Green JOBS
RFCS RESEARCH PROJECT

Leveraging the competitive advantages of end-of-life underground coal mines to maximise the creation of green and quality jobs

Grant Agreement 101057789

Deliverable 1.2

Comprehensive overview of the project

European Commission

Research Fund for Coal & Steel

Author

Dr. Pedro Riesgo Fernández, University of Oviedo, Spain

Deliverable 1.2	
Due date of Deliverable	31.12.2022
Start - End Date of Project	01.07.2022 – 31.12.2025
Duration	3.5 years
Deliverable Lead Partner	UNIOVI
Dissemination level	Public
Work Package	WP 1
Digital File Name	D1.2 Comprehensive overview of the project
Keywords	Project overview, state of the art, approach, outcome

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Executive Summary

GreenJOBS focuses on repurposing end-of-life underground coal mines by deploying emerging renewable energy and circular economy technologies to promote sustainable local economic growth and maximise the number of green, quality jobs.

To achieve this goal, GreenJOBS will leverage five competitive advantages of underground coal mines: (1) Mine water for geothermal and green hydrogen; (2) Connections to the grid that can be adapted to inject the electricity produced; (3) Large waste heap areas for installing photovoltaic/wind; (4) Deep infrastructure suitable for unconventional pumped hydro storage using dense fluids; and (5) Fine coal waste for recycling into dense fluids, soil substitutes for restoration and rare earths.

Figure 1 presents a graphical abstract of the GreenJOBS proposal for the case of a Virtual Power Plant where the energy produced is sold to the grid or to power electro-intensive industries or companies located close to the mines with constant energy consumption.

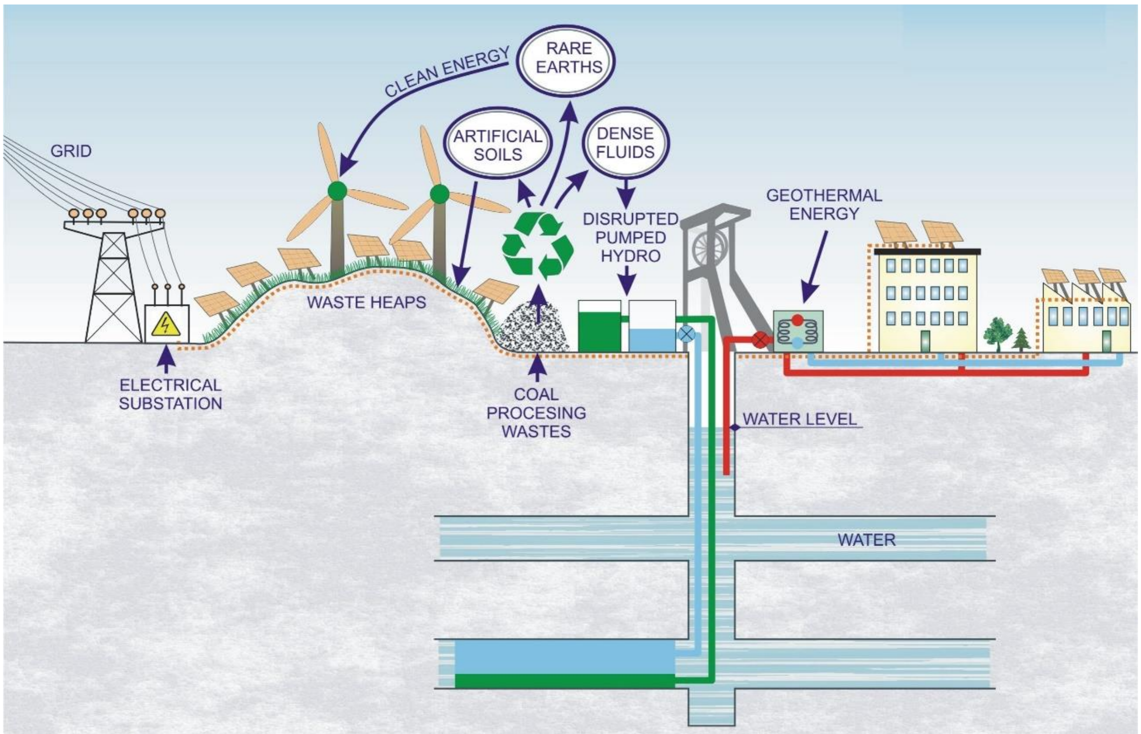

Figure 1. Graphical abstract of the GreenJOBS proposal.

1 Problem

The European Green Deal Communication, presented by the European Commission in December 2019, presents some targets to be considered within the coal-related RFCS proposals according to the problems tackled by Coal Regions in Transition:

- A power sector must be developed based mainly on renewable sources, complemented by the rapid phasing out of coal.
- Focus on the regions and sectors most affected by the transition because they depend on fossil fuels or carbon-intensive processes.
- Protect people and workers most vulnerable to the transition, providing access to re-skilling programmes, jobs in new economic sectors.

GreenJOBS will specifically address solutions considering the repurposing end-of-life coal mines, one of the sectors most affected by the transition. It will give solutions to the other two problems by deploying emerging renewable energy and circular economy technologies to help develop a renewables-based energy sector, promote sustainable local economic growth and maximise the number of green and quality jobs for former coal mining workers while addressing their training and re-skilling. It will also try to solve the decarbonisation of energy-intensive industries problem by supplying them with green hydrogen.

2 Objectives

The following SMART objectives have been defined for GreenJOBS, against which the project's performance can be measured. They have been sequenced throughout the development of the project and integrated into the broader strategic context of the European Green Deal objectives to be considered in the RFCS proposals:

1. **Stakeholder involvement:** From July 2022 to June 2025, GreenJOBS will establish close contacts with all groups identified as critical stakeholders of the project (state, regional and local authorities from coal regions in transition; coal and coal-based industry; energy-intensive industry; relevant civil society and citizens' associations; trade unions/social partners; academic institutions; and representatives of the EC) to maximise active involvement in the project, informing them regularly through newsletters and presentations on its progress, and through a consultation process. This will be done in conjunction with the initiatives of the Just Transition Platform.
2. **Circular economy technologies popularisation:** From July 2023 to June 2024, GreenJOBS will disseminate through meetings, online chats and presentations, the fine coal waste valorisation technologies developed/analysed within the project to get as many coal mining companies as possible willing to use these technologies. This will be done in conjunction with the initiatives of the Just Transition Platform and the United Nations Economic Commission for Europe on Post-Mining and Sustainable Energy Perspectives.
3. **Emerging renewable energies market penetration:** From July 2024 to June 2025, Green JOBS will disseminate through meetings, online talks and presentations, the specific deployments of emerging renewable energies in the case studies to get as many coal mining companies as possible willing to follow a similar path of a renewable energy-powered future. This will be done in conjunction with the initiatives of the Just Transition Platform and the United Nations Economic Commission for Europe on Post-Mining and Sustainable Energy Perspectives.
4. **Business plans exploitation:** From July to December 2025, GreenJOBS will provide free advice on implementing the innovative business plans to all interested European coal mining companies to maximise and facilitate the exploitation of the project results by end-of-life underground coal mines. This will be done in collaboration with the Just Transition Platform and with the support of the international workshop.
5. **Training and re-skilling programmes implementation:** From July to December 2025, GreenJOBS will provide free assistance in planning and updating training and re-skilling programmes to all interested regional authorities in the coal regions in transition to maximise and facilitate the implementation of the project results. This will be done in collaboration with the Just Transition Platform and with the support of the international workshop.

3 Approach

To maximise the outcomes, GreenJOBS approach will leverage five main competitive advantages that coal mines possess compared to different environments:

1. **Mine water:** Geothermal energy is a renewable source that harnesses the heat from inside the earth, in our case, through the water that floods the mines. From a certain depth, the temperature of the subsoil is constant regardless of the season. Thus, a constant and accessible energy source is available all year round, just a few metres away from us. The water temperature alone is not useful for heating and cooling. However, it can be processed in a geothermal heat pump, which transforms the energy from low to high temperature, becoming suitable for these purposes. On the other hand, mine water represents an essential raw material for producing green hydrogen by electrolysis. This process needs up to 18 tonnes of water - not counting losses - to produce one tonne of hydrogen. Water treatment systems typically need about two tonnes of impure water to produce one tonne of purified water. In other words, one tonne of hydrogen needs not nine, as usually stated, but 18 tonnes of water. If losses are considered, the ratio is close to 20 tonnes of water for every tonne of green hydrogen. Finally, mine water will also be an essential input during the flotation process to obtain the rare earth concentrate produced in the mines from fine coal waste. The concentrate will be sold to hydrometallurgical plants, where a mixed rare earth precipitate will be obtained.
2. **Connections to the grid:** The main barriers to develop new renewable energy production facilities are grid access capacity and connection to transmission and distribution networks. To overcome the first barrier, GreenJOBS will disseminate the importance of governments regulating the procedures for granting all or part of the grid access capacity of grid nodes affected by coal power plant closures to new renewable energy generation facilities that promote the economic and social recovery of Just Transition areas, with a particular focus on employment, business development and fight against depopulation (Just Transition Nodes). As for the second barrier, mines are usually connected to the grid via overhead lines. They are typically connected to medium voltage lines through substations. The lines enter directly into the substations equipped with metering equipment, transformers, and other protective equipment. In this way, they can be easily adapted to inject electricity into the grid. Moreover, these connections facilitate the intallation of electrolysers for producing green hydrogen.
3. **Large waste heap areas:** Extracting coal generates vast amounts of residues during excavation, including overburden, interburden or waste-rock. These large amounts of extractive waste from excavation generated at extraction sites are managed on heaps. Extractive waste heaps are usually reshaped to the angle of natural repose, depending on the extractive waste characteristics, resulting in a geomorphic shape that, either in itself or after placing a cover, provides long-

term stability and adequate stability protection against wind and water erosion. Given that the areas occupied by waste heaps after many years of exploitation are usually huge, it is possible to consider different rehabilitation and subsequent user actions. GreenJOBS proposes to use these areas for renewable energy generation: photovoltaic/wind. This will require the application of rehabilitation techniques that will facilitate the geotechnical stability of the renewable energy generation structures in addition to restoring the land.

4. **Deep infrastructure:** Unconventional pumped hydro storage has a smaller footprint and higher energy density than conventional pumped hydro energy systems. The system uses a high-density fluid and allows for different configurations where upper and lower reservoirs may be at the same elevation, for example, on the surface above an underground mine. By employing high-density fluid, a more compact pumped hydro energy storage system can be achieved. For a given reservoir or tank volume, the energy storage capacity is proportional to the fluid density. For example, when the high-density fluid has a density of 3x, the system's energy storage capacity is 3 times that when water is used. It is due to the mass flow rate is about 3 times more than that of water. Alternatively, the system can produce the same amount of energy output using less volume of fluid and/or less height differential between the upper and lower reservoirs. Thus, coal mines' deep infrastructure is very suitable for designing a system to satisfy output requirements: large height differentials and very deep galleries that eliminate the need for a bottom pressure vessel, with pressure relatively stable and close to that due to overburden.
5. **Fine coal waste:** Significant amounts of fine coal waste are stored in landfills, a residue from coal processing. GreenJOBS will valorise this residue through:

   a) *Recycling into dense fluids:* Unconventional pumped hydro energy storage system employs a high-density fluid, such as a slurry, which has a density greater than water. GreenJOBS will test the feasibility to use fine coal waste from the three case studies to develop a new low viscosity high-density fluid in which the liquid is fine coal waste suspended in water.
   b) *Recycling into soil substitutes for restoration:* Large waste heap areas have to undergo rehabilitation to achieve the geotechnical stability of the renewable energy generation structures, but, in addition, the land has to be restored. GreenJOBS will test the feasibility of developing artificial substitutes for soils suitable to several plant communities, addressing coal mining waste heaps. To achieve this goal, blend feasibility tests of fine coal waste from one of the project's case studies and wastes from closely located agricultural industries, coal-fired power plants, and water plants will be developed.
   c) *Rare earths recovery:* According to the United States Department of Energy (2017), both coal processing waste and ash residues have received attention for the economic value of the rare earths they might contain, particularly heavy rare earth elements. Data appear to show that cleaning enriches some

rare earths. Praseodymium is the only rare earth that is consistently enriched by at least a factor of four. However, the enrichment seen at the finest particle size occurs for all rare earths. Further, it supports the observation that the rare earths occur in considerable measure as finely divided material in coal and coal by-products within preparation plant streams. GreenJOBS will explore at the laboratory level the possibility to concentrate mixed rare earth oxides based on their high density, paramagnetic and non-conducting properties from the case studies' fine coal wastes.

4 Methodology

The proposal is structured into seven Work Packages (WP) to develop the project's methodology, plus a risk assessment and an economic assessment to ensure a consistent approach.

Apart from WP1 that addresses the project's coordination and management, the rest are presented in Figure 2.

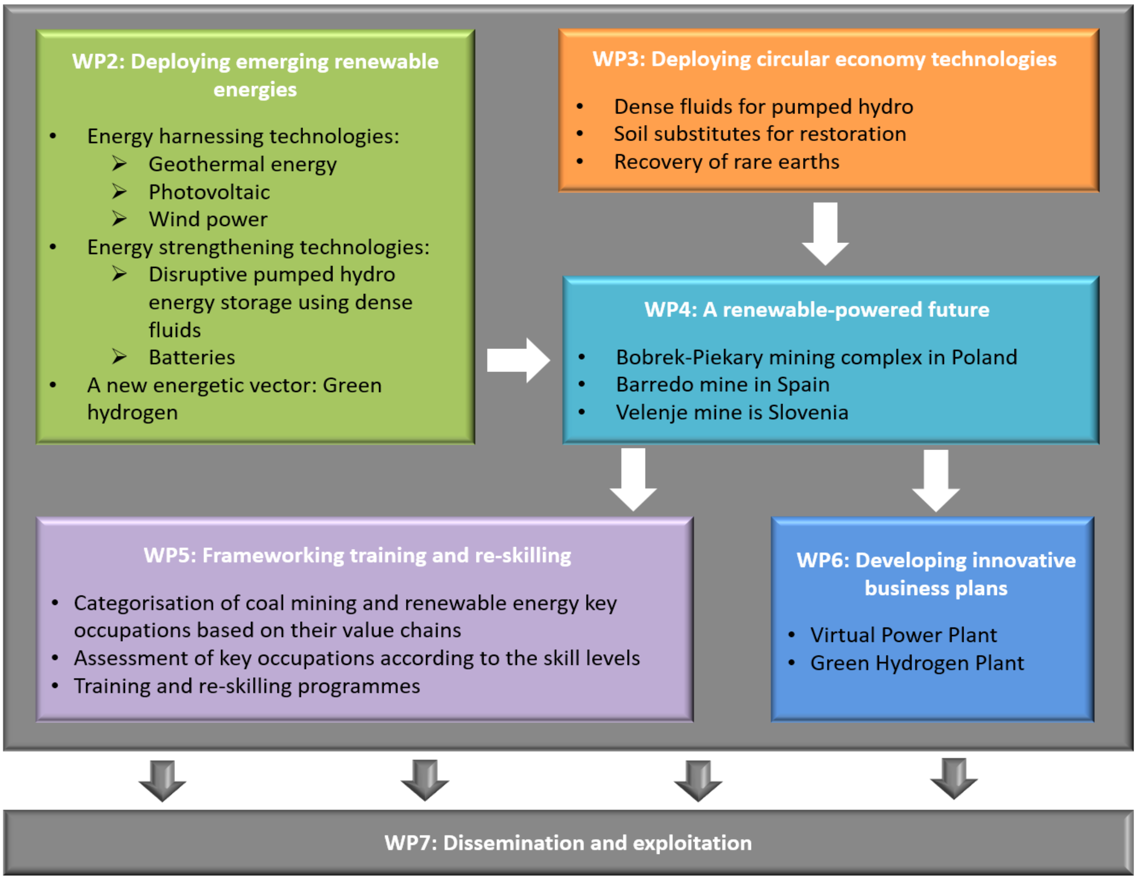

Figure 2. Methodology of the proposal.

4.1 Work Package 1: Project coordination and management

In this work package, all the coordination tasks are included: overall technical coordination of the project; organisation and management of meetings; distribution of technical data and information among partners; preparation of minutes and integration of reports; and administrative issues, including relations with the European Commission.

This work package also includes regular feedback to the Research Executive Agency (REA) about the issues faced regarding the Just Transition. It includes the preparation of the Comprehensive Overview of the project (State of the Art, problem, proposed approach and expected outcome) that has to be submitted within six months from the starting date of the action.

Finally, it will also cover the design, implementation and maintenance of the project website.

4.2 Work Package 2: Deploying emerging renewable energies

First, this work package will analyse the technical specifications, cost data and operational constraints and develop a detailed assessment of the job creation potential per MW installed, for commissioning and operation, for the deployment of energy harnessing technologies. In this way, coal mining companies will be able to assess the available renewable resources, as well as identify which options are optimal in terms of cost-benefit and employment for the conditions in the study area:

a) **Geothermal energy:** The heat pump usage for space heating and cooling powered by solar or wind energy can be classified as a truly renewable technology. Technologies for direct uses like district heating or geothermal heat pumps are widely used and considered mature. As the heating and cooling demand in Europe represents about half of the EU's final energy consumption, the importance of this energy to bring down the barriers to clean energy uptake in Europe is high. On the other hand, generating electricity is more inefficient than heating and cooling as, for this purpose, high or medium temperature resources are needed.
b) **Photovoltaic:** Solar photovoltaic panels are currently the most widespread type of solar photovoltaic technology. Panels can be used individually, or several can be connected to form arrays. Because of this modular structure, photovoltaic systems can be built to meet almost any electric power need. The cost of manufacturing solar panels has plummeted dramatically in the last decade, making them affordable, with a lifespan of roughly 30 years.
c) **Wind power:** Wind power is one of the fastest-growing renewable energy technologies. Usage is on the rise worldwide, in part because costs are falling. Wind turbines are commonly located on hilltops, coming in various shapes, although the windmill is the most common. The amount of power that can be harvested from wind depends on the size of the turbine and the length of its blades. The output is proportional to the dimensions of the rotor and the cube of the wind speed. When wind speed doubles, wind power potential increases by a factor of around eight.

Second, to maintain a competitive supply of electricity, energy storage is necessary. Storage can absorb excess electricity generation and re-inject it later, effectively reducing curtailment due to excess generation or demand constraints. It can do this both in a market or in a vertically integrated environment. This work package will therefore undergo an equally detailed analysis for the deployment of the selected energy strengthening technologies needed to support the available renewable resources, as well as a detailed assessment of the job creation potential per MWh-MW of storage capacity:

a) **Unconventional pumped hydro:** The great majority of global electricity storage capacity deployed up to the present day is pumped hydro due to its favourable technical and economic characteristics. The unconventional pumped hydro storage using dense fluids has similar efficiency to conventional pumped hydro but with a yield of up to three times more, depending on the density of the dense fluid. It allows large scale storage unlocking the potential of renewable energies, taking advantage of coal mines' deep infrastructure but without the need to operate in a non-flooded mine. On the other hand, the pump/turbine and electrical equipment are on the surface, representing easy maintenance. The galleries eliminate the need for a bottom pressure vessel, with pressure relatively stable and close to that due to overburden.
b) **Batteries:** Although unconventional pumped hydro storage can perform rapid ramping, avoiding photovoltaic and wind curtailment and loss of load, it needs several minutes to respond to signals. Thus, batteries should be used but only for short periods. As batteries have proven to be remarkably rapid in responding to signals (from sub-seconds to seconds), with costs declining notably while technical parameters such as degradation rates and energy density keep improving, they will play a vital role in the flexibility of the energy storage system to be designed in each case study.

Third, this work package will undergo a detailed assessment of a new energetic vector: Green hydrogen, produced by the electrolysis of water and electricity from renewable sources. It is a clear alternative to selling renewable energy to the grid or to power electro-intensive industries with constant energy consumption. Again, technical specifications, cost data, and operational constraints will be analysed. A detailed assessment of job creation potential per MW installed or per MW of electrolysers capacity installed for commissioning and operation will be developed.

The urge to reduce greenhouse gas emissions, the increasing costs for CO_2 emission certificates, and the increasing ambition in climate mitigation put pressure on conventional production processes in energy-intensive industries such as steel, cement, chemicals, and others. Green hydrogen becomes a vital decarbonisation option in processes where electrification and other solutions such as material and energy efficiency improvements are not available.

Green hydrogen can also play a complementary role to renewable electricity: (1) as an energy storage system (even seasonal) thanks to its large volume and extended lifetime in a similar way to how strategic reserves of natural gas or oil is used, making it possible supplying renewable hydrogen reserves to support the electricity grid; or (2) by opening up the option of hydrogen mobility, one of the keys to help decarbonise transport, especially long-distance maritime transport, rail and heavy goods transport by road.

Finally, the alternative to blending hydrogen into the existing natural gas grid would undermine gas quality standards, posing a risk to the operations of many industrial users that rely on a high and constant gas quality for their processes. Moreover, European gas networks can only integrate very low amounts of hydrogen into the existing infrastructure due to a phenomenon known as "hydrogen embrittlement" that causes damages to the infrastructure. Thus, blending hydrogen into existing gas networks is likely not an efficient development for renewable energy.

4.3 Work Package 3: Deploying circular economy technologies

This work package will develop a detailed assessment of circular economy technologies based on the valorisation of fine coal waste, a by-product of coal processing often stored in landfills, which directly addresses and complements the project's specific needs. As in the previous work package, technical specifications, cost data, and operational constraints will be analysed, and job creation potential based on the production capacity for commissioning and operation will be assessed.

a) **Dense fluids:** To develop the high-density fluid required for the unconventional hydro energy storage system, GreenJOBS will conduct specific research using fine coal waste and adequate additives from the three case studies. Low-density fraction separation, density, fluidity, water/slurry interface and remobilisation tailor-made tests will be developed at TRL 5-6.
b) **Soil substitutes:** In order to restore waste heap areas before the installation of photovoltaic/wind renewable energy infrastructure, GreenJOBS will conduct research assessing the feasibility of developing soil substitutes for restoration using different combinations of fine coal waste from one case study (in two of the cases no such soil substitute is necessary) together with local by-products and substances considered as "non-recoverable" waste, such as sewage sludge, spent mushroom compost, decarbonisation lime from water screening processes, etc. After appropriate blending of wastes, Phyto-germination tests will be developed to assess the potential support of the vegetation at TRL 5-6.
c) **Rare earths:** GreenJOBS will conduct mineralurgical studies at TRL 5-6 to identify potential approaches for the concentration of rare earths by gravimetric separation (rare earth minerals have a significant density), followed by magnetic separation of high field intensity (rare earth minerals are paramagnetic), and high voltage electric separation (rare earth minerals are mainly non-conductive). Finally, froth flotation tests will also be carried out.

4.4 Work Package 4: A renewable-powered future

GreenJOBS will use three case studies to plan site-specific deployments of the emerging renewable energies and circular economy technologies addressed in the previous two work packages, to develop a renewable-powered future for these areas, focusing on the flexibility of the energy systems and the complementarity of circular economy technologies. Flexibility is the leading enabler of renewable energy integration. It can be defined as the ability to cope with the variability and uncertainty introduced by renewable energies on different time scales, from the very short to the long term, avoiding energy curtailments (IRENA, 2018).

Case studies were selected to cover main types of underground coal mining: (1) underground longwall mining in Poland with sub-horizontal hard coal seams; (2) underground sub-level caving in Spain with sub-vertical hard coal seams; and (3) underground longwall top coal caving in Slovenia with one of the thickest known lignite seams in the world.

GreenJOBS will first determine the deployment possibilities of geothermal, photovoltaic and wind renewable energies for each case study. The deployment of geothermal energy will be based on district heating and cooling networks that allow multiple energy sources to be connected to multiple energy consumption points through a set of pipelines.

The development of district networks for the surrounding residential/industrial areas allows for integrating renewable sources such as geothermal and photovoltaic into these centralised systems. District networks will help increase photovoltaic deployment by producing synergies concerning transforming heating/cooling customers into prosumers or customers who produce excess electricity from solar panels on their roofs. The aim is to maximise the number of business opportunities and thus the impact on employment.

The second step will be to size each case study's necessary energy storage capacity to avoid renewable energy curtailments and load loss. The IRENA FlexTool (2018) and artificial intelligence tools will be used to optimise the power system operations.

Thirdly, green hydrogen production possibilities will be planned for each case study, considering the real challenge for its affordable production: ensuring a high load factor for the electrolysers. The ideal case for green hydrogen production combines low-cost electricity with a high capacity factor, maximising the use of cheap renewable electricity and minimising the impact of electrolyser depreciation.

The higher the load factor of the electrolyser, the cheaper the cost of a unit of hydrogen will be once the fixed investments are diluted into a more significant amount of product. Electrolyser load factors should generally exceed 50% at current levels of investment costs, but for the cost of green hydrogen production to be reduced, electrolysers should have a higher utilisation rate.

As this is not compatible with the occasional availability of curtailed electricity, the GreenJOBS proposal appears as a promising solution. It could achieve capacity factors well above 50% thanks to energy storage, which can absorb excess electricity generation and re-inject it later, complementing renewable electricity production in terms of availability.

Fourthly, the feasibility of developing soil substitutes to restore waste heaps prior to installing photovoltaic/wind, the development of dense fluids for unconventional pumped hydro energy storage and the recovery of rare earths from fine coal waste will be assessed, where appropriate.

Finally, this work package will design for each case study two business alternatives: a Virtual Power Plant and a Green Hydrogen Plant. The job creation potential in both commissioning and operation periods will be estimated, and the amount of investment required and the costs and benefits to be generated. With this information, an economic assessment will be developed in each case (six in total) to determine their likely commercial viability and economic added value, including capital expenditure (CAPEX), operational expenditure (OPEX), cash flows and expected financial results.

4.5 Work Package 5: Frameworking training and re-skilling

In this work package, GreenJOBS will address the skill gaps of former coal mining workers in the three case studies to establish the workforce's training and re-skilling needs to facilitate the development of the envisaged business alternatives.

A feature of coal mining is that many of the technical skills required vary little between countries and that some of the skills required for operating and maintaining coal mines can be adapted to the operation and maintenance of renewable energies.

Thus, firstly, a categorisation of the key occupations in both coal mining and renewable energies relevant for the proposal will be developed, based on their value chains: research and development, equipment manufacture and distribution, project development, commissioning and handover, operation and maintenance, and cross-cutting/enabling occupations.

Secondly, the key occupations in each of the stages of the value chains will be classified according to the skill levels required: High-skilled: professional/managerial, Medium-skilled: technician/skilled crafts/supervisor, and Low-skilled: semi-skilled & unskilled. A brief assessment of each of these profiles will help determine which occupations are most interesting to benefit from developing new skills and serve as a reference guide for planning or updating curricula to complete skills or develop new skills.

Thirdly, relevant training and re-skilling programmes will be designed to facilitate upgrading skills and transfer these former coal mining occupations to the renewable energy sector. The programmes can serve as reference guidelines for planning or updating curricula to upgrade skills or develop new skills at different educational levels: vocational schools and apprenticeships, continuing education and training at all levels, and university level courses.

4.6 Work Package 6: Developing innovative business plans

Based on the experience gained in the three case studies where specific deployments of emerging renewable energy and circular economy technologies were considered, this work package will develop an innovative business plan for each business alternative considered within the case studies: one for a Virtual Power Plant and one for a Green Hydrogen Plant.

A business plan is a written document that describes how a company, usually a start-up or a company that has decided to move in a new direction, defines its objectives and how it will achieve them. A business plan sets out a written roadmap for the company from a marketing, financial, and operational point of view. They are important documents used to attract investors before a business has established a proven track record. They are also a good way for companies to keep themselves on target going forward.

The business plans to be developed by GreenJOBS will include at least the following components: (a) Executive summary, (b) Organisation background, (b) Business description, (c) Market analysis, (d) Marketing and sales strategy, (e) Operational plan, (f) Management and organisation, (g) Financial projections, and (h) Risk assessment.

The business plans will be drawn up to be applied by any coal mining company that decides to undertake either of the two proposed business alternatives. These plans will be generic in those aspects that depend specifically on the particular conditions of each coal mine. By way of example, the financial projections will be templates to be populated with coal mine-specific data, automatically generating cash flow, income statements and balance sheets projections, as well as a break-even calculation and expected financial results (net present value, internal rate of return and payback period) from this data. They will also consider the company's expected financial capital structure in line with its expectations of third party financing.

4.7 Work Package 7: Dissemination & Exploitation (D&E)

This work package concerns the activities to be carried out to support the communication and dissemination of GreenJOBS knowledge and results to the entire European coal industry, the energy-intensive industry, the European Commission, academia and coal regions in transition (including regional authorities, civil society and other stakeholders), as well as to maximise the exploitation of project results by end-of-life underground coal mines.

To this end, a permanent link will be established with the Just Transition Platform to provide regular information and facilitate stakeholder involvement. The project results will be available on the website, and all deliverables will be public. A biannual newsletter will be published and distributed to all stakeholders registered via the website. In addition, the website will have a specific area dedicated to consultation where stakeholders will be able to propose any issues related to the project.

Two promotional videos will be produced: one at the beginning of the project, presenting its goals and objectives, and one near the end of the project, presenting the overall results. At least six presentations will be made at Just Transition Platform Meetings, at workshops of the United Nations Economic Commission for Europe on Post-Mining Perspectives and Sustainable Energy, and other forums, as well as a minimum of 4 open access papers in high impact JCR journals.

An international workshop on the results generated during the project will be held in Poland, as it hosts the prominent coal mining companies in the European Union. In addition, during the last semester of the project and to contribute to the exploitation of the project results, European coal mining companies will receive free advice on implementing the developed business plans. For their part, regional authorities in coal regions in transition will receive free assistance in planning and updating training and re-skilling programmes in their territories.

5 Impact

GreenJOBS is the first European/worldwide project addressing the repurposing of coal mine assets and infrastructure through emerging renewable energy and circular economy technologies that will leverage key competitive advantages of underground coal mines and therefore differs from and enhances any other project focusing on similar technologies but in different environments.

It is also the first European/worldwide project that will provide mining companies with two innovative business plans: a Virtual Power Plant where the energy produced will be sold to the grid or used to power electro-intensive industries or companies with constant energy consumption located close to mines, such as aluminium factories or green data centres; and a Green Hydrogen Plant where renewable hydrogen will be produced by electrolysis of mine water and electricity from renewable sources.

The unconventional pumped hydro energy storage using dense fluids proposed in GreenJOBS has two innovative values compared to what has been already proposed at both European and worldwide levels: firstly, it can operate in flooded mines, mainly eliminating the costs of pumping mine water in general and water used for geothermal in particular, something that is not feasible with other energy storage alternatives such as Graviticitry; secondly, the use of dense fluids allows providing density differentials between the fluids and, the greater the difference, the more efficient the system will be.

It is the first European/worldwide project that will include circular economy technologies to recycle fine coal waste directly addressing and complementing the specific needs of the project: (1) the development of soil substitutes to restore waste heaps before installing photovoltaic/wind; (2) the development of dense fluids for the unconventional pumped hydro energy storage; and, (3) the recovery of rare earths, critical raw materials for the EU, enabling the project's vertical integration into the clean energy value chain.

Finally, GreenJOBS will include for the first time a detailed assessment of job creation potential per MW installed (MWh-MW for storage capacity and MW of electrolysers capacity for H2) for the project's renewables, as well as for the project's circular economy technologies based on their production capacity, both for commissioning and operation. It will also address the skill gaps of former coal mining workers and develop a framework for training and re-skilling, thus protecting the most vulnerable workers to the transition.

6 Anticipated benefits

Perfectly aligned with the European Green Deal objectives, GreenJOBS' innovative business plans for a Virtual Power Plant and a Green Hydrogen Plant will enable coal mining companies to understand, evaluate, design and implement these alternative economic activities, leaving behind short-term patchworks, promoting sustainable local economic growth and maximising the number of green and quality jobs.

GreenJOBS will also contribute to protecting the most vulnerable workers in the transition by including a detailed assessment of the job creation potential, addressing the skill gaps of former coal mining workers and developing a framework for training and re-skilling.

GreenJOBS will leverage key competitive advantages of underground coal mines, enhancing any other project focused on similar technologies and creating sources of wealth and sustainable resources from problems such as coal waste and mine water.

The unconventional pumped hydro energy storage using dense fluids proposed by GreenJOBS can operate in flooded mines, thus eliminating the costs of pumping mine water in general and water used for geothermal in particular, which is not feasible with other energy storage alternatives.

GreenJOBS will help increase photovoltaic deployment by producing synergies in transforming heating/cooling customers into prosumers or customers who produce excess electricity from solar panels on their roofs. The aim is to maximise the number of green and quality jobs by developing as many business opportunities as possible.

Beyond the current extractive, take-make-waste industrial model, circular economy technologies aim to redefine growth, focusing on positive benefits for society. Underpinned by a transition to renewable energy sources, GreenJOBS circular model builds economic, natural and social capital:

- It designs out waste and pollution by valorising fine coal waste, a residue from coal processing. This waste leaves a large footprint on the land as coal cleaning residues have a higher proportion of impurities, such as pyrite, being dangerous discards for the environment as they can cause acid mine drainage.
- It keeps materials in use by recycling fine coal waste into dense fluids used by unconventional pumped hydro energy and recovering rare earths, a critical raw material for the European Union, enabling a vertical integration of the project into the clean energy value chain.
- It helps regenerate natural systems by developing soil substitutes to restore waste heaps before installing photovoltaic/wind, using different combinations of

fine coal waste and local by-products and substances considered "non-recoverable" waste as sewage sludge, spent mushroom compost, etc.

GreenJOBS goal to produce green hydrogen becomes a vital decarbonisation option in processes where electrification and other solutions are not available, facilitating the transition to a carbon-neutral industrial base in energy-intensive industries such as steel, cement, etc., providing opportunities and attracting investment and innovation to coal regions.

Finally, GreenJOBS will disseminate the importance for governments to regulate procedures and establish requirements for granting all or part of the grid access capacity of grid nodes affected by coal power plant closures to new renewable energy generation facilities that, in addition to technical and economic requirements, consider the environmental and social benefits for the regions and sectors most affected by the transition (Just Transition Nodes).

Annex: State of the art

1. Relevant ongoing and closed projects

The projects most relevant to GreenJOBS objectives belong to the RFCS. There are only two relevant projects in direct relation to renewable energy deployment: one on hydropower storage in open-pit mines and one on geothermal energy.

It is necessary to search H2020 to find more relevant projects related to renewables.

Other RFCS projects are related to the recycling of mining waste, the restoration of waste heaps and their rehabilitation addressing sustainable uses such as implementing renewable energy infrastructures.

- **ATLANTIS (RFCS-101034022-2021, 2021-2024):** "*An interdisciplinary feasibility study on hybrid pumped-hydro power storage of excess energy in open-pit coal mines*". GreenJOBS will take advantage of lessons learned from ATLANTIS's technical and feasibility assessment on transforming open-pit coal mines into hybrid pumped-hydro power storage projects using excess energy from the electric grid and renewable sources.
- **MINRESCUE (RFCS-899518-2020, 2020-2023):** "*From mining waste to valuable resource: New concepts for a circular economy*". GreenJOBS will closely follow the concepts that MINRESCUE will develop for recycling and upcycling waste geomaterials generated by coal mining activities, especially when they can be adapted to improve recycling of fine coal waste into dense fluids, soil substitutes for restoration or rare earths.
- **RECOVERY (RFCS-847205-2019, 2019-2023):** "*Recovery of degraded and transformed ecosystems in coal mining-affected areas*". Focusing on land rehabilitation and ecological restoration of coal mining-affected areas, one of the accomplished objectives of RECOVERY was to develop artificial substitutes for soils suitable to several types of plant communities, addressing "difficult terrains" in coal mining waste heaps. This knowledge will be used to develop blend feasibility tests of fine coal waste from the project case studies and wastes from closely located agriculture industries and water plants.
- **SUMAD (RFCS-847227-2019, 2019-2022):** "*Sustainable use of mining waste dumps*". GreenJOBS will take advantage of the geotechnical, sustainability, environmental, socio-economic, and long-term management challenges applicable to different sustainable rehabilitation schemes, focusing on the technical viability of developing renewable energy infrastructure: photovoltaic and wind.
- **TRACER (H2020-836819, 2019-2022):** "*Facilitating the transition to a sustainable energy system in coal intensive regions*". GreenJOBS will closely follow

decentralised electricity production assessment (social, environmental and technological) built upon mobilising many stakeholders.
- **BestRES (H2020-691689-2016, 2016-2019):** "*Best practices and implementation of innovative business models for renewable energy aggregators*". It aimed to identify best practices for renewable electricity generation like wind and photovoltaic leads to price deterioration during production hours in Europe. GreenJOBS will identify best practices business models for renewable electricity generation among the ones investigated in BestRES for aggregating various renewable sources, storage and elastic demand.
- **LoCAL (RFCR-CT-2014-00001, 2014-2017):** "*Low-Carbon After-Life: Sustainable use of flooded coal mine voids as a thermal energy source - a baseline activity for minimising post-closure environmental risks*". LoCAL seeks to unlock mine waters commercially viable potential as a thermal energy resource for flooded coal mine workings. GreenJOBS will use the knowledge related to controlling technical barriers to geothermal energy implementation and the optimum market pathways that maximise socio-economic benefits.

2. Relevant international literature

The existence of very recent scientific papers in all the areas addressed by the project (wind, photovoltaic, hydrogen, geothermal, underground pumped hydro energy storage in coal mines, circular economy in mining and employment prospects of renewable deployment) shows that GreenJOBS addresses topics directly related to the current state of research.

- Madlener, R., & Specht, J.M. (2020). **An exploratory economic analysis of underground pumped-storage hydropower plants in abandoned deep coal mines**. *Energies 13(21)*, 5634. https://doi.org/10.3390/en13215634.
  This study researches the concept of underground pumped-storage hydropower plants in closed-down underground hard coal mines in Germany, concluding that under favourable conditions, it seems both technically feasible and economically reasonable. More specifically, an extension of a tubular system seems the most promising option.
- Temiz, M., & Javani, N. (2020). **Design and analysis of a combined floating photovoltaic system for electricity and hydrogen production**. *International Journal of Hydrogen Energy, 45(5)*, 3457-3496. https://doi.org/10.1016/j.ijhydene.2018.12.226.
  In this paper, the electrical energy demand of a small community is investigated where a floating photovoltaic system and integrated hydrogen production unit are employed.
- Ortega, M., del Río, P., Ruiz, P., Nijs, W., & Politis, S. (2020). **Analysing the influence of trade, technology learning and policy on the employment**

prospects of wind and solar energy deployment: The EU case. Renewable and *Sustainable Energy Reviews 122*, 109657. https://doi.org/10.1016/j.rser.2019.109657.
This paper estimates the gross employment stemming from deploying three renewable electricity technologies –photovoltaic, wind onshore and wind off-shore – up to 2050 for all Member States of the European Union. It uses a novel analytical methodology to provide disaggregated results per activity in the supply chain for different scenarios.

- Menendez, J., Ordonez, A., Alvarez, R., & Loredo, J. (2019). **Energy from closed mines: Underground energy storage and geothermal applications**. *Renewable & Sustainable Energy Reviews 108*, 498-512. https://doi.org/10.1016/j.rser.2019.04.007.
This paper explores the use of abandoned mines for underground pumped hydroelectric energy storage, compressed air energy storage plants and geothermal applications, presenting a case study in which the three uses are combined in just one mine.
- Kinnunen, P., & Kaksonen, A. (2019). **Towards circular economy in mining: Opportunities and bottlenecks for tailings valorisation**. *Journal of Cleaner Production 228*, 153-160. https://doi.org/10.1016/j.jclepro.2019.04.171.
The use of mining waste as a raw material resource, a solution to the limited metal supply, is addressed in this paper. In order to speed up the transformation towards the circular economy in the mining industry, the paper fills in the knowledge gaps for tailings valorisation.
- Bodis, K., Kougias, I., Taylor, N., & Jager-Waldau, A. (2019). **Solar photovoltaic electricity generation: A lifeline for the European coal regions in transition**. *Sustainability 11(13)*, 3703. https://doi.org/10.3390/su11133703.
This paper analyses to what extent the use of photovoltaic electricity generation systems can help with a socially fair transition in the coal regions of the EU. The solar photovoltaic potential is assessed in selected regions where opencast coal mines are planned to cease operation.

3. Other relevant documents

- European Commission (2020). **A hydrogen strategy for a climate-neutral Europe**. COM(2020) 301 final. Brussels, 8.7.2020. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2020%3A301%3AFIN
A priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy. The EU presents a roadmap towards a hydrogen ecosystem in Europe to 2050 that will guide us to develop a Green Hydrogen Plant's feasible and innovative business plan.
- International Renewable Energy Agency (IRENA) (2018). **Power System Flexibility for the Energy Transition: IRENA FlexTool methodology**. https://www.irena.org/-

/media/Files/IRENA/Agency/Publication/2018/Nov/IRENA_Power_system_flexibility_2_2018.pdf?la=en&hash=B7028E2E169CF239269EC9695D53276E084A29AE
GreenJOBS will use this tool to optimise electricity generation, storage and investments. It will help explore the flexibility of the planned electricity system to improve it and design the optimal energy storage capacity to support the project's innovative business plans.

- United States Department of Energy (2017). **Report on Rare Earth Elements from Coal and Coal Byproducts**. Report to Congress, January 2017.
  https://www.energy.gov/sites/prod/files/2018/01/f47/EXEC-2014-000442%20-%20for%20Conrad%20Regis%202.2.17.pdf
  GreenJOBS will use this report showing how coal cleaning enriches some rare earths to assist in designing the concentration process. They occur in considerable measure as finely divided material in coal and coal by-products within the preparation plant.

4. Relevant patents

There is only one patent of significant relevance to GreenJOBS. It was developed by one of the partners of the project, MAGELLAN & BARENTS, S.L. This International Application discloses a disruptive pumped hydro energy storage system that employs a high-density fluid, such as a slurry, or a combination of a high-density fluid and a lower-density fluid, such as water, to increase power output. The system has a smaller footprint and higher energy density than conventional pumped hydropower energy systems, being an optimum option to leverage the competitive advantage of deep infrastructures available in coal mines.

WO 2019/202456 A1 (24 October 2019): "*Pumped hydro energy storage system and method*". The fluid is a binary fluid system, with a high-density fluid and a lower-density fluid, such as water. The lower-density fluid flows through the turbine unit of the system, avoiding the need to modify the system to handle the high-density fluid while achieving improved power output. The system can be configured with one atmospheric reservoir for a higher-density fluid and another one for a lighter-density fluid. Each of them is connected to a pressurised cavity which is filled with the higher-density or lighter-density fluid. The atmospheric tanks may be at the same elevation, or the tank with high-density fluid might be higher for increased energy output.

https://patentimages.storage.googleapis.com/46/97/46/f195d872d9493d/WO2019202456A1.pdf