GreenJOBS
RFCS RESEARCH PROJECT

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

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Deliverable 2.2

Solar Photovoltaic deployment

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Executive Summary

The present document constitutes the Deliverable 2.2 "Solar Photovoltaic deployment" in the framework of the project titled "Leveraging the competitive advantages of end-of-life underground coal mines to maximise the creation of green and quality jobs" (Project Acronym: GreenJOBS, Grant Agreement No 101057789).

This document has been prepared to provide a detailed description of the activities within Task 2.1 (T2.1), entitled "Energy harnessing technologies", on the scope of Work Package 2 (WP2), entitled "Deploying circular economy technologies".

Photovoltaic solar technology is one of the fastest-growing renewable energy technologies in Europe, also in the world, and is playing an increasingly important role in the global clean energy and carbon free transition.

However, as any technology, the deployment of solar PV projects embeds a number of challenges, boundaries and cons.

Difficulties related the lack of raw materials, the increasing prices of PV cells or any electronic device; or related to important requirements to cover, such as land needs, environmental regulations or the "Do No Harm principle", among others, may lead the deprecation of some of these investment initiatives.

Thus, a deeper knowledge of such boundaries may help to figure out how to reduce or overcome such difficulties during the project definition and to define the priorities in the technological development. For example, identifying most appropriate locations where to elaborate consistent viability analysis, adapting the technology to the site. To do that, an exhaustive revision of the different elements conforming a solar PV system is conducted by section 2.

On the other hand, the closure of coal mining sites initiates another "challenge", the compromise of recovering and restoring, as much as better, mines infrastructures, assets and lands; apart from mitigating the huge social and economic impact in local or regional communities apart from any other collateral effects.

In this sense, at section 3, main typologies and features of coal mines have been described, defining a generic characterization of such facilities. It is expected to identify and highlight those singularities of mining areas which could create them a competitive advantage as potential locations where to promote solar PV installations. Aspects like the existence of Points of Interconnections could contribute to reduce costs, or timing in executing projects; also, the needs of restoring lands could facilitate permits or licences related to the use of lands for PV projects.

Taking this into account, at section 4 two different, but complementary, scenarios have been identified and drafted, as potential use cases. The characterization of this use cases and the definition of specific operational requirements will help to reinforce arguments in favour of using coal mining areas as proper locations of PV systems; but also, to select best technologies to better fit the aforementioned requirements.

These use cases will be analysed in deep as demo site at section 6, as well as a set of lighthouse PV projects will be identified and sketched at section 5 as exemplary and best practice.

This document concludes Photovoltaic (PV) solar energy, as one of the key technology renewable energy sources aimed by GreenJOBS project, will contribute the repurposing of end-of-life coal-related assets and infrastructure at coal mines.

1 Introduction

At present, coal mining regions in energy transition and after many years of industrial activity can create new opportunities for economic growth and job creation based in renewable energy sources. Despite the potential benefits of reusing coal mining sites, there are also challenges to overcome. One of the main obstacles is ensuring that the reuse of these sites is done in a safe and environmentally responsible manner.

Additionally, it is crucial to engage with local communities to ensure that any proposed reuse plans align with their needs and interests. By repurposing these sites, these regions can not only contribute to the transition towards clean energy but also create new economic opportunities and job creation. This approach could ultimately lead to the development of a more sustainable and thriving economy for these regions.

EU also recognizes the importance of local communities in the transition to a low-carbon economy. The EU's strategy includes measures to promote citizen participation and engagement in renewable energy projects, such as community energy initiatives and cooperative models for energy production.

The European Green Deal is a comprehensive strategy proposed by the European Union (EU) to achieve a climate-neutral and sustainable economy by 2050. The strategy is designed to transform the EU's economy to ensure a more prosperous, sustainable, and inclusive future for the region. The photovoltaic (PV) solar industry is expected to play a major role in achieving these targets.

The application of solar photovoltaic technology in decommissioned coal mining installations provides an opportunity for mining regions to transition towards sustainable and environmentally-friendly energy sources. By repurposing these sites, mining regions can contribute to global decarbonisation goals, create new job opportunities, and support economic development. However, the retrofitting of mining infrastructure and the management of solar energy intermittency remain as challenges that need to be addressed in order to make this transition successful.

On the other hand, the closure of coal mining sites initiates the compromise of recovering and restoring mines infrastructures, assets and lands. Mines usually occupy large areas of land and they are typically connected to the grid through overhead lines and substations, which can be easily adapted for injecting electricity from PV farms into the grid.

Coal mining has produced a significant amount of waste material. This extractive waste is often placed in heaps, which were reshaped to achieve natural stability and protect against erosion. These heaps can occupy vast areas of land, making them a potential target for repurposing.

GreenJOBS suggests using these areas as an attractive option for photovoltaic systems location. Also, tips lakes appearing after the mining activity in open pits could be exploited for floating PV farms.

The development of solar PV plants in coal mining areas can also contribute to local economic development. The renewable energy sector has the potential to attract investment and stimulate economic growth in regions that have experienced job losses and economic decline due to the decline of the coal industry. These regions can provide a range of skilled professionals and large post-mining areas locations as waste heaps and pit lakes for required by photovoltaic plants.

FAEN will lead this task with the cooperation of UNIOVI, GIG and DMT-THGA.

2 State of art of solar PV technology

Photovoltaic solar energy is one of the key technology renewable energy sources aimed by GreenJOBS project to enable the repurposing of end-of-life coal-related assets and infrastructure at coal mines.

Solar photovoltaic (PV) technology has undergone significant advancements over the past few decades, resulting in increased efficiency, reduced costs, and broader applications.

Solar photovoltaic (PV) basically uses electronic devices, also called solar cells, to convert sunlight directly into electricity. This process is achieved through the use of semiconductor materials, such as silicon, that absorb photons from sunlight and generate electrons. These electrons are then collected by electrodes to form an electric current, which can be used to power electrical devices or stored in batteries.

Solar PV installations are highly modular and ranges in size from small solar home kits and rooftop installations of less than 100 kW capacity, right up to systems with capacity in the hundreds of megawatts.

Photovoltaic systems are used in a wide range of applications and can be designed in a range of configurations, including grid-connected for energy production or self-consumption purpose, stand-alone systems, fixed or tracking, flat plate or concentrator operation (Pearsall, 2017). In terms of generating capacity, the applications of PV systems could be divided into three general categories:

- **Small scale 5 to 100 kW (peak)**; decentralized, onsite application on residential structures ranging from single family dwellings to apartment complexes.
- **Intermediate scale 100 kW to 10 MW (peak)**; decentralized, onsite service, commercial or industrial application (hospitals, colleges, shopping centers, office buildings, factories, government buildings, etc.)
- **Large scale 10 MW to 1000+ MW (peak)**; central power applications ranging from community scale systems to large scale remote systems.

Small and intermediate scale systems may also vary in the ways in which they are integrated with other energy requirements and interfaced with existing utility services. For example, electricity from photovoltaic systems may be collected and used for lighting, water heating, recharging electric vehicles and other electrical applications. Furthermore, it could be used for storage systems that could be added to provide greater independence from existing grids or utilities may be relied upon to provide extensive backup.

Table 2-1. Utility-scale solar vs. community solar farms (Energysage, 2023)

UTILITY-SCALE SOLAR FARMS	COMMUNITY SOLAR FARMS
Sell electricity directly to utilities	Sell electricity to customers
A large operation for increased energy production	Smaller in size compared to utility-scale farms
Power produced here is either owned directly by a utility or solid wholesale to utility buyers via a PPA	Allow customers to purchase a share of the farm and the energy produced by that farm

On the other hand, intermediate and large scale usually are referred as solar farms, sending solar energy to electricity grids. Solar farms could be classified as utility-scale solar farms and community solar farms. As showed at Table 2.1, the main difference between the two is their customers – utility-scale solar farms sell solar generation directly to energy utilities, while community solar farms could sell directly to end-consumers of electricity, such as homeowners.

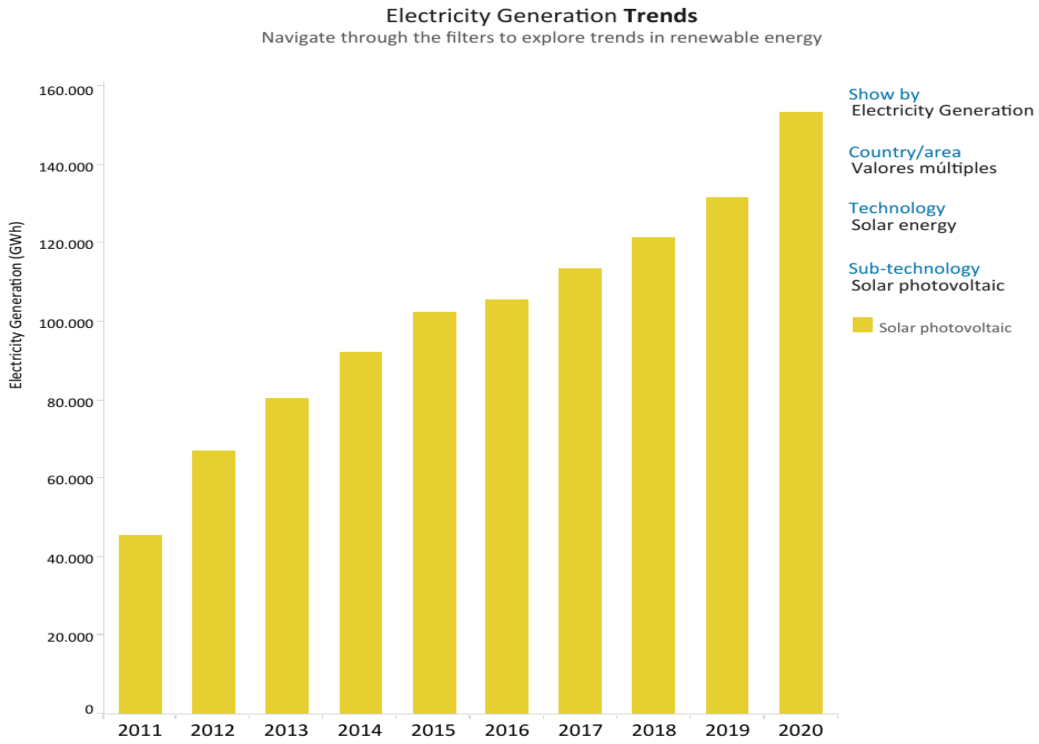

Figure 2-1. Solar Electricity Generation Trends (IRENA, 2023)

Solar PV technology is one of the fastest-growing renewable energy technologies and is playing an increasingly important role in the global energy transformation. The total installed capacity of solar PV reached 710 GW globally at the end of 2020. About 160 GW of new solar PV capacity was added in 2020, as showed at Figure 2-1. Solar Electricity Generation Trends the largest capacity addition of any renewable energy source.

The manufacturing process for solar PV technology based on silicon involves several steps, including wafer production, cell manufacturing, module assembly, and system integration. The process is highly automated and involves sophisticated equipment and machinery.

The cost of manufacturing solar panels has plummeted dramatically in the past decade, making them not only affordable, but also often the cheapest form of electricity. Solar module prices fell by up to 93% between 2010 and 2020. During the same period, the global weighted-average levelized cost of electricity (LCOE) for utility-scale solar PV projects fell by 85% (IRENA, 2022).

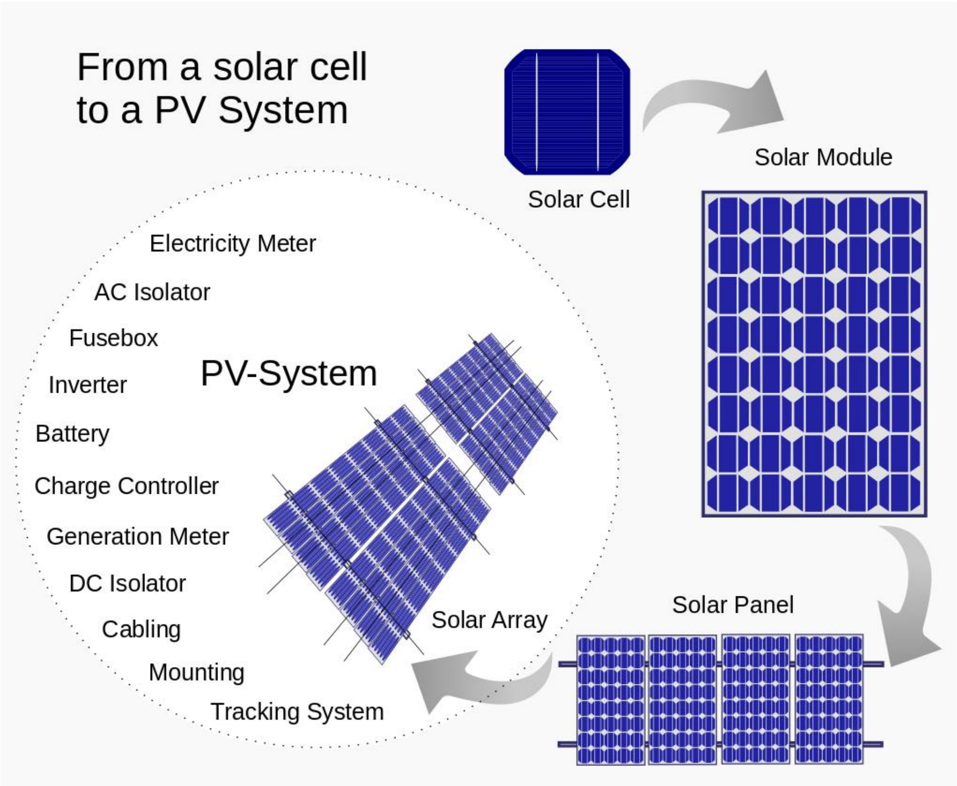

Figure 2-2. Diagram of the possible components of a photovoltaic system (Rfassbind, 2022)

More than an “as usual” review or current state of the art analysis on photovoltaic solar energy technology, which is better compiled at referenced papers, i.e.: (Hernández-Callejo, Gallardo-Saavedra, & Alonso-Gómez, 2019), (Parida, B.; Iniyan, S.; Goic, R.; 2011). This section aims to provide a view of main elements and equipment, as represented at Figure 2-2. Diagram of the possible components of a photovoltaic system

(Rfassbind, 2022), making up a solar photovoltaic farm1 (at least at community or utility-scale2) highlighting such parts that could be considered as singular elements when the solar PV project is envisioned to be carried out at coal mines.

A solar PV system is commonly configured as grid connected (large scale PV farms or self-consumption systems) or standalone (off grid) installation. At a grid connected PV system, the photovoltaic panels or array are connected to the utility grid through a power inverter unit allowing them to operate in parallel with the electric utility grid.

On the other hand, a stand-alone or off-grid PV system uses photovoltaic panels and deep cycle batteries (or other type of energy storage) to store its solar energy providing a complete self-contained solar power system. However, this type of solar system works fine providing there is enough solar radiation during the day to recharge the batteries for use during the night. A hybrid PV system could be considered, mostly applied for a self-consumption application, where a grid connection exits but also including the battery storage capacity, taking advances of both configurations.

Main elements to be taken into consideration in a grid connected PV system, apart from the PV panels, include the mounting system and the connection to the power grid. Additionally, the stand-alone solar PV system will incorporate the storages system (see deliverable D2.4 - Unconventional pumped hydro deployment, and D2.5 - Batteries deployment).

2.1 Photovoltaic cells. Materials.

The technology behind the generation of solar energy is based on photovoltaic (PV) cells that are made up of a variety of materials. The PV cell converts sunlight into electrical energy without an intervening heat engine or rotating equipment. The efficiency of these PV cells is a critical factor in determining the viability of solar energy as a reliable and sustainable energy source. The materials forming the cells are those that determine its efficiency.

Photovoltaic cells (ScienceDirect, 2023) are made of various semiconductors, which are materials that are only moderately good conductors of electricity. The materials most commonly used are silicium (Si) and other compounds like cadmium. These cells are packed into modules that produce a specific voltage and current when illuminated.

[1] A solar farm is generally a large-scale solar installation. Solar farms are most often community solar projects or utility-scale solar power plants. Solar farms usually have hundreds to thousands of solar panels installed in a large field.

[2] The Solar Energy Industries Association (SEIA) defines a solar project as “utility-scale” if it has a name-plate capacity of 1 MW. However, the National Renewable Energy Laboratory labels a solar project “utility-scale” if it has 5 MW of solar energy capacity.

In recent years, there have been significant advancements in the materials used in solar modules, as well as innovations in the design and manufacturing of solar cells. The main materials used in the manufacturing of a solar cells are:

Silicon:

Silicon is the most commonly used material in the manufacture of PV cells. It is abundant and has excellent semiconductor properties, which makes it ideal for use in PV cells. Silicon PV cells can be classified into two categories: monocrystalline and polycrystalline. Monocrystalline silicon cells are made from a single crystal of silicon, whereas polycrystalline silicon cells are made from multiple crystals of silicon. Silicon cells solar cells are relatively efficient and durable, but they are also relatively expensive to manufacture.

Thin Film:

Thin-film PV cells are made using a variety of materials, including cadmium telluride (CdTe), copper indium gallium selenide (CIGS), and amorphous silicon (a-Si). Thin-film PV cells are less efficient than silicon PV cells but are less expensive to manufacture. CdTe PV cells have the highest efficiency of all thin-film PV cells, and they are commercially available. CIGS PV cells have demonstrated higher efficiency even than a-Si PV cells.

Perovskite:

Perovskite PV cells are a relatively new technology that has gained a lot of attention in recent years due to their high efficiency and low cost. Perovskite is a mineral that has a crystal structure that is ideal for use in PV cells. Perovskite PV cells have demonstrated efficiencies of over 25%, which is comparable to silicon PV cells. However, perovskite PV cells are still in the development phase, and commercialization is not yet widespread (Roca I Cabarrocas P. 2022).

Organic:

Organic PV cells are made using organic materials, such as polymers, instead of inorganic materials, such as silicon or perovskite. Organic PV cells are less efficient than silicon or perovskite PV cells, but they are cheaper to manufacture, present great flexibility and easier manufacturability. Organic PV cells have demonstrated efficiencies of up to 16%.

One area of innovation in Organic PV technology has been the development of new materials for use in tandem solar cells, which are solar cells that use multiple layers of different materials to capture a wider range of the solar spectrum. Tandem solar cells have the potential to achieve efficiencies of up to 40%, which would make them among the most efficient solar cells ever developed (Naichia et al. 2013).

Quantum dot solar cells (QDSC)

QDSC are a relatively new technology that has shown promise in increasing the efficiency of solar cells that is based on the concept of using quantum dots as the absorber layer in a solar cell. Quantum dots are nanoscale particles that have unique optical and electronic properties and they are sandwiched between two electrodes. The efficiency of a QDSC is dependent on the size of the quantum dots, the type of materials used and the design of the device. The efficiency of the cells is over 13% but there are promising researches for improving it.

In conclusion, the materials used in the manufacture of PV cells have a significant impact on the efficiency and cost of solar energy. Silicon PV cells are the most widely used and have the highest efficiency, but they are also the most expensive. Thin-film PV cells are less efficient but are cheaper to manufacture. Perovskite PV cells have the potential to be both highly efficient and cheap to manufacture, but they are still in the research and development phase. Organic PV cells are also in the research and development phase and have the potential to be cheap to manufacture, but they are less efficient than other types of PV cells. Tandem Organic PV cells and QDSCs are promising technologies that are emerging. Overall, continued research and development of materials for PV cells are necessary to increase the efficiency and reduce the cost of solar energy.

2.2 Solar modules. Technology advances.

Solar modules consist of solar cells, which are connected in series and parallel to form a module. Its efficiency depends on several factors, including the type of solar cell technology used (see section 2.2), the module design and the manufacturing process.

Module design

The design of the solar modules is influenced by several factors, including the type of solar cell technology used (see section 2.2), the size and shape of the module and the materials used for encapsulation and backing.

Researchers are working in designs that can improve the absorption of sunlight and reduce energy losses in the module. One design is the use of bifacial solar modules, which are designed to capture solar energy from both the front and back sides of the module, which allows them to generate more electricity than traditional modules that only capture energy from one side. Bifacial modules can be made using a variety of materials, including crystalline silicon, thin-film, and even organic materials. In addition to higher energy yields, bifacial modules also offer greater design flexibility, as they can be mounted on tracking systems that follow the sun throughout the day. Bifacial solar modules have been shown to increase energy yields by up to 30%, compared to traditional modules.

Other design is the thin-film solar module, on the other hand, are made using thin layers of thin film PV cells, using materials such as amorphous silicon or cadmium telluride. Thin-film modules offer potential advantages over traditional silicon-based modules, including lower manufacturing costs, higher energy yields in low-light conditions, and greater flexibility. Thin-film modules can also be made in a variety of shapes and sizes, which makes them ideal for use in building-integrated photovoltaic (BIPV) applications.

Other innovative design are the shingled solar modules, which use interdigitated solar cells to increase efficiency and reduce shading losses. Shingled solar modules are also more durable and resistant to environmental stressors than traditional solar modules.

Researches are also working on improving the reliability of solar modules. Solar modules are exposed to various weather conditions, including rain, snow and hail, which can cause physical damage to the module. Researches are working on developing new encapsulation materials and designs that can protect solar cells from damage and extend, in this way, the lifetime of the module.

Manufacturing process

Innovations in manufacturing processes have led to improvements in the cost-effectiveness and scalability of solar modules. Roll-to-roll manufacturing processes, for example, allow solar modules to be produced at a lower cost and with greater precision than traditional batch processes. In addition, automated manufacturing processes are being developed to further reduce costs and improve the efficiency of solar module production.

2.3 Inverters.

Solar photovoltaic technology has been experiencing rapid growth in recent years, with solar panels becoming more efficient and affordable. However, the performance of solar photovoltaic systems heavily depends on the inverter technology used to convert the DC power generated by the solar panels into usable AC power. This section shows the latest advances and research in inverter technology which have focused on improving system efficiency, reliability, and flexibility.

Grid-forming inverters, multi-string inverters, transformerless inverters, advanced control strategies, and wide bandgap semiconductors have all shown promise in improving the performance of solar photovoltaic systems (Akbari et al. 2019).

Grid-forming inverters (GFIs) have been proposed as an alternative to traditional grid-following inverters for solar photovoltaic systems. GFIs have the capability to provide a stable grid voltage and frequency, making them ideal for remote areas with weak or no grid connection. Recent research has focused on improving the control algorithms for GFIs to ensure that they can maintain stable grid conditions.

Multi-string inverters have been developed to increase the flexibility and efficiency of solar photovoltaic systems. These inverters allow for multiple solar panel strings to be connected to a single inverter, reducing the number of inverters needed and improving overall system efficiency. Recent research has focused on improving the design of multi-string inverters to reduce their size, weight, and cost.

Transformerless inverters have become increasingly popular in recent years due to their higher efficiency and lower cost compared to traditional transformer-based inverters.

Recent research has focused on improving the reliability and safety of transformerless inverters, particularly with regard to insulation and ground-fault protection.

Advanced control strategies for solar photovoltaic inverters have been developed to improve the efficiency and stability of solar photovoltaic systems. These include maximum power point tracking (MPPT) algorithms, reactive power control, and active power curtailment. Recent research has focused on developing new control strategies that can improve system performance under various operating conditions.

Wide Bandgap (WBG) Semiconductors in solar photovoltaic inverters has the potential to significantly improve system efficiency and reduce the size and weight of inverters. Recent research has focused on developing WBG-based inverters that can operate at higher switching frequencies, reducing the size of passive components and improving system efficiency.

Taking this into account, new research trends on PV inverters are focused on:

- developing new converter systems (including back-to-back, floating, new systems with improved compatibility, lower losses, for superconducting technologies applications i.e., medium voltage, high current, etc.) for higher efficiencies.
- Smaller, more compact and/or lower voltage, higher current converter topologies, including floating that can result in significant cost savings for floating PV systems.
- Applied of DC GIS into VSC MVDC, HVDC converters, including economic benefits on overall system solution.
- On technical analysis of trade-offs in performance but also on ambient condition impact, maintenance, reliability, dimensioning, testing procedures.

2.4 Solar PV mounting systems

PV modules can be connected in series or parallel to produce larger voltages or currents. PV systems rely on sunlight, have no moving parts, are modular to match power requirements on any scale, are reliable, and have a long life (Kalogirou, 2009).

Previously, the solar PV systems was classified between, rooftop-mounted or building-integrated systems, community solar projects and utility-scale solar power plants. Solar modules are assembled into arrays on some kind of mounting system, which may be classified as roof mount, ground mount, or pole mount.

2.4.1 Roof mount and solar racking systems

When a solar panel is installed on a roof, only panels are visible, however, beneath the panels is a structure that holds the solar panels. This structure is called solar racking or solar mounting. The solar racking is therefore an integral part of every solar installation and certainly very important since it connects the solar panel system to the roof. The solar racking system has to be able to withstand heavy winds as well as extreme temperatures. Furthermore, the solar racking system is responsible to transfer the weight of the solar panels to the roof structure and it has to make sure, that the weight is distributed and not fixed on just some points because of the roofs static. Most of the time, these mounting systems are made out of aluminum because of the lightness of the material while being white strong, resistant and durable.

2.4.2 Ground Mount – solar mounting system

A key aspect of the solar structure at post-mining coal areas is for producing ground-mounts that perform in difficult soil conditions, a common issue among former coal sites. The process of extracting coal leaves behind mine heaps, a mixture of different soils and rocks pulled from the earth that has low compaction, like fill dirt, and makes it difficult for developing that land for residential or commercial purposes.

Ground-mounted PV systems are usually used at large, utility-scale photovoltaic power farms. The PV array consist of solar modules held in place by racks or frames that are attached to ground-based mounting supports. In general, ground mounted PV systems can be at the optimal tilt angle and orientation (as compared to roof mounted systems that can be non-optimal particularly for retrofits). Ground-based mounting supports include basically: a) pole mounts, which are driven directly into the ground or embedded in concrete. b) foundation mounts, such as concrete slabs or poured footings, and c) Ballasted footing mounts, such as concrete or steel bases that use weight to secure the solar module system in position and do not require ground penetration.

This type of mounting system is well suited for sites such as landfills or coal waste heaps, also simplifying decommissioning or relocation of solar module systems.

Ground mounts are normally consist of steel held in concrete with aluminum rails holding up aluminum modules. Thus, new trends on roof and ground mounting technology are specially focus, apart from providing more cost-effective mounitng systems, on minimising their environmental impact and spetially working on new materials, being the main research lines focus on using more environmentally friendly materials such as recycled plastics or biobased material, to reduce the consumption of metals are any other critical raw material.

2.4.3 Ballasted Ground Mount Solar Panels

Ballasted Ground Mount installations provide the lowest cost ground mount strategy. The Ballasted strategy is also the quickest to install. This strategy is exactly what is installed on a Commercial building flat roof. Solar panels are installed onto a stone foundation. Next, the solar panels are attached to plastic trays. Then, the plastic trays are weighed down by dozens of concrete blocks. This installation maximizes solar production in the summer months due to a 10-degree tilt.

New trends on ballasted ground technology, as in previous bullets, aims at minimising the environmental impact, taking this into account main research lines are focus on recycled and aggregates and arids, as well as on recycles plastics and another environmentally friendly materials.

2.4.4 Floating solar mounting system

Floating solar systems are installations that are mounted on bodies of water, such as ponds, lakes and reservoirs. Solar panels are mounted on floating platform that are anchored.

From last half of the 2010s, floating solar photovoltaic farms have expanded in a very important way, and is forecast to grow exponentially in the early 2020s (Cazzaniga & Rosa-Clot, 2021). These floating farms come together a set of advantages over PV farms on land, one of them related to mounting systems on water surfaces may be less expensive than the cost of land.

The platforms are made of materials that are resistant to water and UV radiation, such as high –density polyethylene (HDPE) and ethylene-vinyl acetate (EVA).

Floating PV (FPV) has huge potential in uncovered waterbodies, presenting an opportunity for solar energy production in areas where difficult terrain or land constraints make ground-mounted systems impractical. However, FPV also face a plethora of challenges for various environmental conditions such as wind, wave, currents, water level variations and humid and corrosive environment that could adversely affect the electrical output and life of the plant.

Taking this into account, new trends on Floating PV (FPV) technology aims at expanding functional requirements, minimising the environmental impact. Some research initiatives are focus on:

- Predictive yield models with dynamic behaviour of the PV floats, temperature effects and wave induced mismatch losses.
- New components that satisfy the structural and functional requirements, coping with soiling and fouling, degradation, corrosion, environmental stress cracking, UV stabilisation, exposure to water, salinity, humidity, algae growth, toxicity).
- Demonstrate low impact on ecosystem biodiversity by assessing direct impacts of FPV on aquatic systems and biodiversity, and to satisfy end-of-life recycling aspects.

2.5 Systems for connection to the Grid

As aforementioned, a Solar PV system can be classified as grid-connected, self - consumption or stand-alone or off-grid system. Large PV systems, commonly referred as solar farms, are commonly connected to the power grid, such connection point is called the **"point of interconnection", or POI**.

The POI is different for utility-scale farms and community solar scale projects, as far as their dimension and capacity are different SolarLandLease (2023). A community solar project is smaller than a utility-scale project. Project size are used to be measured in terms of capacity.

Community solar projects are typically 10 MW or smaller. These projects almost always connect to a three-phased distribution line. A distribution line is conceptually the same as a transmission line but moves electricity at a much lower voltage.

On the other hand, utility-scale projects connect by either connecting directly to a substation or tapping a transmission line (usually 69 kV or higher).

2.5.1 Interconnecting With a Substation

A substation is a fenced facility owned and operated by an utility. Its purpose is to convert high voltages to low voltages, or vice versa. Substations are necessary because of differences in voltages. Electricity is transmitted over distances at much higher voltages to reduce power losses. Power generating plants such as solar farms output power at different voltages, too.

Substations are near transmission line towers. In more rural areas, they are typically at the outer edges of towns or close to power generating facilities, manufacturing plants, or drilling and mining operations. In urban areas, transmission lines are usually located along major roads or highways.

If the nearest transmission line to the PV installation has a voltage of 115 kV, the output voltage from the solar farm needs to “step up” to 115 kV to feed power into it.

A substation is generally an ideal place for a solar farm to interconnect because the facility is already built and the design of these facilities makes it easier to interconnect.

2.5.2 Interconnecting With a Line Tap

The alternative POI to a substation is a line tap, which is essentially “tapping into” a high-voltage power line, sometimes through a switchyard that will need to be constructed. This can be more expensive and technically more challenging.

One challenge is that the cost of interconnecting with a transmission line increases with the voltage of that line. It is not cost-effective to connect a small project to a very high-voltage transmission line. In addition, very large projects usually require a connection to a higher-voltage line.

On the other hand, unless the solar plant is right next to a transmission line or substation, a dedicated transmission line called a generation tie (“gen-tie”) will need to be built. The farther away the utility substation is from your property, the more expensive the gen-tie will be to build.

In both cases, interconnecting with a substation or with a line tap, it must be considered the capacity of the local grid before the connection. The infrastructure may not have enough capacity to handle the electricity currently flowing through them plus all of the electricity that the proposed solar farm would generate. The electrical equipment at some substations may also need to be upgraded to handle the additional interconnection of a solar farm.

Taking this into account, new trends on power systems, substation and distribution lines are focused on a more effective and efficient solutions for transporting and seamlessly integrating renewable and non-dispatchable energy with new electricity transmission technologies, in particular using superconducting technologies, power electronics and hybrid Alternate Current – Direct Current grid solutions as well as MT HVDC (Multi Terminal High Voltage Direct Current) solutions. More in specific, some outstanding research initiatives are focus on:

- SF6-free technology for new equipment in substations.
- DC breaker integrated in Multi-terminal DC (MTDC) systems, including DC breaker for integration with Superconducting cables.

2.6 Storage Systems

Additionally, the stand-alone solar PV and self-consumption systems could incorporate the storages system (see deliverable D2.4 - Unconventional pumped hydro deployment, and D2.5 - Batteries deployment).

2.7 Supervisory control and monitoring system

Supervisory control and monitoring systems are an important component of photovoltaic (PV) technology, providing a centralized platform for monitoring and controlling the performance of PV systems. These systems use sensors, control systems, and communication networks to collect and transmit data about the performance of PV systems, enabling operators to optimize performance and troubleshoot issues in real-time.

In a typical PV system, a the system will collect data from various sensors and devices, such as inverters, meters, and weather stations, and transmit that data to a central control center. This data can include information about the performance of individual PV modules, the power output of the system, and environmental conditions such as temperature and sunlight intensity. The SCADA system can also be used to control various aspects of the system, such as the output of individual inverters or the orientation of PV modules.

One of the primary benefits is its ability to provide real-time monitoring of PV system performance, allowing operators to quickly identify and address issues that could impact system performance or reliability. For example, a malfunctioning inverter or a broken PV module can be detected and alert operators, allowing for quick repairs and minimizing downtime.

Supervisory control and monitoring systems can also be used to optimize the performance of PV systems, by analyzing data and adjusting system parameters to maximize energy production. For example, the output of individual inverters based on the output of PV modules or adjust the orientation of PV modules based on changes in sunlight intensity can be adjusted.

Monitoring systems can provide valuable data analytics and reporting capabilities, allowing operators to track and analyze system performance over time. This data can be used to identify trends, optimize system performance, and provide valuable insights into the behavior of PV systems.

The new trends on digitalization of PV systems are focus on speeding up of (from early-adoption to upscaling) of new digital technologies in the energy sector such as cyber-security and privacy tools or data centered technologies (data gobernance, interoperatbiliy principles or AI) tailor-made for the specific requirements of the energy system. Some example could be, forescating tools for energy production or aggregated demand or complete a comprehensive ontology for energy assets usable from designer, promoters, investors, enginers to facility manager or consumers and citizen.

3 Features of the implementation of technology in a post-mining area

3.1 Main features in post-mining areas for the installation of PV plants

The coal mining activity has an important impact into the areas where the activity is being developed, from the social, economic and environmental point of view. Creation of direct and indirect jobs, new business and SMEs in the area help to improve local economy and social rates.

The mining activity leverages the construction, maintenance and exploitation of singular infrastructure and resources. Deep-water ports, road and rail networks, access to power and water, are key items to building mining projects; also, several coal-fired power plants are built close to the coal mining areas and, sometimes, energy intensive industries taking advantage of a great quality supply of electricity. Altogether are key elements to dynamize the local economy of the region and in consequence the social situation.

Thus, once the closure process of a coal mine is initiated, special attention should be paid to mitigate the economic, social and environmental impact in the region and in the local communities. Moving to the last stage of coal mines, after the closure of the mine activity, the mine reclamation process is crucial for regions in coal transition, not only from the environmental and ecological perspective, but also from the social and economic. Among others, a flooding process happens in both, open pit and underground mines, in the first leading to the so-called pit lakes, in the second, appearing the need to keep the operation of dewatering pumps.

The mine reclamation is the process of modifying the mines areas and the land that has been mined to ecologically functional or economically usable state. Mine reclamation has to be focus on recovering, from an ecological point of view, lands, sites and landscapes. This meets a variety of crucial goals ranging from the restoration of productive ecosystems to the creation of industrial, economical and municipal resources, all of them leading the use and promotion of land, flooded areas, or electrical facilities.

Taking this into account, one option of redevelopment of such areas could be by the promotion of solar PV plants. Several utility-scale solar developers are already planning and constructing arrays across coal communities and mining areas.

3.1.1 Typologies of mines

Coal can be extracted from the earth either by surface mining or underground mining.

3.1.1.1 Surface Mining

If coal is less than 61 meters (200 feet) underground, it can be extracted through surface mining. In surface mining, workers simply remove any overlying sediment, vegetation, and rock, called overburden. Economically, surface mining is a cheaper option for extracting coal than underground mining. About two and a half times as much coal can be extracted per worker, per hour, than is possible with underground mining.

The environmental impacts of surface mining are very important. The landscape is literally torn apart, affecting habitats and entire ecosystems. Surface mining can also cause landslides and subsidence (when the ground begins to sink or cave in).

The Surface Mining Control and Reclamation Act of 1977, in the United States, the Directive 2006/21/EC3 in EU, or the Mining Act 1978 from Australia, provides guidelines to help fix these problems and clean up abandoned mining sites.

The three main types of surface coal mining are strip mining, open-pit mining, and mountaintop removal (MTR) mining. This typology of mining activity usually causes the apparition of flooded areas (mining pit lakes) and coal waste heaps, both, suitable land areas for installing solar PV systems.

3.1.1.2 Underground Mining

Most of the world's coal reserves are buried deep underground. Underground mining, sometimes called deep mining, is a process that retrieves coal from deep below the Earth's surface—sometimes as far as 300 meters (1,000 feet). Miners travel by elevator down a mine shaft to reach the depths of the mine, and operate heavy machinery that extracts the coal and moves it above ground (Nationalgeographic, 2023).

The immediate environmental impact of underground mining appears less important than surface mining. There is little overburden, but underground mining operations leave significant tailings. Tailings are the residue left over from the process of separating coal from gangue, or economically unimportant minerals.

There are three major types of underground coal mining: longwall mining, room-and-pillar mining, and retreat mining. This typology of mining activity usually causes the apparition of flooded underground galleries with needs of dewatering pumps; abandoned buildings, infrastructure and facilities to restore and also coal waste heaps. Thus, these locations offer stable energy demand and urban areas and land, both, necessary requirements to promote the installation of a solar PV system.

3.1.2 Power System at mines

A complex set of Auxiliary Mining Equipment aims to meet the needs of mining operation but also to ensure a safe and productive mine site. From ventilation systems, pneumatic or hydraulic air compressed installation, rock support equipment, belt storage magazine or belt conveyance equipment. Mining operators require fit-for-purpose hydraulic, pneumatic, and electromechanical systems for mining machinery and vehicles (MiningTechnology, 2023). Mining involves extensive use of hydraulic, pneumatic, and electromechanical equipment and systems throughout the mine development and operation, from shaft sinking, raise boring, and rock excavation, to ore haulage, handling, and processing.

Altogether making the mining activity a high demand energy process. The mining industry accounts for 10 percent of world energy consumption.

Taking this in mind the power systems in a mining site (ElectricalEngineeringPortal, 2023), mainly equipment and systems related to the grid connection (substation, transformers, protections equipment and ancillary systems) are facilities which may be easily recovered, refurbished and used in any mine sites recovering process, i.e.: by deploying an utility-scale PV farms at mine areas.

3.2 Post-coal mines sites opportunities for the installation of solar PV plants

In the previous section has been highlighted the following elements as the most relevant when a solar PV system is projected:

- Solar cells and Panels,
- Mounting systems,
- Grid connections,
- Storage possibilities,
- Control and monitoring,

Revisiting such elements, designing solar PV farms shows some inconveniences, a non-comprehensive list of cons is listed below, where coal mines could overcome or minimize such difficulties.

Table 3-1. Post-mining areas opportunities

CONS	Coal Mines relieve
They require a lot of space	*Land restoration is needed*
Only work when the sun is shining (and energy storage can be expensive)	*Potential Pumped storage hydropower (PSH) plants*
Have an upfront cost (specially on grid connections)	*Existing POI and grid connection*
Enough capacity of the power grid to accept a new power generation	*Power network in coal areas has usually high capacity, due to existence of thermal power plants.*
A deregulated EU electricity market provoke certain uncertainties and investment risks	*Possibilities to self-consumption to supply own existing demand, also by conforming Local Energy Communities around the sites*

source: https://www.solarlandlease.com/solar-farm-connect-grid

By other hand, the technologies harnessing renewable energy sources are characterized by a power density several orders of magnitude lower than fossil fuels. As a consequence, the transition to these sources of energy is expected to intensify the global competition for land. The deployment of renewable energy technologies such as solar and wind power requires more land area to generate the same amount of electricity as a fossil fuel power plant. For example, a 1 MW solar photovoltaic (PV) power plant typically requires 2-3 hectares of land to generate electricity, depending on the efficiency of the PV modules and the site-specific factors such as solar irradiance and shading.

The competition for land can be a significant challenge for the deployment of renewable energy technologies, especially in densely populated or environmentally sensitive areas. The potential impacts of land use changes associated with renewable energy deployment include loss of wildlife habitat, changes in land use patterns, and conflicts with other land uses such as agriculture and forestry.

To address these challenges, there is a need for careful planning and siting of renewable energy projects to minimize their environmental impacts and maximize their benefits. This may involve using previously disturbed or degraded lands for renewable energy deployment, designing projects to minimize their footprint and visual impacts, and engaging local communities and stakeholders in the planning and decision-making process.

In summary, while the deployment of renewable energy technologies may require more land area than fossil fuels, careful planning and management can help to minimize their environmental impacts and maximize their benefits.

Taking this into account, coal mines sites appear as quite interesting location to place solar PV projects, facilitating the design and implementation by reducing cost or environmental impact, or energy performance, reducing ROI and payback periods and improving cost-benefit analysis.

Crossing such elements with the singularities and features of mining areas as potential sites to place solar PV farms, in order to optimize the cost-benefit analysis and other parameter like social, economic and environmental indicators, four items must be analysed in details: a) mounting systems, b) grid connection, c) storage capabilities and d) land use.

3.2.1 Solar PV Mounting systems features in a post-mining area

Some particularities related to the mounting systems should be taking into account when a solar PV farm is projected to be placed at a mining site,

In mining areas, the terrain can be loose and challenging, making it difficult to install traditional solar PV mounting systems. However, advancements in technology and engineering have led to the development of innovative solar PV mounting systems that can withstand these conditions and provide a reliable source of renewable energy.

One important consideration when installing solar PV mounting systems in post-mining areas is the geotechnical study of the terrain. Geotechnical studies are necessary to understand the characteristics of the ground, such as soil type, moisture content, and rock quality, which can affect the stability and performance of the mounting system. The results of the geotechnical study can be used to design a mounting system that is suitable for the specific ground conditions and to identify any potential risks or challenges that may need to be addressed. Furthermore, it is necessary to define the grip requirements. The terrain may be uneven, and traditional mounting systems may not provide adequate grip to ensure stability. Therefore, it is crucial to choose a mounting system that is designed to provide sufficient grip, even in loose or uneven ground conditions.

In addition to traditional ground-mounted solar PV systems, floating solar PV farms are becoming an increasingly alternative in post-mining areas. These systems consist of solar panels mounted on floating structures, which can be installed on water bodies such as lakes, ponds, or reservoirs. Floating solar PV farms can be a viable solution in post-mining areas of surface mining where can appear ponds. These systems also have the added advantage of reducing water evaporation and improving water quality of this artificial lakes. Despite this solution already exists in the market, research and innovation is still needed to provide improved materials to minimize adverse effects of humidity conditions and chemicals contained in the water.

Solar PV mounting systems can provide a reliable source of renewable energy in post-mining areas. It is important to consider the geotechnical study of the terrain to design a suitable mounting system, the grip improvements needed to ensure stability and the possibility of installing a floating solar PV farm. With the right system in place, mining companies can reduce their carbon footprint and improve their sustainability while also reducing energy costs during the post-mining phase.

3.2.2 Ancillary systems and Grid Connection

The possibility to recover and reuse any electric switchgear, transformers, element of the substation or mine site power system aims at reducing the cost and investment of the solar PV system, at least in a 5%, which should be taking into account when the location is being analysed and selected.

Ancillary systems and grid connection are important components in the development of a reliable and efficient power system. Ancillary systems refer to the support services that are necessary to maintain the stability and quality of voltage and frequency of the power system. This includes services such as spinning reserve, reactive power support, and voltage control, among others.

Grid connection, on the other hand, refers to the physical and electrical connection of power generators and consumers to the grid. This allows for the efficient sharing and distribution of power across different regions and ensures that power is available when and where it is needed.

The integration of renewable energy sources such as solar and wind into the power grid can present challenges for ancillary services and grid connection. Unlike traditional power generators that can be turned on or off as needed, renewable energy sources are intermittent, meaning they are not fully reliable in terms of power output. This presents a challenge for ancillary services and grid connection as they must adapt to the varying power output of renewable energy sources to maintain grid stability.

To address these challenges, advanced technologies and control systems have been developed to provide real-time monitoring and control of the power system, allowing for the quick and efficient adaptation to changing conditions. In addition, energy storage systems can be used to provide backup power and ancillary services when renewable energy sources are not supplying enough power to the system.

3.2.3 Storage capabilities in a post-mining area:

On the other hand, it was explained in previous section how the inclusion of storage capabilities in any solar PV plant, is increasing its flexibility and performance. Mine sites are able to provide some interesting possibilities to exploit such storage capabilities as showed at D2.4 and D2.5.

3.2.4 Solar PV plants Land needs covered by coal mines sites

The closure of coal mines often results in significant amounts of unused land to be restored, the mine site themselves, but also land used to waste material, also known as tailings or waste heaps, both could occupy vast areas of unproductive land.

On the other hand, Above is remarked how land demanding the PV technology is, 1 MW solar PV plant typically requires 2-3 hectares of land. Thus, a promising opportunity exists for the use of these mines sites or waste heaps for hosting photovoltaic power plants. The utilization of tailings in this manner can help recover the land, transform it into a productive area, and provide a source of energy that is sustainable and environmentally friendly.

Photovoltaic installation plants can be built on these tailings, which not only help to generate zero emissions energy but also create new jobs in the renewable and future energy sectors.

The use of tailings from closed coal mines for photovoltaic installation plants offers a promising approach for recovering unproductive lands and generating renewable energy. This approach presents an opportunity for social, environmental, and economic development while creating new job opportunities in emerging renewable energy sectors in “job-demanding” areas. As we look toward the future, renewable energy systems, like photovoltaic installation plants, will play a significant role in meeting our energy needs while reducing our carbon footprint

4 Assessment of job creation potential.

Within the GreenJOBS project, a detailed assessment of job creation potential per MW installed for the project's renewables (photovoltaics, wind energy, hydraulics, and geothermal) and renewable hydrogen based on their production capacity, both for commissioning and operation, was developed.

First, the job-creation potential of renewable energy and hydrogen deployment was tried to be assessed using the input-output analysis introduced by Leontief in the 1930s and later adapted for different purposes. In recognition of his work, Leontieff received the Nobel Prize in Economics. The input-output model (Leontieff, 1986) is a quantitative model in the form of linear equations describing how a product from an industry is distributed within the economy. It represents the interdependencies between different national sectors or multi-regional economies and shows their production structure.

However, the equilibrium equation has several constraints or assumptions (Scholz, et al., 2020) that may pose extreme difficulties for the renewable energies and hydrogen analyzed within the GreenJOBS project: (1) each unit of output requires the same amount of inputs, being independent of the production level, something that goes against the concept of the economy of scale, that represents the cost advantages due to the operation scale or, in other words, increased production, lower cost; (2) there should be no supply restrictions in, for example, the access to raw materials, employment, etc.; and (3) Changes on the output does not cause input substitution, something which implies having a fixed input structure.

As can be easily observed, these constraints affect almost every intrinsic characteristic of renewable energies and hydrogen, particularly the limited access to critical raw materials in Europe, as the EU heavily depends on imports of critical raw materials from third countries. This dependency and the growing global demand due to the shift towards a digital and green economy make supply chains vulnerable. Precisely, the European Critical Raw Materials Act (2023) aims to ensure a secure and sustainable supply of critical raw materials for Europe’s industry, significantly lower the EU’s dependency on imports from single-country suppliers and increase the EU’s resilience by reducing dependencies, increasing preparedness and promoting supply chain sustainability and circularity.

This aspect, together with the fact that the renewable and hydrogen sectors present an extraordinary high-scale economies that change really quickly in time (even for periods of less than one year) and that the input structure is far from fixed, makes it really difficult to analyze the input-output relationships between these renewable energies and hydrogen with this method. Thus, we will use the Employment factor method to analyze the potential job creation.

The employment factor approach estimates the average number of jobs per unit of capacity installed or per unit of energy generated and combines them with energy system data to derive the total number of jobs. Factors are specific to the value chain's technologies and stages/activities (Fragkos & Paroussos, 2018).

We will consider direct employment factors used by other authors, distinguishing per activity and component based on a literature review and using specific base years for the reference employment factors. Direct jobs, crucial for their immediate impact, are employment opportunities created to meet the demand for a product or service. They serve as critical indicators of the economic benefits of renewable energy and hydrogen projects, demonstrating the tangible job opportunities that arise from the development and expansion of renewable energy.

In the context of renewable energies and hydrogen, direct jobs refer to employment opportunities that are directly associated with the development, production, installation, operation, and maintenance of these systems, the key categories being:

- Operation and Maintenance (O&M): Jobs for ongoing operations and maintenance of the PV plant.
- Installation: Jobs for site preparation, construction, and installation.
- Manufacturing: Jobs Related to the production of components.

Then, learning curves developed considering the growing rate of each technology will update the employment factors by activity and component. Finally, if possible, a validation of results comparing them with ex-post results estimated by other authors will be developed.

Direct employment factors

Ortega et al. (2020) calculated the direct employment factors for 2008 for Photovoltaics and Wind on-shore, as presented in Table 4-1.

Table 4-1. ***Direct employment factors for 2008 for PV and Wind on-shore (Ortega et al., 2020)***

	Year	O&M (jobs-year/MW)	Inst. (jobs-year/MW)	Manuf. (jobs-year/MW)
Wind	2008	0.40	2.50	7.50
PV	2008	0.20	6.00	6.50

Rutovitz et al. (2015) calculated the direct employment factors for 2010 and 2012 for almost all renewable energy technologies, as presented in Tables 4-2 and 4-3.

Table 4-2. ***Direct employment factors for 2010 for renewable energies (Rutovitz et al., 2015)***

	Year	O&M (jobs-year/MW)	Inst. (jobs-year/MW)	Manuf. (jobs-year/MW)
Wind	2010	0.40	2.50	12.50
PV	2010	0.40	9.30	29.00
Geothermal	2010	0.70	3.10	3.30

Hydro	2010	0.20	10.80	0.50
Biomass	2010	3.10	3.90	0.40

Table 4-3. Direct employment factors for 2012 for renewable energies (Rutovitz et al., 2015)

	Year	**O&M (jobs-year/MW)**	**Inst. (jobs-year/MW)**	**Manuf. (jobs-year/MW)**
Wind	2012	0.20	2.50	6.10
PV	2012	0.30	11.00	6.90
Geothermal	2012	0.40	6.80	3.90
Hydro-small	2012	2.40	15.00	5.50
Biomass	2012	1.50	14.00	2.90

Using data from Rutovitz et al. (2015) and from Cameron & Van der Zwaan (2015), Fragkos & Paroussos (2018) modelled the direct employment factors for 2015 that are presented in Table 4-4.

Table 4-4. Direct employment factors for 2015 for renewable energies (Fragkos & Paroussos, 2018)

	Year	**O&M (jobs-year/MW)**	**Inst. (jobs-year/MW)**	**Manuf. (jobs-year/MW)**
Wind	2015	0.20	2.60	4.35
PV	2015	0.15	10.40	5.36
Geothermal	2015	0.51	11.20	5.40
Hydro-small	2015	0.28	15.80	10.90
Biomass	2015	0.24	14.00	2.90

Using a different approach, Brown et al. (2020) estimated the number of direct jobs resulting from investments in renewable energies in 2015, as presented in Table 4-5. The data for transmission and distribution can be assumed to be equivalent to battery deployment.

Table 4-5. ***Direct employment factors for 2015 for renewable energies (Brown et al., 2020).*** **Change used: 1.1 USD = 1 EUR**

	Year	**O&M (jobs-year/MW)**	**Inst. (jobs-year/MW)**	**Manuf. (jobs-year/MW)**
Wind	0.43	2.14	4.27	21.36
Transm. & distrib.	0.64	3.18	6.36	31.82
Fossil fuel	0.58	2.91	5.82	29.09
Solar	1.82	9.09	18.18	90.91
Geothermal	1.14	5.68	11.36	56.82

Hydroelectric	1.20	6.00	12.00	60.00
Biomass	0.66	3.32	6.64	33.18

Regarding Green hydrogen production, Rhodium Group (https://rhg.com/research/clean-hydrogen-workforce-development/) estimated that 2023 a 100 MW electrolytic plant would create 45 ongoing jobs and 330 plant investment jobs. On the other hand, the literature focuses more on the global number of jobs than on the number of jobs resulting from power installations or investments.

Learning rates

According to Murphy (2012), the learning rate determines how much a model change at each iteration while moving towards a minimum value. The learning rate influences how the newly production efficiency influences overrides old production efficiency, representing in a metaphoric way the speed at which the production system of a company or product "learns".

Learning rates will be developed considering the growing rate of each technology to update the employment factors by activity and component.

To achieve this goal, we will use the latest data on European energy figures, the Statistical Pocketbook 2023 (European Commission, 2023).

Table 6 presents the installed electricity capacity in GW for several renewable energies and hydrogen from 2010 to 2021.

Table 4-6. ***Installed electricity capacity in GW (European Commission, 2023).***

	2010	2015	2019	2020	2021
Wind	79.0	127.2	167.1	177.1	188.4
Solar	30.6	87.7	120.2	138.5	164.2
Geothermal	0.8	0.8	0.9	0.9	0.9
Hydro	143.0	148.2	150.8	151.1	151.7
Combustible fuels	414.8	412.2	395.7	388.1	379.4
Green hydrogen (MW)*			85.00		162
Batteries**				2.4 GW 3.9 GWh	4.6 GW 7.7 GWh

* Bolard et al. (2023). ** Bielewski et al. (2022).

According to the figures presented in Table 5, the derived linear learning curves for the renewable energies, except geothermal and batteries, are presented in Figure 4-1.

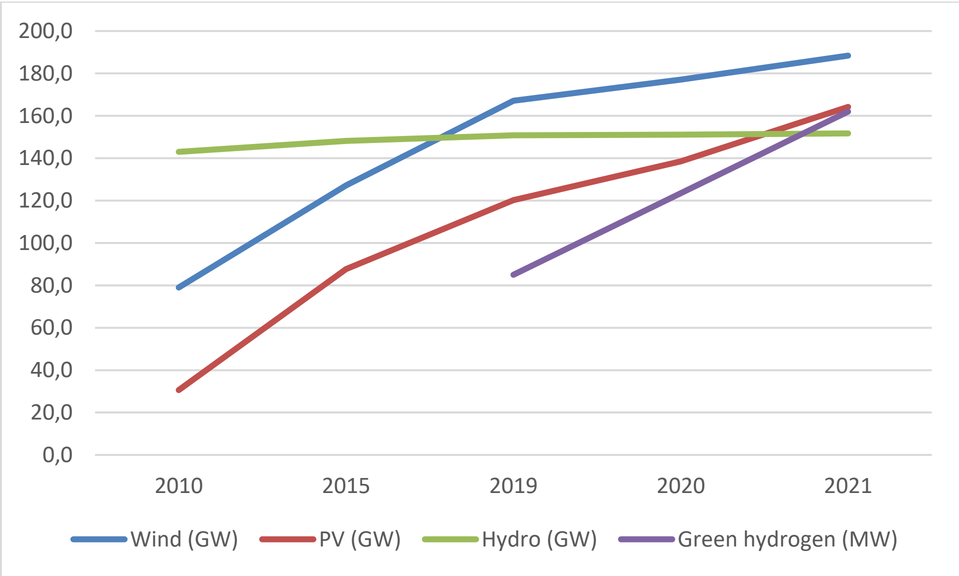

Figure 4-1. Installed electricity capacity for wind energy, PV, hydro and green hydrogen plants.

The trendline slopes to 10.65 for wind energy. The slope for PV energy is 24.78; for hydro, it is 1.08; and for green hydrogen, it is 38.5.

The case of geothermal and batteries is presented in Figure 4-2.

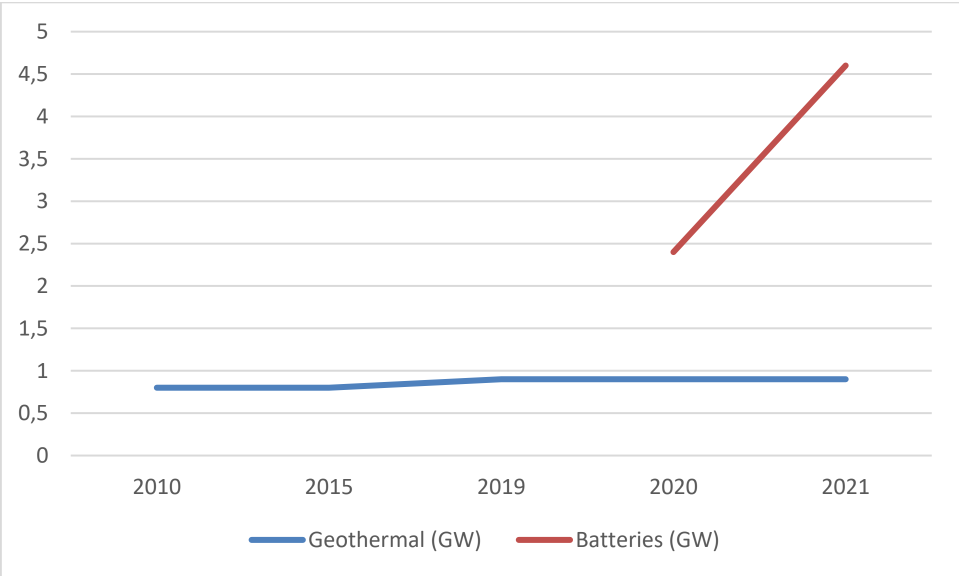

Figure 4-2. Installed electricity capacity for geothermal and batteries

The trendline slopes to 2.2 for batteries and only 0.03 for geothermal.

For the cases of Wind energy, PV, Geothermal and Hydro-small we will use the direct employment factors for 2010 obtained from Rutovitz et al. (2015) and the ones from

2015 obtained by Fragkos & Paroussos (2018). Simultaneously we will consider the trendline slope of the installed electricity capacity.

Estimation of direct, indirect, and induced employment

Finally, and to estimate the direct, indirect and induced employment across renewable energies and hydrogen, we will use as a reference an input/output table using the employment multipliers from Brown et al. (2020), that are presented in Table 4-7.

Table 4-7. Estimation of direct, indirect and induced employment: Full-time equivalent jobs/M€ investment in 2015 (Brown et al., 2020)

	Direct	Indirect	Induced	Total
Wind	0.43	1.35	1.47	3.25
Transmission & distribution	0.64	1.92	2.65	5.21
Fossil fuel	0.58	2.34	2.85	5.76
Solar	1.82	0.64	3.35	5.80
Geothermal	1.14	2.96	3.58	7.68
Hydroelectric	1.20	3.07	3.85	8.13
Biomass	0.66	5.34	3.88	9.88

Photovoltaic energy

For the O&M (jobs-year/MW), the evolution using a more usual exponential trendline is presented in Figure 4-3.

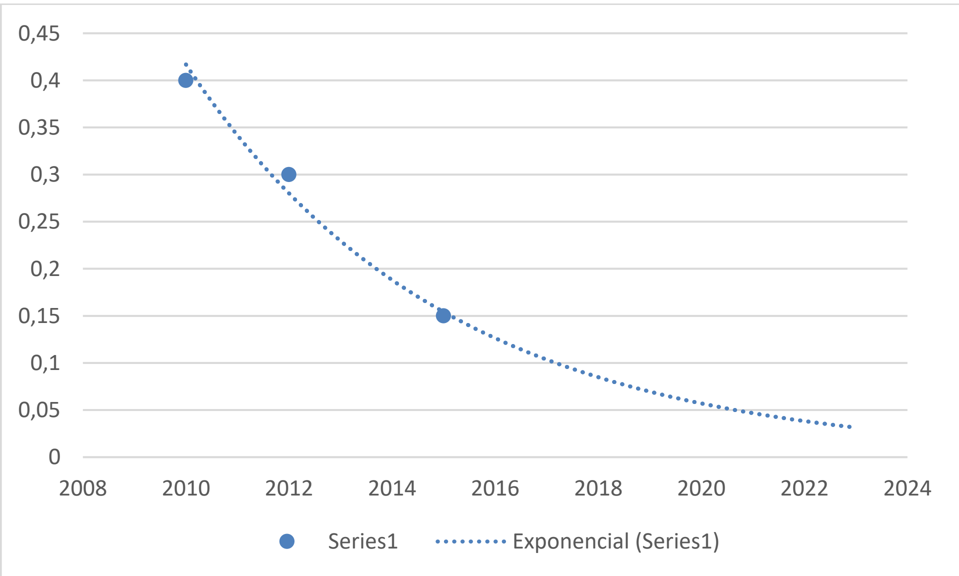

Figure 4-3. O&M (jobs-year/MW) evolution trendline.

For the Installation (jobs-year/MW), the evolution using an exponential trendline is presented in Figure 4-3.

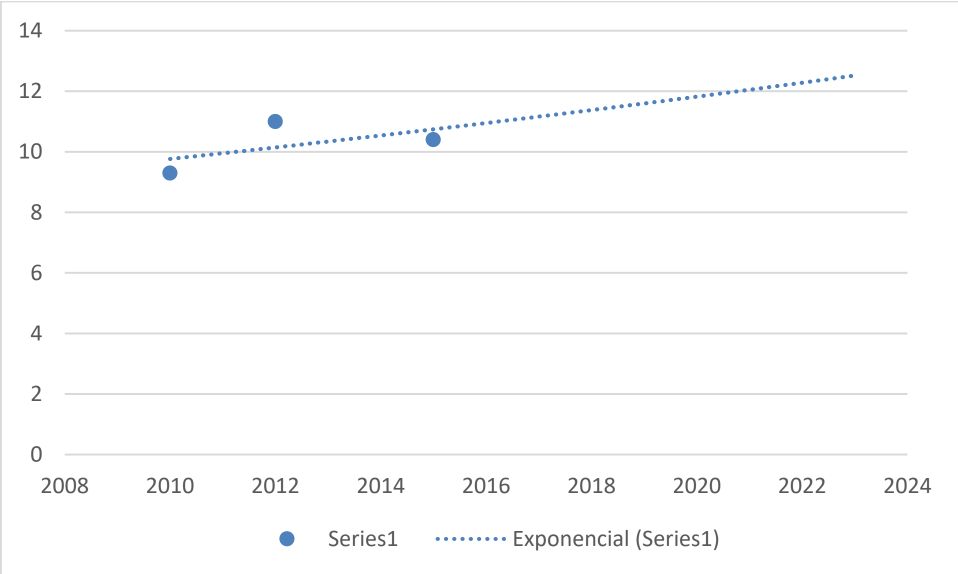

Figure 4-4. Installation (jobs-year/MW) evolution trendline.

In the case of manufacturing jobs and due to the extremely difference in year 2010, we will use only the values given by 2012 and 2025, as presented in Figure 4-5.

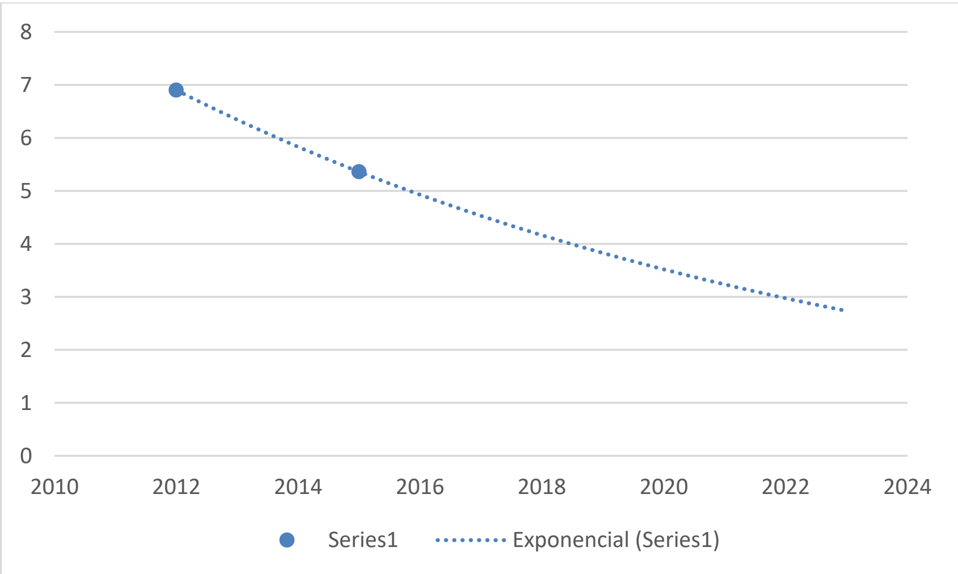

Figure 4-5. Manufacturing (jobs-year/MW) evolution trendline.

Table 4-8 presents the estimations of direct employment factors for Photovoltaic energy by establishing respective increases and decreases based on the derived learning curves but adapted to the usual exponential trends.

Table 4-8. ***Direct employment factors for photovoltaic energies***

	2010	2012	2015	2019	2020	2021	2023
Installed capacity in GW	30.6	*53.44*	87.7	120.2	138.5	164.2	-
O&M (jobs-year/MW)	0.40	0.30	0.15	*0.07*	0.06	*0.05*	*0.05*
Inst. (jobs-year/MW)	9.30	11.00	10.40	*11.60*	11.9	*12.00*	*12.40*
Manuf. (jobs-year/MW)	29.00	6.90	5.36	*3.9*	3.6	*3.2*	*2.5*
Total (jobs-year/MW)	38.7	18.2	15.91	15.57	15.56	15.25	***14.95***

* Estimated values are presented in italics

Thus, assuming a similar reduction between 2019-2021 than between 2021-2023 except in the case of O&M as it is really small already, we can estimate the number of direct jobs for 2023 in 14.95 direct jobs-year/MW.

Finally, using the estimation proportions obtained by Brown et al. (2020), presented in Table 4-7, we obtain the total employment of 46.44 full-time equivalent jobs/MW presented in Table 4-9.

Table 4-9. ***Estimation of direct, indirect and induced employment for Photovoltaic energy:*** **Full-time equivalent jobs/MW**

	Direct	Indirect	Induced	Total
PV	14.95	5.26	26.23	46.44

5 Best PV technology to fit operational requirements of mining areas.

Having in mind the previous sections, this section provides a set of scenarios which properly fit the operational requirements to install solar systems at different typologies of post-mining areas. Two use cases have been identified and detailed.

5.1 Use case 1: Flooded open pit mines: pit lakes

After the closure of the mining activity in open pit mines, a land recovering process has to be initiated. Thus, different alternatives and projects has to be analysed to recover mining assets and lands. All of them should include the administrative processes related to, at least, change the current use of the land.

In this scenario, the installation of a solar PV farms could be a viable and acceptable option to be considered, as far as this project would be fully compliance with the environmental requirements, which will facilitate the administrative and legal requirement to obtain the necessary permits and licences to change the use of land needed to install a solar farm in the country side.

On the other hand, once the mining activity stops in the mining sites, also the maintenance operations, including the dewatering systems, stop. Thus, due to infiltrations and the water natural process, mines (open but also underground pits) sites are used to end up flooding. Taking this in mind, water reservoirs also could complement the surrounding areas to place solar arrays, in this case as a floating solar system.

Last but not least, as aforementioned, mining sites have one point of interconnection (POI) to the grid, but also a power substation and ancillary systems in their premises. Considering the cost of these facilities represents around 5-7% of the investment for a solar PV farm, mining sites will become attractive locations for potential investors. Apart from the fact, having the POI ready to be used, reduces considerably timing, efforts, and money to overcame the administrative and legal process to interconnect the farm to the grid.

Thus, taking in mind these **specific operational requirements**:

1. Open Mining sites need a land recovering plan, accepting a change of use of land to welcome a solar PV farm,
2. Open pit mines offer pit lakes to project a floating solar farm.
3. POI, substations and ancillary facilities and permits already exists,

Open pit mines should be considered as really favourable locations to initiate **floating solar farms**.

Best technology to better fits operational requirements:

- Grid connected better than standalone projects, using interconnection with substation.
- Large scale projects as Solar farms better than solar communities,

- Floating mounting systems would be a viable alternative,
- Based on existing POI, substation and ancillary systems identify the proper technology to adapt and reuse as much as possible former facilities.

5.2 Use case 2: Underground mine in living surrounding area

The concept of Local energy Communities (LEC) is being strongly supported by the European Institutions, from EU policies and funding instruments but also from the legal and regulatory perspective. Thus, the local energy communities appear as one of the clearest initiatives to guide a just and clean energy transition putting the citizen in the centre.

Apart from regulatory and governance issues, out of the scope of this document, two relevant aspects to consider when defining a LEC are: the energy system, where the solar PV technology is the most conventional renewable energy generation systems considered in LECs; as well as, the location where to place the solar array.

In previous section was studied how underground mines areas are usually embedded into living environments and municipalities, which makes sense, as far as usually workers households were built around or close the mines sites. Thus, the existing neighbourhoods around this typology of mines are proper locations to establish LECs, for many reasons, to each more important. Firstly, a traditional and existing cooperative and associative social sense of these neighbourhoods, inherited from mostly all coal regions, exists which is very significant in order to stablish a solar community.

Secondly, the use of existing mine facilities and areas to place solar arrays, apart from residential buildings' roofs, is considered a plus in order to select better locations.

Third, as in the previous use case, the point of interconnection, substation and ancillary systems are there, ready to be recovered and reused.

Last but not least, in order to optimize the matching between the PV generation and the aggregated demand profile, a very singular and demanded feature for local energy communities is the possibility to provide energy demand flexibility to the whole LEC energy system. Underground mines, similarly to open pit mines, also has to overcome the fact that mines tend to flood, thus a dewatering pumping system is needed, which could provide not only a stable consumption but also some flexibility capabilities to the system.

Thus, taking in mind these **specific operational and social requirements**:

1. Underground mining sites need a land and infrastructure recovering plan, offering roofs and space to place solar arrays,
2. Underground mining sites are used to be into high rates of population at urban habitats
3. A traditional associative social sense exits.

4. Underground galleries offer advantages to project a reversible pumping storage system.
5. POI, substations and ancillary facilities and permits already exists,

Underground mining sites should be considered as really favourable locations to initiate a **solar PV energy community with potential flexibility capabilities**.

Best technology to better fits operational requirements:

- Grid connected better than standalone projects, interconnecting with a line tap
- Medium scale farms more appropriate to solar communities' governance,
- Roofs, ground and carport would be viable alternatives for mounting systems,
- Based on existing POI, substation and ancillary systems identify the proper technology to adapt and reuse as much as possible former facilities.

6 Best Practices

A set of best practices selected as representative use cases of installation of solar PV plants in coal post-mining areas are showed below.

6.1 A 170 MW Solar plant in Klettwitz, Germany.

Owner: GP Joule and Trina Solar.

This hybrid Wind and PV farm, grid connected, was built on a former lignite open cast mine in Brandenburg, Germany (Trinasolar, 2023).

Figure 6-1. (Photo Credit) © TrinaSolar

6.2 A 3 MW Prapretno solar power plant in Hrastnik, Zasavje, Slovenia,

Owner: Holding Slovenske Elektrarne (HSE)

This facility, grid connected, was built on a rehabilitated landfill that belonged to the defunct coal-fired Trbovlje thermal power plant (BalkanGreenEnergyNews, 2023).

Figure 6-2. (Photo Credit) ©Holding Slovenske Elektrarne (HSE); HTZ; balkangreenenergynews.com

6.3 A 24.5 MW floating solar plant in Grafenwörth, Austria

Owner: BayWa subsidiary ECOwind along with Austrian energy supplier EVN

This floating solar plant, grid connected, is located on the water surface of 2 lakes created by former sand and gravel pits in Grafenwörth, Austria (baywa-re, 2023).

Figure 6-3. (Photo Credit) ©BayWa r.e. - ECOwind

7 DEMOSITE INSTALLATION. MAIN ECONOMIC AND TECHCNICAL CHARACTERISTICS

The aim of this chapter is to simulate a project of installation of a photovoltaic farm producing electric energy in a mining area and thus to have a general idea about the initial technical and economic aspects.

7.1 Demosite 1: Large scale Solar Farm in a coal waste heap.

This facility will have a useful life of 30 years with an approximate capacity of 50MW and the estimated investment is 40 M€.

The configuration and layout of the photovoltaic installation covered by this report will consist of 14 sub-fields, each sub-field corresponding to an inverter, with a total of 127,296 panels of 390 Wp each. The subfields are configured in two types:

- Type I: (10 inverters) The panels are grouped in 26 units in series forming a string, with 20 strings being connected in parallel at each of the 18 inverter inputs.

- Type II: (4 inverters) The panels are grouped into 26 units in series to form a string, with 18 strings connected in parallel at each of the 18 inverter inputs.

The photovoltaic generator consists of 127,296 monocrystalline silicon monofacial silicon panels of 390 Wp each distributed by 10 + 4 sub-fields as detailed in previous bullets. Strings can be fixed installation or in trackers with E-W tracker, connected in parallel to the corresponding inverter. The total peak power of the photovoltaic installation is 49,645 KWp.

The support structure is responsible for ensuring a good anchorage of the solar generator, facilitating the installation and maintenance of the panels, while providing not only the necessary orientation, but also the ideal angle of inclination for a better use of radiation.

The type of support chosen for this design is distributed in two rows of modules in a vertical position, suitable for regular and irregular terrain.

The support framework is made of galvanized steel with great structural resistance and long endurance to outdoor conditions, suitable for directly securing the module and the base. This structure adheres to the torsion tube by means of screwable clamps, so no welding is required in-field. This tracker has only five foundations, providing a quicker and less expensive installation. The modules are directly secured to the rigid steel rails, to eliminate vibration and thermal expansion and the risks of over-tightening associated with aluminium clasps. The greater height-to-width ratio maximizes irradiation, reducing shade intensity and adjustment losses.

The photovoltaic modules as mentioned before of this project have the following characteristics.

Table 7-1. Panel characteristics

PHISICAL CHARACTERISTICS	
Width (mm)	992
Height (mm)	2.000
Thickness (mm)	35
Weight (Kg)	22,5
ELECTRICAL CHARACTERISTICS	
Power (Wp)	390
Short-circuit current Icc(A)	10,17
Maximum power current IMP(A)	9,66
Open circuit voltage UCA(V)	48,2
Maximum Power Voltage UMP(V)	40,4

Also, the following table shows the main characteristics of the inverter.

Table 7-2. Inverter characteristics

Operating temperature (ºC)	-35 to 60
Power (@40ºC) (KVA)	3550
Output voltage (V)	645
Frequency (Hz)	50
THDi (%)	<3
PMP voltage (V)	913-1310
Efficiency (%)	98.9
Degree of protection	IP54
Dimensions (L x W x H) (m)	3,7 x 2,2 x 2,2
Weight (kg)	5750
Communications	Modbus TCP

The photovoltaic farm will consist for a total installed capacity of 50 MW. The units will be connected to a grid and operated in dispatch mode. The technical specifications of the photovoltaic farm have been designed to ensure efficiency, reliability, and cost-effectiveness.

The photovoltaic farm will have a minimum efficiency of 18%, which is the ratio of the amount of electricity produced to the amount of sunlight received by the solar panels. The efficiency of the solar panels is affected by various factors such as temperature, shading, and orientation. The photovoltaic farm will be designed to maximize the efficiency of the solar panels and ensure optimal performance.

The minimum load of the unit will be 10%, which means that the unit can operate at a minimum output of 200 kW. The efficiency of the unit at minimum load will be 90%, which means that the unit will operate efficiently even at low output levels.

The upward ramping constraint for the units will be 2% per unit per minute, which means that the units can increase their output by 2% per minute. The downward ramping constraint for the units will be 1% per unit per minute, which means that the units can decrease their output by 1% per minute. These ramping constraints are designed to ensure smooth and gradual changes in output levels and avoid sudden fluctuations in the grid.

The operation and maintenance cost estimated of the unit will be €10 per MWh. This cost includes the cost of monitoring, maintenance, and repairs. The photovoltaic farm will be designed for easy maintenance and repairs to minimize downtime and maximize uptime.

The availability of the unit will be 95%, which means that the unit will be available for operation 95% of the time. This availability rate is based on the expected downtime for maintenance and repairs.

The maximum contribution to the upward reserve out of the available generation in dispatch mode will be 5%. This means that the photovoltaic farm will be able to provide upward reserves to the grid up to a maximum of 5% of its available generation.

The maintenance and operating costs per year will be €30,000 per MW, which means that the annual maintenance and operating cost for the photovoltaic farm will be €1.5 million.

Other relevant cost to consider is the grid connection, which depends on the characteristics of the specific project. the Agency of the Cooperation of Energy Regulators (ACER) publishes periodically prices to estimate the cost of AC substations. Based on this data, the cost of a substation depends either by the amount of installed capacity (38,000 € / MVA) or by the voltage level (42,500 € / kV).

Other relevant factor to consider when pricing a substation is the number of transformers, bays, busbars and voltages, we would obtain the following indicators:

- From 1-4 transformer bays: 33,000 € / kV
- From 5-8 transformer bays: 35,500 € / kV

- For more than 9 transformer bays: 44,000 € / kV

Another interesting information could be the average price of a power transformer: 10,000 € / MVA.

According to the 2019 PV Status Report from the Joint Research Center (JRC), the European Commission's science and knowledge service, we can approximate the cost of a photovoltaic plant to be 1 € / Wp for domestic use but for industrial use we will consider 0,4 € / Wp taking into account the economy of scale. By combining it to 38,000 € / MVA, we obtain that the cost of the substation could represent 5% of the total project and in some cases up to 10%.

The investment cost for the photovoltaic farm will be €800,000 per MW, which means that the total investment cost for the 50 MW photovoltaic farm will be €40 million. This investment cost includes the cost of equipment, installation, and commissioning.

The cost of starting up will be €50,000 per MW, which means that the total cost of starting up the photovoltaic farm will be €2.5 million. This cost includes the cost of testing, commissioning, and initial maintenance.

The lifetime of the units will be 30 years, which means that the photovoltaic farm will operate for at least 30 years before the units need to be replaced. This lifetime is based on the expected lifespan of the solar panels and inverters.

A generic case economic assessment of a Virtual Power Plant was developed to determine the likely commercial viability of the project, the impact on employment and the economic added value. Firstly, Table 6-3 presents the photovoltaic parameters for a 50-ha waste heap area with an installed capacity of 1 MW/ha, a capacity factor of 20% and 50% of energy to be stored.

Table 7-3. Photovoltaic farm deployment parameters

Parameter	Value
Installed capacity	50 MW
Estimated investment (plant life: 30 years)	40 M€
Capacity factor (% time of use of the installation per year)	20%
Daily production (50 MWh x 30% x 24 hours)	600MWh
Fraction of energy to be sold, the rest to be stored	50%
Daytime energy sold (360 MWh x 50%)	180MWh
Daytime energy price	40 €/MWh
Daytime revenue (180 MWh x 40 €/MWh)	7,200 €
Photovoltaic annual revenues (7,200 € x 365)	2,63 M€
Annual expenditure (staff, maintenance and overheads)	1,50 M€

Following table presents the cash flows for the first three years, using constant, from Year 1, the annual depreciation of 6.7%, and working capital of about 9% of operating revenues. Operating revenues estimated for year 1 are 10 M€, growing 5% each year.

Table 7-4. Cash flows calculation for photovoltaic plant (k€)

Item	Year 1	Year 2	Year 3
Capital expenditure	(40,000)		
Working capital	(900)	(945)	(997)
Operating revenues	10,000	10,500	11,025
Operating expenses	(1,5)	(1,5)	(1,5)
Depreciation (30 years)	(2,680)	(2,680)	(2,680)
EARNINGS BEFORE INTEREST AND TAXES	5,82	6,32	6,85
Taxes (25%)	(1,455)	(1,580)	(1,711)
NET INCOME	4,365	4,740	5,134
CASH FLOW (Net income + Depreciation)	1,685	2,060	2,454

Finally, considering an 8% capital cost, the expected financial outcomes for 10 years will be by Net Present Value (NPV):

$$NPV = -40{,}000 + \frac{1{,}685}{(1+0{,}08)} + \frac{2{,}060}{(1+0{,}08)^2} + \cdots + \frac{2{,}454}{(1+0{,}08)^{30}} = 36{,}487k€$$

Internal rate of return (IRR) = 2,68%

We can conclude that the project is a profitable investment opportunity based on its NPV and IRR. The positive NPV suggests that the project's future cash flows are expected to generate returns higher than the required rate of return (8% in this case), while the IRR indicates that the project's cash flows will yield a return of approximately 2.68%, which is above the cost of capital.

The installation is expected to have a useful life of around 30 years, according to the manufacturer's recommendations. This will result in a reduction of 47,000 Mg of CO2 emissions per year during this period.

Regarding the determination the job creation potential per megawatt, understanding this metric is crucial as it provides insights into the socio-economic benefits of renewable energy projects, specially in terms of employment generation. This information can be used to evaluate the impact of the project on local communities and to make informed decisions regarding investments in renewable energy infrastructure. To calculate the jobs per MW, we use the table 4-9 obtaining the next results:

Direct jobs: 748

Indirect jobs: 263

Induced jobs: 1,312

The total jobs estimated are 2,322 for this demosite project.

7.2 Demosite 2: Solar PV System in an underground mine in a living surrounding area.

The possibility of finding a solution that allows for the reduction of the cost of electricity supply for several activity centers by taking advantage of local energy resources was proposed as a future project development.

Among these centers are the facilities have a supply connected to the grid, the proposed solution consists of a photovoltaic solar installation that falls under the self-consumption regime under the administrative, technical, and economic conditions of self-consumption of electrical energy.

In this document, an initial assessment of the current situation of the complex is carried out, and a solution is proposed in the aforementioned terms. The analysis is carried out taking into account the current electrical load and consumption data. Based on this reference situation, as well as the requirements set forth by the complex's managers, the photovoltaic solar installation is dimensioned. Additionally, a cost and profitability analysis is performed.

According to the aforementioned constraints and considering the availability of energy resources in the environment, a possible solution for electrical self-consumption is proposed, based on a generation system using a photovoltaic solar plant.

A preliminary evaluation of the records on solar radiation shows an annual average of 3,530 kWh/m^2 day and the dimensions of a photovoltaic plant of 200kW is proposed.

Figures 6-1 and 6-2 shows the location of solar photovoltaic plant projected.

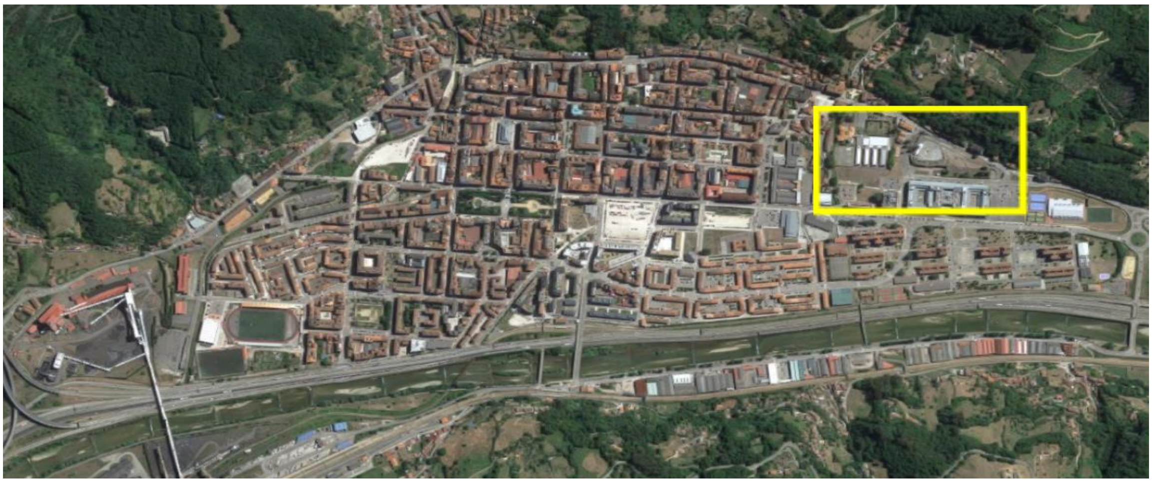

Figure 7-1. General view of location.

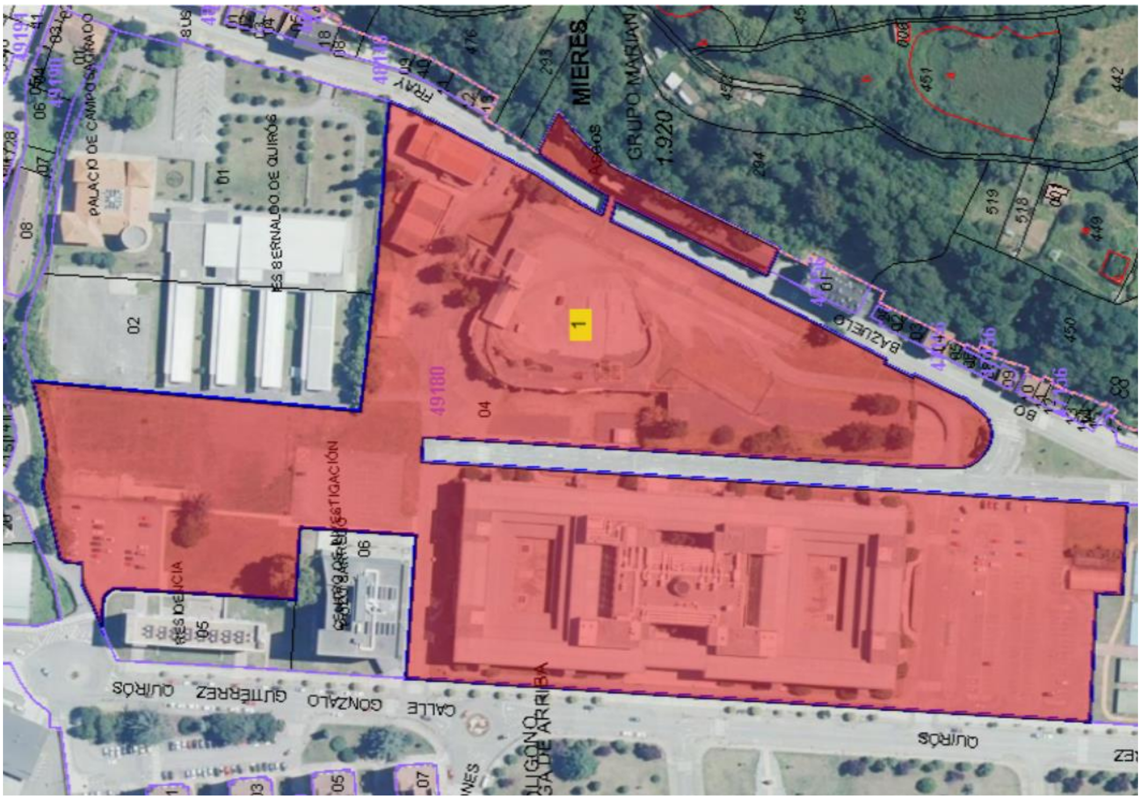

Figure 7-2. General view of and the new photovoltaic plant location projected.

The calculations take into account the performance coefficient of the modules and the losses produced in the different elements of the installation:

- Losses due to orientation, inclination, and shading
- Losses in energy conversion in the modules due to temperature, reflectance, etc.
- Losses due to the performance of the inverter and other equipment
- Losses due to Joule effect in wiring

In this sense, the orientation angles shown below are considered, according to the geometry and orientation of the terrain, and with the purpose of accommodating the largest number of modules. As for the inclination, an angle of 35º is considered in order to maximize production.

A generic case economic assessment of a Virtual Power Plant was developed to determine the likely commercial viability of the project, the impact on employment and the economic added value. Table 6-5 presents the photovoltaic parameters of panels and inverter equipment in a 2,000 m^2 area (approx.).

This facility will have a useful life of 25 years with an approximate production of 222,400kW/year, a generation power of 192 kWp and 1,159 hours equivalent. The estimated investment for this is 200,000 €.

Table 7-5. Photovoltaic plant deployment parameters

Parameter	Value
Installed capacity	200 kW
Estimated investment (plant life: 30 years)	0,20 M€
Module Power	410Wp
Module Surface Area (capture)	2.01 m2/unit (1.92 m2/unit)
Performance coefficient	20.4%
Units	468 (39 x 12)
Location	Ground
Occupied Surface Area	2,020 m2 (aprox)
Inclination	35º
Orientation	0º S
Generation Power	191.9 kWp
Inverter Power	200 kW
Inverter number	1
DC Power Range Inverter	135-230 kW
Inverter Efficiency	96.5%

An orientation angle of 0º is considered, since the available surface area in field 1 is sufficient to accommodate the modules facing south and thus achieve greater efficiency. The configuration of the photovoltaic fields, in terms of the number of modules in series and parallel branches, has been carried out taking into account the maximum limits set by the technical specifications of the inverters regarding the allowable values of voltage and input current (DC).

The number and power of the inverters are a consequence of the power of the photovoltaic field and the chosen configuration. As a general rule, since inverters have ranges of admissible input power (DC), it is assumed that the ratio between the generation power and the inverter power(s) should fall within the range of 0.7 - 1.2.

The following is an economic evaluation to verify the feasibility of implementing the photovoltaic solar plant.

Considering the size of the installation and the other considerations mentioned in previous sections, an estimate of investment costs is made based on reference data from equipment available in the market and construction methods of similar projects. The values shown in Table 6-6 should be considered indicative and in no case as a final budget (including installation costs).

Table 7-6. Investment costs

Concept	Cost
Modules and structure	154,700 €
Inverters	35,500 €
Regulation system	4,600 €
Wiring and other equipment	17,900 €
TOTAL	212,700 €

Related to the expenses related to the control and maintenance of the installations it must be highlighted that, regarding control, these types of installations are fully automated, and do not require the presence of specific personnel for this purpose. The required actions are limited to occasional surveillance and monitoring of the levels of energy generated, electricity billing, and other administrative tasks. Therefore, the hiring of additional personnel is not necessary, and the expenses attributable to the operation are considered negligible. Regarding maintenance, the installations must follow a preventive maintenance program that ensures acceptable performance throughout their useful life. This program defines a series of operations and their periodicities. The estimated costs of the maintenance service, to be contracted externally to a specialized company is 2,000 €/year.

Before carrying out the economic viability analysis, certain factors must be taken into account and hypothetical conditions must be established.

To evaluate this, the annual economic benefit introduced and the payback period of the investment are analysed. The payback of the investment will occur due to the savings generated by a lower expense in the energy term as a result of the reduction of the electricity consumption from the grid.

In this sense, the estimated cost of the energy term for first year is €140,000/year.

A gradual reduction in production from the fifth year onwards was also considered in the production forecasts due to an expected decrease in the performance of the modules. Similarly, the investment required to replace the inverters within the analysis period is taken into account, since their useful life is shorter than that of the other components of the installation. Additionally, an annual variation rate of the energy term price of 1.3% is considered, according to the evolution experienced in recent years and using conservative criteria, and an interannual variation rate of the Consumer Price Index (CPI) of 0.8%, for maintenance costs. Furthermore, the estimate has been made assuming that the investment will be financed exclusively with own resources, without resorting to subsidies or a bank loan, which means the absence of annual financial expenses.

7 presents the cash flows for the first three years, using a working capital of about 9% of operating revenues. Operating revenues estimated for year 1 are 140,000€, growing 5% each year and an 8% of capital cost for NPV and IRR calculus.

Table 7-7. Cash flows calculation for photovoltaic plant (€)

Item	**Year 1**	**Year 2**	**Year 3**
Capital expenditure	(212,700)		
Working capital	(13,410)	(13,30)	(13,892)
Operating revenues	140,000	147,000	154,350
Operating expenses	(2,000)	(2,026)	(2,052)
EARNINGS BEFORE INTEREST AND TAXES	125,590	131,674	138,406
Taxes (25%)	(31,398)	(32,918)	(34,602)
NET INCOME	94,193	98,756	103,804
CASH FLOW	(131,217)	107,347	114,912

Although the cash flow is negative in the first year, from the second year onwards it becomes positive, which is a good indicator. Based on this cash flow, the values obtained for NPV and IRR are -43,474.50€ and 11.35% respectively. The IRR is higher than the discount rate considered (8%), indicating that the project could be considered viable. The obtained NPV has a negative value, but it should be noted that this is in the third year while the useful life of the installation is 25 years, so its viability is confirmed within the actual useful life period (16 years).

Given the specific context and scale of the proposed 200 kW photovoltaic solar installation, it is important to address the potential for job creation. The project size and nature indicate minimal direct employment opportunities. The installation is designed to be fully automated, requiring no specific personnel for daily operations. The only labor required is for externalized yearly maintenance, which does not necessitate hiring additional permanent staff.

The following factors justify this conclusion:

1. **Automation of Operations**: The installation's operations are automated, reducing the need for continuous human intervention.

2. **Externalized Maintenance**: Maintenance activities are contracted out to specialized companies, requiring only occasional checks and not permanent staff.

3. **Negligible Operational Expenses**: The operational expenses, apart from maintenance, are considered negligible, emphasizing the lack of need for dedicated personnel.

Despite the limited job creation potential, this aspect should have been explicitly addressed in the report to provide a comprehensive understanding of the project's employment impact. This would align with the comprehensive approach taken in assessing the project's technical and economic feasibility.

However, using the table 4-9, it is estimated that the project will create the next jobs as follows:

Direct jobs: 3

Indirect jobs: 1

Induced jobs: 5

The total jobs estimated are 9 for this demosite project.

By including this clarification, stakeholders can have a clear expectation of the employment outcomes related to the installation, enhancing transparency and completeness in project reporting. This detailed evaluation ensures that all aspects of the project's impact are considered, providing a comprehensive overview of its feasibility and benefits.

8 Conclusions & lessons learned

This report's final section presents the main conclusions and lessons learned. The report demonstrates a potentially effective of photovoltaic technology that can serve as a link and transition between an outdated industrial network, like coal mines, and the advancement of sustainable energy sources that represent the energy future. As a result of the evaluations, several significant implications and conclusions were drawn:

1. The repurposing of end-of-life coal-related assets and infrastructure at coal mines for solar photovoltaic (PV) installation plants offers a promising approach for recovering unproductive lands and generating renewable energy.

2. Solar PV technology is highly modular and ranges in size from small solar home kits to systems with capacity in the hundreds of megawatts, offering a democratised electricity production.

3. Due to the huge variety of features and types of mine sites, a multi-criteria reasoning analysis should be performed to determine the best technology by scenario.

4. Leveraging closed coal mines for photovoltaic installation plants presents an opportunity for social, environmental, and economic development while creating new job opportunities in emerging renewable energy sectors.

5. Renewable energy systems based on photovoltaic installation plants will play a significant role in meeting our energy needs while reducing our carbon footprint in the future.

9 Glossary

CAPEX – Capital expenditure

COP – Coefficient of performance

DMT-THGA – DMT-Gesellschaft für Lehre und Bildung mbH

FAEN – Fundación Asturiana de la Energía

FPV – Floating PV

GIG – Główny Instytut Górnictwa

HUNOSA – Hulleras del Norte, S.A.

IRR – Internal rate of return

M&B – Magellan & Barents

NPV – Net present value

OPEX – Operational expenditure

O&M – Operation & maintenance

POI – Point of Interconnection

PP – Payback period

PV – Photovoltaic

PVM – Premogovnik Velenje Mine

REA – Research Executive Agency

ROI – Return of Investment

SWOT – Strengths, weaknesses, opportunities, and threats

TRL – Technology readiness level

UNIOVI – Universidad de Oviedo

WEGLO – Węglokoks S.A.

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