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

101034042-POTENTIALS-RFCS-2020

Deliverable 3.2

Scenarios classification map

European Commission

Research Fund for Coal & Steel

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Deliverable 3.2	
Due date of Deliverable	31.07.2022
Start - End Date of Project	01.07.2021 – 30.06.2023
Duration	2 years
Deliverable Lead Partner	GIG
Dissemination level	Public
Work Package	WP 3
Digital File Name	D3.2 Scenarios classification map
Keywords	Criteria, Actions, Policies, Multicriteria analysis, MULTIPOL software

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Executive summary

In this Task, a multi-criteria analysis of the previously developed scenarios (actions)was performed using MULTIPOL software.

To achieve this goal, first, it was necessary to select representative actions (scenarios) and micro-actions (micro-scenarios), among the ones developed under Task 3.1 Constructing exploratory scenarios, using morphological analysis and addressing business models that rely on renewable energy, contribute to the circular economy or scale energy storage. Mainly, the scenarios and micro-scenarios that can be developed without obtaining specific synergies from end-of-life mine sites, coal-fired power plants (and related infrastructure), and closely related neighbouring industries were not considered here.

Second, it was necessary to select several evaluation criteria 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.

Third, policies were selected directly relating to one of the Commission priorities for 2019-2024: the European Green Deal.

Once actions/micro-actions, criteria and policies were selected, the evaluation of actions/micro-actions and policies related to criteria was performed. These evaluations were also developed with the participation of POTENTIAL partners and external experts from the countries involved in the project.

The result was a rank of actions and micro-actions by policy and a closeness map between actions and micro-actions and policies that can be used to determine which actions are to be chosen whilst taking into consideration policies as well as convergences between policies and given actions.

The results obtained in this study provide a good starting point for the design of specific business models, which often will be combinations of actions and micro-actions.

1 Introduction

The general objective of the POTENTIALS Accompanying Measure 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 in transition (and related infrastructure), along with closely related neighboring industries.

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

During Task 3.1, the construction of exploratory scenarios developing business models that rely on renewable energy, contribute to the circular economy or scale energy storage was accomplished. The result of this work were the "scenarios space", characterized by all the feasible combinations of components and variables of the system.

The main objectives of this deliverable are:

- Evaluating business models option from coupled coal mines and coal-fired power plants in the process of their closure, as well as closely related neighboring industries using multicriteria assessment.
- Building a scenario classification map to creating a ranking of profiles from which the best business model options can be obtained.

Task 3.2 that will be led by GIG with the cooperation of all the partners will use multicriteria analysis as the methodology to explore possible recombination of the elements that make up the studied system.

The MORPHOL tool, created by Michel Godet and Francois Bourse and developed by the Institut d'Innovation Informatique pour l'Entreprise 3IE, will be used for this purpose.

Like all other multi-criteria methods, MULTIPOL compares different actions or solutions to a problem, related to many criteria and policies. The aim of using MULTIPOL is to help in decision making by creating a simple and evolutionary analysis matrix of available actions and solutions.

MULTIPOL (acronym for MULTI-criteria and POLicy) is one of the simplest existing multi-criteria applications but by no means the least useful. It is based on the evaluation of actions through means of weighted average, similar to the evaluation of students in a class calculated according to coefficients per subject.

Classic multi-criteria approaches are used in MULTIPOL: census possible actions; analyse consequences and elaborate criteria; evaluate actions; define policies and sort actions. MULTIPOL is innovative because of its simplicity and ease in using. Hence, every action is evaluated taking into consideration each criterion with the aid of a simple scale. Evaluation is possible via either questionnaires or meetings with experts, where a consensus is necessary.

Furthermore, action evaluation is not uniform in that different contexts related to the objective at hand are also taken into consideration. One of these contexts is a policy: a set of weights tuned to criteria. These sets of weights will represent different value systems for decision makers; strategic options; multiple scenarios; and evaluations including a time domain. In practice, experts assign a weight for every policy, on the basis of the criteria ensemble.

For every policy, MUTLIPOL assigns an average score to actions. With this is created a table of classification profiles compared to actions related to policies. Risk awareness relative to uncertainty or to conflicting hypotheses is attained via the action classification map, which in turn is created from the mean and standard deviation of scores obtained for each policy.

MULTIPOL is a simple method which takes into consideration uncertainty and tests the robustness of results coming from different policies. It is evolutionary thanks to its simplicity. In order to enrich the analysis, new criteria, weights and actions can be included both during and after the study. The simplicity of aggregate criteria (weighted mean) ensures the compatibility between actions.

However, if the goal becomes to create a map composed of many actions, difficulties arise in considering synergies, incompatibilities and the repeated use of selected actions. This inconvenience is found in all multi-criteria methods. A more detailed analysis is needed to overcome this obstacle, in all of these methods.

The results of MULTIPOL multicriteria analysis will be a good starting point for the design of specific business models, which often will be combinations of various actions and micro-actions.

2 Structure of the MULTIPOL method

The MULTIPOL software supports the evaluation process and helps policy makers to make decisions within different decision environments. In such a context, it evaluates the actions/micro-actions delivered by the MORPHOL software (actions), attempting at the same time to define strategic directions and choices for the effective implementation of each action (Stratigea, 2013). Another words MULTIPOL software constitutes a discrete multicriteria evaluation method, capable of dealing with qualitative information [Godet 1999, Godet 2002]. The method is used for the evaluation of alternative scenarios, integrating a participatory approach through the involvement of experts or citizens, depending on the problem at hand. The specific method is based on the evaluation of policies and actions/micro-actions by means of a weighted average, taking into consideration the uncertainty and testing the effectiveness of different policies and actions/micro-actions as to the evaluated scenarios (possible option). In general, MULTIPOL's aim is to help decision-making by drawing up a simple and evolving analysis grid of the different actions, micro-actions or other solutions available to the decision-maker [Godet 2002, Panagiotopoulous & Stratigea 2014].

The basic input of the MULTIPOL evaluation method consists of [Godet 2004, Stratigea & Giaoutzi 2012]:

- **Criteria**: defined as measurable aspects of judgment by which a dimension of the various choice possibilities under consideration can be characterized [Voogd 1983]. They are considered as the cornerstone of any evaluation process for rating the performance of alternative scenarios, policies and policy measures involved in the MULTIPOL evaluation process. Two groups of criteria were included in the analyses: technical criteria (relating to the technical aspects of closing coal mines and coal-fired power plants, developed in WP 2.3; they were not used in the multi-criteria analysis, but only in the statistical analysis) and criteria related to the scenarios for using decommissioned coal mines and coal-fired power plants developed in Task 3.1 (Figure 1).
- **Actions/Micro-actions**: defined as structured future developments [Lindgren & Bandhold 2003, Ringland 2002, Robinson 1990, Schwartz 1991], within which goal and objectives set for the system/problem at hand are achieved. The analyses included actions (which can be independently implemented in a closed coal mine and/or coal-fired power plant) and micro-actions (as an accompanying activities with actions and/or other micro-actions) developed as a morphological analysis with the MORPHOL software in Task 3.1 (Figure 1).
- **Policies**: as strategies for the achievement of goals and objectives in a specific planning exercise, which are closely relating to the political, social, economic and physical context, within which the evaluation is taking place [Stratigea &

Papadopoulou 2013b, Stratigea & Giaoutzi 2012]. Policies that directly relate to the Green Deal policy are included in the analyses (Figure 1).

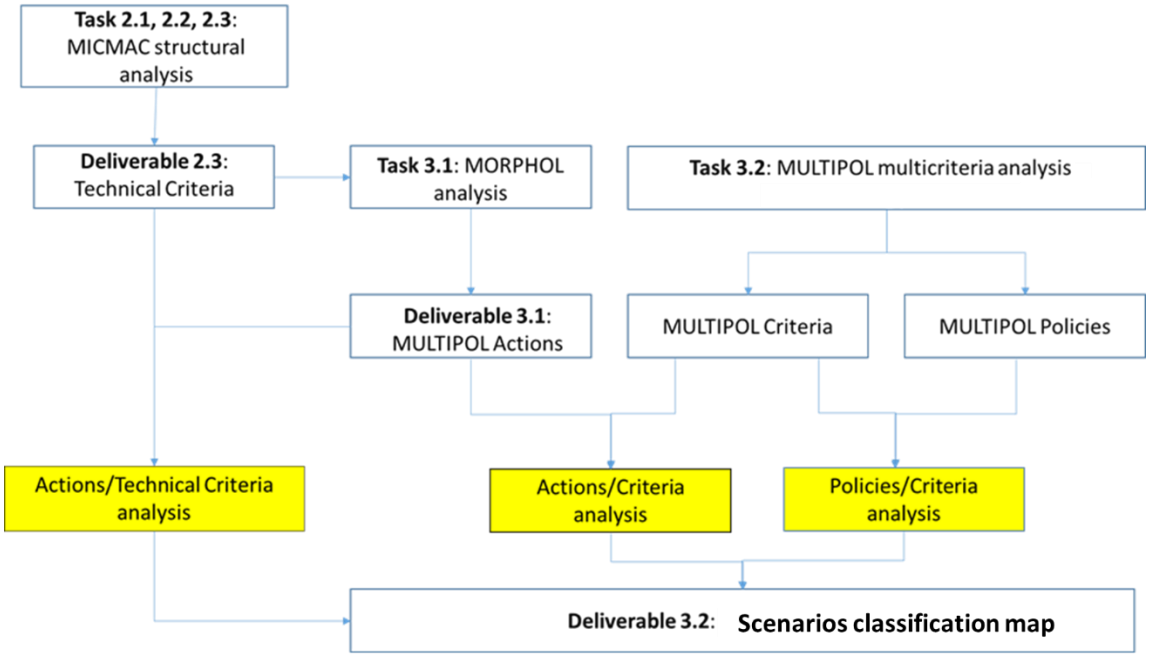

Figure 1. Scheme of actions taken under WP 3.2

Below are presented the results obtained from the MULTIPOL evaluation exercise, used for building the policy options in order to achieve the targets set. These results refer to the outcome of the evaluation of actions/micro-actions in respect of policies and the evaluation of policies in respect of actions/micro-actions.

Each multicriteria evaluation results in:

- *table of scores*, calculated by applying the set of weights of the 'matrix evaluation of actions/micro-actions related to criteria' to the 'matrix of policies related to criteria'. Other information such as the mean, standard deviations and the rank of actions/micro-actions by policy can also be found in this matrix.
- *profile map*, presenting the performance of policy measures in respect of policies and the performance of policies with respect to actions/micro-actions,
- *sensitivity map*, represents action/micro-actions score (x-axis) related to the calculated standard deviation (y-axis), and
- *closeness map* - this is achieved via Correspondence Analysis (CA). CA is a multivariate statistical technique proposed by (Dodge, 2003). It is conceptually similar to principal component analysis but applies to categorical rather than continuous data. In a similar manner to principal component analysis, it provides a means of displaying or summarizing a set of data in two-dimensional

graphical form. Its aim is to display on a two-dimensional plane any structure hidden in the multivariate setting of the data table.

3 Input data and evaluation principles

The instructions for completing all the matrices are presented in Annex 1, as follows:

- Evaluation of actions and micro-actions with respect to technical criteria.
- Evaluation of actions and micro-actions with respect to MULTIPOL criteria.
- Evaluation of policies with respect to MULTIPOL criteria.

Technical criteria refers to the criteria developed using structural analysis in *Task 2.3 Identifying the key variables*.

MULTIPOL criteria refers to evaluation criteria emanating from the goal and objectives of the study.

3.1 Input data

3.1.1 Technical criteria

The first ten technical criteria were developed using structural analysis performed with the MICMAC software in *Task 2.3 Identifying the key variables*. Technical criteria CT11 and CT12 were developed during works in *Task 3.1 Constructing exploratory scenarios* (technical criteria related to economics, which was not included in *Task 2.3 Identifying the key variables*). The technical criteria are shown in Table 1.

Table 1. Technical criteria and their descriptions

No.	Technical Criteria CT	Description
CT1	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. The character of local areas determines the kind and quantities of infrastructure facilities and connectivity, the local economic development, the ecological value and potentials of the area, etc. The characteristic of the surrounding areas will be crucial for some business opportunities.
CT2	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 provided from the surroundings of coal mines and power plants. The available area of an end-of-life coal mine and power plant that can be used for the deployment of alternative technologies is considered a major asset (apart from waste disposal areas).
CT3	Available infrastructures for new technologies/projects	The variable refers to infrastructure that may facilitate the adaptation of the power plant (internal and external). Internal infrastructure: water demineralization, water decarbonation, hydrogen cooling, turbine oil installation, desulphurization, NO_x reduction, dust reduction, ash removal, steam production, coal transportationinfrastructure, CO_2 capture installation. External infrastructure: water treatment plant, raw water pumping station, landfills, temporary storage areas, power distribution/transmission grid connection, water accessibility, road infrastructure, railway infrastructure.
CT4	Concessions, contracts and other regulations	Variable refers to obligations such as to provide thermal energy supply after the decommissioning or arising from concessions, contracts and others, which may condition the future repurposing of the coal power plant. It refers to also, the amount of time (years) during which the power plant will still have the concession for power generation, can be considered.
CT5	Land use restrictions	This variable refers to any kind of land use restrictions different from waste heaps, mainly related with territorial development plans approved by the authorities, that may condition specific industrial, commercial, business centers or residential deployments. The optimization of the areas should be based on socio-economic and environmental criteria helping to achieve sustainable development with the intention of increasing economic gains and improving environmental quality, but it is limited by present territorial development plans that, in some cases, are susceptible to be changed by the authorities.
CT6	Waste heaps physical characteristics	Variable refers to waste heap physical characteristics - geotechnical stability, angel of natural response, geomorphic shape and waste heap's height and area.
CT7	Waste heaps development constraints	Variable refers to waste heap development constraints (gas and fire hazards, status of reclamation).
CT8	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. Depending on the mining companies, extracting wastes and coal processing wastes are deposited together or separately. In case that they are deposited separately, it may be possible to extract valuable substances (rare earth minerals) from coal processing wastes.
CT9	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 and to monitoring of flooded level, hydrogeological and geotechnical aspects.
CT10	Pumped water chemistry/quality	The variable determines the quality and chemistry of pumped mining water (salt, hazardous substances).
CT11	Investment costs	The variable refers to the investment costs to be taken into account when designing the use of closed coal mines/electric power plants to adapt the existing infrastructure to new economic activities (renovations, modifications, purchase of new equipment).
CT12	Returns on investments (benefits)	Returns on investment, understood not only as financial (economic) returns in the strict sense, but also environmental, and social returns.

3.1.2 MULTIPOL criteria

The evaluation taking place by use of the MULTIPOL software was based upon a number of evaluation criteria, emanating from the goal and objectives of the study. Defining criteria were the outcome of interaction among researches, external experts and the stakeholders, in the context of a participatory planning process, aiming at grasping priorities, and embodying them in the next processes. The interface in the MULTIPOL software gives access to input main criteria information:

- abbreviation (short label),
- name (long label),
- weight (the weight for all criteria was taken as '1'), and
- description.

Table 2. MULTIPOL criteria and their descriptions

No.	MULTIPOL Criteria CM	Description
CM1	**Energy security**	Reliable, affordable acces to all fuels and energy sources (IEA)
CM2	**Renewable resources (greening)**	The elimination of the use of non-renewable resources, use of renewable sources as much as technically and economically possible
CM3	**Investment cost**	Action investment cost - CAPEX (the higher cost, the more demanding investment)
CM4	**Benefits**	Economic benefits, added-value from investment
CM5	**Regional development**	Increased competitiveness of the region, prosperity, welfare, commercial and social impact on the area
CM6	**Environment**	Environmental and ecological impact
CM7	**Job creation**	Impact on employment

3.1.3 Actions and micro-actions

Actions and micro-actions were developed under *Task 3.1 Constructing exploratory scenarios* and are presented with descriptions in Table 3 (actions) and Table 4 (micro-actions). This interface in the MULTIPOL software gives access to input main actions/micro-actions information:

- abbreviation (short label),
- name (long label), and
- description.

Table 3. Actions and their descriptions

No	Short label	Long label	Description
1	A1_VIRTUAL	Virtual power plant	The action refers to the renewable energy produced (solar photovoltaic and wind power on the waste heaps, unconventional pumped hydro storage using dense fluids, geothermal energy), will be sold to the grid or used to power companies with constant energy consumption located in the near area, such as factories or green data centers.
2	A2_H2	Green hydrogen plant	The action refers to green hydrogen plant where renewable hydrogen will be produced by electrolysis of mine water and electricity from renewable sources. It is a clear alternative to selling surplus of generated renewable energy to the grid or to power industries with constant energy consumption. The energy produced will be stored and used to power electro-intensive industries located close to the area.
3	A3_ECOPARK	Eco-industrial park	The action refers to eco-industrial parks, which are 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, optimizing material, resource and energy flows within the industrial parks. Sustainable energy generation technologies comprise solar and wind energy production together with energy storage, as well as geothermal energy in order to provide cooling/heating to the companies/industries that will take part of the Eco-industrial park.
4	A4_TOURIST	Cultural heritage and sports/recreations areas using green energy	The action assumes the production of green energy at the coal mine and coal-fired power plant while adapting them for tourism purposes.
5	A5_PANELS	Floating PV panels at flooded open-pit coal mine	The action refers the use of floating PV panels at flooded open-pit coal mines. The lake water will be used for the required cooling of the floating PV panels. Possible synergies include forest restoration of the broader area, whereas extracting critical metals from mining wastes will contribute to a circular economy.

6	A6_PHS	Pumped hydroelectric storage (PHS) at former open-pit coal mines	The action refers to implementing pumped hydroelectric storage (PHS) at former open-pit coal mines. The synergies that will be developed include a wind farm and a solar power plant in the broader mining area. In addition, synergies with local customers who own small-scale solar panels will be arranged. Using wastewater in soil additives coupled with the extraction of critical metals from mining wastes will contribute to a circular economy.
7	A7_FISHES	Fisheries in flooded open-pit coal mines	The development of fisheries in flooded open-pit coal mines is an unconventional The action of incremental innovation that integrates already developed methods that have not been implemented together at a former coal mine. Energy will be generated via biogas produced by fishery residues with the anaerobic digestion method. Developing an ecotoxicity laboratory will provide constant monitoring of the water quality. The laboratory will also promote significant scientific research concerning the effects of possible hazardous substances on fish. The production of fish by-products from fish wastes, such as fish glue, oil for paints and resins, will contribute to circular economy.
8	A8_C/O_CGT	Combined-cycle gas turbine (CCGT) power plant powered by natural gas	The action refers to use of coal-fired power plant infrastructure to combined-cycle plant works to produce electricity and captures waste heat from the combined cycle and open cycle gas turbines to increase efficiency and electrical output.
9	A9_MINEGAS	Mine gas utilization for gas-powered CHP power units	The action refers to use of utilization mine gases for gas-powered CHP (Combined Heat and Power) units.
10	A10_SMR	Small modular reactors (SMRs)	The action assumes the use of coal-fired power plant/mine infrastructure to produce clean energy using small modular reactors (SMRs).
11	A11_BIOFUE	Biofuels combustion energy plant	The action refers to the change from fossil fuel combustion power plants to energy production by processing biofuels.
12	A12_SALT	Molten salt plant	Molten salt plants are using energy storage in the form of tanks with heated molten salt. They allow to smooth the fluctuation of renewable energies such as solar and wind. Nevertheless, and in order to achieve better efficiencies, they preferable should be coupled with concentrated solar power (CSP) plants where a heat transfer fluid (HTF) such as oil absorbs the energy.

13	A13_APV	Agrophotovoltaics (APV) at former open-pit coal mine areas	The action concerns the implementation of agrophotovoltaics (APV) at former open-pit coal mines. Synergies with local customers who own small-scale solar panels will be arranged. Forest restoration at the areas of the open pit mine will be considered for further reduction of GHG emissions.

Table 4. Micro-actions and their descriptions

N°	Short label	Long label	Description
1	AM1_BATT	Ancillary services provided by batteries	Ancillary services run regulatory operations in the background, performing multiple functions - monitoring, balancing and repairing the energy infrastructure. In the event of a disturbance, ancillary services work to restore values such as voltage and frequency back to their normal range. To date, a major portion of these services have primarily been performed by conventional power stations, however, in future, renewable energy providers will also have to make a contribution towards grid stability. Furthermore, seamless coordination is required between grid and plant operators." "In order to guarantee a high level of quality, reliability and security of electricity transmission and distribution, the grid operators need to work continuously to keep the frequency, voltage and load of the grid operating equipment within the permitted tolerance limits or to return them to their normal range after a disturbance. These services, which are essential for maintaining a functioning electricity supply, are called ancillary services. These are split into four different ancillary services: operational management, frequency control, voltage control and system restoration.
2	AM2_HEAPS	Recovery of resources from coal mining waste heaps	The action refers to the circular mining technology based on waste heap materials recovery. The fact that wastes are landfilled separately according to their characteristics is very important. On the other hand, it should be possible to install a material recovery plant, something that has to be permitted according to the territory development plant.
3	AM3_C2H4	Usage of methane from degasification units on closed coal mines	The action refers to use of methane from degasification units on closed coal mines.

4	AM4_WATER	Circular mining technologies for pumped water material recovery.	The action refers to the circular mining technologies The action for pumped water material recovery - should be necessary to install a mine water treatment plant and no land use restriction are foreseen.
5	AM5_FOREST	Forest restoration at former open-pit coal mines	The action refers to reforestation of the former open-pit coal mines will give several advantages that include the decrease of GHG emissions, as well as the protection against natural hazards (such as landslides and flooding events).
6	AM6_IT	Large scale IT infrastructure - power plant	The action refers to use of coal-fired power plant infrastructure for "mining" cryptocurrencies (bitcoin, stabecoin, etc) and secure data collection and storage using green energy.
7	AM7_THERMA	Geothermal energy	The action refers to the use of closed coal mines for geothermal energy production.
8	AM8_GRAVIT	Gravitricity	The action refers to gravitricity system uses heavy weight configurations in a deep shaft of closed coal mines, suspended by a number of cables, each of which is engaged with an electric winch capable of lifting its share of the weight. Electricity is stored in the form of potential energy by raising the weights. Power is then generated by lowering the weights to turn a generator.
9	AM9_FLUIDS	Dense fluids	The action refers to production and storage energy using dense fluids.
10	AM10_HPUMP	Underground hydro-pumping	The action refers to production and storage energy in the closed coal mine shafts using hydro-pumping (capacity less than 20MW).

3.1.4 Policies

Policies are presented with descriptions in Table 5, representing the policies that directly relate to one of the Commission priorities for 2019-2024: the European Green Deal. Climate change and environmental degradation are an existential threat 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.

Table 5. Policies and their descriptions

No	Short label	Long label/description
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.

This interface in the MULTIPOL software gives access to input main actions/micro-actions information:

- abbreviation (short label),
- long label (description), and
- weight (the weight for all policies was taken as '1').

3.2 Evaluating principles

3.2.1 Evaluation of technical criteria with respect to actions/micro-actions

Assessment technical criteria (CT) with respect to actions and micro-actions was performed. The impact of technical criteria (labelled CT1 to CT12) with respect to actions (labelled A1 to A13) and micro-actions (labelled from AM1 to AM10) with respect to technical criteria were evaluated. The scoring of actions/micro-actions with respect to criteria goes from “-20” (the strongest negative impact) to “0” (no impact/neutral impact), and to “+20” (the strongest positive impact).

3.2.2 Evaluation of actions/micro-actions related to MULTIPOL criteria

Evaluation of actions (labelled from A1 to A13) and micro-actions (labelled from AM 1 to AM10) related to MULTIPOL criteria (labelled from CM1 to CM7) were made. In other words, the Matrix values corresponded to actions/micro-actions evaluation with respect to MULTIPOL criteria. The scoring of actions/micro-actions with respect to criteria goes from “0” (minimum score) to “20” (maximum score).

3.2.3 Evaluation of policies related to criteria

Evaluation of policies (labelled from P1 to P3) related to MULTIPOL criteria (labelled from CM1 to CM7) were performed. In other words, the matrix values corresponded to policy evaluation with respect to MULTIPOL criteria. As this concerns the set of criteria

weights, the sum in the row must always equals 100. There is no maximum limit to the value of the weights entered – in the extreme case one weight equals 100, so the rest of the scoring is rated 0.

4 Schedule of conducted activities and scientific meetings

In order to obtain the final list of actions, micro-actions and criteria a set of workshops, both in person and online were conducted. The meetings gathered the experience of consortium partners of the project together with external experts/stakeholders.

The most important contributions are presented below.

4.1 On-line workshop on 22 July, 2022

The first meeting discussed the first version of the matrixes. Eleven technical criteria (10 criteria from Deliverable 2.3 and one, new criteria – investment cost), 4 policies and 27 scenarios (actions/micro-actions) were proposed, which can be found in Annex 2, and were sent to all Partners before meeting on 22 July, 2022.

The 27 scenarios were assigned to three groups: group 1 (scenarios that may not be feasible - red cells in Annex 2), group 2 (scenarios that complementary to other, and should be analyzed as micro-scenarios – green cells in Annex 2), and group 3 (there were doubts about their inclusion as actions – orange cells in Annex 2), and group 4 (other scenarios – white cells in Annex 2) - and then, finally, they were assigned into actions and micro-actions.

The following comments and conclusions to the first version of the matrixes with criteria, policies and actions were offered (Annex 2):

Experts from Technische Hochschule Georg Agricola (THGA) agreed on four categories of Policies, including “energy security” that was afterwards considered one of the MULTIPOL criterion. THGA proposed to denominate "economic growth" as "regional economic growth" because the experts were taking into consideration certain mine and plant locations and not the macroeconomic level. Moreover, they agreed that investment costs must be part of the list of criteria, because that is an economic necessity.

THGA experts also proposed the following changes to the definition of policies:

- Relating to "energy security" they proposed to replace the first sentence by: "Energy security is the availability to fulfill (regional/national/European) energy needs anytime.
- Relating to "job creation" they proposed an addition at the end: "... Certainly, the net effect has to take into account the job losses in the replaced conventional energy production."

- Relating to "climate mitigation" they believed it is difficult to understand the second half of the sentence, and proposed instead "... including positive effects on air quality."
- Relating to "economic growth" they proposed to add always the word "regional" before economic growth, and furthermore in the last sentence of the definition made an inclusion: "... as and so far new green jobs and their added value are place-based in the regions where the old coal mines and power plants had been and that means in a broader perspective they will be located in the EU."

At the request of THGA experts the principles of assessment and the rating scales in the matrixes were explained: for matrix criteria – action, and for matrix policy – action.

Experts from Central Mining Institute (GIG) agreed that the addition of investment costs is a good criteria, as many investments will not be realized due to very high costs, which should be estimated at this stage to avoid losses. They proposed to add also a criteria related to the immediate neighborhood of the socio-economic area, as it can be expected that, as a criteria for the implementation of this scenario, it will be necessary to secure the labor force, road infrastructure and social acceptance (the proximity of some solutions and their implementation scenarios may cause resistance from the local community).

Relating to "policies" GIG experts proposed to add space planning policies and environmental policies.

It was also suggested to combine action A26 (Biomass combustion energy plant) with action A27 (Biofuels combustion energy plant), and to combine action A5 (Cultural heritage and sports using green energy), action A21 (Green energy relax and extreme mine & plant) and action A25 (Cultural/Recreation areas).

Experts from HUNOSA pointed out the necessity to prepare a clear lists of Criteria, Policies and Actions for the external use. In this respect they thought it can be confusing to score the actions/criteria table and policies/criteria).

Experts from CERTH regarding the actions from “uncolored” cells (annex 2) agreed that, all of these are feasible, especially actions A2 (Green hydrogen plant), A6 (Floating PV panels at flooded open-pit coal mines), A7 (Agrophotovoltaics (APV) at former open-pit coal mine areas), A8 (Pumped hydroelectric storage (PHS) at former open-pit coal mines), A11 (Combined Cycle Gas Turbines - CCGT plant) , A14 (Open cycle gas turbine, block heat and power plant, gas engine), and A26 (Biomass combustion energy plant) have a high potential to be implemented.

CERTH agreed that although scenario A3 (Molten salt plant) presents the disadvantage of low efficiency of energy transformation, it is considered to be feasible. It is a technology already proven and used in Italy, Spain, U.S., China.

CERTH suggested that the following scenarios should be considered as micro-actions: A10 (Ancillary services provided by batteries), A16 (Lithium recovery form mine water), A17 (Usage of methane from degasification units on closed coal mines), A18 (Circular mining technologies based on waste heap materials recovery), A19 (Circular mining technologies scenario for pumped water material recovery), A20 (REE recovery from coal mining waste heaps), and A22 (Forest restoration at former open-pit coal mines).

CERTH proposed that A12 (Electrolysis powered by PV and/or Wind turbines, CCGT, Use of energy for recycling of minerals from pumped mine water) could be considered as an action because it provides numerous advantages, such as the production of energy via environmentally neutral sources (PV and/or Wind turbines), and the recycling of minerals from pumped mine water that contributes to circular economy.

During the meeting a consensus with respect to the criteria developed in Task 2.3. was reached, and the most important technical criteria directly related to the closure of coal mines and coal-fired power plants, criteria related to the introduction of new technologies into the plants were selected.

In summary, the following agreement were reached:

- to combine action A26 (Biomass combustion energy plant) with action A27 (Biofuels combustion energy plant);
- to combine action A5 (Cultural heritage and sports using green energy), action A21 (Green energy relax and extreme mine & plant) and action A25 (Cultural/Recreation areas);
- to combine A23 (ENERMINECOIN – mine) and A24 (ENERMINECOIN – power plant) into A24 (Large scale IT infrastructure - power plant);
- to change the following micro-actions into actions: A28 (Geothermal energy), A29 (Dense fluids), A30 (Gravitricity), and A31 (Hydro-pumping);
- to expand the area of action A11 (Combined Cycle Gas Turbines (CCGT) plant), and change the name of action A11 into Combined Cycle Gas Turbines (CCGT) plant, Open cycle gas turbines (OCGT);
- to expand the area of action A16 (Lithium recovery form mine water), and change the name of action A16 into Recovery of resources from mine water, in order to make it more generic and include all relevant technologies;
- to reduce the area of action A15 (Small modular reactors (SMRs), Open cycle gas turbines, CCGT), and change the name of A15 to Small modular reactors SMRs.

Furthermore, it was agreed that scenarios should be considered in two groups: main scenarios (actions) and accompanying/additional scenarios (micro-actions). It was also agreed that the proposed policies should be adapted to be fully compatible with the European Green Deal policy. As the technical criteria developed in Task 2.3 are related to the closure of the coal mine/coal-fired power plant itself, a consensus was reached

to introduce additional criteria that *sensu stricto* are related to the feasibility of implementing the analyzed scenarios.

4.2 Workshop on 18 August, 2022

The next meeting - internal to GIG - was held on 18 August 2022. During the meeting a first division of scenarios developed in Task 3.1 into 12 actions and 14 micro-actions was made. Also experts from different countries were proposed:

ACTIONS:

- A1 Virtual power plant (UNIOVI & HUNOSA, GIG),
- A2 Green hydrogen plant (UNIOVI&HUNOSA, GIG),
- A3 Eco-industrial park (UNIOVI&HUNOSA, GIG),
- A4 Cultural heritage and sports/recreation areas using green energy (GIG),
- A5 Floating PV panels at flooded open-pit coal mines (CERTH),
- A6 Agrophotovoltaics (APV) at former open-pit coal mine areas (CERTH),
- A7 Pumped hydroelectric storage (PHS) at former open-pit coal mines (CERTH),
- A8 Fisheries in flooded open-pit coal mines (CERTH, GIG),
- A9 Combined Cycle Gas Turbines plant. Open Cycle Gas Turbines plant (VGBE, GIG & GIG external experts),
- A10 Mine gas utilization for gas-powered CHP power units (VGBE, GIG & GIG external experts),
- A11 Open cycle gas turbine, block heat and power plant, gas engine (VGBE, GIG & GIG external experts),
- A12 Small modular reactors - SMRs (VGBE, GIG & GIG external experts).

MICRO-ACTIONS:

- AM1 Ancillary services provided by batteries (VGBE, GIG & GIG external experts),
- AM2 Molten salt plant (UNIOVI&HUNOSA),
- AM3 Recovery of resources from mine water (THGA, GIG),

- AM4 Recovery of resources from coal mining waste heaps (THGA, GIG),
- AM5 Usage of methane from degasification units on closed coal mines (THGA, GIG external experts),
- AM6 Circular mining technologies based on waste heap materials recovery (UNIOVI&HUNOSA, GIG),
- AM7 Circular mining technologies for pumped water material recovery. (UNIOVI&HUNOSA, GIG),
- AM8 Forest restoration at former open-pit coal mines (CERTH),
- AM9 Large scale IT infrastructure - power plant (GIG),
- AM10 Biofuels combustion energy plant (GIG external experts),
- AM11 Geothermal energy (UNIOVI&HUNOSA, GIG),
- AM12 Gravitricity (GIG),
- AM13 Dense fluids (UNIOVI&HUNOSA),
- AM14 Hydro-pumping (GIG).

The number of policies has also been reduced from 5 to 3 so that they are fully consistent with the European Green Deal policy:

- P1 Climate – defined as no net emissions of greenhouse gases by 2050,
- P2 Growth – defined as economic growth decoupled from fossils resources use,
- P3 People - - defined as “no person and no place behind”.

An additional economic criterion (CT 12 Returns on investments - benefits) was added to the 11 technical criteria, related to the process of coal mine and coal-fired power plant closure.

Eight criteria relating directly to the feasibility of implementing new technologies in closed coal mines and coal-fired power plants were also proposed:

- CM1 Energy security - defined as reliable, affordable access to all fuels and energy sources (IEA),

- CM2 Renewable resources (greening) – defined as the elimination of the use of non-renewable resources, use of renewable sources as much as technically and economically possible,
- CM3 Investment cost – defined as an action investment cost - CAPEX (the higher cost, the more demanding investment),
- CM4 Benefits – defined as economic benefits, added-value from investment,
- CM5 Regional development – defined as increased competitiveness of the region, prosperity, welfare, commercial and social impact on the area ,
- CM6 Spatial planning – defined as commercial and social impact on the area,
- CM7 Environment – defined as an environmental and ecological impact,
- CM8 Job creation – defined as an impact on employment.

It was decided that for the selected actions/micro-actions, evaluation should be carried out with the involvement of external experts. Due to lack of relevant experience and in order to increase the reliability of the results obtained, it was considered appropriate to include external experts in the assessment of the following actions: A8 (Combined Cycle Gas Turbines - CCGT plant. Open Cycle Gas Turbines OCGT plant), A9 (Mine gas utilization for gas-powered CHP power units), A10 (Small modular reactors SMRs), A11 (Biofuels processing energy plant), and a micro-action AM1 (Ancillary services provided by batteries).

In addition, the instructions for completing the matrixes have been prepared and revised. The manual described in detail the way of evaluation (Annex 1):

- Evaluation of actions and micro-actions with respect to technical criteria.
- Evaluation of actions and micro-actions with respect to MULTIPOL criteria.
- Evaluation of policies with respect to MULTIPOL criteria.

4.3 Workshop on 23 August, 2022

The next meeting at GIG was held on 23 August 2022. During the meeting the first analyses obtained using MULTIPOL for selected actions and micro-actions were presented.

Working meeting between GIG staff and external experts from Polish Power Plants Association and Tauron was held the same day remotely. At this meeting the matrixes

for the action A8 (Combined Cycle Gas Turbines CCGT plant. Open Cycle Gas Turbines OCGT plant) were developed. The results achieved during the expert analysis, with a brief comments, are presented in Table 6.

Table 6. Results from an expert analysis with Polish Power Plants Association and Tauron staff - Action A9

Action	Technical Criteria	Comments	Value
A8	CT1	Proximity to industry has a "positive impact" - cooperation, we have heat so we have to get it out of the way.	15
A8	CT2	Even though the area is partly occupied this is an added value.	15
A8	CT3	It would be ideal if there was a large plant next to the site that produces gas.	18
A8	CT4	This is not a relevant criterion for Poland, but in other countries, once granted a licence for a plant, it gives the possibility to continue industrial activity.	7
A8	CT5	A pipeline will be needed, which could be a problem. It should be noted that the overall restrictions for gas are less demanding.	5
A8	CT6	Criteria neutral, under the assumption that we do not need to carry out reclamation.	0
A8	CT7	Negative impact on installations.	-5
A8	CT8	No impact.	0
A8	CT9	A positive impact, water from a flooded mine is cleaner.	10
A8	CT10	A positive impact, the better water quality the more favourable.	10
A8	CT11	Cheaper than nuclear power, capital expenditure is less than for greenfield sites.	7

A8	CT12	Profits from the power market and heat sales.	10

Action	MULTIPOL Criteria	Comments	Value
A8	CM1	No comments.	20
A8	CM2	Supports greening.	10
A8	CM3	No comments.	7
A8	CM4	No comments.	10
A8	CM5	No comments.	5
A8	CM6	Lower emissions.	5
A8	CM7	No comments.	10

4.4 On-line workshop on 1 September, 2022

Next working meeting between GIG staff and external experts from Polish Power Plants Association and Tauron was held on 1 September 2022. During the workshop the matrixes for the action A11 (Small modular reactors SMRs) and micro-action AM1 (Ancillary services provided by batteries) were developed. The results achieved during the expert analysis, with a brief comments, are presented in Tables 7 and 8.

Table 7. Results from an expert analysis with Polish Power Plants Association and Tauron staff - Action A11

Action	Technical Criteria	Comments	Value
A11	CT1	It all depends on the power of the reactor (up to 300 MW).	18
A11	CT2	Infrastructure, water.	18
A11	CT3	A problem with the mine, because land deformations	18

		have to be taken into account.	
A11	CT4	Positive, it is possible to use the existing infrastructure.	5
A11	CT5	Proximity to the mine and possible ground instability are significant.	2
A11	CT6	No impact.	0
A11	CT7	No impact.	0
A11	CT8	No impact.	0
A11	CT9	Water availability 'a plus', but water may cause uplift.	15
A11	CT10	The quality of water matters.	10
A11	CT11	The positives are the availability of the grid, water and roads. Expensive investment.	7
A11	CT12	Very expensive investment.	2

Action	MULTIPOL Criteria	Comments	Value
A11	CM1	Very strong impact.	20
A11	CM2	With this technology, industry can be 'decarbonised', but it is not itself a green technology.	3
A11	CM3	No comments.	15
A11	CM4	No comments.	10
A11	CM5	Long construction time. Important investment.	15
A11	CM6	Only the risk of plant failure and waste management are relevant.	18

A11	CM7	Regional: supervision and control. Highly specialised workforce is needed.	10

Table 8. Results from an expert analysis with Polish Power Plants Association and Tauron staff – micro-action AM1

Action	Technical Criteria	Comments	Value
AM1	CT1	Indicated proximity.	15
AM1	CT2	Plenty of space.	15
AM1	CT3	Network infrastructure (connections, security) is a positive. Larger set of batteries. Network connectivity is important.	20
AM1	CT4	It is not relevant.	5
AM1	CT5	Depends on the size of the battery. The electromagnetic field is irrelevant.	5
AM1	CT6	Low and high temperatures are harmful. Due to the need for a building, the location on the heap is dropped.	0
AM1	CT7	No impact.	0
AM1	CT8	No Impact.	0
AM1	CT9	No Impact.	0
AM1	CT10	No Impact.	0
AM1	CT11	There is no need to build either a line or a building, no cost to connect to the network.	20
AM1	CT12	It will avoid problems with the system. Securing the system. Cost of avoided losses. We are currently talking about 100-200 MW of storage. High cost - not	8

		economical.	

Action	MULTIPOL Criteria	Comments	Value
AM1	CM1	A strong relationship. Stabilisation function.	20
AM1	CM2	Allows the use of more renewable (non-controlled) sources.	20
AM1	CM3	No comments.	5
AM1	CM4	No comments.	8
AM1	CM5	Low relation. More renewable sources could be used.	2
AM1	CM6	Low environmental impact. We use and recycle correctly.	1
AM1	CM7	No impact.	0

4.5 Workshop on 2 September, 2022

Working meeting between GIG staff and external expert prof. Eugeniusz Krause was held on 2 September 2022. As a result of the meeting the matrixes for the action A9 (Mine gas utilization for gas-powered CHP power units) were developed . The results achieved during the expert analysis, with a brief comments, are presented in Table 9.

Table 9. Results from an expert analysis with prof. Eugeniusz Krause - Action 9

Action	Technical Criteria	Comments	Value
A9	CT1	There must be something done with the heat received, it must be close to the consumer.	15
A9	CT2	Not much space is needed.	5

A9	CT3	Warm gas.	20
A9	CT4	Gas pipeline required.	10
A9	CT5	Slightly negative impact.	-5
A9	CT6	No impact.	0
A9	CT7	No impact.	0
A9	CT8	No impact.	0
A9	CT9	A very high level of importance.	-20
A9	CT10	No impact.	0
A9	CT11	Costly, but not as costly as SMRs	-10
A9	CT12	If pumping has to be maintained (this cost is dropped) then the return on investment is 3-4 years (operation 10-12 years).	15

Action	MULTIPOL Criteria	Comments	Value
A9	CM1	Low impact.	1
A9	CM2	No impact.	0
A9	CM3	Low impact.	5
A9	CM4	High impact.	15
A9	CM5	We have the heat.	3
A9	CM6	Surface emissions.	15

A9	CM7	Few people are needed for the service.	2

4.6 Workshop on 13 September, 2022

Working meeting between GIG staff and external expert Mr. Zbigniew Gieleciak – President of the Regional Centre for Water and Wastewater Management was held on 13 September 2022. During the workshop the matrixes for the action A11 (Biofuels combustion energy plant) were developed. The results achieved during the expert analysis, with a brief comments, are presented in Table 10.

Table 10. Results from an expert analysis with Mr. Zbigniew Gieleciak – President of the Regional Centre for Water and Wastewater Management - Action A11

Action	Technical Criteria	Comments	Value
A11	CT1	High impact, supply logistics, use of electricity (provision of consumer - energy recovery plant/center), combustion of biofuels (biodegradable/residual waste).	10
A11	CT2	Burning of wastewater sludge > 5ha, products will need to be recycled/optimized, potential for synergies.	20
A11	CT3	Access to grid, mine/fire water, biofuel delivery - rail/road infrastructure.	5
A11	CT4	New investment.	0
A11	CT5	The waste disposal site, proximity to water reservoirs.	-10
A11	CT6	No impact.	0
A11	CT7	No impact.	0
A11	CT8	No impact.	0
A11	CT9	No impact.	0

A11	CT10	Ventilation from mines/radioactivity of mine water - radon.	0
A11	CT11	Each mine has its own boiler house/chimney. It's easy to get 'hooked up' to this.	5
A11	CT12	Additional value for degraded areas. Infrastructure available, so investment return will be quicker.	7

Action	MULTIPOL Criteria	Comments	Value
A11	CM1	Increases regional/enterprise energy security.	15
A11	CM2	Depends on whether we use renewable resources or "green" waste.	15
A11	CM3	Low cost compared to other green technologies (biomass/biofuels - installation runs 24h/365 days/year - 8000 MWh/year on up to 1 ha; photovoltaics 100 MWh/year/1-1.5 ha; wind power 2200-2500 MWh/year under the assumption of wind speed > 4.5 m/s).	15
A11	CM4	Depends on the scale of the project and the potential for synergies (e.g. heating a water park).	10
A11	CM5	Increase regional development.	12
A11	CM6	High impact.	15
A11	CM7	Scale of the project/ optimization of the staff.	10

4.7 On-line Workshop on 14 September, 2022

On 14 September 2022, a workshop was held between the Partners in an on-line format. A brainstorming session resulted in the following decisions:

- Micro-action **Molten salt plant** was transferred to action group (**A12 Molten salt plant**).

- Micro-actions *Recovery of resources from coal mining waste heaps* and *Circular mining technologies based on waste heap materials recovery* were combined into micro-action **AM2 Circular mining technologies based on waste heap materials recovery**.

- Micro-actions *Recovery of resources form mine water* and *Circular mining technologies for pumped water material recovery* were combined into micro-action **AM4 Circular mining technologies for pumped water material recovery**.

- Micro-action *Hydro-pumping* was renamed **AM10 Underground hydro-pumping**.

- *Spatial planning* criteria from the MULTIPOL criteria (7 MULTIPOL criteria remain) was removed.

4.8 Workshop on 28 October, 2022

At the last meeting in GIG on 28 October 2022, the results obtained from the multi-criteria analysis were discussed. An optimization of the matrices was performed by analyzing the results for similar technologies. By consensus, it was considered that the results for similar technologies could not diverge significantly from each other. The amendments are shown in tables 11 and 12 and were sent out to the Project Partners for verification.

Table 11. Results of revisions of Actions - MULTIPOL criteria

Action-MULTIPOL Criteria	Comments	Old value	New value
A5-CM1	Value for action 5 should not be different with respect to action 1 (both use PV panels).	15	10
A6-CM1	PHS in open-coal mines is a proven technology for energy storage so the value should be higher.	10	20
A7-CM1	This value was lowered as experts were not able to give a proof of this action on influence on energy security.	5	0
A8-CM1	Due to the current situation with gas (geopolitical context) it was proposed to lower value to 15.	20	15

A12-CM1	Proven technology for energy storage so value 20 is proposed to keep it at the same level as A10 and A6.	18	20
A13-CM3	It cannot be so different in respect to A1 and A5.	0	8
A5-CM4	Should be in the line with the benefits of A1 and A13.	15	8
A6-CM4	The value was lowered compared with SMRs.	15	10
A9-CM4	The value was lowered compared with SMRs.	15	10
A13-CM4	Should be in the line with the benefits of A1 and A9.	15	10
A6-CM5	PHS is implemented at open-coal mine which are in the most cases far from cities.	15	10
A5-CM7	Changed to be in the line with the value for action A13.	10	10
A6-CM7	Changed to be in the line with the value for action A13.	10	10
A7-CM7	Changed to be in the line with the value for action A13.	15	10

Table 12. Results of revisions of Micro-actions - MULTIPOL criteria

Micro-actions – MULTIPOL criteria	**Comments**	**Old value**	**New value**
MA3-CM1	This technology does not secure such a high energy security in comparison to other storage technologies.	15	5
MA3-CM2	This value was lowered in comparison with other greening technologies.	15	5
MA10-CM4	During the normalisation process (comparison with other actions) it was decided to lower the value to 10.	20	10
MA3-CM5	During the normalisation process (comparison with other actions) it was decided to lower the value to 10.	15	10
MA5-CM5	After consensus meeting it was decided that there is an impact of this action to the regional development.	0	5

Experts from CERTH proposed for action A7 (Fisheries in flooded open-pit coal mines) to increase the value given to criteria CM1 zero to 1 as, "Energy will be generated via biogas produced by fishery residues with the anaerobic digestion method".

By consensus, the remarks were accepted.

The final, consensus-based input to the MULTIPOL multi-criteria analysis from all partners and external experts is presented below (Tables 13-15).

Table 13. Evaluation of ACTIONS with respect to MULTIPOL CRITERIA

Actions / MULTIPOL Criteria		Actions short label	Consensus values						
			CM1	**CM2**	**CM3**	**CM4**	**CM5**	**CM6**	**CM7**
			Energy security	**Renewable resources (greening)**	**Low investment barriers**	**Benefits**	**Regional development**	**Environment**	**Job creation**
A1	Virtual power plant	A1_VIRTUAL	10	20	8	10	10	15	3
A2	Green hydrogen plant	A2_H2	15	20	4	5	20	20	5
A3	Eco-industrial park	A3_ECOPARK	10	15	10	5	17	15	20
A4	Cultural heritage and sports/recreation areas using green energy	A4_TOURIST	5	5	10	5	15	20	5
A5	Floating PV panels at flooded open-pit coal mines.	A5_PANELS	10	15	10	8	10	15	5
A6	Pumped hydroelectric storage (PHS) at former open-pit coal mines	A6_PHS	20	20	7	10	10	15	5
A7	Fisheries in flooded open-pit coal mines	A7_FISHES	1	5	12	10	10	10	8
A8	Combined Cycle Gas Turbines (CCGT) plant. Open Cycle Gas Turbines (OCGT)	A8_C/O_CGT	15	10	13	10	5	5	10
A9	Mine gas utilization for gas-powered CHP power units	A9_MINEGAS	1	0	15	10	3	15	2
A10	Small modular reactors (SMRs)	A10_SMR	20	3	2	10	20	18	15
A11	Biofuels processing energy plant	A11_BIOFUE	15	15	15	10	12	15	10
A12	Molten salt plant	A12_SALT	20	20	16	10	10	15	5
A13	Agrophotovoltaics (APV) at former open-pit coal mine areas	A13_APV	15	20	8	10	10	15	8

Table 14. Evaluation of MICRO-ACTIONS with respect to MULTIPOL CRITERIA

Micro-actions / MULTIPOL Criteria		Micro-actions short label	Consensus values						
			CM1	**CM2**	**CM3**	**CM4**	**CM5**	**CM6**	**CM7**
			Energy security	**Renewable resources (greening)**	**Low investment barriers**	**Benefits**	**Regional development**	**Environment**	**Job creation**
AM1	Ancillary services provided by batteries	AM1_BATT	20	20	15	8	2	1	0
AM2	Circular mining technologies based on waste heap materials recovery	AM2_HEAPS	0	0	10	10	10	16	5
AM3	Usage of methane from degasification units on closed coal mines	AM3_C2H4	5	5	10	10	10	15	5
AM4	Circular mining technologies for pumped water material recovery	AM4_WATER	0	10	10	3	7	15	5
AM5	Forest restoration at former open-pit coal mines	AM5_FOREST	0	0	15	10	5	20	5
AM6	Large scale IT infrastructure - power plant	AM6_IT	0	5	15	15	0	5	0
AM7	Geothermal energy	AM7_THERMA	20	20	16	10	15	20	5
AM8	Gravitricity	AM8_GRAVIT	15	15	2	5	10	10	5
AM9	Dense fluids	AM9_FLUIDS	20	20	5	10	5	20	5
AM10	Underground hydropumping	AM10_HPUMP	20	20	2	10	10	20	5

Table 15. Evaluation of POLICIES with respect to MULTIPOL CRITERIA

Policies \ Criteria		CM1 Energy security	CM2 Renewable resources (greening)	CM3 Investment cost	CM4 Benefits	CM5 Regional development	CM6 Environment	CM7 Job creation	SUM
P1	**Climate** (No net emissions of greenhouse gases by 2050)	40	20	10	0	0	30	0	100
P2	**Growth** (Economic growth decoulped from fossils resources use)	20	10	25	10	10	5	20	100
P3	**People** (No person and no place left behind)	15	0	15	0	20	10	40	100

5 Result of analysis and discussion of the results

5.1 Result for the analysis technical criteria and actions/micro-actions

Tables 16 . Result for the analysis technical criteria and actions

Actions / Technical Criteria		CT1 Character of the local area / proximity to industry	CT2 Available space for new technologies/projects	CT3 Available infrastructures for new technologies/projects	CT4 Concessions, contracts and other regulations	CT5 Land use restrictions	CT6 Waste heaps physical characteristics	CT7 Waste heaps development constraints	CT8 Material type deposited on the waste heaps	CT9 Flooding status of the mine	CT10 Pumped water chemistry/quality	CT11 Investment costs with respect to greenfield	CT12 Returns on investments (benefits)
A1_VIRTUAL	Virtual power plant	10	20	20	20	-12	0	-20	0	0	0	0	0
A2_H2	Green hydrogen plant	20	20	20	20	-15	0	-15	0	0	15	-20	10
A3_ECOPARK	Eco-industrial park	15	10	10	5	-15	0	-15	0	-5	10	-10	10
A4_TOURIST	Cultural heritage and sports/recreation areas using green energy	0	5	10	-10	-10	-5	-10	0	0	0	-10	-10
A5_PANELS	Floating PV panels at flooded open-pit coal mines	15	20	20	-10	-5	0	0	10	20	-10	-10	15
A6_PHS	Pumped hydroelectric storage (PHS) at former open-pit coal mines	15	20	20	-10	-5	0	0	5	10	-10	-13	15
A7_FISHES	Fisheries in flooded open-pit coal mines	15	20	20	-15	-5	-5	0	10	20	-20	-8	10
A8_C/O_CGT	Combined Cycle Gas Turbines (CCGT) plant. Open Cycle Gas Turbines (OCGT)	15	15	18	7	5	0	-5	0	10	10	7	10
A9_MINEGAS	Mine gas utilization for gas-powered CHP power units	15	5	20	10	-5	0	0	0	-20	0	-10	15
A10_SMR	Small modular reactors (SMRs)	18	18	18	5	2	0	0	0	15	10	7	2
A11_BIOFUE	Biofuels processing energy plant	10	20	5	0	-10	0	0	0	0	0	5	7
A12_SALT	Molten salt plant	10	20	20	-10	-15	0	0	0	0	0	-20	10
A13_APV	Agrophotovoltaics (APV) at former open-pit coal mine areas	15	20	20	-10	-10	-5	-20	10	0	-20	-12	15

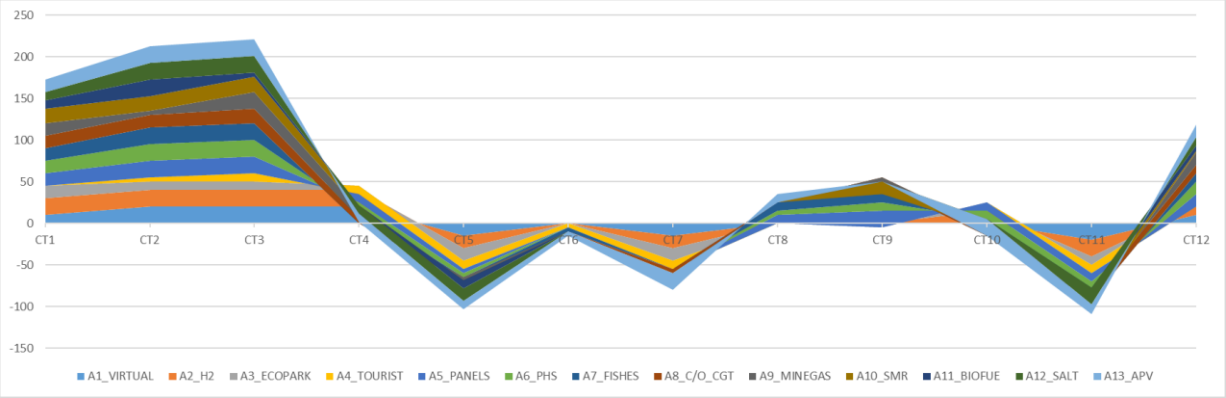

Figure 2. Cumulative layered graph showing the impact of technical criteria on actions

Analyzing the impact of technical criteria on action, it can be observed that (Figure 2):

- technical criteria CT5 (Land use restrictions), CT7 (Waste heaps development constraints) and CT11 (Investment costs with respect to greenfield) have a negative impact on the implications of new actions technologies in coal mines and/or coal-fired power plants destined for closure.
- technical criteria CT1 (Character of the local area / proximity to industry), CT2 (Available space for new technologies/projects), CT3 (Available infrastructures for new technologies/projects), and CT12 (Returns on investments - benefits) have a positive impact on the implications of new actions technologies in coal mines and/or coal-fired power plants destined for closure.

The other criteria have little (usually positive) or no impact.

Tables 17. Result for the analysis technical criteria and micro-actions

Micro-actions / Technical Criteria		CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9	CT10	CT11	CT12
		Character of the local area / proximity to industry	Available space for new technologies/projects	Available infrastructures for new technologies/projects	Concessions, contracts and other regulations	Land use restrictions	Waste heaps physical characteristics	Waste heaps development constraints	Material type deposited on the waste heaps	Flooding status of the mine	Pumped water chemistry/quality	Investment costs with respect to greenfield	Returns on investments (benefits)
AM1_BATT	Ancillary services provided by batteries	15	15	20	5	5	0	0	0	0	0	20	8
AM2_HEAP	Circular mining technologies based on waste heap materials recovery	20	10	10	10	-10	20	-15	20	0	0	-15	20
AM3_C2H4	Usage of methane from degasification units on closed coal mines	15	10	10	20	20	0	0	0	15	10	15	15
AM4_WATER	Circular mining technologies for pumped water material recovery	4	2	2	3	-10	0	0	0	-5	15	-10	5
AM5_FOREST	Forest restoration at former open-pit coal mines	15	0	0	5	-10	20	-10	10	0	-10	-5	10
AM6_IT	Large scale IT infrastructure - green power plant (energy from renewable resources)	0	10	5	0	0	0	0	0	0	0	-5	15
AM7_THERMA	Geothermal energy	10	10	10	5	-10	0	0	0	-10	0	-10	20
AM8_GRAVIT	Gravitricity	20	20	20	-5	0	0	0	0	-10	0	-20	-10
AM9_FLUIDS	Dense fluids	20	15	10	15	-5	0	-5	0	0	0	-15	10
AM10_HPUMP	Underground hydropumping	10	0	10	-20	0	0	0	0	-20	-10	-10	20

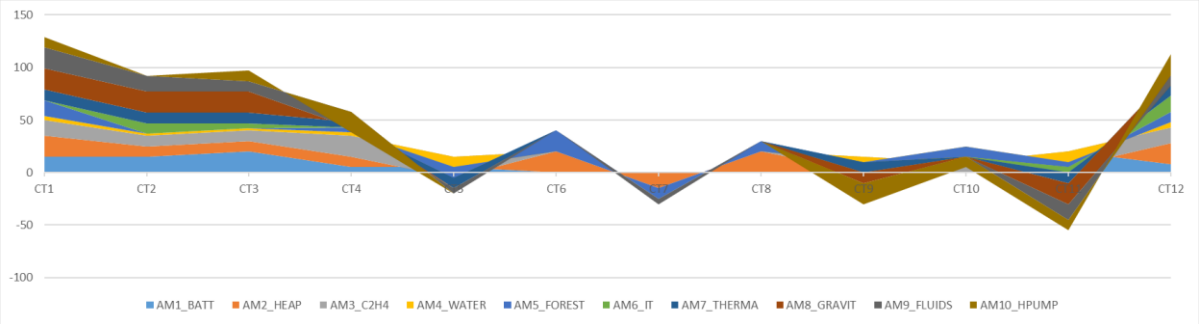

Figure 3. Cumulative layered graph showing the impact of technical criteria on micro-actions

Analyzing the impact of technical criteria on micro-action, it can be observed that (Figure 3):

- technical criteria CT5 (Land use restrictions), CT7 (Waste heaps development constraints), CT9 (Flooding status of the mine) and CT11 (Investment costs with respect to greenfield) have a negative impact on the implications of new micro-actions technologies in coal mines and/or coal-fired power plants destined for closure.
- technical criteria CT1 (Character of the local area / proximity to industry), CT2 (Available space for new technologies/projects), CT3 (Available infrastructures for new technologies/projects), CT6 (Waste heaps physical characteristics) CT8 (Material type deposited on the waste heaps) and CT12 (Returns on investments - benefits) have a positive impact on the implications of new micro-actions technologies in coal mines and/or coal-fired power plants destined for closure.

The other criteria have little (usually positive) or no impact.

5.2 Result for the MULTIPOL analysis for actions

5.2.1 Evaluation of actions related to policies

This interface holds the scores of actions related to policies. In other words, these are calculated by applying the set of weights of the 'matrix evaluation of actions related to criteria' to the 'matrix of policies related to criteria'. Other information such as the mean, standard deviations and the rank of actions by policy can also be found in this matrix (Table 18).

Table 18. 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 evaluation of actions with respect to the policy P1 (Climate) gave the highest ranks to actions: A12 (Molten salt plant), A6 (Pumped hydroelectric storage PHS at former open-pit coal mines), and A2 (Green hydrogen plant).

The evaluation of actions with respect to the policy P2 (Growth) gave the highest ranks to actions: A12 (Molten salt plant), A11 (Biofuels processing energy plant), and A3 (Eco-industrial park).

The evaluation of actions with respect to the policy P3 (People) gave the highest ranks to actions: A3 (Eco-industrial park), A10 (Small modular reactors - SMRs), and A11 (Biofuels processing energy plant).

5.2.2 Profile map: actions/policies

Figure 4 displays the policy score obtained for every action. It represents the matrix of evaluation of actions related to policies.

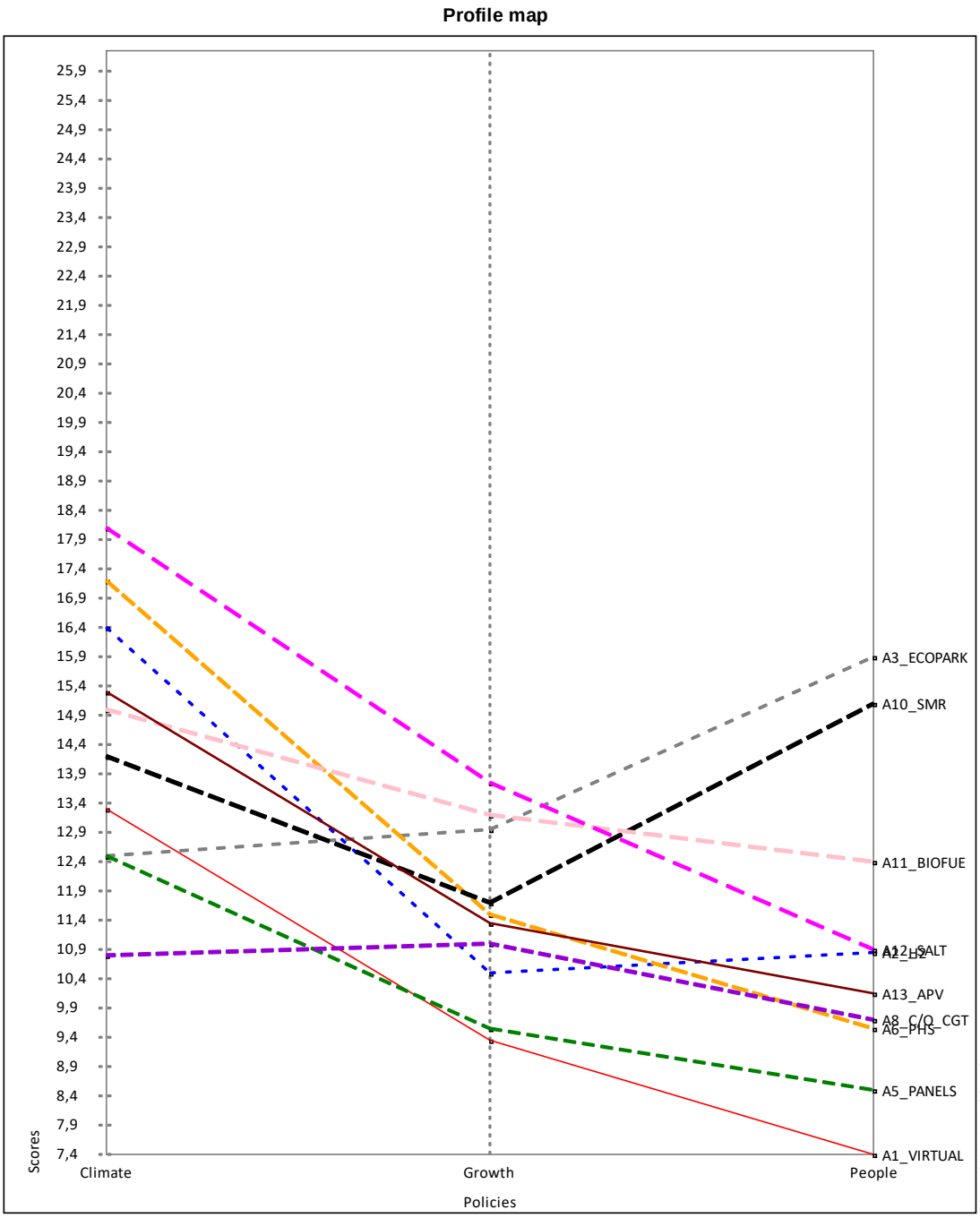

Figure 4. The policy score obtained for every action

5.2.3 Map of classification sensitivity: actions/policies

This map is created from data of the evaluation of actions related to policies matrix (Figure 5).

It represents action score (x-axis) related to the standard deviation calculated (y-axis).

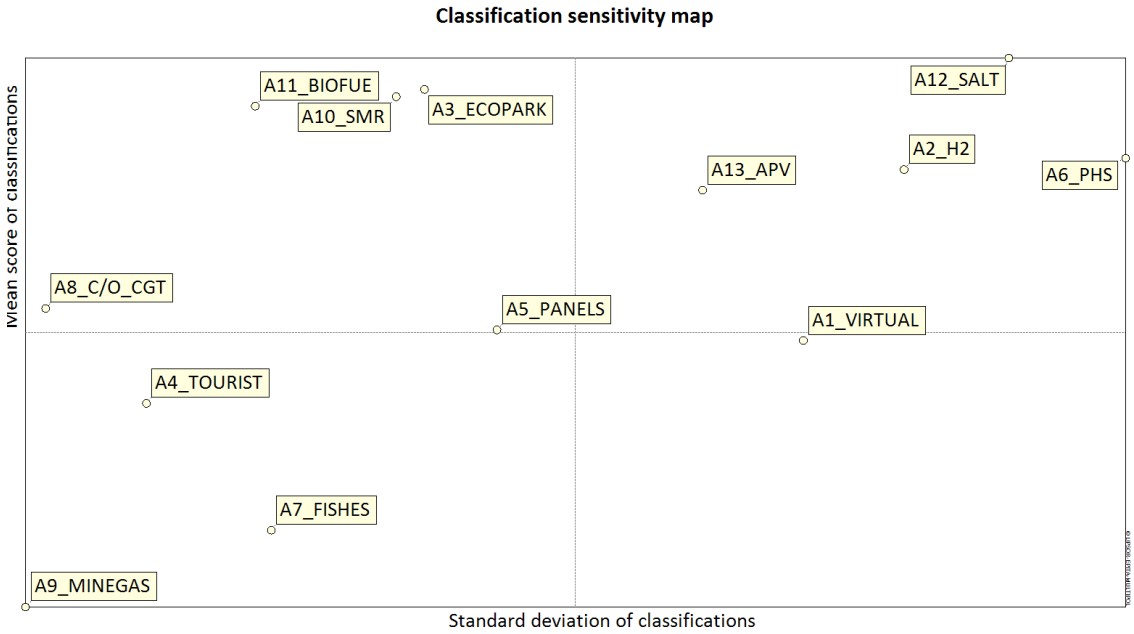

Figure 5. Dependence between action score related to the standard deviation

The highest mean and the lowest standard deviation correspond to actions: A11 (Biofuels processing energy plant), A10 (Small modular reactors - SMRs), and A3 (Eco-industrial park). This means that these actions have a high mean for all policies, while the resulting values for each of the three policies are close to each other.

The highest mean and the highest standard deviation correspond to actions: A13 (Agrophotovoltaics APV at former open-pit coal mine areas), A2 (Green hydrogen plant), A12 (Molten salt plant), and A6 (Pumped hydroelectric storage PHS at former open-pit coal mines).

5.2.4 Closeness map between actions and policies

This map is used to determine which actions are to be chosen whilst taking into consideration policies as well as convergences between policies and given actions (Figure 5).

This is achieved via Correspondence Analysis (CA) and is computed using the matrix of evaluation of actions related to policies.

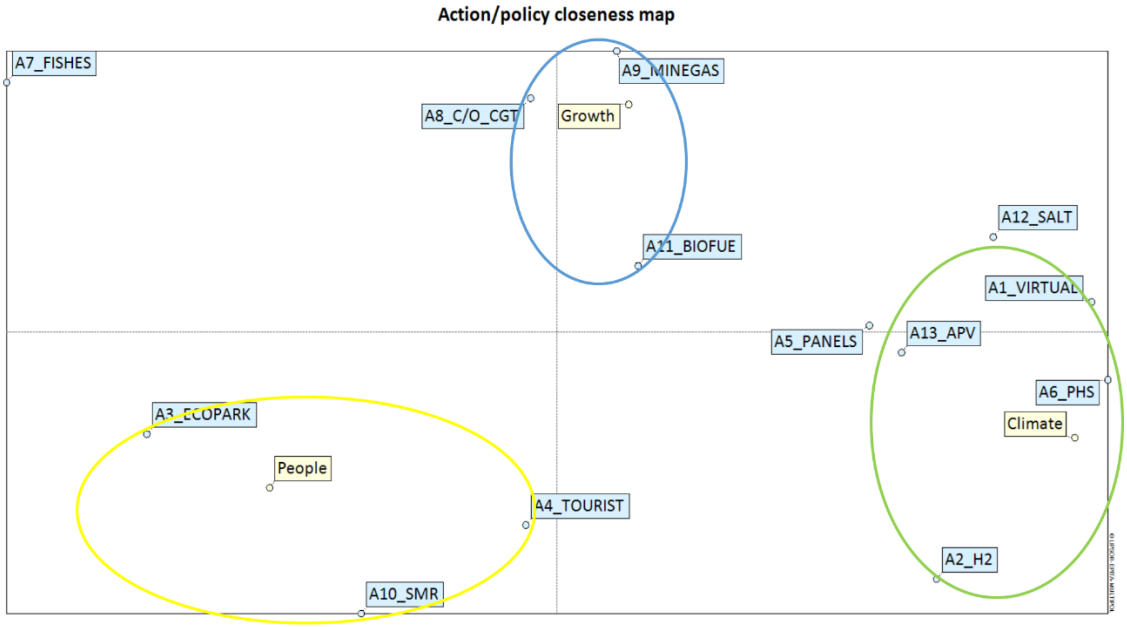

Figure 6. Action/policy closeness map

Based on this analysis, it can be concluded that the closest actions to the P1 policy (Climate) are (green ellipse): A6 (Pumped hydroelectric storage PHS at former open-pit coal mines), A1 Virtual power plant), and A2 (Green hydrogen plant) and A13 (Agrophotovoltaics APV at former open-pit coal mine areas).

The closest actions to the P2 policy (Growth) are (blue ellipse): A9 (Mine gas utilization for gas-powered CHP power units), A8 (Combined Cycle Gas Turbines – CCGT plant. Open Cycle Gas Turbines – OCGT plant), and A11 (Biofuels processing energy plant).

The closest actions to the P3 policy (People) are (yellow ellipse): A3 (Eco-industrial park), A10 (Small modular reactors - SMRs), and A4 (Cultural heritage and sports/recreation areas using green energy).

5.3 Result for the MULTIPOL analysis for micro-actions

5.3.1 Evaluation of micro-actions related to policies

This interface holds the scores of micro-actions related to policies. In other words, these are calculated by applying the set of weights of the 'matrix evaluation of micro-actions related to criteria' to the 'matrix of policies related to criteria'. Other information such as the mean and the standard deviations can also be found in this matrix (Table 19).

Table 19. 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

The evaluation of micro-actions with respect to the policy P1 (Climate) gave the highest rank to micro-actions: AM7 (Geothermal energy), AM9 (Dense fluids), and AM10 (Underground hydro-pumping).

The evaluation of micro-actions with respect to the policy P2 (Growth) gave the highest rank to micro-actions: AM7 (Geothermal energy), AM1 (Ancillary services provided by batteries), and AM9 (Dense fluids).

The evaluation of micro-actions with respect to the policy P3 (People) gave the highest rank to micro-actions: AM7 (Geothermal energy), AM10 (Underground hydro-pumping), and AM9 (Dense fluids).

5.3.2 Profile map: micro-actions versus policies

These graphs (Figure 7) displays the policy score obtained for every micro-action. It represents the matrix of evaluation of micro-actions related to policies (from Table 20).

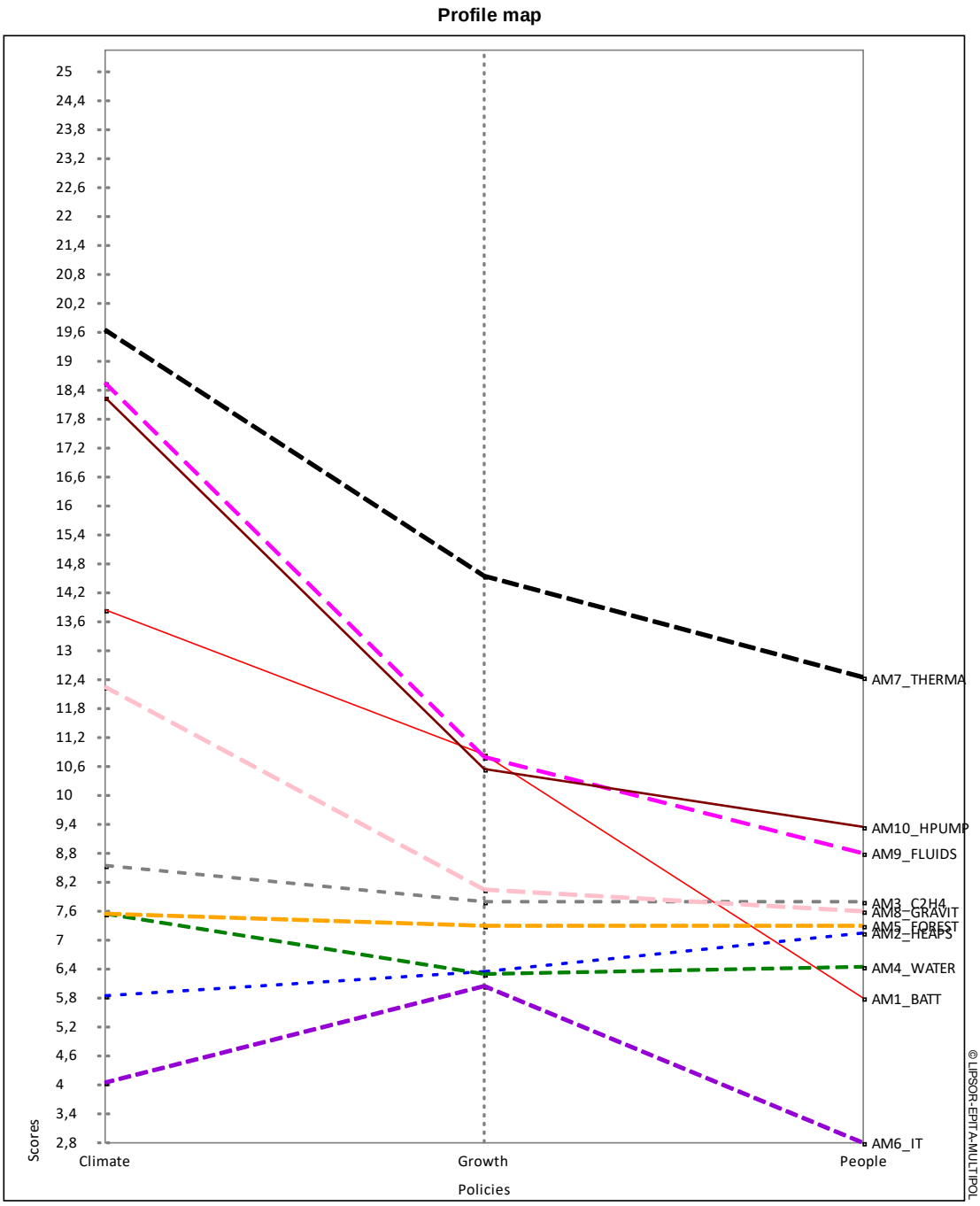

Figure 7. The policy score obtained for every micro-action

5.3.3 Map of classification sensitivity: micro-actions/policies

This map is created from data of the evaluation of micro-actions related to policies matrix (Figure 8).

It represents micro-action score (x-axis) related to the standard deviation calculated (y-axis).

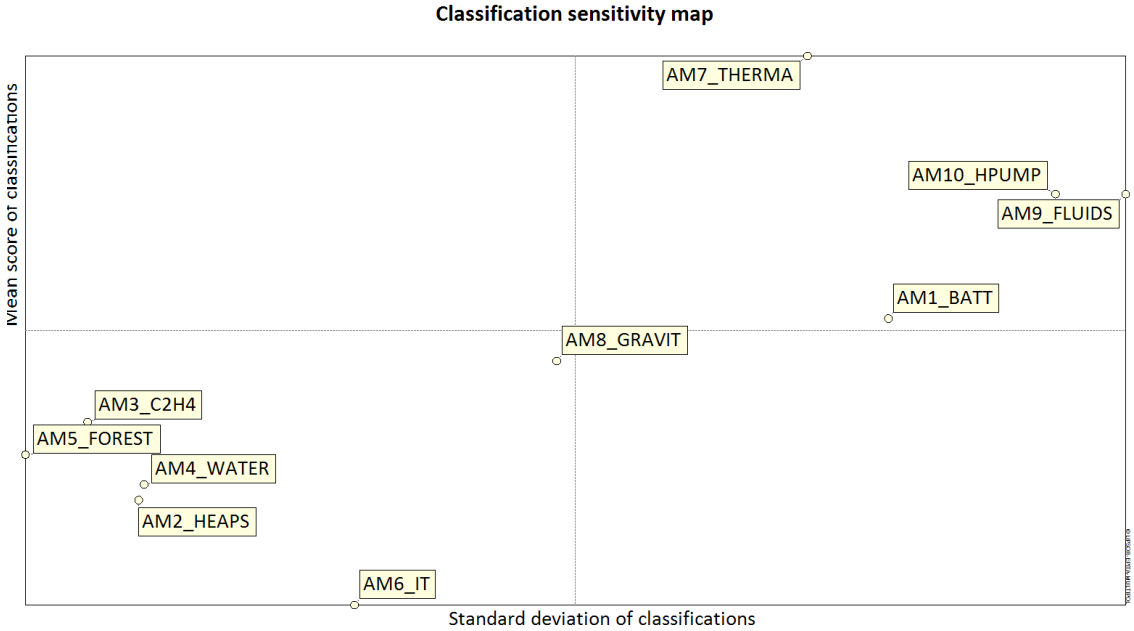

Figure 8. Dependence between micro-action score related to the standard deviation

None of the micro-actions have the high mean and low standard deviation.

The high mean but also a high standard deviation have micro-actions: AM7 (Geothermal energy), AM10 (Underground hydro-pumping), and AM9 (Dense fluids).

5.3.4 Closeness map between micro-actions and policies

This map is used to determine which micro-actions are to be chosen whilst taking into consideration policies as well as convergences between policies and given micro-actions (Figure 9).

This is achieved via Correspondence Analysis (CA) and is computed using the matrix of evaluation of micro-actions related to policies.

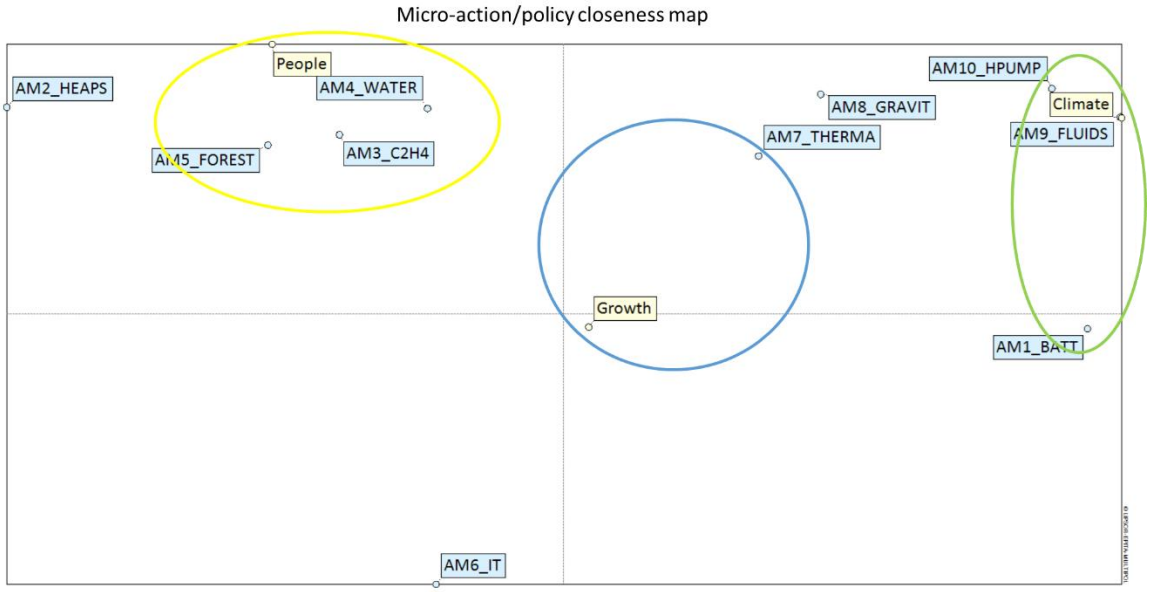

Figure 9. Micro-action/policy closeness map

Based on this analysis, it can be concluded that the closest micro-actions to the P1 policy (Climate) are (green ellipse): MA9 (Dense fluids), AM10 (Underground hydro-pumping), and AM1 (Ancillary services provided by batteries).

The closest action to the P2 policy (Growth) is AM7 (Geothermal energy) – blue circle.

The closest actions to the P3 policy (People) are (yellow ellipse): AM5 (Forest restoration at former open-pit coal mines), AM3 (Usage of methane from degasification units on closed coal mines), and AM4 (Circular mining technologies for pumped water material recovery).

6 Conclusions and lessons learnt

Two multi-criteria analyses were carried out: for 13 actions and for 10 micro-actions. Both actions and micro-actions were defined and analyzed morphologically with the MORPHOL software in Task 3.1. The analyses also used 7 criteria designed by consensus among project participants and 3 policies resulting directly from the principles of the European Green Deal. Additionally, analyses were performed on the impact of technical criteria on actions and micro-actions.

In Table 20, the summary results for the MULTIPOL analysis for actions are shown.

Table 20. Summary results of MULTIPOL analysis (actions)

Analysis 1: Evaluation of actions related to policies			
Policy	**Rank 1**	**Rank 2**	**Rank 3**
Climate policy	Molten salt plant	Pumped hydroelectric storage (PHS) at former open-pit coal mines	Green hydrogen plant
Growth policy	Molten salt plant	Biofuels processing energy plant	Eco-industrial park
People policy	Eco-industrial park	Small modular reactors (SMRs)	Biofuels processing energy plant
Analysis 2: Map of classification sensitivity: actions/policies			
Sensitivity	**Rank 1**	**Rank 2**	**Rank 3**
High mean/low standard deviation	Eco-industrial park	Small modular reactors (SMRs)	Biofuels processing energy plant
High mean/high standard deviation	Agrophotovoltaics (APV) at former open-pit coal mine areas	Green hydrogen plant	Molten salt plant
Analysis 3: Closeness map between actions and policies			
Closeness to	**Rank 1**	**Rank 2**	**Rank 3**
Climate policy	Pumped hydroelectric storage (PHS) at former open-pit coal mines	Virtual power plant	Agrophotovoltaics (APV) at former open-pit coal mine areas Green hydrogen plant
Growth policy	Mine gas utilization for gas-powered CHP power units	Combined Cycle Gas Turbines (CCGT) plant. Open Cycle Gas Turbines (OCGT)	Biofuels processing energy plant
People policy	Eco-industrial park	Small modular reactors (SMRs)	Cultural heritage and sports/recreation areas using green energy

The evaluation of actions with respect to the policy P1 (Climate) and to the policy P2 (Growth) the highest rank was given to action A12 (Molten salt plant), and with respect to the policy P3 (People) was given to action A3 (Eco-industrial park).

Analysis of the map of classification sensitivity shows that the highest mean for all three policies, with the lowest standard deviation, is characterized by actions: A3 (Eco-industrial park), A10 (Small modular reactors - SMRs), and A11 (Biofuels processing energy plant).

Closeness map analysis between actions and policies shows that the action A6 (Pumped hydroelectric storage (PHS) at former open-pit coal mines) is the closest to policy P1 (Climate), while action A9 (Mine gas utilization for gas-powered CHP power units) is the closest to policy P2 (Growth) and action A3 (Eco-industrial park) to policy P3 (People).

In Table 21, the summary results for the MULTIPOL analysis for micro-actions are shown.

Table 21. Summary results of MULTIPOL analysis (micro-actions)

Analysis 1: Evaluation of micro-actions related to policies			
Policy	**Rank 1**	**Rank 2**	**Rank 3**
Climate policy	Geothermal energy	Dense fluids	Underground hydropumping
Growth policy	Geothermal energy	Ancillary services provided by batteries	Dense fluids
People policy	Geothermal energy	Underground hydropumping	Dense fluids
Analysis 2: Map of classification sensitivity: micro-actions/policies			
Sensitivity	**Rank 1**	**Rank 2**	**Rank 3**
High mean/low standard deviation	None		
High mean/high standard deviation	Geothermal energy	Underground hydropumping	Dense fluids
Analysis 3: Closeness map between micro-actions and policies			
Closeness to	**Rank 1**	**Rank 2**	**Rank 3**
Climate policy	Dense fluids	Underground hydropumping	Ancillary services provided by batteries
Growth policy	Geothermal energy	None	
People policy	Forest restoration at former open-pit coal mines	Usage of methane from degasification units on closed coal mines	Circular mining technologies for pumped water material recovery

The evaluation of micro-actions with respect to the policies the highest rank was given to AM7 (Geothermal energy) with respect to the policy P1 (Climate), the policy P2 (Growth) and the policy P3 (People).

None of the micro-actions have both a high mean and a low standard deviation relative to the all three policies. Analysis of the map of classification sensitivity shows that the highest mean for all three policies, with the high standard deviation, is characterized by micro-actions: AM7 (Geothermal energy), AM10 (Underground hydro-pumping), and AM9 (Dense fluids).

Closeness map analysis between micro-actions and policies shows that the micro-action AM9 (Dense fluids) is the closest to policy P1 (Climate), micro-action AM7 (Geothermal energy) to policy P2 (Growth) and micro-action AM4 (Forest restoration at former open-pit coal mines) to policy P3 (People).

An additional analysis of the impact of the CT technical criteria on actions and micro-actions showed a wide variation in results, which was due to the wide range of technologies proposed. However, it can be noted that of all the technical criteria, a strong and negative impact is demonstrated between: technical criteria CT5 (Land use restrictions), and technical criteria CT 11 (Investment costs with respect to greenfield) as they have a negative impact on the implications of new actions and/or micro-actions technologies in coal mines and/or coal-fired power plants destined for closure.

One of the main problems encountered during the elaboration of this study was the non-uniform approach to the issue of certain actions and micro-actions in different countries, i.e. action A11 Biofuels processing energy plant is being perceived differently in Poland, than in Spain, where the availability of biofuels differs a lot. On the other hand, Micro-action AM7 Geothermal energy, which is not currently implemented in coal mines in Poland, has found application in closed coal mine in Spain. For this reason, a number of meetings were hold, including with external experts, to reach a final consensus on the values included in the analysis.

The first matrixes (Annex 2) differs significantly from the final matrixes. This is due to the fact that during the consecutive workshop meetings, the criteria, actions and policies evolved - by consensus the criteria were optimized, the policies were adapted to the European Green Deal policies, and the number of actions and micro-actions were reduced by combining similar technologies. This was successful despite the different perspectives on technologies by scientists and experts from different countries.

Although each scenario can be site specific, the exercise in Task 3.2 was to identify a set of actions and micro-actions that could be applied in the changing circumstances in closed coal mines and coal-fired power plants.

The results obtained in this study provide a good starting point for the design of specific business models, which often will be combinations of various actions and micro-actions.

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Annex 1: MULTIPOL MATRIX INSTRUCTION MANUAL

MULTIPOL ANALYSIS INSTRUCTION MANUAL

First step: **Assessing the impact of technical criteria on proposed actions**

In the **matrix 1** we evaluate the impact of the technical criteria (labelled CT 1 to CT 12) on the proposed actions and micro-actions (labelled A1 to A25). The expert evaluates each impact on a scale from 0 (no impact) to 20 (the strongest impact). When the criteria has a negative impact on the action we enter a negative weight – a value of (-20) determine the strongest negative impact.

Example:

Instructions: the scoring of actions (in rows from A1 to A25) with respect to criteria (in columns from CT1 to CT12) goes from -20 (the strongest negative impact) to 20 (the strongest positive impact). A value of 0 indicates no impact/neutral impact between technical criteria the actions.

Actions \ Technical Criteria			CT1	CT2	CT3	CT4	CT5	CT6	CT7	CT8	CT9	CT10	CT11	CT12
A1	Virtual power plant	Action	10	10	20	20	-10	0	-20	0	0	0	0	0

Second step: **Multi-criteria analysis performed with MULTIPOL software**

For the purposes of multi-criteria analysis with the MULTIPOL software, it is necessary to perform two matrix:

- **Matrix 2**: Evaluation of relationships of actions (A) with respect to criteria (CM).
- **Matrix 3**: Evaluation of relationships of policies (P) with respect to criteria (CM).

The **matrix 2** presents the evaluation of actions (labelled A1 to A25) with respect to criteria (labelled CM1 to CM 7). The scoring of actions with respect to criteria goes from 0 (no relationship) to 20 (the strongest relationship). We do not distinguish in this analysis whether the relationship is positive or negative.

Example:

Instructions: the scoring of actions (in rows from **A1** to **A25**) with respect to MULTIPOL criteria (in columns from **CM1** to **CM7**) goes from **0** (no relationship between actions and criteria) to **20** (the strongest relationship between actions and criteria).

Actions \ Criteria			CM1	CM2	CM3	CM4	CM5	CM6	CM7
A1	Virtual power plant	Action	10	20	0	10	10	10	0

The **matrix 3** presents the evaluation of policies (labelled P1 to P3) with respect to criteria (labelled CM1 to CM 7). As this concerns the set of relationships weights, the row sum must always equal 100. There is no maximum limit to the value of the weights entered – in the extreme case one weight equal 100, if the rest of the relationship is rated 0. We do not distinguish in this analysis whether the relationship is positive or negative.

Example:

Instructions: Matrix values correspond to policy evaluation with respect to the criteria. As this concerns the set of criteria weights, the row must always equal 100.

Policies \ Criteria		CM1	CM2	CM3	CM4	CM5	CM6	CM7	SUM
P1	Climate (No net emissions of greenhouse gases by 2050)	10	35	25	0	10	10	10	100

Annex 2: THE FIRST VERSION OF THE MATRIXES WITH CRITERIA, POLICES AND ACTIONS

Criteria:

No.	Variable	Description
C1	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. The character of local areas determines the kind and quantities of infrastructure facilities and connectivity, the local economic development, the ecological value and potentials of the area, etc. The characteristic of the surrounding areas will be crucial for some business opportunities.
C2	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 provided from the surroundings of coal mines and power plants. The available area of an end-of-life coal mine and power plant that can be used for the deployment of alternative technologies is considered a major asset (apart from waste disposal areas).
C3	Available infrastructures for new technologies/projects	The variable refers to infrastructure that may facilitate the adaptation of the power plant (internal and external). Internal infrastructure: water demineralization, water decarbonation, hydrogen cooling, turbine oil installation, desulphurization, NO_x reduction, dust reduction, ash removal, steam production, coal transportationinfrastructure, CO_2 capture installation. External infrastructure: water treatment plant, raw water pumping station, landfills, temporary storage areas, power distribution/transmission grid connection, water accessibility, road infrastructure, railway infrastructure.
C4	Concessions, contracts and other regulations	Variable refers to obligations such as to provide thermal energy supply after the decommissioning or arising from concessions, contracts and others, which may condition the future repurposing of the coal power plant. It refers to also, the amount of time (years) during which the power plant will still have the
C5	Land use restrictions	This variable refers to any kind of land use restrictions different from waste heaps, mainly related with territorial development plans approved by the authorities, that may condition specific industrial, commercial, business centers or residential deployments. The optimization of the areas should be based on socio-economic and environmental criteria helping to achieve sustainable development with the intention of increasing economic gains and improving environmental quality, but it is limited by present territorial development plans that, in some cases, are susceptible to be changed by the authorities.
C6	Waste heaps physical characteristics	Variable refers to waste heap physical characteristics - geotechnical stability, angel of natural response, geomorphic shape and waste heap's height and area.
C7	Waste heaps development constraints	Variable refers to waste heap development constraints (gas and fire hazards, status of reclamation).
C8	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. Depending on the mining companies, extracting wastes and coal processing wastes are deposited together or separately. In case that they are deposited separately, it may be possible to extract valuable substances (rare earth minerals) from coal processing wastes.
C9	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 and to monitoring of flooded level, hydrogeological and geotechnical aspects.
C10	Pumped water chemistry/quality	The variable determines the quality and chemistry of pumped mining water (salt, hazardous substances).
C11	Investment costs	The variable refers to the investment costs to be taken into account when designing the use of closed coal mines/electric power plants to adapt the existing infrastructure to new economic activities (renovations, modifications, purchase of new equipment).

POLICY:

No.	Policy	Description
P1	Energy security	Energy security is the relationship between national security and the availability of natural resources for energy consumption. Moving away from fossil fuels requires increased production of other types of energy, including green energy, as well as energy storage. Main threats of energy security are: political or domestic instability of energy-producing countries, reliance on foreign countries for oil/gas, manipulation of energy sources and unreliable energy stores.
P2	Job creation	The positive job creation effect of renewable energy is a result of longer and more diverse supply chains, higher labour intensity, and increased net profit margins. Jobs in renewable energy can be created directly and indirectly along the entire value chain, including in the manufacturing and distribution of equipment; the production of inputs such as chemicals; or even in services like project management, installation, operation, and maintenance. Those working in the agricultural sector, particularly women and the youth, can benefit from job increases in the harvesting of feedstock and other biomass. Improved energy supply through renewable sources can also contribute to the expansion of existing economic activities in other sectors. Jobs created through renewable energy production furthermore carry the benefit of less hazardous working conditions.
P3	Climate mitigation	Transitioning away from fossil fuel-based energy production to green energy from renewable sources will have a positive impact on the climate, including the potential to reduce the intensity of negative its change.
P4	Economic growth	An energy transition based on renewable energy sources can stimulate economic growth, create new jobs and improve people's living conditions. There is also a significant impact on economic growth by significantly reducing the supply of fossil fuels from outside the EU, as green energy jobs will be located within the EU.

Scenarios/Actions:

No.	Action	Description	Company
A1	Virtual power plant	The action refers to the renewable energy produced (solar photovoltaic and wind power on the waste heaps, unconventional pumped hydro storage using dense fluids, geothermal energy), will be sold to the grid or used to power companies with constant energy consumption located in the near area, such as factories or green data centres.	UNIOVI/HUNOSA
A2	Green hydrogen plant	The action refers to green hydrogen plant where renewable hydrogen will be produced by electrolysis of mine water and electricity from renewable sources. It is a clear alternative to selling renewable energy to the grid or to power industries with constant energy consumption. The energy produced will be used to power electro-intensive industries located close to the area.	UNIOVI/HUNOSA
A3	Molten salt plant	The action refers to no pumped hydro storage is possible, one of the technologies with some pilot plants already implemented around the world are Molten salt plants, using energy storage in the form of tanks with heated molten salt. They allow to smooth the fluctuation of renewable energies such as solar and wind. Nevertheless, and in order to achieve better efficiencies, they preferable should be coupled with concentrated solar power (CSP) plants where a heat transfer fluid (HTF) such as oil absorbs the energy.	UNIOVI/HUNOSA
A4	Eco-industrial park	The action refers to eco-industrial parks, which are 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, optimizing material, resource and energy flows within the industrial parks. Sustainable energy generation technologies comprise solar and wind energy production together with energy storage, as well as geothermal energy in order to provide cooling/heating to the companies/industries that will take part of the Eco-industrial park.	UNIOVI/HUNOSA
A5	Cultural heritage and sports using green energy	The action assumes the production of green energy at the coal mine and coal-fired power plant while adapting them for tourism purposes.	GIG
A6	Floating PV panels at flooded open-pit coal mines	The action refers the use of floating PV panels at flooded open-pit coal mines. The lake water will be used for the required cooling of the floating PV panels. Possible synergies include forest restoration of the broader area, whereas extracting critical metals from mining wastes will contribute to a circular economy.	CERTH
A7	Agrophotovoltaics (APV) at former open-pit coal mine areas	The proposed The action concerns the implementation of agrophotovoltaics (APV) at former open-pit coal mines. Synergies with local customers who own small-scale solar panels will be arranged. Forest restoration at the areas of the open-pit mine will be considered for further reduction of GHG emissions.	CERTH
A8	Pumped hydroelectric storage (PHS) at former open-pit coal mines	The action refers to implementing pumped hydroelectric storage (PHS) at former open-pit coal mines. The synergies that will be developed include a wind farm and a solar power plant in the broader mining area. In addition, synergies with local customers who own small-scale solar panels will be arranged. Using waste water in soil additives coupled with the extraction of critical metals from mining wastes will contribute to a circular economy.	CERTH
A9	Fisheries in flooded open-pit coal mines.	The development of fisheries in flooded open-pit coal mines is an unconventional The action of incremental innovation that integrates already developed methods that have not been implemented together at a former coal mine. Energy will be generated via biogas produced by fishery residues with the anaerobic digestion method. Developing an ecotoxicity laboratory will provide constant monitoring of the water quality. The laboratory will also promote significant scientific research concerning the effects of possible hazardous substances on fish. The production of fish by-products from fish wastes, such as fish glue, oil for paints and resins, will contribute to circular economy.	CERTH
A10	Ancillary services provided by batteries	The action refers to ancillary services provided by batteries that support the transmission of electricity from its generation site to the customer or helps maintain its usability throughout the system.	VGB
A11	Combined Cycle Gas Turbines (CCGT) plant	The action refers to use of coal-fired power plant infrastructure to combined-cycle plant works to produce electricity and captures waste heat from the gas turbine to increase efficiency and electrical output	VGB
A12	Electrolysers powered by PV and/or Wind turbines, CCGT, Use of energy for recycling of minerals from pumped mine water	The action refers to use of green energy (electroluser powered by PV and/or wind turbines, Combined Cycle Gas Turbine) for recycling of minerals from pumped mine water.	VGB
A13	Mine gas utilization for gas-powered CHP power units	The action refers to use of utilization mine gases fo gas-powewred CHP (Combined Heat and Power) units.	VGB
A14	Open cycle gas turbine, block heat and power plant, gas engine	The action assumes the use of coal-fired power plant/mine infrastructure to produce clean energy using open cycle gas turbine, block heat and power plant, gas engine.	VGB
A15	Small modular reactors (SMRs), Open cycle gas turbines, CCGT	The action assumes the use of coal-fired power plant/mine infrastructure to produce clean energy using small modular reactors (SMRs), open cycle gas turbines, and CCGT (Combined Cycle Gas Turbines).	VGB
A16	Lithium recovery form mine water	The action refers to recovery lithium from pumped mine water.	THGA
A17	Usage of methane from degasification units on closed coal mines	The action refers to use of methane from degasification units on closed coal mines.	THGA
A18	Circular mining technologies based on waste heap materials recovery	The action refers to the circular mining technology based on waste heap materials recovery. The fact that wastes are landfilled separately according to their characteristics is very important. On the other hand, it should be possible to install a material recovery plant, something that has to be permitted according to the territory development plant.	UNIOVI/HUNOSA
A19	Circular mining technologies scenario for pumped water material recovery	The action refers to the circular mining technologies The action for pumped water material recovery - should be necessary to install a mine water treatment plant and no land use restriction are foreseen.	UNIOVI/HUNOSA
A20	REE recovery from coal mining waste heaps	The action refers to REE recovery from coal mining waste heaps can be combined with other The actions contributing to the circular economy. It provides alternative REE resources without the need for a mining licence, also minimising the existing or coal wastes.	CERTH
A21	Green energy relax and extreme mine & plant (trail tracks, etc.)	The action refers to use mine waste dumps and underground workings for extreme sports.	GIG
A22	Forest restoration at former open-pit coal mines	The action refers to reforestation of the former open-pit coal mines will give several advantages that include the decrease of GHG emissions, as well as the protection against natural hazards (such as landslides and flooding events).	CERTH
A23	ENERMINECOIN - mine	The action refers to use of mining infrastructure for “mining” cryptocurrencies (bitcoin, stabecoin, etc) and secure data collection and storage using green energy	GIG
A24	ENERMINECOIN - power plant	The action refers to use of coal power plant infrastructure for “mining” cryptocurrencies (bitcoin, stabecoin, etc) and secure data collection and storage using green energy	GIG
A25	Cultural/Recreation areas		GIG
A26	Biomass combustion energy plant		GIG
A27	Biofuels combustion energy plant		GIG