitable indicators for the different case studies were developed through casual chains for each indicator. Critical properties of ecosystem services were addressed, as well as related issues such as pressures, state impacts and responses, informing about cause-effect relationships and reflecting the relevance for mining and post-mining landscapes.

In the case of Figaredo Mine, nine ecosystem services were selected. Food and fibre production were considered for provisioning services with livestock production and forest productivity indicators. As for regulating services, climate regulation has been considered in two ways: temperature and humidity, with the indicators of land surface thermal emissions and evapotranspiration. Also, carbon sequestration and the indicator of above-ground carbon storage are widely used in all ecosystem service assessments. Air quality regulation was considered under air purification with the indicator of dry deposition of pollutants, and flood regulation and storm-water retention were considered in water flow regulation with the indicator of runoff. Erosion control was another ecosystem service considered and an indicator of soil loss. 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, using the impact of shrinkage-related cover patterns as an indicator.

3. GENERATION OF SCENARIOS

The next step of the RECOVERY Project was assessing future case study scenarios. To adequately select the strategies that should be considered, stakeholder consultations were used as a reference, together with the different types of land rehabilitation and ecosystem restoration alternative actions that were proposed within the project: (1) Recolonisation of the site by local vegetation; (2) Commercial forestry plantations; (3) Secondary forests using local plant species; (4) Development for agriculture: arable land and pastures; (5) Leisure and recreational purposes: museums and recreation areas; (6) Areas for physical recreation; (7) Space for wildlife and nature conservation; (8) Development of artificial water bodies, e.g., lakes, reservoirs and streams; (9) Renewable energy generation: photovoltaic and wind power; (10) Industrial areas and business facilities; and (11) Residential areas.

The Smic Prob-Expert technique (Godet, 2000) was used to facilitate the scenario selection. The Smic Prob-Expert tool (http://en.laprospective.fr/) is a cross-impact probability method that aims to define simple and conditional probabilities of hypotheses and events and the probabilities of combinations of the latter, taking into account interactions between events or theories. This method aims to tease out the most plausible scenarios for decision-makers and examine combinations of hypotheses one would have initially excluded.

Figure 4 presents the histogram of influence sensitivity for all the experts participating in the Figaredo Mine's scenarios assessment. The elasticities were calculated via simulations, running the model of relations between probabilities a few times. Six alternatives were considered the most feasible to analyse: (1) Fiber: pine tree plantation for producing wood as a raw material; (2) Food: cows reared for nutritional purposes; (3) Landscape: the reconstruction of a broad-leaved forest similar to the ones already present in the region; (4) Solar: photovoltaic energy; (5) No restore: recolonisation by local vegetation; and (6) physical recreation area. Sensitivity analysis suggests which hypotheses to keep and which to discard to push the system in the direction wanted. The three alternatives with higher influence sensitivity were Fiber, Food and Landscape. Thus, the rest of the analysis will focus on these scenarios.

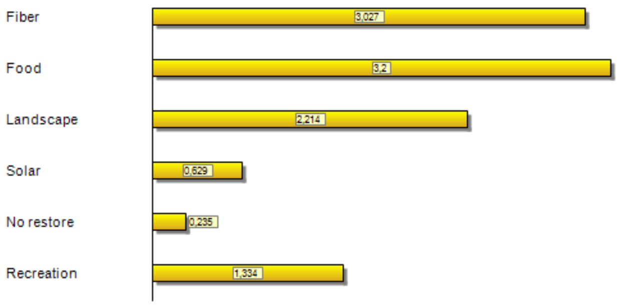


Figure 4 – Histogram of influence sensitivity for the considered scenarios

It must be highlighted that the Smic Prob-Expert method transforms defined hypotheses probabilities by experts into coherent data, respecting the basic probabilities' formulae. Net data computed by the software will replace the raw data provided by experts.

Next, according to Larondelle & Haase (2012), a narrative for each selected scenario was developed, including an overall vision for the new post-mining region and some clear targets. It is presented in Table 1.

Table 1 – Narrative for the different scenarios of Figaredo Mine

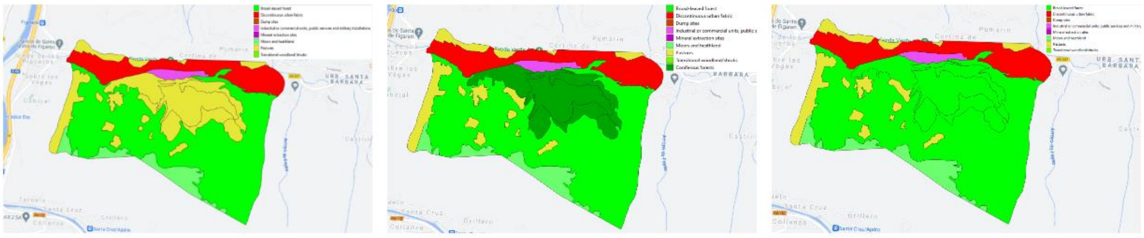
Foreseen projects	Current state or foreseen projects
Scenario I (Fiber)	Scenario I focuses on feeding cows to produce meat, although horses are also bred for nutritional purposes; it is not so common yet. It is a typical use even in pastures with slopes similar to Figaredo's waste heaps.
Scenario II (Food)	Scenario II is characterised by a focus on pine tree plantations for producing wood as raw material. The regional government in Asturias forbids new eucalyptus plantations in many areas (Natura 2000, near the cost, and others). Figaredo mine is close to a Natura 2000 area, so fibre production should focus only on pine tree plantations.
Scenario III (Landscape)	Scenario III is characterised by reconstructing a broad-leaved forest similar to the ones already present in the region: mainly Fraxinus excelsior, Betula alba, Acer pseudoplatanus and Ilex aquifolium. Nevertheless, this can be considered a mixed scenario of a Broad-leaved forest and a physical recreation area. People can walk and undertake nature observation around the area without developing specific infrastructure for physical recreation.

After, narratives were translated into change rules for CORINE Land Cover (European Environment Agency, 2000) land use classes with the if-then-else mode, according to Larondelle & Haase (2012). These change rules, procedures, and conditions for the Figaredo Mine area are shown in Table 2.

Table 2 – Change rules for CORINE Land Cover (CLC) land use classes

Land use	Procedure & conditions
Dumpsites	Set to zero.
Mineral extraction sites	Set to zero.
Transitional woodland/shrubs	Set to zero in all the areas covering the waste heaps. Waste heaps will be re-exploited to valorise the remaining coal. After, they will undergo restoration.
Broad-leaved forest	Broad-leaved forests will be removed from areas overlying former waste heaps to valorise the remaining coal. They will be restored as broad-leaved forests only in the Landscape scenario.

Finally, Figure 5 shows the three scenarios considered after restoration, presented in a GIS web interface.



(a) **(b)** **(c)**

Figure 5 – The three scenarios after restoration: (a) Food; (b) Fibre; (c) Landscape

4. COST-BENEFIT ASSESSMENT

A new valuation methodology for non-provisioning ecosystem services was developed within the RECOVERY Project, as evidence was found regarding the non-comparability caused by the existing approaches. Using different valuation methods for non-provisioning ecosystem services creates a non-comparability in the valuation process that usual used tools such as Multi-criteria decision analysis (Saarikoski et al., 2016) can hardly correct.

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

In the second place, to monetise non-provisioning ecosystem services, the implementation of techniques based on the propagation of imprecise preference statements in hierarchical weighting was used. Once a reference attribute has been selected, the remaining attributes are compared to the reference, considering the specific environment. Then, values to the different scenarios/alternatives for each attribute were given, finally obtaining value intervals for the three scenarios considered.

The monetisation of all non-provisioning ecosystem services was built on the monetary valuation of the attribute with the most direct and market-related valuation possible to achieve consistency: carbon sequestration. It was evaluated according to the European Union (EU) Emissions Trading System, using the average value of EU allowances during 2019 and 2020. Figure 6 presents the prices of EU carbon permits adapted from EMBER (2021) and www.tradingeconomics.com.

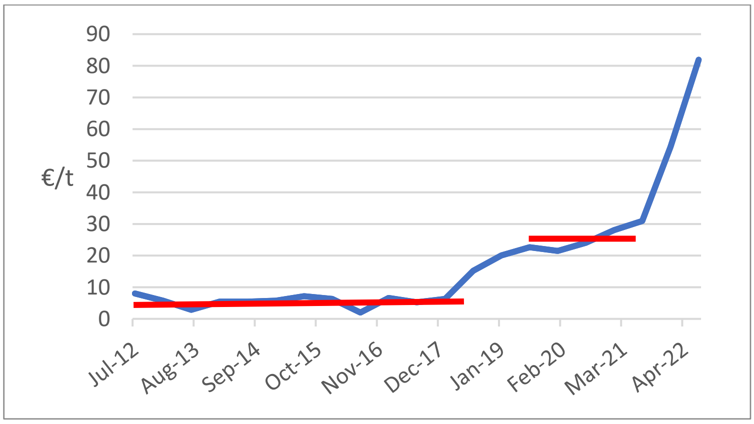


Figure 6 – Prices of EU Carbon Permits (€/t)

Also, the appropriate discount rates to evaluate provisioning ecosystem services were proposed. For this purpose, three different categories of discount rates and goods were distinguished: (1) 1% for non-intensive natural goods production, such as familiar animal exploitation, familiar tree plantations or familiar agriculture; (2) 3-3.5% for intensive natural goods production, such as intensive animal farms, intensive forest exploitation or intensive agriculture; and (3) 6-7% for industrial goods production such as renewable energy production or industrial facilities.

All the cost-benefit assessment developed for the Figaredo Mine is described in the open access paper by Krzemień et al. (2022) entitled “Valuation of ecosystem services based on EU carbon allowances - optimal recovery for a coal mining area”.

5. RESULTS & CONCLUSIONS

Apart from the new framework addressing the valuation of ecosystem services, two specific results from RECOVERY Project should be highlighted: the polygon test and the business plan for developing artificial substitutes for soils addressing “difficult terrains” in coal mining waste heaps.

5.1 Polygon test

An experimental polygon at Libiąż waste heap in Silesia, Poland, belonging to Janina Mine, property of Tauron Wydobycie S.A., was developed for studying plant vegetation (meadow vegetation, shrubs and wetland habitat plants) on the artificial soil mixes developed within the project. Libiąż waste heap was chosen as an example of challenging conditions for reclamation due to the intensive slope erosion and **the high acidic character of wastes (Figure 7).**

Figure 7 – Libiąż waste heap and the erosion slopes

Figure 8 presents the polygon test construction with the materials used.

Figure 8 – Polygon test construction

Seeds were sowed and planted in the fall of 2020. Figure 9 presents the planting of vegetation on the artificial soil.

Figure 9 – Polygon test construction

Currently, the research is studying the phenomenon of falling out of some species planted. It is possible to see the first effects of the work (Figure 10). Some plant species tolerate artificial soil conditions very well, whereas others have shown much lower resistance to artificial conditions.

Figure 10 – First effects of the work

5.2 Business plan

A specific business plan was built addressing the development of artificial substitutes for coal mining waste heaps, considering that the European Commission covers 60% of the project's overall budget through the Research Fund for Coal and Steel (RFCS). Indirect costs represent 35% of personnel costs, and they will be dedicated to covering the travels of the personnel concerning the project development and general expenses. Table 3 presents the project's operating expense (OPEX), which was foreseen to last four years.

Table 3 – Operating expenses (OPEX) in Euros

Operating expense (OPEX)	2019	2020	2021	2022	2023	TOTAL
Staff costs	5,813	11,625	11,625	11,625	5,813	46,500
Indirect costs (travel and general expenses)	2,034	4,069	4,069	4,069	2,034	16,275
Raw materials, transport, preparation and planting	-	41,800	-	-	-	41,800
Maintenance and care of plants	-	1,500	500	500	500	3,000
Dedicated workshop	-	-	-	-	1,000	1,000

Total OPEX	7,847	58,994	16,194	16,194	9,347	108,575

Raw materials operating expense includes geotextile, fabric from wastewater treatment plants, dolomite aggregate (31-63 mm), wildflower and grass seeds (meadow plants), perennial seeds (xerophyte and wetland plants), shrub seeds (bush communities) and overburden clays.

Table 4 shows the project's capital expense (CAPEX).

Table 4 – Capital expenses (CAPEX) in Euros

Capital expense (CAPEX)	%	2019	2020	2021	2022	2023	TOTAL
Own expense	40%	(18,211)	58,994	(9,864)	16,194	(3,682)	43,430
European Commission (RFCS) financing	60%	26,058	-	26,058	-	13,029	65,145
Total CAPEX	100%	7,847	58,994	16,194	16,194	9,347	108,575

The following benefits could be expected during at least the five years after the completion of the project, being conservative: (1) Benefits derived from the selling of substrates, 40,000 euros/year; (2) Benefits derived from avoiding losses derived from failures of restoration projects, 10,000 euros/year; (3) Benefits derived from avoiding to pay for the contamination with acid waters, 4,500 euros/year. The consortium's cost of elaborating the project has been estimated at 15,000 euros, considered a saving/income during 2024.

According to the previous considerations, the cash flow calculations are presented in Table 5 (years 2019-2023) and Table 6 (2024-2028).

Table 5 – Cash flows (2019-2023) in Euros

Concept	2019	2020	2021	2022	2023
Expenses	(7,847)	(58,994)	(16,194)	(16,194)	(9,347)
Incomes (RFCS financing)	26,058	-	26,058	-	13,029
Cash flows	18,211	(58,994)	9,864	(16,194)	3,682

Table 6 – Cash flows (2024-2028) in Euros

Concept	2024	2025	2026	2027	2028
The net benefit of selling substrates	40,000	40,000	40,000	40,000	40,000
Net benefit avoiding losses	10,000	10,000	10,000	10,000	10,000
Savings acid contamination	4,500	4,500	4,500	4,500	4,500
Project elaboration benefit	15,000	-	-	-	-
Cash flows	69,500	54,500	54,500	54,500	54,500

Assuming a weighted average cost of capital (WACC) of 10% during the duration of the project, the following values are obtained: Net present value (NPV) of 113,503 €; Internal rate of return (IRR) of 50%; and Payback period (PP) of 5 years, or the first year after the end of the research period. Thus, the development of artificial substitutes for coal mining waste heaps has a high safety margin. Moreover, the year after the end of the investment, benefits will appear without considering and evaluating the intangible benefits the company will achieve.

5.3 Conclusions

The RECOVERY project has demonstrated that even though coal mining is severely declining in the European Union, it can still contribute applicable knowledge and technology. The use of former coal mining areas has the potential of conferring a second chance for an economic growth decoupled from resource use in these regions so that no person and no place is left behind.

ACKNOWLEDGEMENTS

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