POTENTIALS

RFCS AM PROJECT

Synergistic potentials of end-of-life coal mines and coal-fired power plants, along with closely related neighbouring industries: update and re-adoption of territorial just transition plans

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Deliverable 4.1

Business model choices justification

European Commission

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Authors

Dr Pedro Riesgo Fernández, University of Oviedo (Spain)

Dr Gregorio Fidalgo Valverde, University of Oviedo (Spain)

Dr Alicja Krzemień, Central Mining Institute (Poland)

Mr Aleksander Frejowski, Central Mining Institute (Poland)

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Executive summary

This Deliverable aims to justify the business model choices among the relevant business models or actions/micro-actions selected in *Deliverable 3.2 Scenarios classification map* employing a multi-criteria analysis.

The justification approach was initially based on evaluating actions/micro-actions related to Green Deal policies. However, other aspects were considered:

1. Technical criteria or relevant variables for scenario development, previously identified in *Deliverable 3.1 Exploratory scenarios*.
2. Technology Readiness Level (TRL), to assess the maturity of new technologies.
3. European taxonomy, to establish which economic activities are environmentally sustainable.
4. Synergistic potential, to take advantage of the joint potential of end-of-life mine sites and coal-fired power plants (and related infrastructure), along with closely related neighbouring industries, to stimulate new economic activities, developing jobs and economic value.
5. Circular economy, to enable resources to maintain their highest value for as long as possible, aiming to eliminate waste through the superior design of materials, products, and systems, including business models.
6. Sector coupling, to improve the efficiency and flexibility of energy systems and their reliability and adequacy by integrating energy end-use and supply sectors.

A second step was to analyse the phases of the coal sector transition and the timeline for ceasing or scaling down these activities. The World Bank and the Research Fund for Coal and Steel (RFCS) were used as references for this analysis.

Finally, an outline of the expected transition process towards the Union's 2030 targets for energy and climate and a climate-neutral economy of the Union by 2050, in line with the objectives of the integrated national energy and climate plans and other existing transition plans, was developed.

The outline was based on the Regulation of the EU on the Governance of the Energy Union and Climate Action, which applies to the five dimensions of the Energy Union, which are closely related and mutually reinforcing, that each Member State should setout in its integrated national energy and climate plans.

1 Introduction

Work Package 4 is to justify the selection of business model choices and their adaptation according to the expected transition process to update and re-adopt territorial just transition plans.

Specific objectives are:

1. To support the update and re-adoption of territorial just transition plans, show how these synergies can be used to develop new business models, define concrete prospects and transition plans from different implementation scenarios, and justify the business model choices.

2. To undergo an economic impact assessment to determine the economic diversification potential, the likely commercial viability, and the added value of the proposed business models.

3. To undergo a social impact assessment, analysing the expected job losses and requalification needs.

4. To undergo a territorial impact assessment to analyse the potential territorial impact of the business model proposals.

Within this work package, *Task 4.1 Justifying the business models choice and outlining the transition process*, comprises the activities to be carried out to justify the business models choice (e.g., contribution to the transition to a climate-neutral economy, leading to substantial reductions in greenhouse gas emissions going below the relevant benchmarks, etc.) and to adapt them according to the expected transition process, with a timeline for ceasing or scaling down activities such as coal and lignite mining or coal-fired electricity production.

Based on this, an outline of the expected transition process will be developed, pointing out how this process aligns with the objectives of different National Energy and Climate Plans and other existing transition plans.

2 Business models, policies and criteria

Within Work Package 3, business models options from coupled coal mines and coal-fired power stations in the process of phasing out and closely related neighbouring industries were evaluated by Multicriteria assessment using the MULTIPOL tool, developed by the Institut d'Innovation Informatique pour l'Entreprise 3IE.

The evaluation was developed via questionnaires sent to stakeholders: European coal industry, policymakers, scientists, trade unions, NGOs and coal industry nearby local communities. To achieve a consensus, a remote meeting was also organised.

First, the list of scenarios and micro-scenarios obtained from the morphological analysis that was developed with the MORPHOL software in *Deliverable 3.1 Exploratory scenarios* was arranged and transformed into the list of relevant business models (actions and micro-actions) that appear in Table 2-1 and Table 2-2 after eliminating some scenarios that, in most of the cases, were feasible to be developed without achieving any essential synergies from the end-of-life coal mines and coal-fired power plants, along with closely related neighbouring industries areas.

Table 2-1. List of relevant business models (actions)

N°	Short label	Long label
1	Virtual	Virtual power plant
2	Hydrogen	Green hydrogen plant
3	Ecopark	Eco-industrial park
4	Tourist	Cultural heritage and sports/recreation areas
5	FloatingPV	Floating PV panels at flooded open-pit coal mines
6	Pumping	Pumped hydroelectric storage at former open-pit coal mines
7	Fisheries	Fisheries in flooded open-pit coal mines
8	CCGT	Combined-cycle gas turbine (CCGT) power plant powered by natural gas
9	Minegas	Mine gas utilization for gas-powered CHP power units
10	Nuclear	Small modular reactors (SMRs)
11	Biofuels	Biofuels combustion energy plant
12	Moltensalt	Molten salt plant
13	Agrophotovoltaics	Agrophotovoltaics at former open-pit coal mine areas

Second, policies were selected considering that climate change and environmental degradation are existential threats to Europe and the world.

To overcome these challenges, the European Green Deal will transform the EU into a modern, resource-efficient and competitive economy, ensuring the three policies presented in Table 2-3.

Table 2-2. List of relevant business models (micro-actions)

N°	Short label	Long label
1	Batteries	Ancillary services provided by batteries
2	Wasteheaps	Recovery of resources from coal mining waste heaps
3	Methane	Usage of methane from degasification units in closed coal mines
4	Water	Circular mining technologies for pumped water material recovery
5	Forest	Forest restoration at former open-pit coal mines
6	Information	Large-scale IT infrastructure - power plant
7	Geothermal	Geothermal energy
8	Gravitricity	Storage of energy in the form of potential energy using weights
9	Dense fluids	Storage of energy using dense fluids.
10	Hydropumping	storage energy in the closed coal mine shafts

Table 2-3. List of European Green Deal policies

N°	Short label	Long label
1	Climate	No net emissions of greenhouse gases by 2050
2	Growth	Economic growth decoupled from resource use
3	People	No person and no place left behind

Third, six evaluation criteria were defined emanating from the goal and objectives of the study.

Defining criteria was the outcome of interaction among researchers, external experts and the stakeholders in a participatory planning process, aiming at grasping priorities and embodying them in the subsequent processes.

The list of evaluation criteria is presented in Table 2-4.

Table 2-4. List of evaluation criteria

N°	Short label	Long label
1	Security	Energy security
2	Greening	Renewable resources
3	Cost	Low investment barriers
4	Benefits	Economic benefits
5	Development	Regional development
6	Environment	Impact on environment
7	Employment	Job creation

Fourth, the list of technical criteria developed within *Deliverable 3.1 Exploratory scenarios* was also considered (Table 2-5).

Table 2-5. List of technical criteria

No	Short Label	Description
1	The character of the local area - proximity to industry	This variable refers to the characteristics of the surrounding areas: urban, suburban, villages, agricultural, industrial, post-industrial, etc. This variable will also refer to the existence of electro-intensive industries in the proximity of the coal mine/coal power plant, likely to use H2 as an energy input to reduce greenhouse gas emissions; and to the existence of industries with constant energy consumption, such as green data centres or aluminium factories.
2	Available space for new technologies/ projects	This variable refers to the accessible space for new technologies installation (apart from waste disposal areas). The space consists of all the area [ha] provided by the surroundings of coal mines and power plants.
3	Available infrastructures for new technologies/projects	The infrastructure that may facilitate the adaptation of the power plant can be internal and external.
4	Concessions, contracts and other regulations	Obligations such as providing thermal energy supply after the decommissioning or arising from concessions, contracts and others may condition the future repurposing of the power plant. Also, the amount of time (years) during which the power plant will still have the concession for power generation.
5	Land use restrictions	This variable refers to any kind of land use restrictions different from waste heaps, mainly related to territorial development plans approved by the authorities, that may condition specific industrial, commercial, business centres, or residential deployments.
6	Waste heaps of physical characteristics	To develop different rehabilitation actions for the waste heaps, it is important to consider previously their geotechnical stability. 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.
7	Waste heaps of development constraints	A fire hazard at the waste heap, a Gas hazard at the waste heap, and the Status of reclamation of the waste heap can be combined in the variable such as Waste heap development constraints, with the variables representing the development hypothesis for a given working horizon.
8	Material type deposited on the waste heaps	This variable refers to the specific characteristics of the materials that are deposited in the waste heaps as well as if they are separated in extractive waste and coal processing waste or mixed together.
9	Flooding status of the mine	The variable describes the flooding status of a liquidated mine related to the depth to which it was flooded and the flooded area.
10	Pumped water chemistry/quality	The variable determines the quality and chemistry (the content of mineral substances & pH) of pumped mining water. On the other hand, pumped mine water may contain hazardous substances that are toxic to the environment, such as heavy metals, radioactive elements (226Ra and 228Ra) or PCBs (polychlorinated biphenyls) used in electrical equipment (as dielectric fluids).

Apart from these ten technical criteria, another two technical criteria were introduced in *Deliverable 3.2 Scenarios classification map*:

1. **Investment costs**: The variable refers to the investment costs to be considered when designing closed coal mines/electric power plants to adapt the existing infrastructure to new economic activities (renovations, modifications, purchase of new equipment). The higher cost, the more demanding investment.

2. **Returns on investments (benefits)**: Returns on investment are understood not only as financial (economic) returns in the strict sense but also as environmental and social returns.

Nevertheless, as both investment cost and economic growth were considered within the evaluation criteria, there was no need to repeat them under the technical criteria.

3 Justification approach

The justification approach was initially based on evaluating actions/micro-actions related to Green Deal policies. However, other aspects were considered, which are presented hereafter.

3.1 Green deal policies

3.1.1 Evaluation of actions related to policies

Every relevant business model (action) and policy was evaluated against the selected criteria. Thus, it was possible to obtain the scores of actions related to policies (Table 3-1).

Table 3-1. Evaluation of actions related to policies

ACTIONS	POLICIES			Mean	Standard deviation
	P1: Climate	P2: Growth	P3: People		
1 : A1_VIRTUAL	13,3	9,4	7,4	10	2,5
2 : A2_H2	16,4	10,5	10,9	12,6	2,7
3 : A3_ECOPARK	12,5	12,9	15,9	13,8	1,5
4 : A4_TOURIST	10	8	9,2	9,1	0,8
5 : A5_PANELS	12,5	9,6	8,5	10,2	1,7
6 : A6_PHS	17,2	11,5	9,6	12,8	3,2
7 : A7_FISHES	5,6	7,8	8,1	7,2	1,1
8 : A8_C/O_CGT	10,8	11	9,7	10,5	0,6
9 : A9_MINEGAS	6,4	6,4	5,3	6	0,5
10 : A10_SMR	14,2	11,7	15,1	13,7	1,4
11 : A11_BIOFUE	15	13,2	12,4	13,5	1,1
12 : A12_SALT	18,1	13,8	10,9	14,2	3
13 : A13_APV	15,3	11,4	10,1	12,3	2,2

The scores were calculated by applying the weights of the “matrix evaluation of actions related to criteria” to the “matrix of policies related to criteria”. By doing this way, it was possible to obtain the scores of actions related to policies.

3.1.2 Evaluation of micro-actions related to policies

Like with the actions, every relevant micro-action and policy was evaluated against the selected criteria. Thus, it was possible to obtain the scores of actions related to policies (Table 3-2).

Table 3-2. Evaluation of micro-actions related to policies

MICRO-ACTIONS	POLICIES			Mean	Standard deviation
	P1: Climate	P2: Growth	P3: People		
1 : AM1_BATT	13,8	10,8	5,8	10,1	3,3
2 : AM2_HEAPS	5,8	6,3	7,1	6,4	0,5
3 : AM3_C2H4	8,5	7,8	7,8	8	0,3
4 : AM4_WATER	7,5	6,2	6,4	6,7	0,6
5 : AM5_FOREST	7,5	7,2	7,2	7,3	0,1
6 : AM6_IT	4	6	2,8	4,2	1,3
7 : AM7_THERMA	19,6	14,5	12,4	15,5	3
8 : AM8_GRAVIT	12,2	8	7,6	9,2	2,1
9 : AM9_FLUIDS	18,5	10,8	8,8	12,7	4,2
10 : AM10_HPUMP	18,2	10,5	9,3	12,7	3,9

3.2 Technical criteria

Although the evaluation of actions/micro-actions related to policies was first considered to justify the business models (actions) choice about their contribution to the transition to a climate-neutral economy, their lead to substantial reductions in greenhouse gas emissions going below the relevant benchmarks and their contribution to the generation of jobs and economic growth, the evaluation of actions/micro-actions related to technical criteria was also considered an input for justifying the choices.

3.2.1 Evaluation of actions related to technical criteria

Table 3-3 presents the evaluation of actions related to technical criteria.

Table 3-3. Evaluation of actions related to technical criteria

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9	CT10
A1_VIRTUAL	10	20	20	20	-12	0	-20	0	0	0
A2_H2	20	20	20	20	-15	0	-15	0	0	15
A3_ECOPARK	15	10	10	5	-15	0	-15	0	-5	10
A4_TOURIST	0	5	10	-10	-10	-5	-10	0	0	0
A5_PANELS	15	20	20	-10	-5	0	0	10	20	-10
A6_PHS	15	20	20	-10	-5	0	0	5	10	-10
A7_FISHES	15	20	20	-15	-5	-5	0	10	20	-20
A8_C/O_CGT	15	15	18	7	5	0	-5	0	10	10
A9_MINEGAS	15	5	20	10	-5	0	0	0	-20	0
A10_SMR	18	18	18	5	2	0	0	0	15	10
A11_BIOFUE	10	20	5	0	-10	0	0	0	0	0
A12_SALT	10	20	20	-10	-15	0	0	0	0	0
A13_APV	15	20	20	-10	-10	-5	-20	10	0	-20

3.2.2 Evaluation of micro-actions related to technical criteria

Again, the score of micro-actions in the technical criteria evaluation will be used as auxiliary or supplementary information regarding their justification (Table 3-4).

3.3 Technology readiness level

Another criterion considered is each specific action's Technology Readiness Level (TRL). The TRL concept was initially developed by the National Aeronautics and Space Administration (NASA) to support the development of Space technologies and allow for more effective assessment of and better communication on the maturity of new technologies.

Table 3-4. Evaluation of micro-actions related to technical criteria

	CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9	CT10
AM1_BATT	15	15	20	5	5	0	0	0	0	0
AM2_HEAPS	20	10	10	10	-10	20	-15	20	0	0
AM3_C2H4	15	10	10	20	20	0	0	0	15	10
AM4_WATER	4	2	2	3	-10	0	0	0	-5	15
AM5_FOREST	15	0	0	5	-10	20	-10	10	0	-10
AM6_IT	0	10	5	0	0	0	0	0	0	0
AM7_THERMA	10	10	10	5	-10	0	0	0	-10	0
AM8_GRAVIT	20	20	20	-5	0	0	0	0	-10	0
AM9_FLUIDS	20	15	10	15	-5	0	-5	0	0	0
AM10_HPUMP	10	0	10	-20	0	0	0	0	-20	-10

The European Union's research framework programme Horizon2020 uses the concept of TRL to describe the scope of its calls for proposals; the definitions provided, however, are meant as overall guidance and do not refer specifically to renewable energy technologies.

The study by the European Commission (2017) was meant first to assess the use of TRL in the energy field at the European level: desk research, complemented by surveys and interviews with stakeholders coming from the institutional, industrial and research areas, led to the conclusion that there is still a lack of common understanding around the concept of TRL and further guiding principles would be needed. The study also aimed to develop guidance documents defining TRL in ten renewable energy fields; a Guide of Guides was conceived to be the backbone for any technology-specific definition and, based on its instructions, ten guidance documents were produced and validated by stakeholders in a two step-approach: first through an online survey and then during a one-day workshop. A subcontractor, acting as a reviewer, ensured the documents produced were consistent to update the Guide of Guides; its analysis identified technology-specific issues and a set of common trends for each TRL that may serve as a reference to develop guidance documents in any other energy technology field.

The ten Renewable Energy (RE) technologies under scope were (European Commission, 2017):

- Photovoltaics;
- Concentrated Solar Power (CSP);
- Hydropower;

- Wind;
- RE Heating and Cooling (H&C);
- Geothermal;
- RE Alternative Fuels;
- Ocean Energy;
- Bioenergy - biological pathway; and
- Bioenergy - thermochemical pathway.

The following definitions apply (European Commission, 2017); they are complemented by the United States Department of Energy TRL for geothermal energy:

- **TRL 1 – basic principles observed and reported:** This is the lowest technology readiness level. *Scientific research begins to be translated into applied R&D*. Examples might include paper studies of a technology's basic properties or experimental work that consists mainly of observations of the physical world. Supporting Information includes published research or references identifying the technology's underlying principles. A specific example in Geothermal Technologies Programme (GTP) might be a paper study analysing the technological barriers to developing an Enhanced Geothermal System.

- **TRL 2 – technology concept formulated**: Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are still limited to analytic studies. Supporting information includes publications or references that outline the application being considered and provide analysis to help the concept. The steps from TRL 1 to TRL 2 move the ideas from basic to applied research. Most of the work is analytical, or paper studies emphasise understanding the science better. Experimental work is designed to corroborate the basic scientific observations made during TRL 1 work. An example in GTP might be applying a new concept to developing a high-temperature logging tool or a numerical model.

- **TRL 3 – experimental proof of concept**: Active research and development (R&D) is initiated. This includes analytical studies and laboratory-scale studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated. Supporting information includes results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. At TRL 3, the work has moved beyond the paper phase to experimental work that verifies that the concept works as expected. The technology components are validated, but there is no strong attempt to integrate the components into a complete system. Modelling and simulation may be used to complement physical experiments. Examples in GTP would include laboratory testing and analysis of insulation materials for down-hole tools and preliminary engineering design development.

- **TRL 4 – technology validated in the lab**: The basic technological components are integrated to establish that the pieces will work together. This is relatively “low fidelity” compared with the eventual system. Examples include the integration of ad hoc hardware in a laboratory and testing. Supporting information consists of the results of the integrated experiments and estimates of how the experimental components and experimental test results differ from the expected system performance goals. TRL 4-6 represent the bridge from scientific research to engineering. TRL 4 is the first step in determining whether the individual components will work together as a system. The laboratory system will probably be a mix of on-hand equipment and a few special-purpose components that may require special handling, calibration, or alignment to get them to function. An example in GTP might include the operation and laboratory testing of innovative components in an improvised (e.g., small-scale) electronic submersible pump at room temperature/pressure. The goal of TRL 4 should be narrowing possible options in the complete system.

- **TRL 5 – technology validated in relevant environment (industrial environment in the case of key enabling technologies)**: The basic technological components are integrated so that the system configuration is similar to (matches) the complete application in almost all respects. Supporting information includes results from the laboratory scale testing, analysis of the differences between the laboratory and eventual operating system/environment, and analysis of what the experimental results mean for the eventual operating system/ environment. The significant difference between TRL 4 and 5 is the increased fidelity of the system and environment to the actual application. The system tested is almost prototypical. An example in GTP might be laboratory testing of newly developed packer components in a high-temperature/high-pressure environment. Scientific risk should be retired at the end of TRL 5. The results presented should be statistically relevant.

- **TRL 6 – technology demonstrated in relevant environment (industrial environment in the case of key enabling technologies)**: Engineering-scale models or prototypes are tested in a relevant environment. This represents a significant step up in a technology’s demonstrated readiness. Examples include the fabrication of the device on an engineering pilot line. Supporting information includes results from the engineering scale testing and analysis of the differences between the engineering scale, prototypical system/environment, and analysis of what the experimental results mean for the eventual operating system/environment. TRL 6 begins proper engineering development of the technology as an operational system. The significant difference between TRL 5 and 6 is the step up from the laboratory scale to the engineering scale and the determination of scaling factors that will enable the design of the final system. An example in GTP might be the development of prototype drilling bits subjected to high temperatures and pressures for long, continuous periods. The engineering pilot scale demonstration should be capable of performing all the functions that will be required of a complete manufacturing system. The operating environment for the testing should closely represent the actual operating environment. The goal while in TRL 6 is to reduce engineering risk. The results presented should be statistically relevant.

- **TRL 7 – system prototype demonstration in an operational environment**: This represents a significant step up from TRL 6, requiring the demonstration of an actual system prototype in a relevant environment. An example in GTP might be field testing of a prototype downhole pressure monitor in a geothermal well. A significant amount of automation is expected after this phase if the cost model for a full-scale ramp requires it. 24-hour production (at least for a relevant duration) is expected to discover any unexpected issues that might occur during scale-up and ramp. Supporting information includes results from the full-scale testing and analysis of the differences between the test environment and an analysis of what the experimental results mean for the eventual operating system/environment. The final design is virtually complete. The goal of this stage is to retire engineering and manufacturing risk. To credibly achieve this goal and exit TRL 7, scale is required as many significant engineering and manufacturing issues can surface during the transition between TRL 6 and 7.

- **TRL 8 – system complete and qualified**: The technology has been proven to work in its final form and under expected conditions. This TRL represents the end of true system development in almost all cases. An example in GTP might be demonstrating a new tool/method for integrating seismic and resistivity datasets from an operating geothermal field to more effectively model a reservoir, including comparing observed performance data relative to the previous state-of-the-art. Product performance delta to plan needs to be highlighted, and plans to close the gap will need to be developed. The technology has been proven to work in its final form and under expected conditions. This TRL represents the end of true system development in almost all cases. Product performance delta to plan needs to be highlighted, and plans to close the gap will need to be developed.

- **TRL 9 – the existing system is proven in an operational environment (competitive manufacturing in the case of key enabling technologies; or space)**: The technology is in its final form and operated under the full range of operating conditions. Examples include the actual commercial operation of newly developed logging tools, casing designs, remote sensing techniques, etc., in a geothermal system in its final forms. Emphasis shifts toward statistical process control.

3.4 European taxonomy

The European taxonomy was also considered an essential factor addressing the justification of the selected actions.

To meet the EU's climate and energy targets for 2030 and reach the European green deal's objectives, the EU must direct investments towards sustainable projects and activities. The COVID-19 pandemic reinforced the need to redirect money towards sustainable projects to make economies, businesses and societies – particularly health systems- more resilient against climate and environmental shocks.

To achieve this, a common language and a clear definition of what is 'sustainable' is needed. This is why the action plan on sustainable financing called for a common classification system for sustainable economic activities or an "EU taxonomy".

The EU taxonomy is a classification system establishing a list of environmentally sustainable economic activities. It could be significant in helping the EU scale up sustainable investment and implement the European green deal.

The EU taxonomy provides companies, investors and policymakers with appropriate definitions for economic activities to be considered environmentally sustainable. In this way, it should create security for investors, protect private investors from greenwashing, help companies to become more climate-friendly, mitigate market fragmentation and help shift investments where they are most needed.

The Taxonomy Regulation (European Union, 2020) was published in the Official Journal of the European Union on 22 June 2020 and entered into force on 12 July 2020. It establishes the basis for the EU taxonomy by setting out four overarching conditions that economic activity has to meet to qualify as environmentally sustainable.

The Taxonomy Regulation establishes six environmental objectives:

1. Climate change mitigation.
2. Climate change adaptation.
3. The sustainable use and protection of water and marine resources.
4. The transition to a circular economy.
5. Pollution prevention and control.
6. The protection and restoration of biodiversity and ecosystems.

Different means can be required for an activity to contribute to each objective substantially.

Under the Taxonomy Regulation, the Commission had to develop the actual list of environmentally sustainable activities by defining technical screening criteria for each environmental objective through delegated acts.

The energy sector accounts for approximately 22 % of direct greenhouse gas emissions in the European Union and about 75 % of those emissions when considering energy use in other sectors. It thus plays a crucial role in climate change mitigation. The energy sector has significant potential to reduce greenhouse gas emissions. Several activities in that sector act as enabling activities that facilitate the transition of the energy sector towards renewable or low-carbon electricity or heat. It is, therefore, appropriate to establish technical screening criteria for a wide range of activities related to the energy supply chain, ranging from electricity or heat generation from different sources through transmission and distribution networks to storage, as well as heat pumps and the manufacture of biogas and biofuels.

The substantial contribution criteria for the actions and micro-actions encompassed in POTENTIALS are presented hereafter using the EU Taxonomy Compass (https://ec.europa.eu/sustainable-finance-taxonomy/taxonomy-compass), which provides a visual representation of the contents of the EU Taxonomy, starting with the Delegated Act (European Union 2021) on the climate objectives: climate change mitigation (Annex I) and climate change adaptation (Annex II). The Climate Delegated Act entered into application on 1 January 2022. The EU Taxonomy Compass also includes the contents of the Complementary Delegated Act (European Union, 2022). The Complementary Delegated Act will enter into application on 1 January 2023.

3.4.1 Electricity generation from bioenergy

It refers to the construction and operation of electricity generation installations that produce electricity exclusively from biomass, biogas or bioliquids, excluding electricity generation from blending renewable fuels with biogas or bioliquids.

The substantial contribution criteria are:

1. Agricultural biomass used in the activity complies with the criteria in Article 29, paragraphs 2 to 5, of Directive (EU) 2018/2001. Forest biomass used in the activity complies with the requirements in Article 29, paragraphs 6 and 7 of that Directive.

2. The greenhouse gas emission savings from the use of biomass are at least 80 % concerning the GHG saving methodology and the relative fossil fuel comparator set out in Annex VI to Directive (EU) 2018/2001.

3. Where the installations rely on the anaerobic digestion of organic material, the production of the digestate meets the criteria in Sections 5.6 and criteria 1 and 2 of Section 5.7 of this Annex, as applicable.

4. Points 1 and 2 do not apply to electricity generation installations with a total rated thermal input below 2 MW and using gaseous biomass fuels.

5. For electricity generation installations with a total rated thermal input from 50 to 100 MW, the activity applies high-efficiency cogeneration technology, or, for electricity-only facilities, the activity meets an energy efficiency level associated with the best available techniques (BAT-AEL) ranges set out in the latest relevant best available techniques (BAT) conclusions, including the best available techniques (BAT) conclusions for large combustion plants.

6. For electricity generation installations with a total rated thermal input above 100 MW, the activity complies with one or more of the following criteria:

   - Attains electrical efficiency of at least 36 %;
   - applies highly efficient CHP (combined heat and power) technology as referred to in Directive 2012/27/EU of the European Parliament and the Council(173);
   - uses carbon capture and storage technology. Where the CO2 that would otherwise be emitted from the electricity generation process is captured for underground storage, the CO2 is transported and stored underground under the technical screening criteria set out in Sections 5.11 and 5.12, respectively, of Annex I.

Regarding the do not significant harm criteria about pollution prevention, it states that:

1. For installations falling within the scope of Directive 2010/75/EU of the European Parliament and of the Council(174), emissions are within or lower than the emission levels associated with the best available techniques (BAT-AEL) ranges set out in the latest relevant best available techniques (BAT) conclusions, including the best available techniques (BAT) conclusions for large combustion plants(175). No significant cross-media effects occur.

2. For combustion plants with thermal input greater than 1 MW but below the thresholds for the BAT conclusions for large combustion plants to apply, emissions are below the emission limit values set out in Annex II, part 2, to Directive (EU) 2015/2193.

3. For plants in zones or parts of zones not complying with the air quality limit values laid down in Directive 2008/50/EC, measures are implemented to reduce emission levels taking into account the results of the information exchange(176)

which the Commission publishes following Article 6, paragraphs 9 and 10, of Directive (EU) 2015/2193.

3.4.2 Storage of electricity

It refers to the construction and operation of facilities that store electricity and returns it later in the form of electricity. The activity includes pumped hydropower storage.

The substantial contribution criteria are:

1. The activity is constructing and operating electricity storage, including pumped hydropower storage.
2. Where the activity includes chemical energy storage, the storage medium (such as hydrogen or ammonia) complies with the criteria for manufacturing the related product specified in Sections 3.7 to 3.17 of Annex I. In the case of using hydrogen as electricity storage, where hydrogen meets the technical screening criteria specified in Section 3.10 of Annex I, the re-electrification of hydrogen is also considered part of the activity.

Regarding the do not significant harm criteria about water, the EU Taxonomy indicates that in case of pumped hydropower storage not connected to a river body, the activity complies with the criteria set out in Appendix B to this Annex; in case of pumped hydropower storage connected to a river body, the activity complies with the criteria for DNSH to sustainable use and protection of water and marine resources specified in Section 4.5 (Electricity production from hydropower).

Regarding the do not significant harm criteria about the circular economy, the EU Taxonomy indicates that a waste management plan is in place and ensures maximal reuse or recycling at the end of life under the waste hierarchy, including through contractual agreements with waste management partners, reflection in financial projections or official project documentation.

3.4.3 Manufacture of hydrogen

It refers to the manufacture of hydrogen and hydrogen-based synthetic fuels.

The substantial contribution criteria are:

1. The activity complies with the life-cycle GHG emissions savings requirement of 73.4% for hydrogen [resulting in life-cycle GHG emissions lower than 3tCO2e/tH2] and 70% for hydrogen-based synthetic fuels relative to a fossil fuel comparator of 94g CO2e/MJ in analogy to the approach set out in Article 25(2) of and Annex V to Directive (EU) 2018/2001.

2. Life-cycle GHG emissions savings are calculated using the methodology referred to in Article 28(5) of Directive (EU) 2018/2001 or using ISO 14067:2018(119) or ISO 14064-1:2018(120).

3. Quantified life-cycle GHG emission savings are verified in line with Article 30 of Directive (EU) 2018/2001, where applicable, or by an independent third party.

4. Where the CO2 that would otherwise be emitted from the manufacturing process is captured for underground storage, the CO2 is transported and stored underground, per the technical screening criteria set out in Sections 5.11 and 5.12, respectively, of Annex I.

3.4.4 Storage of thermal energy

It refers to the construction and operation of facilities that store thermal energy and returns it later in the form of thermal energy or other energy vectors.

No substantial contribution criteria are foreseen.

Regarding the do not significant harm criteria about the circular economy, a waste management plan is in place. It ensures maximal reuse, remanufacturing or recycling at the end of life, including through contractual agreements with waste management partners, reflection in financial projections or official project documentation.

3.4.5 Production of heat/cooling from geothermal energy

It refers to the construction or operation of facilities that produce heat/cooling from geothermal energy.

The substantial contribution criteria are:

1. The life-cycle GHG emissions from the generation of heat/cool from geothermal energy are lower than 100gCO2e/kWh.

2. Where available, life-cycle GHG emissions are calculated based on project-specific data using Commission Recommendation 2013/179/EU or ISO 14067:2018 or ISO 14064-1:2018.

3. An independent third party verifies quantified life-cycle GHG emissions.

Regarding the do not significant harm criteria about pollution prevention, the EU Taxonomy indicates that for the operation of high-enthalpy geothermal energy systems, adequate abatement systems are in place to reduce emission levels in order not to hamper the achievement of air quality limit values set out in Directives 2004/107/EC and 2008/50/EC.

3.4.6 Electricity generation using solar photovoltaic technology

It refers to constructing or operating electricity generation facilities using solar photovoltaic (PV) technology.

No substantial contribution criteria are foreseen.

Regarding the do not significant harm criteria about the circular economy, the activity assesses the availability of and, where feasible, uses equipment and components of high durability and recyclability that are easy to dismantle and refurbish.

3.4.7 Electricity generation using wind power technology

It refers to constructing or operating electricity generation facilities that produce electricity from wind power.

No substantial contribution criteria are foreseen.

Regarding the do not significant harm criteria about the circular economy, the activity assesses the availability of and, where feasible, uses equipment and components of high durability and recyclability that are easy to dismantle and refurbish.

The substantial contribution criteria are:

1. The economic activity has implemented physical and non-physical solutions (‘adaptation solutions’) that substantially reduce the essential physical climate risks that are material to that activity.

2. The physical climate risks that are material to the activity have been identified from those listed in Appendix A by performing a robust climate risk and vulnerability assessment. The climate risk and vulnerability assessment are proportionate to the scale of the activity and its expected lifespan.

3. The climate projections and assessment of impacts are based on best practices and available guidance and take into account the state-of-the-art science for vulnerability and risk analysis and related methodologies in line with the most recent Intergovernmental Panel on Climate Change reports, scientific peer-reviewed publications and open source or paid models.

4. The adaptation solutions implemented: do not adversely affect the adaptation efforts or the level of resilience to physical climate risks of other people, of

nature, of cultural heritage, of assets and other economic activities; favour nature-based solutions or rely on blue or green infrastructure to the extent possible; are consistent with local, sectoral, regional or national adaptation plans and strategies; are monitored and measured against pre-defined indicators and remedial action is considered where those indicators are not met; where the solution implemented is physical and consists in an activity for which technical screening criteria have been specified in this Annex, the solution complies with the do no significant harm technical screening criteria for that activity.

3.4.8 Pre-commercial stages of advanced technologies to produce nuclear energy

It refers to the research, development, demonstration and deployment of innovative electricity generation facilities, licenced by Member States' competent authorities under applicable national law, that produce energy from nuclear processes with minimal waste from the fuel cycle.

The substantial contribution criteria are:

General criteria pertaining to a substantial contribution to climate change mitigation and Do no significant harm ('DNSH')

1. The project related to the economic activity ('the project') is located in a Member State which complies with all of the following:

    a) The Member State has fully transposed Council Directive 2009/71/Euratom(205) and Council Directive 2011/70/Euratom(206);

    b) the Member State complies with the Treaty establishing the European Atomic Energy Community ('Euratom Treaty') and with legislation adopted on its basis, in particular, Directive 2009/71/Euratom, Directive 2011/70/Euratom and Council Directive 2013/59/Euratom(207), as well as applicable Union environmental law adopted under Article 192 TFEU, in particular, Directive 2011/92/EU of the European Parliament and of the Council(208) and Directive 2000/60/EC of the European Parliament and of the Council(209);

    c) the Member State has in place, as of the approval date of the project, a radioactive waste management fund and a nuclear decommissioning fund which can be combined;

    d) the Member State has demonstrated that it will have resources available at the end of the estimated useful life of the nuclear power plant corresponding to the estimated cost of radioactive waste management and decommissioning in compliance with Commission Recommendation 2006/851/Euratom(210);

e) the Member State has operational final disposal facilities for all very low-, low- and intermediate-level radioactive waste, notified to the Commission under Article 41 Euratom Treaty or Article 1(4) of Council Regulation (Euratom) No 2587/1999, and included in the national programme updated under Directive 2011/70/Euratom;

f) the Member State has a documented plan with detailed steps to have in operation, by 2050, a disposal facility for high-level radioactive waste describing all of the following:

   i. Concepts or programs and technical solutions for spent fuel and radioactive waste management from generation to disposal;

   ii. concepts or plans for the post-closure period of a disposal facility's lifetime, including the period during which appropriate controls are retained and the means to be employed to preserve the knowledge of that facility in the longer term;

   iii. the responsibilities for the plan implementation and the key performance indicators to monitor its progress;

   iv. cost assessments and financing schemes.

   For point (f), Member States may use plans drawn up as part of the national programme required by Articles 11 and 12 of Directive 2011/70/Euratom.

2. The project is part of a Union financed research programme, or the project has been notified to the Commission under Article 41 of the Euratom Treaty or with Article 1(4) of Council Regulation (Euratom) No 2587/1999, where either of these provisions is applicable, the Commission has given its opinion on it under Article 43 of the Euratom Treaty, and all the issues raised in the opinion, with relevance for the application of Article 10(2) and Article 17 of Regulation (EU) 2020/852, and of the technical screening criteria laid down in this Section have been satisfactorily addressed.

3. The Member State concerned has committed to report to the Commission every five years for each project on all of the following:

   a) the adequacy of the accumulated resources referred to in point 1(c);

   b) actual progress in the plan implementation referred to in point 1(f).

Based on the reports, the Commission shall review the adequacy of the accumulated resources of the radioactive waste management fund. The nuclear decommissioning fund referred to in point 1(c), and the progress in the implementation of the documented plan referred to in point 1(f). It may address the opinion of the Member State concerned.

4. The activity complies with national legislation that transposes the legislation referred to in points 1(a) and (b), including as regards the evaluation, in particular through stress tests, of the resilience of the nuclear power plants located on the territory of the European Union against extreme natural hazards, including earthquakes. Accordingly, the activity takes place on the territory of a Member State where the operator of a nuclear installation:

   a) has submitted a demonstration of nuclear safety, whose scope and level of detail are commensurate with the potential magnitude and nature of the hazard relevant to the nuclear installation and its site (Article 6, point (b), of Directive 2009/71/Euratom);

   b) has taken defence-in-depth measures to ensure, among other things, that the impact of extreme external natural and unintended man-made hazards is minimised (Article 8b(1), point (a) of Directive 2009/71/Euratom);

   c) has performed an appropriate site and installation-specific assessment when the operator concerned applies for a licence to construct or operate a nuclear power plant (Article 8c(a) of Directive 2009/71/Euratom).

5. The activity fulfils the requirements of Directive 2009/71/Euratom, supported by the latest international guidance from the International Atomic Energy Agency (‘IAEA’) and the Western European Nuclear Regulator’s Association (‘WENRA’), contributing to increasing the resilience and the ability of new and existing nuclear power plants to cope with extreme natural hazards, including floods and extreme weather conditions.

6. Radioactive waste, as referred to in points 1(e) and (f), is disposed of in the Member State in which it was generated unless there is an agreement between the Member State concerned and the Member State of destination, as established in Directive 2011/70/Euratom. In that case, the Member State of the destination has radioactive waste management and disposal programmes and a suitable disposal facility in operation in compliance with the requirements of Directive 2011/70/Euratom.

Additional criteria pertaining to a substantial contribution to climate change mitigation

1. The activity aims at generating electricity using nuclear energy. Life-cycle greenhouse gas (GHG) emissions from electricity generation from nuclear energy are below the threshold of 100 g CO2e/kWh.

2. Life-cycle GHG emission savings are calculated using Commission Recommendation 2013/179/EU or ISO 14067:2018 or ISO 14064-1:2018.

3. An independent third party verifies quantified life-cycle GHG emissions.

Regarding the do not significant harm criteria about water, the EU Taxonomy indicates that Environmental degradation risks related to preserving water quality and avoiding water stress are identified and addressed following a water use and protection management plan developed in consultation with stakeholders concerned.

To limit thermal anomalies associated with the discharge of waste heat, operators of inland nuclear power plants utilise once-through wet cooling by taking water from a river or a lake control:

a) the maximum temperature of the recipient freshwater body after mixing, and
b) the maximum temperature difference between the discharged cooling water and the recipient freshwater body.

The temperature control is implemented under the individual licence conditions for the specific operations, where applicable, or threshold values in line with Union law.

The activity complies with the Industry Foundation Classes (IFC) standards.

Nuclear activities comply with requirements on water intended for human consumption of Directive 2000/60/EC and Directive 2013/51/Euratom laying down provisions for the protection of the general public's health concerning radioactive substances in water intended for human consumption.

Regarding the do not significant harm criteria about the circular economy, the EU Taxonomy indicates that a plan for the management of both non-radioactive and radioactive waste is in place and ensures maximal reuse or recycling of such waste at the end of life under the waste hierarchy, including through contractual agreements with waste management partners, the reflection in financial projections or the official project documentation.

During operation and decommissioning, the amount of radioactive waste is minimised, and the amount of free-release materials is maximised following Directive

2011/70/Euratom and in compliance with the radiation protection requirements laid down in Directive 2013/59/Euratom.

A financing scheme is in place to ensure adequate funding for all decommissioning activities and the management of spent fuel and radioactive waste, in compliance with Directive 2011/70/Euratom and Recommendation 2006/851/Euratom.

An Environmental Impact Assessment is completed before constructing a nuclear power plant, per Directive 2011/92/EU. The required mitigation and compensatory measures are implemented.

The relevant elements in this Section are covered by Member States' reports to the Commission under Article 14(1) of Directive 2011/70/Euratom.

Regarding the do not significant harm criteria about pollution prevention, the EU Taxonomy indicates that non-radioactive emissions are within or lower than the emission levels associated with the best available techniques (BAT-AEL) ranges set out in the best available techniques (BAT) conclusions for large combustion plants. No significant cross-media effects occur.

For nuclear power plants greater than 1 MW thermal input but below the thresholds for the BAT conclusions for large combustion plants to apply, emissions are below the emission limit values set out in Annex II, part 2, to Directive (EU) 2015/2193.

Radioactive discharges to air, water bodies and ground (soil) comply with individual licence conditions for the specific operations, where applicable, or national threshold values in line with Directive 2013/51/Euratom(211) and Directive 2013/59/Euratom.

Spent fuel and radioactive waste are safely and responsibly managed under Directive 2011/70/Euratom and Directive 2013/59/Euratom.

An adequate capacity of interim storage is available for the project, while national plans for disposal are in place to minimise the duration of temporary storage, in compliance with the provision of Directive 2011/70/Euratom that considers radioactive waste storage, including long-term storage, as an interim solution, but not an alternative to disposal.

3.5 Synergistic potential

The general objective of the POTENTIALS project is to identify and assess the challenges, opportunities and impacts related to the synergistic potentials of end-of-life mine sites and coal-fired power plants (and related infrastructure), along with closely related neighbouring industries.

It will take advantage of their joint potential to stimulate new economic activities, developing jobs and economic value, especially concerning Coal Regions in Transition, and supporting the update and re-adoption of territorial just transition plans.

This goal explores business models that rely on renewable energy and contribute to the circular economy or scale energy storage, guaranteeing a sustainable and combined use of assets otherwise overlooked in the high-velocity environments of phasing out processes.

Thus, to justify the business model's choice, the synergistic potential of the different actions was considered a crucial analysis criterion.

3.6 Circular economy

According to the United States Environmental Protection Agency (EPA) (2022), a circular economy is one that "keeps materials, products, and services in circulation for as long as possible". It also refers to "an economy that uses a systems-focused approach and involves industrial processes and economic activities that are restorative or regenerative by design, enables resources used in such processes and activities to maintain their highest value for as long as possible, and aims for the elimination of waste through the superior design of materials, products, and systems (including business models)".

Examples of circular economy in the POTENTIALS project environment are as follows:

3.6.1 Mine water

From a certain depth, the temperature of the subsoil is constant regardless of the season. Thus, a continuous and accessible energy source is available all year round, just a few metres away from us in underground coal mines. The water temperature alone is not useful for heating and cooling. However, it can be processed in a geothermal heat pump, transforming the energy from low to high temperature, becoming suitable for these purposes.

On the other hand, mine water may be an essential raw material for producing green hydrogen through electrolysis.

3.6.2 Waste heap areas

Extracting or burning coal generates vast amounts of residues, and these large amounts of waste are managed on heaps. 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 are usually huge, it is possible to consider different rehabilitation and subsequent user actions. For example, these areas can be used for renewable energy generation: photovoltaic/wind, requiring the application of rehabilitation techniques that will facilitate the geotechnical stability of the renewable energy generation structures in addition to restoring the land.

3.6.3 Deep infrastructures

Coal mines, both open pit and underground, usually have deep infrastructures that can serve alternative purposes such as installing pumped hydro storage.

In the case of underground coal mines, a more compact pumped hydro energy storage system can be achieved by employing high-density fluids. The energy storage capacity is proportional to the fluid density for a given reservoir or tank volume. For example, when the high-density fluid has a density of 3x, the system's energy storage capacity is three times that when water is used. It is due to the mass flow rate being about three times more than water. Alternatively, the system can produce the same energy output using less fluid volume and less height differential between the upper and lower reservoirs.

3.6.4 Connections to the grid

One main barrier to developing new renewable energy production facilities is the connection to transmission and distribution networks.

Mines are typically connected to medium voltage lines through substations, and the lines enter directly into the substations equipped with metering equipment, transformers, and other protective equipment. This way, they can be easily adapted to inject electricity into the grid. In the case of coal-fired power plants, they have excellent connections to transmission and distribution networks.

3.7 Sector coupling

Sector coupling involves the increased integration of energy end-use and supply sectors, improving the efficiency and flexibility of the energy system as well as its reliability and adequacy. Additionally, sector coupling can reduce the costs of decarbonisation. To foster the full potential of sector coupling in several end-use and supply applications, existing techno-economic, policy and regulatory barriers must be removed. Furthermore, a more integrated approach to energy systems planning is needed (European Parliament, 2018).

Sector coupling is a concept that has been developed in Germany but has been gaining attention elsewhere in Europe. Originally, sector coupling referred primarily to the electrification of end-use sectors like heating and transport, intending to increase the share of renewable energy in these sectors (on the assumption that the electricity supply is, or can be, largely renewable) and providing balancing services to the power sector.

More recently, sector coupling has broadened to include supply-side sector coupling. Supply-side integration focuses on integrating the power and gas sectors through technologies such as power-to-gas. The European Commission also uses this broader notion of sector coupling and understands it as a strategy to provide greater flexibility to the energy system so that decarbonisation can be more cost-effective.

This broad definition of sector coupling is very similar to that of energy system integration, which has been defined as: "*the process of coordinating the operation and planning of energy systems across multiple pathways and geographical scales to deliver reliable, cost-effective energy services with minimal impact on the environment*".

According to Clean Energy Wire (https://www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system), "*sector coupling refers to the idea of interconnecting (integrating) the energy consuming sectors - buildings (heating and cooling), transport, and industry - with the power producing sector*".

4 Justifying the business models choice

4.1 Molten salt plants

The Molten salt plants (MSP) have the highest mean in the evaluation of actions related to policies: 14.2, having scored in two policies within the first three scores: 18.1 in the Climate policy and 13.8 in the Growth policy. However, the standard deviation is quite extensive: 3, as the Climate policy score is very high, but the score for People policy is relatively low: 10.9.

Addressing the evaluation of technical criteria, concessions, contracts, and other regulations, such as providing thermal energy after decommissioning, could be a negative aspect for developing the action. Something similar happens with territorial development plans that may condition specific industrial development in areas different from waste heaps.

According to Roper et al. (2022), molten salts are mainly used for thermal energy storage when connected to a concentrated solar power (CSP) plant due to their excellent properties for heat retention. The retained heat can be used to provide heat or to provide electricity. In the case of delivering electricity, it is necessary to transform the heat via Rankine or Brayton conversion cycles. This poses a problem that must be analysed on a case-by-case basis, and much research is still needed. However, power-to-heat-to-power energy systems using molten salts may give a total end-use ration of 87.4% (68.2% heat and 19.2% power), according to Bauer et al. 2021.

Thus, the TRL of power cycle coupling is still relatively low, precisely because of limited modern research, as well as because of the existence of still many chemistry challenges such as corrosion, tritium generation, and materials compatibility; the high radiation/high-temperature environment that is necessary for this technology posing a problem on the reliability of mechanical valves; the sensitivity of commercial instrumentation and control (I&C) technologies to this environment; the modelling challenges in reactor systems, etc.

Geyer (2022) also stated that with thermal energy storage systems using the technology of sensible heat (e.g., molten salts, rock material, concrete), today's market readiness is R&D/pilot.

Regarding the European taxonomy, the do not significant harm criteria about circular economy indicates that a waste management plan should be in place and ensures maximal reuse, remanufacturing or recycling at the end of life, including through contractual agreements with waste management partners, reflection in financial projections or official project documentation.

In the case of molten salts, this may pose a handicap as waste management, reuse, or recycling is not easy and cheap to achieve.

The optimal places for installing MSPs are former coal-fired power plants, as most of the areas in Europe where coal mining took place are inadequate for installing CSP plants except in the case of Spain.

The synergistic potential is high as they are a storage technology that can develop synergies with any renewable energy production.

Apart from benefiting from the connections to the grid, no other circular economy activities can be achieved with MSP.

Finally, a sector coupling between the power and the heating sectors may be achieved with this technology.

4.2 Eco-Industrial parks (with virtual power plant)

The Eco-Industrial park (with virtual power plant) has the second highest mean in the evaluation of actions related to policies: 13.8, having scored in two policies within the first three scores: 15.9 in the People policy and 12.9 in the Growth policy. Moreover, it has a slight standard deviation: 1.5, as the Climate policy score is very similar to the score for the Growth policy: 12.5.

Addressing the evaluation of technical criteria, territorial development plans may condition specific industrial development in areas different from waste heaps. Also, waste heap development constraints or hazards like fire because of the gas may compromise the reclamation and development hypothesis, such as photovoltaic/wind installations. Additionally, the flooding status of the mine may also condition geothermal developments.

TRL of the two leading technologies involved in eco-industrial parks are high: photovoltaic and geothermal (wind energy presents much more specific requests than photovoltaic). Addressing storage technologies, the TRL will depend on the particular technology selected. From higher to lower TRL, there are different alternatives: pumped hydro storage (PHS), Lithium-ion batteries, compressed air energy storage (CAES), redox flow batteries, unconventional pumped hydro storage (UPHS) using dense fluids, etc.

Regarding the European taxonomy and addressing photovoltaic energy, no substantial contribution criteria are foreseen, and regarding the do not significant harm criteria about the circular economy, the activity assesses the availability of and, where feasible, uses equipment and components of high durability and recyclability and that is easy to dismantle and refurbish, something straightforward to achieve.

In the production of heat/cool from geothermal energy, the only consideration is that life-cycle greenhouse gas (GHG) emissions from the generation of heat/cool from geothermal energy have to be lower than 100gCO_2e/kWh.

With the storage of electricity and regarding the do not significant harm criteria about water, the EU Taxonomy indicates that in case of pumped hydropower storage not connected to a river body, the activity complies with the requirements set out in Appendix B to Annex I.

In the case of pumped hydropower storage connected to a river body, the activity complies with the criteria for DNSH to sustainable use and protection of water and marine resources specified in the electricity production from hydropower.

Regarding the do not significant harm criteria about the circular economy, the EU Taxonomy for the storage of energy indicates that a waste management plan is in place and ensures maximal reuse or recycling at the end of life following the waste hierarchy, including through contractual agreements with waste management partners, reflection in financial projections or official project documentation.

However, these requirements do not pose particular difficulties at all.

The optimal places for installing Eco-industrial parks (with virtual power plant) are end-of-life coal mines according to the possibility of developing geothermal energy. However, the whole concept can be extended to coal-fired power plants and closely related neighbouring industries.

Regarding circular economy activities that can be achieved by employing eco-industrial parks, many of them can be considered: mine water for geothermal energy; waste heap areas for photovoltaic/wind; deep infrastructures for pumped hydro storage both with water or with dense fluids; and connections to the grid to buy/sell electricity.

Finally, sector coupling is achieved by interconnecting (integrating) buildings and industry heating and cooling from geothermal energy with the power production sector via photovoltaic/wind, giving greater flexibility to the energy system so that decarbonisation can be more cost-effective.

This broad definition of sector coupling is very similar to that of energy system integration, which has been defined as: "*the process of coordinating the operation and planning of energy systems across multiple pathways and geographical scales to deliver reliable, cost-effective energy services with minimal impact on the environment*".

According to Clean Energy Wire (https://www.cleanenergywire.org/factsheets/sector-coupling-shaping-integrated-renewable-power-system), "*sector coupling refers to the* *idea of interconnecting (integrating) the energy consuming sectors - buildings (heating and cooling), transport, and industry - with the power producing sector*".

4.3 Biofuels (combustion)

Biofuels have the third higher mean in the evaluation of actions related to policies, with two scores among the first three: 13.2 in the Growth policy and 12.4 in the People policy. Moreover, the standard deviation is minimal: 1.1, with the score for the Climate policy even higher than the other ones: 15.0.

Addressing the evaluation of technical criteria, territorial development plans may condition specific industrial development in areas different from waste heaps.

Electricity generation from biofuels has very high TRLs. Also, the incineration or co-incineration of municipal waste with energy recovery.

Regarding the European taxonomy, both the substantial contribution criteria and the do not significant harm criteria about pollution prevention has specific restrictions, sometimes according to the power of the plants (MW), related to the material used in the activity; the greenhouse emissions savings; the emissions levels; the generation technologies; the electrical efficiency; and the use of carbon capture and storage. Moreover, agricultural and forest biomass poses a significant problem related to the availability of these fuels in Europe, being in most cases dependent on imports.

The optimal places for energy generation from biofuels are former coal-fired power plants. Considering this, the synergistic potential with end-of-life mine sites and closely related neighbouring industries is inexistent.

Apart from benefiting from the connections to the grid, no other circular economy activities can be achieved with biofuels.

Finally, no specific sector coupling may be achieved with this technology.

4.4 Biofuels (production)

Another focus can be on manufacturing biofuels, liquid or gaseous transport fuels, such as biodiesel and bioethanol, made from biomass. They serve as a renewable alternative to fossil fuels in the EU's transport sector, helping to reduce greenhouse gas emissions and improve the EU's security of supply. This alternative was not previously foreseen, but after a meeting with the Polish coal-fired power plant association, it was suggested as an exciting opportunity. That is why it was introduced in this analysis.

As in the case of biofuel combustion, territorial development plans may condition specific industrial development in areas different from waste heaps. Also, biofuel production has very high TRLs.

However, while biofuels are essential in helping the EU meet its greenhouse gas reduction targets, biofuel production typically takes place on cropland previously used for agriculture to grow food or feed. Since this agricultural production is still necessary, biofuel production may lead to the extension of agricultural land into non-crop land, possibly including areas with high carbon stock, such as forests, wetlands and peatlands. This process is known as indirect land use change (ILUC). As it may cause the release of CO2 stored in trees and soil, ILUC poses a risk to the greenhouse gas savings resulting from increased biofuel production.

Regarding the European taxonomy, the do not significant harm criteria about pollution prevention has specific restrictions: a gas-tight cover on the digestate storage is applied for biogas production. For anaerobic digestion plants treating over 100 tonnes per day, emissions to air and water are within or lower than the emission levels associated with the best available techniques (BAT-AEL) ranges set for anaerobic treatment of waste in the latest relevant best available techniques (BAT) conclusions, including the best available techniques (BAT) conclusions for waste treatment. No significant cross-media effects occur.

In the case of anaerobic digestion of organic material, where the produced digestate is used as fertiliser or soil improver, either directly or after composting or any other treatment, it has to meet the requirements for fertilising materials set out in Component Material Categories (CMC) 4 and 5 for digestate or CMC 3 for compost, as applicable, in Annex II to Regulation EU 2019/1009 or national rules on fertilisers or soil improvers for agricultural use.

The optimal places for biofuel production are former coal-fired power plants. Considering this, the synergistic potential with end-of-life mine sites and closely related neighbouring industries is inexistent.

Apart from benefiting from the connections to the grid, no other circular economy activities can be achieved with biofuels.

Finally, sector coupling with the transport sector is achieved with this technology.

4.5 Small modular reactors

Small modular reactors (SMRs) are the fourth action in the classification according to the evaluation related to policies: 13.7, with only one score among the three first ones. The score in the People policy is the second of all, and the standard deviation of the scores is low: 1.4, as the Climate policy scores 14.2 and the Growth policy scores 11.7.

Addressing the evaluation of technical criteria, no specific conditions were specified. Due to safety reasons, the requirements start with political decisions that are very difficult to achieve and to very detailed location constraints.

According to Liu (2014), the TRLs of the different parts of an SMR are TRL 7 for the steam generator; TRL 8-9 for the primary coolant pump; TRL 7 for the fuel and core; and TRL 7 for the engineered safety features. They estimated that ten years would be necessary to lift the TRL to 9. Thus, we are focusing on a non-mature technology.

Regarding the European taxonomy, the name "*Pre-commercial stages of advanced technologies to produce nuclear energy*" gives a clear idea about the technology's maturity. Moreover, as with typical nuclear plants, the general criteria pertaining to a substantial contribution to climate change mitigation and do no significant harm is extensive and challenging. The same happens with the additional criteria related to a substantial contribution to climate change mitigation. Please refer to point 3.4.7 to address these requirements in detail.

The only places that may be suitable for installing SMRs are former coal-fired power plants. Considering this, the synergistic potential with end-of-life mine sites and closely related neighbouring industries is inexistent.

Apart from benefiting from the connections to the grid, no other circular economy activities can be achieved with SMRs, as underground coal mines cannot be considered for nuclear waste storage due to safety reasons related to water and terrain stability.

Finally, no specific sector coupling may be achieved with this technology.

4.6 Pumped hydroelectric storage

The pumped hydroelectric storage (PHS) analysed here refers only to former open-pit coal mines.

PHS are the fifth action in the classification according to the evaluation related to policies: 12.8. Only one score is among the first three, precisely the Climate policy: 17.2. On the other hand, the standard deviation of the scores in the higher one among all the actions considered: 3.2. The Growth policy scores an 11.5 and the People policy scores below ten: 9.6.

Addressing the evaluation of technical criteria, concessions, contracts, and other regulations after the decommissioning may be a negative aspect for developing the action. Something similar happens with territorial development plans that may condition this specific development. Also, the pumped water chemistry/quality may be a big handicap, as the water may contain hazardous substances that are toxic to the environment, such as heavy metals, radioactive elements, polychlorinated biphenyls (PCBs), etc.

The TRL of this technology is 9, so no problems will arise with its implementation.

Regarding the European taxonomy, in the case of pumped hydropower storage connected to a river body, the activity complies with the criteria for DNSH to sustainable use and protection of water and marine resources specified in the electricity production from hydropower.

One of the main problems of this technology is that it can only be implemented in particular open-pit coal mine areas, and it is not applicable anywhere else.

Again, apart from benefiting from the connections to the grid, no other circular economy activities can be achieved with PHS.

Finally, no specific sector coupling may be achieved with this technology.

4.7 Green hydrogen plant

The last action with a relatively high score when analysing policies is the green hydrogen plant: 12.6, with quite a high standard deviation of 2.7, but with all the scores above ten. The People policy has a score of 10.9, and the Growth policy has a score of 10.5.

Addressing the evaluation of technical criteria, territorial development plans may condition specific industrial development in areas different from waste heaps. Also, waste heap development constraints or hazards like fire because of the gas may compromise the reclamation and development hypothesis, such as photovoltaic/wind installations.

Producing hydrogen through alkaline electrolysis stands at an early adopted TRL of 9.

Regarding the European taxonomy, the substantial contribution criteria are related to the life-cycle GHG emissions savings requirement that in the case of green hydrogen is 73.4%, resulting in life-cycle GHG emissions lower than three tCO_2e/tH_2, something not especially difficult for the green hydrogen.

The optimal places for installing green hydrogen plants are end-of-life coal mines. However, the whole concept can be extended to coal-fired power plants and feed closely related neighbouring industries.

Circular economy activities can be derived by coupling, for example, electrolysers with geothermal energy production to recover the residual heat from the electrolysers and inject it into the geothermal circuit.

Moreover, mine water can feed the electrolysers after undergoing a reverse osmosis and deionisation process, which is only possible with good water qualities. Also, using pumped hydropower storage to facilitate the use of renewable energy during a more extended period, something beneficial for the electrolysers, is another example of a circular economy.

Several sector couplings are possible in this action: with the heating and cooling sector via the previously explained hybridisation between electrolysers and geothermal district heating; also, via blending part of the hydrogen into the existing natural gas grid, and finally, by coupling with the transport sector via hydrogen storage and transportation to a hydrogen refuelling station, helping to decarbonise transport by road.

4.8 Micro-actions

The micro-actions with a high score related to policies are the following ones:

1. Geothermal.
2. Dense fluids hydro pumping.
3. Hydro pumping storage.
4. Batteries.

Geothermal energy is the micro action with the higher punctuation in the three policies, as well as the higher mean: 15.5. Moreover, it has the lower standard deviation of these four technologies: 3. Thus, also taken into account its TRL of 9, this technology should always be considered when technically and economically feasible in the future development scenarios of end-of-life underground coal mines.

Batteries should be considered for energy storage, as they have the second higher TRL from the analysed storage technologies. They can also support the transitional states of other energy storage technologies. Relating energy storage via pumping, dense fluids hydro pumping is better positioned than hydro pumping storage, with the same mean but a more significant standard deviation. Nevertheless, as both technologies are still in intermediate TRLs and the technical requisites for both are sensibly different, starting with the flooding situation of the pit, their selection will depend more upon the specific site characteristics than any other thing.

4.9 Business model choice

According to the aspects analysed within the justification approach: Green Deal policies, technical criteria, TRL, European taxonomy, synergistic potential, circular economy and sector coupling, Eco-industrial parks (with virtual power plant) are the most appropriate and exciting business model choice to be selected, according to the punctuation that was given to the different aspects, following the previous explanations (Figure 4-1).

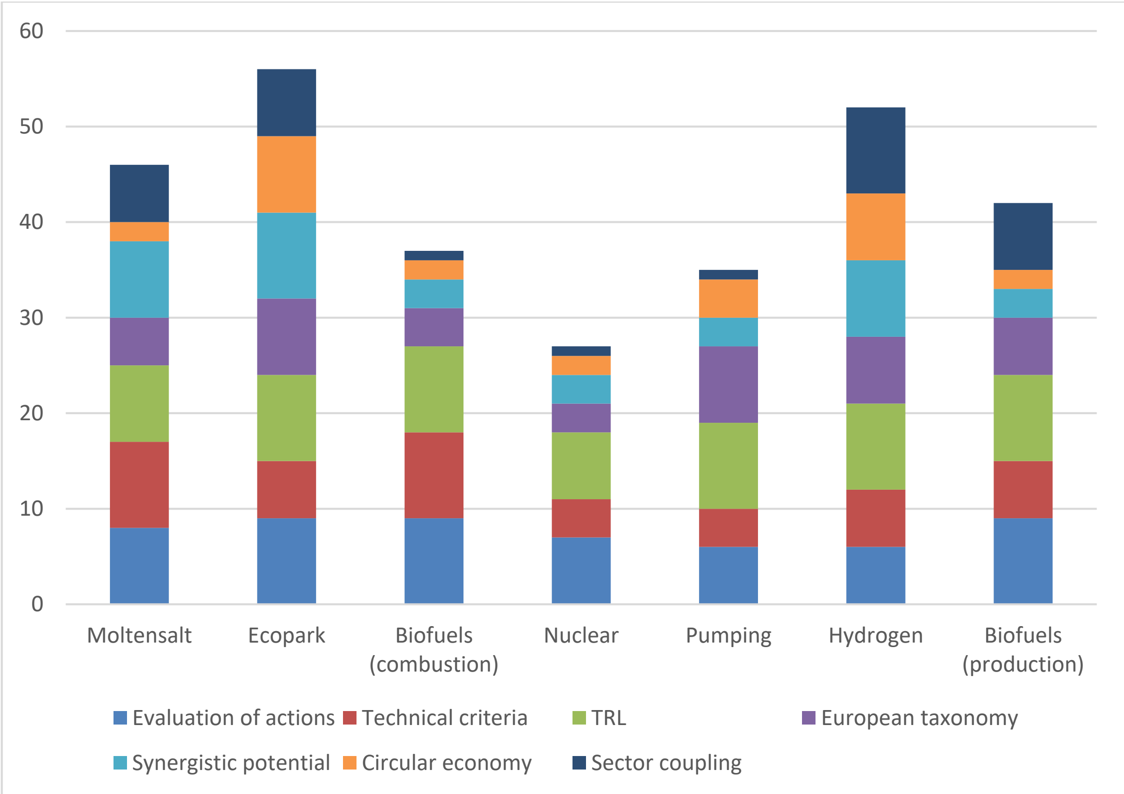

Figure 4-1. Business model choice punctuation

The action refers to an integrated alternative for sustainable energy generation technologies and circular economy contributions at these sites. The main objective of industrial parks is to reduce waste and pollution by promoting short-distance transport and optimising material, resource, and energy flows within the industrial parks. Sustainable energy generation technologies comprise solar and wind energy production with energy storage and geothermal energy to provide cooling/heating to the companies/industries participating in the Eco-industrial park.

They had the second mean in the evaluation of actions, high TRLs of the technologies involved (photovoltaic and geothermal), no problematic requirements regarding the European taxonomy, an exciting contribution to the circular economy and a high level of sector coupling.

Eco-industrial parks (with virtual power plant) may be complemented with a green hydrogen plant, according to their high TRL, provided that specific economic subventions are obtained to achieve balanced financial results. Another possibility is combining them with a Molten salt plant as a storage option that may complement geothermal energy production.

Eco-industrial parks (with virtual power plant) should be supported by pursuing financial privileges and other benefits to boost and diversify the economy of the area, attracting external investment: tax exemptions for businesses, access to preferential credits from National authorities, European Investment Bank, European Bank for Reconstruction and Development, EU; local business support institutions, and others.

4.10 Micro-actions choice

Undergoing a similar punctuation process according to the aspects considered within the justification approach: Green Deal policies, technical criteria, TRL, European taxonomy, synergistic potential, circular economy and sector coupling, Figure 4-2 presents the Micro-actions classification.

Geothermal energy is the most appropriate and exciting micro-action choice to be selected. However, although batteries are situated far below geothermal energy, they should be considered for energy storage, as they are the first technology in this area. Batteries are closely followed by the two pumping technologies: dense fluids and hydro pumping, with lower TRLs in both cases.

As pumping technologies increase their TRLs in the future, they will probably surpass batteries, and the scenario may radically change.

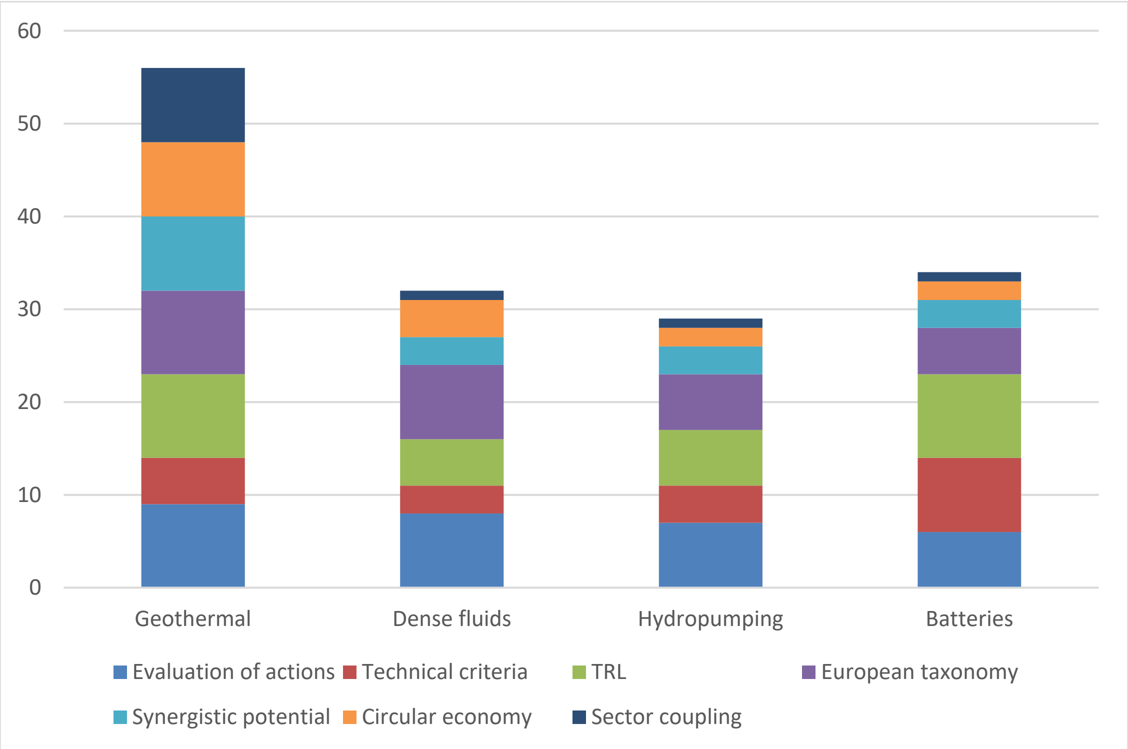

Figure 4-2. Micro-actions choice punctuation

5 Phases of the coal sector transition

In this chapter, coal sector transition phases are analysed, as well as the timeline for ceasing or scaling down these activities.

The *Managing Coal Mine Closure, Achieving a Just Transition* (World Bank, 2018) report, in its *Pillar 3: Land and environmental remediation*, also referred to as "*environmental reclamation, and repurposing of former mining land and other assets*", indicated that comprehensive mine closure projects seek to repurpose lands and ensure adequate physical mine closure:

1. Prevent negative impacts on soil, water and air resources in and near mine areas.

2. Restore the quality of soils to their pre-mining level.

3. Maintain or improve the landscape and functional quality.

It also refers to three distinct phases of the coal sector transition: (i) pre-closure; (ii) closure; and (iii) regional transformation.

Considering these antecedents and the experience achieved with several Research Fund for Coal and Steel (RFCS) projects, the phases of the coal sector transition are presented hereafter.

5.1 Pre-closure phase (preparing a closure plan)

The pre-closure phase steps are as follows:

5.1.1 Managing environmental risks

Any negative impact or environmental risks related to soil, water, air, and the surface must be analysed to manage the closure phase.

Identifying environmental risks is a multi-hazard and multi-risk process that requires integrating interrelated environmental processes and combining their effects when considering hazard identification and risk characterisation. The purpose is to provide technical guidance on the implementation of some necessary steps that should be undertaken to develop a sound and sustainable mine closure plan.

The aim is to minimise the environmental impacts and risks during the closure and post-closure periods under the general principle that the property must take responsibility and minimise all risks that can be foreseen.

In practical terms, this step should provide a planning tool that allows the design of a logical, stepwise approach to closure that can be progressively refined during the closure period and allows to address of all relevant environmental risks.

In the case of coal mines and coal-fired power plants, soil pollution impacts have been analysed to estimate the need to decontaminate certain areas.

Addressing coal mines exclusively, adequate management of environmental risks requires to analyse:

1. The effects of subsidence addressing geomechanical and surface deformation would adequately describe rock mass behaviour in a region of flooded underground coal mines. This allows obtaining the distribution of deformation indicators on the ground surface, such as displacements or stresses. In addition, the distribution of these indicators in the rock mass can be achieved.

2. The groundwater pollution impacts estimate the environmental impact associated with water rebound.

3. The surface liquid emissions and surface water pollution impacts provided the component complex concentrations in the aqueous phase, the free ion activity and the fraction of each component for each colloidal phase.

4. The greenhouse gas emissions from closed mines on the surface determine the places of possible gas outflow to the surface.

Once these risks are analysed, identification and prioritisation of areas exposed to these risks must be developed, and risk treatment alternatives relevant to different sites and environmental conditions should be identified.

After evaluating the performance of alternative risk mitigation strategies (reducing the risk to acceptable levels) and the cost of these strategies, the most feasible alternatives should be selected together with the transitional/permanent monitoring that could guarantee a hazard level in compliance with land reuse and the use of natural resources.

5.1.2 Planning ecological restoration

Considering the analysed environmental risk and their most feasible treatments, land rehabilitation and ecological restoration of coal mining-affected areas aim to accelerate the recovery of degraded and transformed ecosystems to a good ecosystem status.

The best way of achieving this goal is to assess the contribution of these ecosystems to human well-being by employing the “ecosystem-services” concept, evaluating the consequences of alternative courses of action to ensure their capacity to provide benefits to society is not diminished while increasing the impact of rehabilitation and ecological restoration actions on society and environment, demonstrating the opportunities to improve overall public welfare.

The steps to be taken should be as follows:

1. **Assessment of ecosystem services**: after a detailed description of the area, adequate boundaries should be defined based on the existing spatial connectivity and functional cohesion. Then, a detailed field mapping of the area and a revision of the available online geospatial data has to be developed and used to delineate, categorise and map the different land covers.

2. **Generation of scenarios**: taking into account the need to improve socio-economic outcomes and to catalyse the development of new jobs, different types of land rehabilitation and ecosystem restoration actions should be considered to generate various scenarios: Recolonisation of the site by local vegetation; Commercial forestry plantations; Secondary forests using local plant species; Development for agriculture: arable land and pastures; Leisure and recreational purposes: museums and recreation areas; Areas for physical recreation; Space for wildlife and nature conservation; Development of artificial water bodies, e.g., lakes, reservoirs, streams, etc.; Renewable energy generation: photovoltaic and wind power; Industrial areas and business facilities; Residential areas, etc. Particular emphasis should be given to consultation of scenarios with stakeholders (local authorities, neighbourhood associations, the coal mining industry, trade unions, and environmental NGOs) to guarantee the success of the whole process.

3. **Evaluating ecosystem services**: The relevance of the ecosystem services (ES) should be guided by the importance of the respective ecosystem services for the post-mining development of the specific landscape. The relevant ES have to provide economic alternatives for the mining-based economy and support the financial viability of the transformation process. The relevance of the regulating services is guided by the environmental conditions from the transformed mining landscape, which must be regulated to support the living conditions in the post-mining area. The cultural services relevant to the study area should contribute to the aesthetic restoration of the post-industrial landscape and can also provide economic opportunities based on the touristic attractiveness of the reclaimed post-mining landscape. Finally, the provisioning services in the assessment represent the base for economic alternatives to the mining-related economy. For each ES, the following information has to be collected: ES indicator, measuring

methods, scientific references, primary data sources, type of valuation and sources of uncertainty.

4. **Cost-benefit assessment**: The objective is to develop a cost-benefit evaluation of the different scenarios by quantifying the costs and economic value of the ecosystem services provision to determine which scenarios will deliver the most significant benefits concerning their costs. The net present value (NPV) for every generated scenario has to be estimated so that net economic consequences in the ecosystem services provision can be established. Including uncertainty issues in the cost-benefit assessment to consider the limitations of valuation techniques in situations of radical uncertainty will help investigate the whole process's robustness.

5.1.3 Evaluating business models

Based on the result of the previous steps and to stimulate new economic activities and jobs in Coal Regions in Transition, sound management decisions should be based on a prospective analysis of business models that rely on renewable energy, contribute to the circular economy or scale energy storage, guaranteeing a sustainable and combined use of assets and resources, otherwise overlooked in these high-velocity environments of phasing out processes.

5.1.4 Developing a business plan

Finally, an innovative business plan for each business model selected has to be developed.

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 essential to attract investors before a business establishes a proven track record, and they are also a good way for companies to keep themselves on target going forward.

The business plans should 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.

They should also include cash flow projections, income statements and balance sheets projections, a break-even calculation and expected financial results (net present value, internal rate of return and payback period) from this data. They should also consider the company's anticipated financial capital structure in line with its expectations of third-party financing.

Together with the business plans, it should be necessary to address the skill gaps of former coal mining workers to establish the workforce's training and re-skilling needs to facilitate the development of the envisaged business alternatives and other small businesses that can be uptaken by the laid-off workers. The results could be: (a) guidelines for planning or updating curricula to upgrade skills, and (b) develop new skills at different educational levels: vocational schools and apprenticeships, continuing education and training at all levels, and university-level courses.

5.2 Closure phase (implementing the closure plan)

The implementation of the closure plan should start with the restoration of the areas according to the planning for ecological restoration.

Artificial soil substitutes could help rehabilitate highly acidic waste heaps while facilitating the conversion of by-products and substances considered "non-valuable" wastes into valuable products (circular economy).

Dismantling obsolete installations, decontaminating polluted areas, and flooding the pits (if necessary or foreseen in the case of underground coal mines) are also implemented in this closure phase. However, the process of flooding the pits in the case of underground coal mines may take several years, so it could happen that the flooding should continue during the post-closure phase.

It has to be highlighted that some technologies that could be considered in the pre-closure phase may require implementing infrastructure to be developed previously to flood the pits.

Simultaneously, training and re-skilling programmes must be developed to facilitate upgrading/new skills and the transfer from former coal-related occupations. Also, offering the laid-off workers small business support services that respond to local demand for goods and services (World Bank, 2018).

During this closure phase, investors should seek to develop the business models foreseen during the post-closure phase. This action should be supported by pursuing financial privileges and other benefits to boost and diversify the economy of the area, attracting external investment: tax exemptions for businesses, access to preferential credits from National authorities, European Investment Bank, European Bank for Reconstruction and Development, EU; local business support institutions, and others.

5.3 Post-closure phase (regional transformation)

In this final phase, the selected business models should be fully developed and continue with long-term economic diversification to achieve the foreseen regional transformation.

5.4 Timeline for ceasing or scaling down activities

The timeline for ceasing or scaling down activities may vary according to the specific conditions of the area. However, according to Krzemień et al. (2016), five years should be the appropriate timeframe to develop the pre-closure phase. As it is not possible in many cases to foresee the closure of the mine with such anticipation, a two years period should be the minimum requirement to undergo this phase.

6 Outline of the expected transition process

An outline of the expected transition process towards the Union's 2030 targets for energy and climate and a climate-neutral economy of the Union by 2050, in line with the objectives of the integrated national energy and climate plans and other existing transition plans, is developed in this chapter, based on the business model choices justification previously implemented.

The outline is based on the Regulation of the EU on the Governance of the Energy Union and Climate Action, which applies to the five dimensions of the Energy Union, which are closely related and mutually reinforcing, that each Member State should set out in its integrated national energy and climate plan (European Union, 2018).

6.1 Energy security

National objectives concerning (a) increasing the diversification of energy sources and supply from third countries, the purpose of which may be to reduce energy import dependency; (b) increasing the flexibility of the national energy system; and (c) addressing constrained or interrupted supply of an energy source, to improve the resilience of regional and national energy systems, including a timeframe for when the objectives should be met.

6.2 Internal energy market

a) The level of electricity interconnectivity that the Member State aims for in 2030 in consideration of the electricity interconnection target for 2030 of at least 15 %, with a strategy with the level from 2021 onwards defined in close cooperation with the Member States affected, taking into account the 2020 interconnection target of 10 % and the indicators of the urgency of action based on price differential in the wholesale market, nominal transmission capacity of interconnectors concerning peak load and to installed renewable generation capacity as set out in point 2.4.1 of Section A of Part I of Annex I. Each new interconnector shall be subject to a socio-economic and environmental cost-benefit analysis and implemented only if the potential benefits outweigh the costs;

   key electricity and gas transmission infrastructure projects, and, where relevant, modernisation projects that are necessary for the achievement of objectives and targets under the five dimensions of the Energy Union; and national objectives related to other aspects of the internal energy market, such as increasing system flexibility, in particular through policies and measures related to market-based price formation in compliance with applicable law; market integration and coupling, aiming to increase the tradeable capacity of existing interconnectors, smart grids, aggregation, demand response, storage, distributed generation, mechanisms for dispatching, re-dispatching and curtailment and real-time price signals, including a timeframe for when the objectives should be met, and other national objectives related to the internal energy market as set out in point 2.4.3 of Section A of Part 1 of Annex I.

6.3 Energy efficiency

a) The indicative national energy efficiency contribution to achieving the Union's energy efficiency targets of at least 32,5 % in 2030, as referred to in Article 1(1) and Article 3(5) of Directive 2012/27/EU, based on either primary or final energy consumption, primary or final energy savings, or energy intensity. Member States shall express their contribution in terms of the absolute level of primary energy consumption and final energy consumption in 2020 and the absolute level of primary energy consumption and final energy consumption in 2030, with an indicative trajectory for that contribution from 2021 onwards. They shall explain their underlying methodology and the conversion factors used;

b) the cumulative amount of end-use energy savings to be achieved over the period 2021-2030 under point (b) of Article 7(1) on the energy saving obligations under Directive 2012/27/EU;

c) the indicative milestones of the long-term strategy for the renovation of the national stock of residential and non-residential buildings, both public and private, the roadmap with domestically established measurable progress indicators, an evidence-based estimate of expected energy savings and wider benefits, and the contributions to the Union's energy efficiency targets according to Directive 2012/27/EU following Article 2a of Directive 2010/31/EU; and

d) the total floor area to be renovated or equivalent annual energy savings to be achieved from 2021 to 2030 under Article 5 of Directive 2012/27/EU on the exemplary role of public bodies' buildings.

6.4 Decarbonisation

a) *concerning greenhouse gas emissions and removals* and to contribute to the achievement of the economy-wide Union greenhouse gas emission reduction target: the Member State's binding national target for greenhouse gas emissions and the annual binding national limits according to Regulation (EU) 2018/842; the Member State's commitments following Regulation (EU) 2018/841; and where applicable to meet the objectives and targets of the Energy Union and the long-term Union greenhouse gas emissions commitments consistent with the

Paris Agreement, other purposes and targets, including sector targets and adaptation goals;

b) *concerning renewable energy*, to achieve the Union's binding target of at least 32 % renewable energy in 2030 as referred to in Article 3 of Directive (EU) 2018/2001, a contribution to that target in terms of the Member State's share of energy from renewable sources in the final gross consumption of energy in 2030, with an indicative trajectory for that contribution from 2021 onwards. By 2022, the meaningful course shall reach a reference point of at least 18 % of the total increase in the share of energy from renewable sources between that Member State's binding 2020 national target and its contribution to the 2030 target. By 2025, the indicative trajectory shall reach a reference point of at least 43 % of the total increase in the share of energy from renewable sources between that Member State's binding 2020 national target and its contribution to the 2030 target. By 2027, the indicative trajectory shall reach a reference point of at least 65 % of the total increase in the share of energy from renewable sources between that Member State's binding 2020 national target and its contribution to the 2030 target. By 2030, the indicative trajectory shall reach at least the Member State's planned contribution. If a Member State expects to surpass its binding 2020 national target, its meaningful course may start at the level it is projected to achieve. The Member States' meaningful trajectories, taken together, shall add up to the Union reference points in 2022, 2025 and 2027 and the Union's binding target of at least 32 % renewable energy in 2030. Separately from its contribution to the Union target and its indicative trajectory for this Regulation, a Member State shall be free to indicate higher ambitions for national policy purposes.

6.5 Research, innovation and competitiveness

a) National objectives and funding targets for public and, where available, private research and innovation relating to the Energy Union, including, where appropriate, a timeframe for when the objectives should be met, reflecting the priorities of the Energy Union Strategy and, where relevant, of the SET-Plan. In setting out its goals, targets and contributions, the Member State may build upon existing national strategies or plans that are compatible with Union law; and

b) where available, national 2050 objectives related to promoting clean energy technologies.

6.6 The transition process of the proposed business model

Concerning energy security, the proposed business model of an eco-industrial park, complemented or not with the production of green hydrogen, will help increase the diversification of energy sources while improving the resilience of regional – and, by extension, national – energy systems.

Referring to the internal energy market, the proposed business model of the eco-industrial park, complemented or not with the production of green hydrogen, will help to achieve national objectives related to aspects of the internal energy market, such as increasing system flexibility.

Focusing on energy efficiency, the proposed business model will contribute to achieving the indicative milestones of the long-term strategy for renovating the national stock of residential and non-residential public and private buildings.

Addressing decarbonization, the proposed business model will help achieve the economy-wide Union greenhouse gas emission reduction target and increase the share of renewable energy from renewable sources.

Concerning renewable energy, the proposed business model will help achieve the Union's binding target of at least 32 % renewable energy in 2030 of decarbonisation.

Finally, regarding research, innovation and competitiveness objectives, eco-industrial parks may build upon existing national strategies or plans compatible with Union law and, where available, national 2050 objectives related to the promotion of clean energy technologies.

7 Conclusions and lessons learnt

Although the justification approach was initially based on evaluating actions/micro-actions related to Green Deal policies, the rest of the aspects analysed within the justification approach were crucial to select the specific action to be developed.

According to this approach, Eco-industrial parks (with virtual power plant)are the most appropriate and exciting business model choice for the considered areas. They may be complemented with a green hydrogen plant, according to their high TRL, provided that specific economic subventions are obtained to achieve balanced financial results. Eco-industrial parks (with virtual power plant) have the second mean in the evaluation of actions, high TRLs of the technologies involved (photovoltaic/wind and geothermal), no problematic requirements regarding the European taxonomy, an exciting contribution to the circular economy and a high level of sector coupling. In the second place, they may be complemented with a green hydrogen plant and even with a molten salt plant to undergo energy storage.

Eco-industrial parks for the POTENTIALS project can be defined as:

Eco-industrial parks (with virtual power plant) *as an integrated alternative to be developed within coupled end-of-life coal mine sites and coal-fired power plants along with surrounding residential/industrial areas for sustainable renewable energy generation (geothermal and photovoltaic/wind), storage technologies, circular economy contributions and synergies for reducing waste and pollution by promoting short-distance transport and optimising the park's material, resource, and energy flows, producing the goods needed for the industrial transition in Europe and cooperating to its achievement.*

Eco-industrial parks should be based on district networks that allow multiple energy sources to be connected to various energy consumption points, helping to increase photovoltaic deployment by transforming heat and power energy customers into prosumers or customers with excess electricity from solar panels on their roofs. Eco-industrial parks should be supported by pursuing financial privileges and other benefits to boost and diversify the area's economy, attracting external investment: tax exemptions for industries, access to preferential credits from National authorities, European Investment Bank, and others.

Addressing micro-actions, Geothermal energy should always be considered when technically and economically feasible in future development scenarios, together with batteries, as they have the second higher TRL from the analysed storage technologies.

Relating energy storage via pumping, dense fluids hydro pumping is better positioned than hydro pumping storage, with the same mean but a more significant standard deviation. Nevertheless, as both technologies are still in intermediate TRLs and the technical requisites for both are sensibly different, starting with the flooding situation of the pit, their selection will depend more upon the specific site characteristics than any other thing.

The lessons relevant to POTENTIALS from the business model choices justification can be summarised as follows:

1. The following aspects should be considered to select the most suitable and feasible action for a specific area: Green Deal policies, technical criteria, Technology Readiness Level (TRL), European taxonomy, synergistic potential, circular economy and sector coupling.

2. While the European taxonomy represented a pivotal aspect of justifying business model choices, technical criteria or relevant variables for scenario development were not decisive in their justification.

3. Some of the actions proposed by the experts have low Technology Readiness Levels (TRLs), effectively invalidating them as viable solutions. This is the case with Small modular reactors (SMRs). In other cases, such as floating PV panels, they are still not allowed by legislation in several European countries.

4. The timeline for ceasing or scaling down activities may vary according to the specific conditions of the area. However, although five years should be an appropriate timeframe to develop the pre-closure phase, it is not possible in many cases to foresee with such anticipation the closure of the mine, so two years may be pointed out as the minimum requirement to undergo this phase.

5. Despite the business model choice selected during the closure phase, all actions should be supported by pursuing financial privileges and other benefits to boost and diversify the area's economy, attracting external investment. Without this support, it will not be easy to achieve the pursued objectives.

6. Finally, any business model considered contributes to the achievement of the Union’s 2030 targets for energy and climate and a climate-neutral economy of the Union by 2050, in line with the objectives of the integrated national energy and climate plans.

8 Glossary

AEL – Associated emissions levels

APV – Agrophotovoltaics

BAT – Best available technique

CCGT – Combine-Cycle Gas Turbine

CAES – Compressed Air Energy Storage

CSP – Concentrated Solar Power

DNSH – Do no significant harm

EPA – United States Environmental Protection Agency

ES – Ecosystem Services

EU – European Union

GHG – Greenhouse gas

GTP – Geothermal Technologies Programme

I&C – Instrumentation and control

ILUC – Indirect land use change

IT – Information Technology

MICMAC – Software tool for structural analysis developed by the Institut d'Innovation Informatique pour l'Entreprise 3IE

MORPHOL – Software tool for morphological analysis developed by the Institut d'Innovation Informatique pour l'Entreprise 3IE

MSP – Malten Salt Plant

NASA – National Aeronautics and Space Administration

NPV – Net Present Value

PHS – Pumped Hydroelectric Storage

PCBs – Polychlorinated Biphenyls

PV – Photovoltaic

R&D – Research and Development

RE – Renewable Energy

RE H&C – Renewable Heating and Cooling

RFCS – Research Fund for Coal and Steel

SMR – Small Modular Reactors

TRL – Technology Readiness Level

UNIOVI – University of Oviedo

UPHS – Unconventional Pumped Hydro Storage

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