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Just Transition in Practice:

Sustainable projects in coal regions

The Green Tank
Policy solutions for a sustainable future

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The Just Transition Challenge

On December 11 2019, the European Commission (EC) announced the European Green Deal (EGD), which now constitutes the European Union's (EU-27) new development strategy until 2050[1]. EGD's cornerstone is the commitment for Europe to become the first climate neutral continent by 2050. Given that in the 30-year period between 1990 and 2020 the EU-27 managed to reduce its net greenhouses gas emissions by only 35.9%[2], it becomes clear that achieving net zero in the next thirty years until 2050 is a major challenge which will require the drastic transformation of all sectors of the economy. This will in turn have major socio-economic consequences for regions where the economy is based on polluting activities and therefore must be completely transformed and re-oriented towards a sustainable direction. It is for this reason that Just Transition is one of the three fundamental objectives of the EGD with the characteristic aim of "leaving no one behind". According to the EC, there are 101 NUTS-3 level regions in EU-27, currently undergoing transition, hosting a variety of polluting economic activities[3].

The impacts of transition are expected to be particularly pronounced in a special category of transition regions, those where coal (lignite and hard coal) is mined and/or burned. The transition challenge in these regions is even greater due to the dominant role that such activities have in local economies and land use, but also due to their immense negative impacts on the environment, air quality, the natural resources and public health. According to EC data, there are 28 NUTS-2 level coal mining regions in EU-27[4], and 96 in total where either one of those two most polluting solid fossil fuels is mined or burned or both[5]. Comparing the data for the 28 NUTS-2 mining regions with those for the 101 NUTS-3 transition regions hosting any high carbon intensity economic activity, it is found that less than half (47) of the NUTS-3 transition regions mine lignite or hard coal, while four of the 28 NUTS-2 coal mining regions have not yet started their transition process.

The coal industry employs 237,000 people (2020 data) while many additional indirect jobs also depend on the value chain of these fossil fuels in the respective regions[6]. All these jobs are now in jeopardy, as is the economic survival of entire coal regions, especially since coal-based electricity production in EU-27 plummeted between 2015 and the Paris Agreement and 2020 (an almost 50% drop). In 2021 there was a partial comeback of coal compared to the historic low in 2020, mainly due to the explosion in fossil gas prices. However, the electricity production from lignite and hard coal in 2021 remained below 2019 levels[7].

The decreasing trends of coal-based electricity generation are expected to continue as all EU-27 Member States -with the exception of Poland- are now committed to specific coal phase out dates, seventeen of which, by 2030[8]. In addition, the increased climate ambition in the ongoing revision of the EU Emissions Trading System (EU ETS), as reflected in both the EC's proposal and the views of the majority dominating in the vote of the European Parliament's Committee on Environment, Public Health and Food Safety (ENVI) in May 2022, will lead to steadily high -if not higher than current- carbon prices throughout the 4th EU ETS phase (2021-2030). Since CO_2 prices affect the operating costs of coal plants much more

than that of fossil gas plants, electricity generation from hard coal and lignite is expected to remain uncompetitive especially after the fossil gas price crisis begins to partially subside. Therefore, the path to energy transition away from lignite and hard coal is expected to continue in the coming years.

The Just Transition Mechanism

To support coal regions as well as other regions in transition in meeting the challenge of transforming their economies, the EU-27 established the Just Transition Mechanism[9]. This mechanism aspires to channel approximately €55 billion during the 2021-2027 programming period in order to ensure a socially just transition leaving no one behind. After all, Just Transition, together with climate neutrality and biodiversity protection, are the three main objectives of the European Green Deal.

The Just Transition Mechanism is founded on three pillars. The first pillar is the Just Transition Fund (JTF) with €17.5 billion (€19.2 billion in current prices) coming from the European budget and the Next Generation EU instrument, which are expected to mobilize investments of €25.4 billion during the 2021-27 period. The allocation of JTF's resources among the 27 Member States, as well as the categories of investments that are eligible for funding and those that are excluded, are described in detail in the corresponding Just Transition Fund Regulation[10]. The second pillar is the InvestEU program which will provide guarantees and an advisory hub, to support private investments amounting to a total of €10-15 billion. The third pillar is a lending facility for public sector investments. It is expected to combine €1.5 billion in grants from the EU budget with €10 billion in loans from the European Investment Bank to mobilize €18.5 billion of public investments.

Territorial Just Transition Plans

In order for the Member States to access these financial resources, they must prepare the so-called "Territorial Just Transition Plans" (TJTPs), together with the relevant authorities of the territories concerned. These plans should identify the territories most negatively affected, where JTF support should be concentrated and describe specific actions to be undertaken to reach a climate-neutral economy, notably as regards the conversion or closure of facilities involving fossil fuel production or other greenhouse gas intensive activities. Those territories should be precisely defined, and correspond to NUTS level 3 regions or should be parts thereof. The plans should detail the challenges and needs of those territories and identify the type of operations needed in a manner that ensures the coherent development of climate-resilient economic activities that are also consistent with the transition to climate-neutrality and the objectives of the Green Deal. Only investments in accordance with the transition plans should receive financial support from the JTF, while the TJTPs should be part of the programmes (supported by the ERDF, the ESF+, the Cohesion Fund or the JTF, as the case may be), which in the end are approved by the Commission.

Based on the latest available data presented during the Just Transition Platform meeting in May 2022[11], progress in the preparation, submission, evaluation and final approval of TJTPs has been slow. Sixteen Member States have sent informal draft plans to the European Com-

mission (just two more than the corresponding number reported at the previous platform meeting held in November 2021), while only five of them are being reviewed by Member States following initial input and comments from the European Commission. Moreover, just three Member States (Austria, Greece and Finland[12]) have formally submitted their TJTPs (two in November 2021) for final evaluation by the European Commission, whereas one Member State (most probably Greece[13]) is at the final stage before approval and adoption of its Territorial Just Transition Plans.

At this crucial stage for the development and scrutiny of the Territorial Just Transition Plans by the European Commission, it is imperative to support truly sustainable investments, as only such projects will ensure a socially equitable transition in the long term. This need is further exacerbated by the REPowerEU plan announced on 18 May 2022 by the European Commission aiming at achieving the European Union's independence from Russian fossil fuel imports, with an emphasis on Russian fossil gas, by 2027[14]. The plan dedicates the overwhelmingly larger part of €300 billion in dedicated resources for the development of large- and small-scale RES, electricity grids, electricity storage infrastructure, energy savings and increases in energy efficiency, the acceleration of heat pump installation as well as the production of biomethane and green hydrogen, while emphasizing citizen engagement and participation through the mandatory establishment of renewable energy communities for areas with a population of at least 10,000 inhabitants. It is therefore clear that the Territorial Just Transition Plans being currently negotiated between the Member States and the European Commission, as well as those to be developed in the coming months must be aligned with the central priorities of REPowerEU in order to contribute to the common European goal.

Sustainable Just Transition projects

For these reasons, this review provides good examples of projects mainly from across Europe at various stages of development which can serve as a guide for developing sustainable Territorial Just Transition Plans, especially for coal mining regions. Emphasis is placed on projects that retain the energy character of such regions through the deployment of large-scale renewables and electricity storage infrastructure of various technologies, as well as small-scale renewable projects by energy communities. Projects of the primary sector are also presented, while the potential that lignite mining regions have in particular to combine agro-livestock activities with the production of clean energy through the development of agro-photovoltaic systems is also highlighted. In addition, the main characteristics of projects in the tourism sector showcasing the industrial heritage of mining regions as well as projects which transformed former lignite fields to areas suitable for recreation activities are also presented. Furthermore, of special interest are projects aiming at promoting sustainable mobility and programs which have already been developed or are now being developed by several Member States to re-skill workers in mining regions in order for them to find jobs in other sectors of the economy. Finally, good examples of various forms of economic zones in mining regions are presented. Such zones form an organizational framework which provides services and incentives for the development of new economic activities, suitable for the successful transition of coal mining regions to the post-coal era. For an overview, see a map of sustainable projects in coal regions.

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12. Informal briefing

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JUST TRANSITION MILESTONES

2015 2016

Paris Agreement

EU-ETS reform: EC allows Member States to use public revenue from auctioning CO_2 allowances for Just Transition purposes

NGOs-EP: Proposal to establish a distinct Just Transition Fund (JTF) at EU level

2017

Failure to establish a distinct European JTF
Inclusion in the Modernization Fund

Establishment of Coal Regionsin Transition Platform (CRiT)

2018

1st Forum of the Just Transition Mayors (Kozani, Greece)

EP: Proposal to finance Just Transition from the EU budget 2021-2027

2019

2nd Forum of the Just Transition Mayors (Weisswasser, Germany)

Signing of the Declaration of Just Transition Mayors

Presentation of the Forum of Mayors initiative to the Coal Regions in Transition Platform

2020

EU Green Deal, Just Transition Mechanism, Proposal for a Regulation of the Just Transition Fund

Launch of the Just Transition Platform and Coal Regions in Transition virtual week

Launch of the Initiative for coal regions in transition in the Western Balkans and Ukraine

Covid-19 crisis - Next Generation EU instruments adds funds to Just Transition Fund

3rd Forum of Mayors on Just Transition (Bytom, Poland)

2021

Approval of the Regulation of the Just Transition Fund

Approval of the Regulation on the public sector loan facility under the Just Transition Mechanism

Territorial Just Transition Plans: preparation and evaluation

Just Transition Platform Meeting-Coal Regions in Transition virtual week and Carbon-intensive Regions Seminar

Launch of 4 Working Groups for carbon-intensive regions

4th Forum of Mayors on Just Transition (Stara Zagora, Bulgaria)

2022

Just Transition Platform Meeting-Coal Regions in Transition virtual week and Carbon-intensive Regions Seminar

Approval of the 1st Territorial Just Transition Plans and corresponding funding for Greece

1. Renewable Energy

Workers in coal mining regions and coal plants possess a unique skill set in energy-related activities as well as experience of working under difficult conditions and sophisticated safety protocols, which are all very useful for the renewable industry. Moreover, the local communities in coal mining regions are typically in favor of retaining the energy character of their region, in the post-coal era as this is more suitable to the tradition the region has developed over the years. In conjunction with the undisputable priority the EU Member States have given to the deployment of renewables as a means to mitigate the climate crisis, while also producing cheap energy, the abovementioned elements, render the development of renewable energy an almost natural fit for coal regions in transition. In the following pages we review a variety of wind, solar and geothermal projects of both large and smaller scales that are already in place or at different stages of development in coal regions across the EU.

Table 1: Summary of renewable energy projects in coal mining regions

Project name	Country	Region	Characteristics	Status	Year	Additional information
Wind energy						
Klettwitz wind park complex	DE	Klettwitz, Brandenburg	89 MW	Operating	1999	497 ha; 120 jobs in construction phase; European Route of Industrial Heritage.
Oakdale Colliery wind park	UK	Caerphilly Borough County, Wales	4 MW	Operating	2014	Public-private partnership; preceded by 6-year, £10 million reclamation project.
Solar energy						
Kozani solar park	EL	Kozani, Western Macedonia	204.3 MW	Operating	2022	438 ha; €130 million; 350 jobs in construction phase.
Senftenberg solar complex	DE	Meuro, Brandenburg	168 MW	Operating	2011	380 ha; $400 million
Göttelborn solar park	DE	Göttelborn, Saarland	8.4 MW	Operating	2004	165 ha
Espenhain solar park	DE	Espenhain, Saxony	5 MW	Operating	2004	16 ha; €22 million
Jaworzno solar park	PL	Jaworzno, Silesian	5 MW	Operating	2020	Owned by Tauron; co-financed ($717,000) by the Katowice Provincial Fund for Environmental Protection & Water Management.
Adamów solar park	PL	Turek, Greater Poland	70 MW	Operating	2021	Owned by ZE PAK SA; 5-year PPA with Polsat.; PLN163.8 million.

Project name	Country	Region	Characteristics	Status	Year	Additional information
Western Macedonia solar parks	EL	Western Macedonia	2 GW	Partially operating - under construction	2021	200 MW are under construction (4/2021); 500 ha; €83.7 million; 300 jobs in construction phase.
Megalopolis solar parks	EL	Arkadia, Peloponnese	550 MW	Under construction	2021	First 2 projects, (39 MW & 11 MW) are under construction.
Geothermal energy						
Pozo Barredo geothermal project	ES	Mieres, Asturias	6 MW	Operating	2019	€3 million (€500,000 from ERDF)
Heerlen geothermal project	NL	Heerlen, South Limburg	-	Operating	2015	3 phases: pilot in 2003, Minewater in 2008, Minewater 2.0 in 2015; 65% reduction in CO_2 emissions.
Small scale renewables						
Green to Households	SK	Bratislava	83 MW of small-scale PV, heat pumps, high efficiency devices, biomass boilers	Operating	2015	€115 million; €45 million in 1st phase (2015-2018) from national funds & ERDF.
Energy Communities	HU	Various	4-10 projects of 1 MW each	Planning	2022-2023	€11.4 million from Modernisation Fund for energy communities, aggregators and active consumers.

1.1 Wind energy

Klettwitz wind park complex (Germany)

The Klettwitz wind park complex is located on the site of the former Klettwitz open cast lignite mine (operating period 1949-1991) in Schipkau, in the Lusatia lignite district in Germany. The wind park was founded in 1999, employing at least 120 workers during its construction. Today it occupies 497 hectares. It originally consisted of 44 wind turbines with a capacity of 63 MW, and was the then largest wind park in Europe. In 2015 it was repowered and as of 2019 it consists of 58 wind turbines with a total installed capacity of 89 MW in two sections, the northern "Klettwitz Nord" and the southern "Klettwitz Süd". Further extensions of existing wind parks have already been approved or are in the planning stage.

The wind park has also been a driving force for other investments in renewable energy in the region. For example, Vestas Blades Deutschland GmbH –a subsidiary of Danish Vestas Wind Systems A/S, a world leader in wind turbines– opened a new blade plant at Industrial Park Emanuel near Lauchhammer and Klettwitz wind parks in May 2002[15].

The industrial heritage of the region, including equipment and machinery used in former coal mines is also showcased. For example, the overburden conveyor bridge used until 1992 in the open cast mine in Klettwitz-Nord is now open to visitors and is one of the main points of interest along the European Route of Industrial Heritage[5].

Oakdale Colliery wind park (United Kingdom)

The Oakdale Colliery wind project is located in the brownfield of the former Oakdale Colliery coal mine in Wales. It started operating in 2014 and it covers approximately 162 hectares. With a total capacity of 4 MW the project's two wind turbines generate approximately 10 GWh/year, enough to power approximately 2,400 households. A six-year reclamation project that cost £10 million took place before the construction of the park, which was ultimately carried out through a public-private partnership between Partnerships for Renewables and a Welsh local authority[16]. In addition to local benefits in terms of job creation, the project provides revenues to the local community, as Partnerships for Renewables pays rent to the Welsh local authority for using the area. Also, community benefit packages of about €11.000 per year were scheduled to be invested during the lifetime of the wind park in other projects creating social, economic and environmental benefits[17].

1.2 Solar energy

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Kozani solar park (Greece)

The 204.3 MW solar park of Hellenic Petroleum S.A. is situated in Kozani, Western Macedonia, Greece, near the retired Kardia lignite-fired power plant. It was inaugurated in April 2022. The park, commissioned by Juwi Hellas S.A., is currently the largest one in Greece and the Eastern Mediterranean, and one of the largest ones in Europe, consisting of 18 individual solar plants and 509.000 bifacial panels in total manufactured by the Chinese company JinkoSolar[18]. It spans 437.9 hectares and will cover the needs of 75,000 households, or the equivalent of 40% of the household electricity consumption of the Region of Western Macedonia, while reducing CO_2 emissions by 320,000 tonnes annually[19]. The total investment for the project was €130 million, 75 of which were provided by the European Bank for Reconstruction and Development (EBRD), in the form of an investment in the successful Eurobond tap issued by Hellenic Petroleum S.A.[20]. More than 350 jobs were created during its construction, while dozens of direct and indirect jobs are expected to be created during its operation, most of which will be local[21].

Senftenberg solar complex (Germany)

The Senftenberg solar park complex is located on agricultural reclaimed sites of the former open cast lignite mine of Meuro, in Lusatia, Brandenburg, Germany, which operated from 1958 until 1999. The photovoltaic complex has a total capacity of 168 MW, consisting of the solar parks of Schipkau (72 MW) and Senftenberg I, II and III (96 MW)[22], covering a total of 500 hectares. It went into operation in 2011 and produces electricity for 80,000 households[23]. About 90% of the project was constructed by Canadian Solar Inc., which

provided 636,000 CS6P-P modules, powering 148 MW of the project's total output. In 2012, it was named the best solar project in the world by the POWER-GEN International team[24]. It cost more than $400 million[25,26]. The operating companies of the solar fields are Saferay GmbH and GP Joule GmbH. With 380 hectares, the largest share is owned by the agricultural enterprise Agrargenossenschaft Großräschen e.G.[27].

Göttelborn solar park (Germany)

Göttelborn solar park is situated on the site of the former underground lignite mine of Göttelborn in Saarland, southwest Germany, and was put in operation in 2004. The park generates 8.4 MW from 49,000 panels and covers an area of 165 hectares[5].

Espenhain solar park (Germany)

The solar park is situated on a former coal dust dump of the decommissioned open cast lignite mine of Espenhain, in Leipzig, Germany. The site was a deposit for lignite dust, thus it was contaminated and before it could be used for other purposes, the lignite dust had to be buried under earth. It generates 5 MW of electricity, enough to meet the needs of 1,800 households and consists of 33,500 panels, spanning 16 hectares. The panels are made of monocrystalline silicon and are capable of handling high voltage, as well as delivering a high energy yield (150 watts each). The plant cost €22 million and in 2004, when it went into operation, was the world's biggest solar park[28].

Jaworzno solar park (Poland)

A 5 MW solar park was built in 2020 in Poland's second biggest coal-fired power generator, Jaworzno I Power Plant. The state-owned power company Tauron constructed the plant under its Green Return program, a broader photovoltaic development program implemented in post-industrial areas belonging to the Tauron group. The solar park was co-financed by the Provincial Fund for Environmental Protection and Water Management in Katowice, southern Poland (WFOŚiGW), through a contract signed for a $717,000 (PLN3 million) preferential loan[29].

Adamów solar park (Poland)

A 70 MW solar park is situated in the depleted opencast Adamów brown coal mine, in Turek, Greater Poland (Wielkopolska). The park is the largest one in Poland as of November 2021, when it was completed. It is owned by the Polish electricity provider Zespół Elektrowni Pątnów-Adamów-Konin SA (ZE PAK SA) and sells power to the Polish telecommunications group Polsat, under a 15-year power purchase agreement (PPA) signed between the two companies. It consists of 155,554 panels and it cost PLN163.8 million ($40.4 million) to construct[30].

Western Macedonia solar parks (Greece)

The Greek Public Power Corporation (PPC) is expected to install photovoltaics with a total capacity of 2 GW in Western Macedonia through its subsidiary PPC Renewables. The first phase of this project began with a mega-project of 230 MW capacity in Ptolemaida, that will be, upon its completion, among the largest ones in Europe and the largest in Greece. It consists of three separate segments. Two smaller projects with a capacity of 15 MW each and their individual substations were already completed in 2021. The third one with a capacity of 200 MW is under construction as of April 2021. It will cover an area of approximately 500 hectares, consisting of bifacial panels and a single-axis tracker. It will generate 352 GWh of electricity per year, which corresponds to the consumption of about 75,000 households. The cost for the third segment only is estimated at €83.7 million[31], while at least 300 workers are estimated to be employed during its construction[32]. PPC Renewables locked through a tender a tariff of €49.11 per MWh for it[33], a record low at the time.

Megalopolis solar park (Greece)

In 2020, PPC Renewables launched the procedures to tender a large photovoltaic project in Megalopolis, Peloponnese, with a total capacity of 500 MW, starting from a project of two segments, with a capacity of 39 MW and 11 MW respectively. According to PPC's Strategy update of November 2021, the 50 MW project is under construction[34]. It will comprise single-axis systems and bifacial panels, while a new medium to high voltage substation for its connection to the grid will also be built. The project will not claim fixed tariffs by participating in the Greek Regulatory Authority for Energy (RAE) tenders, but will operate according to the rules of the target model, through a bilateral power supply contract (PPA), which has been signed between PPC and PPC Renewables[35].

1.3 Geothermal energy

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Pozo Barredo geothermal project (Spain)

The geothermal project with a total capacity of 6 MW, carried out by the Hunosa Group, a state-owned coal mining company founded in 1967, was completed in two phases.

The first phase began in 2006, when it exploited the former Pozo Barredo (Barredo Well) underground mine in Mieres, Asturias, Spain, to power the hospital Vital Alvarez and the Research building of the University of Oviedo on the Barredo campus. In 2016, the project was expanded to power the headquarters of the Fundación Asturiana de la Energía (FAEN). The three projects were developed independently, requiring total investments of €1.5 million for a total capacity of 4 MW.

At the end of 2018, Hunosa Group initiated the second phase of the project, Pozo Barredo District Heating, which was completed in the summer of 2019. The new geothermal facility supplies heating to the Mieres Polytechnic School of the University of Oviedo, the Secondary Institute Bernaldo de Quirós Training and the M-9 and M-10 buildings (248 homes in total) of the Vasco Mayacina residential area. The total investment was approximately €1.4 million, with approximately €500,000 secured from the European Regional Development Fund (ERDF). The new district heating system has a capacity of 2 MW.

The commissioning of the whole complex (phases 1 and 2) will prevent emissions of approximately 636 tonnes of CO_2 per year[36].

Heerlen geothermal project (the Netherlands)

The Heerlen geothermal project has been developed over the course of several years since 2003. It is implemented in the former coal mines of the Dutch city of Heerlen in South Limburg, which have been flooded, after their closure in 1976. The former mine-

shafts have been filled with geothermally heated ground waters, which have different temperatures at different depths and are therefore used both for heating and cooling[37]. Specifically, the station is divided into two sections. In the one section, underground mine water is stored in mineshafts and preserved at 35°C for heating purposes. Then the water is conveyed and stored to the second section mineshafts at a 17°C temperature, in order to be used for cooling purposes. The water is collected from five wells in total and is supplied to the connected locations in Heerlen through an underground exchange station and pipe network[38]. The system is fully automatic and demand-driven with the capacity to deliver heating and cooling at any time[39]. Today, the project has been further developed and operates as a "smart grid", through which excess heating and cooling capacity of one customer is used for the needs of others, instead of being wasted[40].

A pilot project operated initially from 2003 until 2008. A second project -Minewater project of the municipality of Heerlen- was launched in 2007. It was co-funded via the European Interreg IIIB North West Europe programme, the 6th EU Framework Program project REMINING-LOWEX (Redevelopment of European Mining Areas into Sustainable Communities by Integrating Supply and Demand Side Based on Low Exergy Principles) and the national agency Agentschap NL[38]. A third project was implemented from 2007 until 2014, with Heerlen being one of the four pilot cities (Herleen and Zagorje[41] in Slovenia, Czeladz in Poland and Cherno More in Bulgaria) of a €39.6 million redevelopment project, co-funded by the EU with € 7,226,357 via the CONCERTO 2 funding programme[42].

In 2013, the Mijnwater B.V. independent company was established, with the municipality of Heerlen as its main shareholder, in order to further develop the project. In 2014, the project Minewater 2.0 up scaled the system to a smart grid, and since 2015, it provides heating and cooling for a floor area of 50 hectares annually, leading to a 65% reduction in CO_2 emissions for these connections[43]. The new system also led to new commercial opportunities, e.g. bringing in new building owners, trading boiler houses and heat pump installations.

1.4 Small scale renewables

Retrieved from v.Energetike, https://bit.ly/3HjXA9O

National project "Green to Households" (Slovakia)

The National project of the Slovak Innovation and Energy Agency aims to construct small-scale renewable plants; for family and residential houses (plants with installed capacity up to 10 KW) in the Bratislava self-governing region. The project includes the installation of solar thermal panels, heat pumps, devices with higher efficiency and biomass boilers, as well as of smart systems controlling energy consumption. The total budget is €115 million and was co-financed by ERDF (via the Operational Programme "Quality of Environment") and national funding. The first phase of the pilot project "Green to Households" was implemented between 2015 and 2018, with a budget of €45 million.

The support mechanism was based on vouchers issued prior to installing the selected systems and devices per household. Specifically, the household requested a voucher, which within 30 days of being issued had to be handed to the contractor. The actual installation took place within 3 months from the issuance of the voucher. Once the installation and the accompanying documents were examined, the voucher was paid. Data as of February 2018 show that 11,803 vouchers had been paid for a total amount of €26.2 million to install devices using renewables with a total capacity of 82.94 MW[44].

Energy Communities in Hungary

The Hungarian Ministry of Innovation and Technology was granted €11.4 million by the Modernisation Fund (approved by the European Investment Bank in February 2021) for the development of energy communities as priority investments, in order to meet the country's targets for renewable energy, carbon emissions' reduction and energy security according to the National Energy and Climate Plan[45]. The aim is to turn consumers into active players of the electricity market, resulting in better energy efficiency and reduced utility costs. This project is the first of its kind funded by the newly established Modernisation Fund.

The funded plan includes a scheme for the period 2022-2023, relating to the establishment and operation of Energy Communities as well as of independent aggregators. The activities of the Energy Communities may also cover additional optional activities related to the development of new renewable energy sources, such as charging infrastructure for electric vehicles or energy storage facilities. It is expected that 4-10 projects of 1MW each will be covered, leading to the creation of 20-50 employment positions during the implementation phase and 8-20 during the operation phases. Salary costs and social charges, costs of services used, materials and equipment are eligible for a 100% financing from the Modernisation Fund, whereas other costs, such as procurement of the equipment, intangible assets and construction investment are eligible for a funding ranging from 30% to 100%. Investment-related costs such as coordination and public procurement costs are also eligible[46].

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2. Energy storage

Storage systems can save excess and "unwanted" electricity generated by renewables (RES) and be used to keep grids running smoothly on days when fluctuations in generation are high. As demand in energy continuously rises globally, the deployment of RES storage facilities is becoming of equal importance to the development of the RES themselves. This is mainly because the majority of electricity generated from RES comes from intermittent sources, namely wind and solar, which are of stochastic nature, i.e., not controllable. So, as the penetration of RES will grow, there will be a growing need too for technologies which can capture and store energy during periods of high supply/ low demand and release it when required.

Storage projects, predominantly in lignite mines or districts that are already implemented, under construction or in the planning process are presented in the following pages, covering the most important storage technologies, namely, thermal storage, batteries, pump-hydro energy storage and hydrogen.

Table 2: Summary of various energy storage technology projects in mining regions

Project name	Country	Region	Characteristics	Status	Year	Additional information
Thermal storage						
ETES	DE	Hamburg-Altenwerder	Volcanic rocks as storage medium	In progress	2019	Siemens-Gamesa; 100 MW discharge capacity by 2022; efficiency ~44%.
Store 2 Power	DE	North Rhine-Westphalia	Molten salts as storage medium	In progress	2020	Collaboration: RWE, DLR, University of Aachen; efficiency ~40%.
Aboño I	ES	Aboño I, Asturias	358 MW; molten salts as storage medium	Proposed	2019	€201 million; 200 jobs in construction; 50 jobs in O&M.
Batteries						
Big Battery Lausitz	DE	Lusatia, Brandenburg	50 MW lithium-ion	Operating	2020	€25 million; operated by LEAG.
Ptolemaida BESS	EL	Ptolemaida, Western Macedonia	250 MW/ 1000 MWh lithium ion	Permitting	2021	€300 million
Arcadia BESS	EL	Megalopolis, Peloponnese	250 MW/ 1000 MWh lithium ion	Permitting	2021	€300 million

Project name	Country	Region	Characteristics	Status	Year	Additional information
Pump-hydro energy storage						
Silvermines	IE	Tipperary County	360MW	Pre-development	2021	Former barite mine; €650 million; 400 jobs in construction jobs; 50 jobs in O&M; to start operation in 2029.
Lewis Ridge Closed Loop pump hydro project	USA	Bell County, Kentucky	200 MW	Permitting	2021	To start operation by 2030.
Kidson pump hydro project	AU	Far-North Queensland	250 MW	Under construction	2021	Former gold mine; A$777 million; 510 jobs in construction; 20 jobs in O&M; to start operation by 2024.
Gravitricity	UK	Edinburgh, Scotland	250 KW	Operating	2021	Same operating principle as pump hydro; high upfront cost; EIB funding for 4-8 MW projects; UK government funding for 4MWh multi-weight demonstrator project.
Hydrogen						
Lusatia reference power plant	DE	Lusatia, Brandenburg	10 MW	Planning	2022	€67 million; H_2 to be used for electricity & transport applications; construction between 2023 and 2024, to start operation by 2025.
Hamburg Green Hydrogen Hub	DE	Hamburg	100 MW	Letter of intent signed by the consortium	2022	Consortium: Vattenfall, Shell, Mitsubishi Heavy Industries (MHI) & Hamburg Wärme; to start operation in 2025.
Bad Lauchstädt Energy Park	DE	Saalekreis district, Saxony-Anhalt	35 MW (fed by a 40 MW wind park)	40 MW wind park under construction	2021	Federal funding of €34 million; H_2 to be used for green mobility and supply of chemical plants
White Dragon project	EL	Western Macedonia	250,000 tonnes of green H_2 per year	Planning	2022	PCI project; € 8 billion; Direct/indirect jobs: 18,000/29,000; to start operation by 2029.

2.1 Thermal energy storage

Electricity storage technologies in the form of heat (thermal storage) currently occupy the second place among all storage technologies, after pump hydro energy storage (PHES) with a total capacity of 2.3 GW worldwide; molten salts technology holds the largest share with 81.5%. These technologies have been used for years in conjunction with solar thermal power systems, offering the latter flexibility in meeting demand even beyond the hours of high sunshine[47]. Solana in Arizona, USA, is globally the largest solar power plant that uses molten salt technology to store electricity. Solana was put in operation in 2013, has a total capacity of 280MW, and is designed to store energy for 6 hours. In conjunction with its storage system, it can supply the grid with 38% of its rated capacity during the course of a year; this utilization rate is significantly higher than that of both solar thermal systems without thermal storage and large-scale photovoltaics (20-25%)[48].

The operation of such systems involves three stages. In the first stage, the electricity generated by RES systems is converted into heat using a resistance. In the second stage this heat is stored by increasing the temperature of a material with high heat capacity . In the third stage, the stored heat is used to produce steam from water, which, in turn, moves the existing turbine of the unit, thus, generating electricity. As the original source of electricity is renewable, the same applies to the electricity that enters the grid during the "discharge" stage. In this way, it is possible for the previously polluting lignite and coal combustion plants to contribute to a 100% clean energy system, completely free of greenhouse gas emissions.

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Electric Thermal Energy Storage (ETES), Siemens Gamesa (Germany)

In 2011, Siemens-Gamesa embarked on the "Electric Thermal Energy Storage" (ETES) project to develop a thermal storage system, using low-cost volcanic rocks as the heat storage medium.

The first pilot system had a storage capacity of just 5MWh, was combined with a small 700KW steam turbine, and was put into operation in 2014 in Hamburg Bergedorf. The success of the first project led to the development of a larger one in Hamburg, whose construction began in November 2017. The system was put into operation in 2019 and is

able to store up to 130MWh of electrical energy drawn from the grid in the form of heat, for a period of one week via a 5.4 MW resistive heater[49]. This thermal energy is converted back into electricity using a 1.4MW steam turbine, which can operate continuously for 24 hours. The system employs 1000 tonnes of volcanic stones to store electricity in the form of heat, at temperatures between 750°C and 800°C; this electricity is produced via an electrical resistance, and transported to the volcanic rocks through special blowers. In addition to electricity, the unit can be "charged" directly with heat[50].

The conversion of electricity into heat is carried out with minimal losses (99% efficiency); however, electricity generation from stored heat is not expected to exceed an efficiency of 45%. Finally, according to the company, the installation cost is 10 times lower than that of large-scale batteries[51].

The company expects that ETES will be available for commercial operation by 2022. By then, the storage will scale up to the level of a few GWh and the corresponding "discharge" capacity will exceed 100 MW; thus, the system will be ready to operate in conjunction with existing lignite and coal combustion plants[52].

"Store 2 Power" thermal energy storage, RWE (Germany)

Molten salts are a more mature thermal storage technology than volcanic rocks, already used in conjunction with solar thermal systems around the world. The salts commonly used in such storage applications are sodium nitrate and potassium nitrate, which have a high heat capacity and are commonly used as components of several fertilizers.

The technology can be used to convert existing lignite and hard coal plants to clean energy storage facilities as follows: Initially, the boiler of the combustion unit is replaced with a suitable heat exchanger, which can operate in combination with the two salt tanks (one of low and one of high temperature). Electricity from wind and/or photovoltaic systems is converted into heat through an electrical resistance; heat then raises the temperature of the salts to 600°C, where they take on a liquid form. The stream of high temperature salts passes through the heat exchanger leading to the production of steam from the water stream, as the salts cool and end up in the low temperature salt tank. The next stages of the power generation process remain the same as in the lignite or coal combustion unit, as the generated steam is fed to the unit's turbine to generate electricity. The difference lies in the origin of the steam. In the case of the original combustion unit, steam was produced by the combustion of lignite or coal; in the case of the combustion unit combined with the molten salts storage system, the steam is produced by the heat of molten salts -a heat generated from stored wind or solar energy. Through this process a previously polluting electricity generation facility can be converted to a clean energy storage facility supporting high shares of renewables in the electricity mix through balancing production and demand.

The "Store 2 Power" project, which runs in Germany, applies the abovementioned technological model. The exact location of the new plant is still unknown, although it will be in the Rhenish lignite area, where the existing power plants are especially suitable, having grid connections and the necessary infrastructure (turbines, generators, trans-

formers and cooling towers). The project aims to transform an RWE hard coal plant in North Rhine-Westphalia into a molten salts energy storage plant with a total efficiency of approximately 40%. The project is a collaboration among RWE (Europe's largest power company), the German Aerospace Center (DLR), and the University of Aachen[53].

This project has the full support of Germany's largest political parties as the intention to convert existing lignite plants into energy storage plants had been included in the 2018 agreement of the German Cooperation Government parties[54]. In addition, the project was included in the proposals of the German Coal Commission that planned the phase out of lignite and coal, and was selected by the German Ministry of Economic Affairs and Energy in 2019 as one of the main projects of "Reallabore der Energiewende", Germany's program for energy transition[55]. The project was also included in the list of projects accompanying the German law[56] on lignite and coal phase-out, based on which €40 billion will be channeled to boost the economy of lignite regions in transition.

Other thermal energy storage projects

Similar projects for the conversion of coal plants to energy storage facilities via the molten salts technology are currently being considered or planned in other countries. In Chile, a collaboration is being formed among the country's Ministry of Energy, the German Ministry of the Environment, the German Aerospace Center (DLR), and GIZ GmbH, in the context of the decarbonization program of the Chilean energy sector[57].

In addition, although the premier choice for the future of the "Aboño I" coal-fired power plant, in Asturias, Spain, appears to be its conversion to a fossil gas plant, EDP, the owner of the plant is also evaluating the possibility of replacing the power plant's boiler with a thermal energy storage system, consisting of molten salt electrical heaters, and allowing electric charge from and discharge to the grid. A first evaluation showed the potential conversion could include a 358 MW storage facility with a discharge time of 2 hours, and a 44% efficiency. The total estimated installation cost of the project is €201 million, with foreseeable job options for 200 workers during construction and 50 in the operation and maintenance phase[58,59].

Finally, the possibility of converting lignite plants to thermal energy storage facilities is also being considered by PPC in Greece as stated by the company's CEO in an answer to a question by a Member of the Greek Parliament[60]. Moreover, a study comparatively evaluating 4 different technology options for the future of PPC's newest lignite plant "Ptolemaida 5" after the seizure of its lignite operation, showed that the option of converting the plant to a molten salt energy storage facility may lead to lower levelized cost of electricity (LCOE) for realistic scenarios on the price evolution of fossil gas as well as emission allowances under the EU ETS[61,62].

2.2 Batteries

Despite their present-day relatively small capacity, batteries have great prospects of increasing the penetration of battery storage technologies, due to both the advancement of technology and the massive reduction of costs. According to Bloomberg New Energy Foundation (BNEF), battery costs have declined by 89% in between 2010 and 2021, from ~$1200/KWh in 2010 to $132/KWh in 2021. This impressive drop can be attributed, inter alia, to the increase in the size of the batteries ordered, the large rise in the sales of electric cars, the penetration of the low-cost cathode chemistry known as lithium iron phosphate (LFP), as well as the reduction of expensive cobalt in nickel-base cathodes. BNEF also predicts that in 2024, the cost of batteries will be below $100/KWh, despite a potential rise in prices in 2022[63]. Moreover, the size of the battery market is projected to increase fivefold from 2019 to 2030, reaching $116 billion per year; this is projected to skyrocket the total installed capacity of batteries worldwide, including that of electric vehicles, from 9 GW in 2018 to 1095 GW in 2040[64]. As the penetration of batteries is increasing worldwide, they have also become increasingly appealing as an energy storage solution in regions of former lignite mines and power plants.

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Big Battery Lausitz (Germany)

In the Schwarze Pumpe industrial park, in Lusatia, Brandenburg, at the same location where a lignite power plant of the same name operated until the 1990s, the biggest short-term storage battery system (lithium-ion technology batteries) in Europe has been built beside the cooling towers of the lignite-fired power station. It has a storage capacity of 50 MW/53 MWh, high voltage (110 KV) connection to the grid and can supply electricity for half an hour upon request. The LEAG-owned project became operational at the end of 2020, with the main contractor to build the battery being the Czech energy company EGEM[65]. The cost was around €25 million, of which €4 million came from the Federal State of Brandenburg[66].

Two battery systems in Greece's former lignite regions (Greece)

Two large-scale energy storage facilities under the names "Ptolemaida Battery Energy Storage System (PTOLEMAIDA BESS)" and "Arcadia Battery Energy Storage System (ARCADIA BESS)", each with a capacity of 250 MW/ 1000 MWh are currently being planned in Greece's former lignite regions in Ptolemaida, Western Macedonia and Megalopoli, Arcadia. Both projects are owned by the Eunice Group and the cost is estimated at €300 million for each installation, whereas both were pre-approved and included in the official national Just Transition Development Plan (SDAM). Construction was initially expected to begin in 2021, allowing for the projects to be fully operational by 2022, provided that the remaining procedures (environmental permit, connection conditions and construction permit) would be completed in time[67]. The first permits were issued in January 2021 by the Greek Regulatory Authority for Energy (RAE)[68,69].

2.3 Pump-hydro

Pumped Hydro Energy Storage (PHES) technology first appeared in the 1890s in Italy and Switzerland[70]; the 1930s brought the first reversible water turbines that could function as both turbines and electricity storage pumps. These turbines had a decisive impact on the advancement of this technology, mainly in the USA and Japan, due to the growing need to manage the production of electricity from nuclear power plants. PHES is the most mature electricity storage technology; there are 325 such systems in operation worldwide with a total capacity of 167.8GW, which represents 97% of the 173.7GW of global total storage capacity. More than 75% of the world's PHES capacity is located in ten countries, and almost half of it (48.5%) is located in just three: China (31.4GW), Japan (27.4GW), and USA (22.6GW). The EU Member State with the highest PHES capacity is Spain, which also ranks 4th in the world with 8GW of PHES capacity, followed by Italy (7.1GW), and Germany (6.5GW)[71].

The principle of operation of PHES is based on the conversion of electricity into potential energy in the energy storage or "charging" phase, and its conversion back into electricity in the generation or "discharge" phase. Energy storage is achieved by pumping water, and electricity is generated by releasing that water into turbine units. The system consists of two reservoirs - the upper and the lower- with an adequate difference in elevation, and a suitable circuit of pipes for the circulation of water. The maturity of the technology in conjunction with the fact that mines can be converted into reservoirs, has made pump-hydro storage an attractive technology to apply in mining regions in transition around the world

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Silvermines Hydro (Ireland)

Silvermines Hydro is a proposed 360MW pump-hydro energy storage facility in Silvermines, County Tipperary, Ireland that will transform a now flooded, abandoned and disused since the early 1990s opencast barite mine, into one of Ireland's leading green energy fa-

cilities. Silvermines Hydro will provide 1.8 GWh of storage and consists of an upper and a lower reservoir with volumes of approximately 2.6 Mm^3 and a head height of 300 m. The project will have 3 x 120 MW synchronous motor/generators and associated turbines[72,73].

It is estimated to leverage private investments of €650 million, and create 400 construction jobs and 50 permanent jobs, plus indirect service jobs[74].

The project is now at an advanced pre-development stage, requiring planning permission, while consultations with all key stakeholders for input into the development process are ongoing[75]. It has been categorized as an EU PCI project and is estimated to be commissioned by 2028[75].

Lewis Ridge Closed Loop Pumped Hydropower Storage project (USA)

Rye Development, a company based in Boston, Massachusetts in the United States, announced on January 4, 2022, that it would develop a pump-hydro project in Bell County, Kentucky, named Lewis Ridge Closed Loop Pumped Hydropower Storage project, with a capacity of 200 MW. The project will be implemented in the broader coal mining area next to the Cumberland River, specifically on a former coal strip mine[76]. The company has filed for a permit for the project with the Federal Energy Regulatory Commission (FERC). With a complex permitting process and a construction period of at least 3 to 5 years, the project is expected to be online after 2030[77].

Kidson pumped hydro storage project (Australia)

The project will utilize two existing mining pits from an abandoned gold mine as the upper and lower reservoirs for a pump-hydro energy storage facility that will have a capacity of 250 MW and will be able to provide up to 2000 MWh in 8 hours. The project reached financial and contractual close in April 2021, with a total funded construction cost of around A$777 million. It was co-financed by the Northern Australia Infrastructure Facility (A$610 million), the Australian Renewable Energy Agency ($47 million), the Clean Energy Finance Corporation (A$3 million), and proceeds from the fully underwritten fundraising undertaken by the Company[78]. It is estimated to contribute A$353 million in net public benefit and to provide 510 jobs during construction and 20 jobs in the operation phase[59].

Construction commenced in May 2021, with completion expected for 2029.

"Gravitricity" - Gravitational storage (United Kingdom)

Gravitricity is an electricity storage project developed by an Edinburgh-based startup with the same name, which stores electricity in the form of potential energy, and is particularly suitable for underground coal mines with vertical shafts of 300m up to 2000m. Gravitricity's principle of operation resembles that of the much more established pump hydro energy storage technology. Excess electricity from intermittent renewable energy sources is stored in the form of potential energy through lifting large weights up to 2000 tonnes. When needed, electricity is released back into the grid when the weights, taking advantage of gravity, are dropped in the mineshafts activating an electricity gen-

erator. This can happen either in very fast and short bursts or for longer periods of time. The process can be repeated several times a day for many years (lifespan of 50 years) without any loss of performance. The technology has been proven to reach full power in less than a second and has a predicted full cycle efficiency between 80% and 90%[79]. A full-scale project of 24 weights, totaling 12,000 tons in an 800m deep well, can power 63,000 homes for more than an hour. By carefully controlling the winches Gravitricity claims it could extend this period by allowing the weights to fall at a slower rate and release electricity over a longer period[80].

Despite the fact that Gravitricity has a rather high upfront cost, an analysis by a team from the Imperial College Environmental Policy Center showed that it is more cost efficient compared to lithium-ion batteries. Specifically, the report found that the electricity released by a typical 10 MW lithium-ion battery project would cost $367 (£283) per MWh over its lifetime, compared to $171 (£132) from a Gravitricity project[81].

In 2021, a 250kW demonstration project was successfully constructed, commissioned, and operated, at the Port of Leith in Edinburgh. Since 2021, Gravitricity has also been exploring a shortlist of mine sites Europe-wide to commence the development of its first 4 to 8 MW full-scale project[82]. The Stařič mine in the Moravian Silesian region of Czechia seems to be the front-runner[83]. The project will be supported by the European Investment Bank (EIB) through EU Innovation Fund grants for Project Development Assistance (PDA)[84]. Moreover, in early 2022, Gravitricity secured funding of £912,410 (out of the total £1,520,684 project cost) from the Department of Business Energy and Industrial Strategy of the United Kingdom government. This grant is dedicated to the delivery of the front-end engineering design (FEED) for a 4MWh multi-weight demonstrator project in a yet undisclosed location in Northern England[85,86].

2.4 Hydrogen (H_2)

Hydrogen (H_2) is a high-density energy carrier that can serve as a means of storing electricity produced from renewable sources and, importantly, for long periods of time. Hydrogen technologies constitute the only storage technologies that can channel stored electricity to other end-use sectors, such as transport, buildings, industrial heat generation, chemical production, and electricity generation. Due to this very potential, hydrogen is considered to have a pivotal role in the decarbonization of the entire European economy, and the central pan-European goal of achieving climate neutrality by 2050. In recent years, there has been increased interest in developing hydrogen storage facilities for a variety of end uses in coal regions in transition.

Retrieved from Hamburg Green Hydrogen Hub, https://bit.ly/3QiSr5T

Lusatia reference power plant (Germany)

The project involves a storage power plant using hydrogen located at the Schwarze Pumpe Industrial Park, in the Lusatian lignite district of Germany. The aim of the project is to create reference solutions for other lignite regions, through the experiences gained from it[87]. In other words, its aim is to develop a guiding concept for the transformation of the lignite-based energy industry with the construction of larger power plants at locations where power plants currently use fossil fuels, and to replace them completely.

The specific power plant will automatically absorb, temporarily store and, if required, release the surplus electricity generated, with hydrogen as a storage medium. Hydrogen will be produced from renewable electricity by electrolysis and could be either available for the transport sector, or converted back into electricity by means of a re-conversion unit (H_2 gas turbine or fuel cell). It will be automatically stored and withdrawn so that a power surplus from renewable energy systems and a temporary power deficiency can be

overcome. The power plant will also be designed so that it can be used to restore the grid in the event of a black-out[88].

The test facility in Schwarze Pumpe will have a manageable output of up to 10 MW. The plant, commissioned to Energiequelle GmbH, will cost approximately €67 million[89]. The planning for the reference power plant will be completed in 2022, and its construction is set to take place between 2023 and 2024, with the final aim to put it into operation in 2025[87].

Hamburg Green Hydrogen Hub (Germany)

The project aims to build a green hydrogen production facility with a 100 MW electrolyser at the site of the coal-fired power plant Moorburg in Hamburg, Germany, which operated only from 2015 until 2020. The site offers the potential for various uses:

- Connection to the national 380,000-volt transmission grid as well as to the 110,000-volt grid of the city of Hamburg.
- Overseas ships can dock directly at the site and use the quay and port facility as an import terminal.
- Connection to the port's future hydrogen network, which is currently being planned by the Hamburg's gas network company[90].

The project is being implemented by a consortium of Mitsubishi Heavy Industries, Shell, Vattenfall and the local energy company Wärme Hamburg, which signed a letter of intent. The project is to start operation in 2025[91].

Bad Lauchstädt Energy Park (Germany)

The "Bad Lauchstädt Energy Park" project in Saxony-Anhalt, Germany, aims to investigate the production, storage, transport and economic use of green hydrogen under real conditions on an industrial scale. Renewable electricity from a new wind park with a 40 MW output will be converted into green hydrogen by means of a large-scale electrolysis facility with an output of around 35 MW, which in turn will be supplied to green mobility applications as well as the chemical industry plants in the neighboring town of Leuna. It will be transmitted via a 20 km gas pipeline operated by ONTRAS that is being repurposed[92,93]. Further development and testing of hydrogen uses started in the third quarter of 2021[94]. In addition, from 2026, preliminary work is scheduled for the hydrogen to be temporarily stored in a specially equipped salt cavern[95]. The total investment for the project is around €140 million. After the project was declared eligible for funding in 2019 as a regulatory sandbox[96] by the German Federal Ministry for Economic Affairs and Energy, it received federal funding of approximately €34 million in September 2021[97].

White Dragon project (Greece)

The "White Dragon" comprises a four-project/innovation cluster, namely the integration of different hydrogen technologies into a complete system[98], energy net metering through fossil gas pipelines, a 100% dedicated hydrogen backbone pipeline, and cross-border hy-

drogen transfer through the Trans-Adriatic Pipeline (TAP). Other uses include hydrogen transport for large end users (refineries, fertilizer companies and fossil gas CHP plants) and mobility[99].

It is a particularly ambitious project aiming to utilize large-scale renewable electricity (~5 GW) for the production of green hydrogen by electrolysis in Western Macedonia, Greece's larger lignite mining center. Solar parks of 500MW[100] will be directly connected to electrolysers for green H_2 production, while the rest of the electricity that will be required will come from variable renewable electricity from the grid, namely from power purchase agreements (PPAs) resulting from solar and wind park surpluses, as well as from hydropower plants[101]. It is worth noting that currently the institutional framework for such PPAs is not available. Hydrogen will then be stored directly (short-term hydrogen storage) and indirectly (streaming through DESFA's, the National Natural Gas Transmission System, pipeline).

Overnight and through short periods of low production of the photovoltaics, the White Dragon will provide the country's power grid with electricity, as a fixed base load co-generation unit of green energy and heat. The generated heat could initially have a complementary use to the district remote heating networks of Western Macedonia, as well as in other applications that require heat and/or cooling (industries, data centers, greenhouses, etc.).

The first three phases of the project (Research & Development, Final Investment Decision and Energy, environment and transportation investment) are to be implemented between 2022 and 2029. The total investment cost is estimated at more than € 8 billion. The project developers also estimate that the project will create 18,000 direct and 29,000 indirect jobs during the design and construction phases and 2,970 direct and 10,400 indirect during operation, from 2030 onwards. Finally, CO_2 savings are estimated at 11.5 million tonnes per year[102].

After a relevant submission by the partners in May 2021, the Greek Ministers of Development and Investment, and Environment and Energy, approved the participation of the White Dragon in the first wave of Important Projects of Common European Interest (IPCEI) "Hydrogenated" in September. The project is currently being technically and financially evaluated for funding by the European Union[103].

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3. Primary sector

The successful transformation of the former lignite regions is dependent on diverse, innovative solutions that help utilize the comparative advantages of each region. Open spaces and valuable arable land are advantages that lignite regions have. Primary sector development, particularly sustainable agriculture practices, constitute an important pillar for the overall development of rural regions. Moreover it is a sector where innovative technologies can be implemented. Smart Agriculture, Internet of Things, carbon farming, precision agriculture are some of the fields where innovation and traditional farming can meet. Also the combined use of areas for photovoltaics and agriculture could be one option for the former lignite areas to sustain their role in the energy transition and at the same time promote sustainable development in the primary sector.

Table 3: Summary of primary sector projects in coal mining regions

Project name	Country	Region	Description	Status	Year	Additional information
Agricultural projects						
Puertollano	ES	Ciudad Real, Castile-La Mancha	908 ha have returned to agricultural and livestock use after their restoration.	Operating	2016	28,000 olive trees, 250,000 kg of olives annually
Sustainable Peatlands	IE	Various	Biomass cultivation for energy uses and aquaculture in former peatlands	Planning	2015	Bord na Mona; species identification between 2015 and 2018; trout and perch in ponds in former peat extraction land.
Agrivoltaics						
Ermakia Project	EL	Ptolemaida, Western Macedonia	Combination of farming with electricity production	Permitting	2022	80 MW PV on a 125.8 ha plot of land in combination with grazing activities.
Morschenich - Alt Agri-PV facility	DE	North Rhine-Westphalia	PV in combination with different plants for various uses	Planning	2021	2 ha for the cultivation of economically viable plants; BioökonomieREVIER structural change initiative.

3.1 Agricultural projects

© ENDESA

Puertollano case (Spain)

In the four mining centers of Andorra, As Pontes, Peñarroya and Puertollano in Spain, the company Endesa has recovered 5,000 hectares, mainly from open coal mines with an investment of more than €100 million. A large part of these hectares, despite being semi-arid and difficult to repopulate, have been dedicated to agriculture or to the development of native vegetation and the raising of local fauna since 2016.

The case of Puertollano stands out, as 908 hectares have been returned to agricultural and livestock use after their restoration. A higher productivity than that of the surrounding undisturbed land is noted. Currently, it has a plantation of 28,000 olive trees with an average annual production of 250,000 kg of olives from which excellent quality of oil is extracted[104].

Sustainable Peatlands (Ireland)

The Bord na Móna project comprises of alternative uses of peatlands following a gradual reduction of peat use for energy that was first announced in 2010 and then a decision to completely phase it out by 2027, was announced in 2019. The alternative uses include biomass cultivation and aquaculture.

Bord na Móna is the only producer of milled peat for electricity generation in Ireland. Three peat power stations remain operational. The project consists of two alternative uses of peatlands. Specifically:

a) Biomass cultivation: This is a pilot project aiming at meeting Ireland' target of 30% co-firing with biomass for the three peat-fired stations which was set in 2015, by testing the potential to grow various plants on peatlands. Between 2015 and 2018 the trials demonstrated that specific species and in particular, reed canary grass, rush and italian rye grass as well as eucalyptus, can be successfully cultivated on the peatland. However, the amounts of biomass produced are not sufficient to meet the 30% co-firing target and, as a result, additional biomass must be imported. For the pilot project, Bord na Móna received funding from the Sustainable Energy Authority of Ireland (SEAI)[105] in 2015.

b) Aquaculture: A project investigating the possibility of growing trout and perch in ponds in former peat extraction land in Ireland is seeing good results halfway in a two-year trial project[106].

3.2 Agrivoltaics

Agrivoltaics refer to a practice of simultaneous use of land for agricultural food production and PV electricity production[107]. In this way, agrivoltaics have the potential to reduce land competition, a typical problem encountered in the transition process of coal mining regions, through the dual use of the land, increase land efficiency and enable the expansion of PV while preserving arable land for agriculture. The agrivoltaic projects can be beneficial for the lignite regions, as they can potentially support land restoration while sustaining their role in the energy transition. The primary sector is a labor intensive sector that can create jobs for the local communities that seek new activities through the transition. Combining two major sectors, agriculture and energy production, through the agrivoltaics, the local communities can benefit most from the deployment of new, transition activities in their regions.

The potential agrivoltaics bring and the existing opportunities for agriculture and energy transition around the globe and especially in Germany, were analyzed by the Fraunhofer Institute for Solar Energy, ISE[108]. According to their analysis, the installed capacity globally of agrivoltaics has increased exponentially, from around 5 MWp in 2012 to at least 2.8 GW in 2020. This was possible because of government funding programs in Japan (since 2013), China (since 2014), France (since 2017), the USA (since 2018), and most recently Korea.

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Ermakia project (Greece)

The Ermakia Solar project is an agri-PV project being developed near the town of Ermakia in the lignite municipality of Eordaia, Ptolemaida in the region of Western Macedonia in Greece. The planned capacity is 80MW and the plant is estimated to produce 106GWh of clean energy every year. The PV plant is planned to be installed on a 125,8 hectaeres

plot of land and the panels will be installed 1,5m above the ground in order to accommodate grazing activities. The installation takes also under consideration the needed water management for the grazing lands and is designed in order to work also as a substitute reserve that allows winter surpluses and summer dryness to be deferred. The action plan further includes the reconstruction of the local creamery to provide processing capabilities to the breeders and boost local economy and the creation of an environmental training center for the promotion of agricultural best practice that will initially focus on stock-raising. The project, being developed by Akuo Energy group is designed according to the Agrinergie[109] best practice model, and is at the latest phase of the licensing procedure, as the environmental impact assessment has been in public consultation until May 2022.

Morschenich-Alt Agri-PV facility (Germany)

The "Innovative Agriculture" (InnoLa) project is a research and demonstration agri-PV facility located at the "Place of the Future" in Morschenich-Alt, a lignite mining region in Rhineland, Germany. It is one of three innovation clusters under the structural change initiative- BioökonomieREVIER[110] funded by the Federal Ministry of Education and Research and secured funding totaling €10 million from 2021 and for the next five years. The consortium consists of the Institutes for Plant Sciences (IBG-2) and Photovoltaics (IEK-5) of the Research Center Jülich, the Fraunhofer Institute for Solar Energy Systems ISE and the system manufacturer SUNFarming GmbH. The district of Düren as the approving authority and the property owner and project developer Hans-Wilhelm Hambloch are also included[111]. The Agri-PV will be built on an almost 2 hectares of lignite land with the aim to investigate how photovoltaics and plant production can be effectively coupled. The plan is to primarily cultivate those plants that are commercially interesting for the farmers, such as rain-sensitive berries, medicinal plants or plant corps for oils, fibers, etc. For the municipality of Merzenich, the Agri-PV system is the first visible Just Transition project in the Morschenich-Alt development region.

Agrivoltaics around the world

Agrivoltaic projects are implemented around the world, not necessarily in lignite regions. Indicative examples include the following:

- **China:** A 1GW solar park, hosting a goji berry plantation is being built on 107 square kilometers of desertified land in the Binhe New District on the eastern banks of the Yellow River in the Ningxia Province. Around 640 MW have so far been connected to the grid. Huawei is providing the inverters for the project. The ecosystem in this region has already improved as the solar power plant is said to effectively reduce land moisture evaporation by between 30% and 40%, andthe vegetation coverage has purportedly increased by 85% while significantly improving the regional climate[112]. The project is being built by the Baofeng Group with inverters provided by Huawei.

- **Spain:** Fivepilot Agri-PV projects on the solar plants of Carmona (Seville), Totana (Murcia), Valdecaballeros & Augusto (Badajoz) and Andorra (Teruel) are being

developed so that photovoltaic panels are combined with crop cultivation and bee hives[113]. The project is promoted by the Enel Group as part of its Endesa initiative.Moreover a project in Totana (Murcia) consists of 85 MW PV developed by Enel Green Power Spain (EGPE). The construction activities began in September 2018 and the plant was commissioned in August 2019, while horticultural species such as red pepper, artichoke, or broccoli are being cultivated simultaneously[114].

•**Netherlands:** Five pilot agrivoltaic power projects are being built in the Netherlands since 2020 in order to test different types of crops: blueberries, red currants, raspberries, strawberries, and blackberries. The project is being implemented by BayWa r.e. and its Dutch subsidiary, GroenLeven. The largest of the projects – a 2.67 MW solar plant deployed on a 3.2-hectare surface devoted to raspberry cultivation – is located in the Dutch municipality of Zevenaar, near the city of Arnhem at the Dutch-German border[115].

•**France:** The Viticulture Agrivoltaics project is located in in the wine-growing region in Piolenc, in Hérault, France[113]. The plant was set, as part of a program to test how agrivoltaics perform in specific crop cultures. For the pilot program, 600m² out of 1,000m² of vines planted were covered by a dynamic agrivoltaic system. As a result, water demand was reduced by 12%-34% for the PV-sheltered vineyards thanks to a reduction in evapotranspiration. Additionally, the aromatic profile of the grape was improved in the agrivoltaic set-up, with 13% more anthocyanins – red pigments – and 9%-14% more acidity[113]. The project is being developed by Sun'Agri. It is due to pass from its demonstration phase which started in 2020 to the commercial phase in 2022.

104. Endesa (6.4.2021), “Convertir una mina en el mayor lago de España”, https://bit.ly/3w1Pgaw

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108. Fraunhofer ISE (2020), “Agrivoltaics: Opportunities for Agriculture and Energy Transition: A Guideline for Germany”, https://bit.ly/3w1QpPk

109. The Agrinergie project was created in 2007 by Akuo Energy group, as a concept that combines farming and energy production on the same site. Based on the observation that ground-based solar panels can reduce the arable land available in an area, Agrinergie project creates synergy with solar power and agriculture. Read more at: Akuo, “AGRINERGIE is the intelligent combination of energy and agriculture in a single project”, https://bit.ly/3wlmY9T.

110. BioökonomieREVIER was founded at the start of 2020 and represents a central measure for shaping structural change through science-based innovations. The innovation laboratories stand for business-related research with the aim of transforming the Rhenish mining area from fossil to bio-based, sustainable management (Forschungszentrum Jülich, BioökonomieREVIER: Innovative Agriculture Cluster Receives Further Funding, https://bit.ly/3kXjIfK)

111. Forschungszentrum Jülich, BioökonomieREVIER:Richtfest für die erste Agri-PV Forschungs- und Demonstrationsanlage im Rheinischen Revier”, https://bit.ly/37zsFcb

112. PV Magazine (3.9.2020), “Giant agrivoltaic project in China”, https://bit.ly/3wivgiU

113. Rated Power (14.9.2021), “Benefits of Agrivoltaics and 5 real-life examples of successful implementations”, https://bit.ly/3w31e3V

114. Endesa (8.10.2021), “Protección de la biodiversidad en las plantas renovables: así es como lo hacemos”, https://bit.ly/38f8hNV

115. PV Magazine (23.7.2020), “Special solar panels for agrivoltaics”, https://bit.ly/3PbBwlg

4. Tourism

Mining and power generation facilities constitute an integral part of the industrial heritage of coal regions in transition. As prime examples of engineering they are often characterized by technological innovation and evolution, while being part of the social history of the regions. As such, many former lignite sites and their infrastructure are protected under the UNESCO World Heritage convention and are transformed into cultural hubs, museums and educational centers. Moreover, reclaimed mining sites create a new natural environment, most commonly, with lakes and parks, and become tourist attraction sites. Therefore, in many cases, sustainable tourism becomes part of the revitalization of former mining areas.

Table 4: Summary of culture and tourism projects in coal mining regions

Project name	Country	Region	Description	Status	Year	Additional information
Industrial heritage						
Zeche Zollverein	DE	North Rhine-Westphalia	Former coal mines in Ruhr area, on the site of the Zeche Zollverein coal mine	Operating	2001	UNESCO World Heritage Site since 2001; more than 250,000 visitors per year.
National Coal Museum "The Big Pit"	UK	South Wales	Mining museum	Operating	1983	UNESCO World Heritage Site since 2000; more than 110,000 visitors per year.
Mining museum "Escucha"	ES	Teruel, Aragon	Mining museum	Operating	2002	Various underground and above ground exhibitions and activities.
Mining History Centre	FR	Nord	Mining museum	Operating	1984	UNESCO World Heritage Site since 2012; more than 150,000 visitors per year.
Guido Mining Museum & Queen Louise Adit	PL	Silesian	Museum and educational centers for children	Operating	1982	-
Tarnowskie Góry Historic Mine	PL	Upper Silesian	Museum	Operating	-	Monumental underground water management system showcasing a 300-year ingenious development of hydraulic engineering.

Project name	Country	Region	Description	Status	Year	Additional information
Planeta Petrila	RO	Hunedoara	Industrial heritage conversion project	In progress	-	Public involvement for the evaluation of the existing potential and the generation of local support around the area's regeneration through culture.
Recreational activities						
Lusatian Tourist Lakes	DE	Brandenburg & Saxony	24 artificial lakes in Lusatia by flooding old coal mines. Activities: leisure, sports, marinas, beaches, hotels, campsites, restaurants and theaters, tour guides at industrial heritage site	Operating	2000	€7.3 million: Federal Ministry for Economic Affairs and Energy, the Free State of Saxony and the Federal State of Brandenburg. €1.23 billion: landscape restoration and engineering until 2022.
Landek Park	CZ	Moravian-Silesian	35 ha park for various activities (mining history, sport, relaxation, and camp spots for up to 2,000 people).	Operating	1990s	-
Most	CZ	Ústí nad Labem	Museums and leisure activities such as a Coal Safari, Most Hippodrome, sports facilities, and picnic areas.	Operating	-	-
As Pontes	ES	Galicia	Artificial lake created in a 2,400 ha area with 1412 cubic meters of water; beaches, recreation areas, water sports.	Operating	2016	The biggest artificial lake in Spain.
Rother Valley Country Park	UK	Yorkshire and the Humber	Recreational lakes and wetlands, nature trails, sports and camping facilities and an education center.	Operating	1990s	Development plan was finished before the mine closures and was the basis for the final design of the mining site; more than 800,000 visitors per year.

Project name	Country	Region	Description	Status	Year	Additional information
Rio Tinto Mining Park	ES	Andalucía	Mining and railways museum along with various activities.	Operating	1994	-
Phönix See	DE	North Rhine-Westphalia	Lake offering leisure and sport activities	Operating	2011	10-year transformation period (2001-2011).

4.1 Industrial heritage

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Zeche Zollverein (Germany)

Zeche Zollverein was once the largest coal mine in the world, as was its coking plant. Today it is a symbol of the conversion of the area from a coal mine to a cultural hub[116]. Former mines in the area of Essen in Germany function as business parks and event venues, hosting music concerts as well as cultural or food festivals. The site was declared a UNESCO World Heritage Site in 2001[117]. The Ruhr museum, whose current location is in the former coal washing plant on the site of the Zeche Zollverein coal mine since 2010, stands out and is estimated to attract over 250,000 visitors each year[5]. Visitors can learn about the history of the Ruhr region and industrialization, by following the evolution of coal mining based on approximately 6,000 exhibits, consisting of preserved machinery and conveyor belts which belong to the former coal mine. They can also reach an observation deck on the roof of the old coal washing plant, which offers a spectacular view of the area. In addition to the permanent exhibition, the museum has extensive collections of geology, history, archeology and photography, which are presented in regular special exhibitions[118].

National Coal Museum "The Big Pit" (United Kingdom)

"The Big Pit" is one of Wales' top tourist attractions. It is one of the few mining museums where visitors can go down to mining sites and visit the places where generations of miners worked, as many features (tunnels, buildings) still remain. The tour is carried out at a depth of 90 meters below the ground by former miners as tour guides. Many of the above-ground exhibitions are also housed in the original coal mines. The Museum is located in a unique industrial landscape, which was designated a World Heritage Site by UNESCO in 2000, in recognition of its international importance to the process of industrialization through iron and coal production. It is estimated that "The Big Pit" attracts over 110,000 visitors each year[119].

Mining museum "Escucha" (Spain)

"Escucha", in the region of Teruel Spain is a mining museum opened in July 2002, at the Se Verá mine, which operated from the beginning of the 20th century until 1968. Visitors are equipped with personal protection equipment used by the miners and go down to the shaft with the personnel transport vehicles that were used. They are guided to a depth of almost 100 meters in exhibitions related to mining work, as well as various minerals. The Museum also has an open-air exhibition of old machinery used in the various surrounding mines, with explanatory paintings. Finally, visitors can also enjoy outdoor recreation, such as, informative mini trails, a mini golf course, ping pong facilities, playgrounds and green areas for picnics and relaxation, as well as a restaurant and a souvenir shop[120].

Mining History Centre (France)

The Mining History Center is the largest mining museum in France and one of the top such attractions in Europe. It is located on the site of the old Delloye coal mine in Lewarde in the Nord department (Douai). Since 2012, the Nord-Pas-de-Calais mining basin has been designated as a UNESCO World Heritage Site. The Mining History Center was created in 1982 at the impetus of the nationalized mining company and opened to the public in 1984. The site includes 8,000m² of industrial buildings in a total area of 8 hectares and the Center welcomes more than 150,000 visitors each year. Visitors have access to thematic exhibitions to learn about how coal is formed, the history of the mining era in the region and the daily lives of miners and their families, as well as galleries depicting the underground world of miners. There is also the "Meet a Miner" option, in which former miners tell their careers and stories about their working conditions, as well as a Scientific Culture Center, which aims to transfer knowledge about energy issues to the general public (issues related to the economy, environment and social consciousness), to improve its understanding of current challenges facing mining and current and future energy sources. It is addressed to different audiences, such as the general public, children, as well as people with a professional interest. Finally, there is a restaurant, and a free picnic area[121]. The Center is subsidized by the French government, the Douai Urban Area and the Heart of Ostrevent local towns.

Guido Mining Museum & Queen Louise Adit (Poland)

The Guido Mining Museum and the exhibition facilities at the Queen Louise Adit have been created at the Guido Mine Complex, a former underground hard coal mine in the region of Zabrze in Silesia, Poland. Guido Mining opened to visitors in 1982. They can see the underground mining machinery at work, including some dating back to the late 1920s, and learn about the development of mining techniques over the past 200 years. The routes include underground excavations from the time when the "Guido" Mine was fully operational. The Queen Louise Adit includes restored buildings and offers exhibition and educational opportunities, especially for children. Moreover, the Guido Mine has a modern zone hosting cultural, business, and entertainment events[122].

Historic Mine in Tarnowskie Góry (Poland)

Tarnowskie Góry lead-silver-zinc mine and its underground water management system is located in the Silesian plateau of southern Poland, in one of Europe's most prominent metallogenic provinces. It possesses a monumental underground water management system that reflects a 300-year ingenious development of hydraulic engineering. The visitors can explore the underground former silver-ore mines, including an entire underground mine with shafts, galleries, and features of the water management system[123]. Since 2017 it has been designated as a UNESCO World Heritage Site and the museum is an Anchor point on the European Route of Industrial Heritage.

Planeta Petrila (Romania)

The future of the Petrila Coal Mine in Jiu Valley, Romania is an ongoing development project, which began before the coal mining activity ended in 2015. In particular, under a 2012 student initiative[124] workshops were organized to identify ways to explore the industrial heritage of the Petrila Mine for the future development of the city of Petrila. Following the cease of coal exploitation, the mine was declared a National Heritage site. In 2017 a dedicated documentary telling the story of the site was launched, while in 2018 cultural events started in the region. The vision for the former lignite region of Planeta Petrila is to create a resilient place to live for 100,000 inhabitants by exploiting its natural resources sustainably and becoming one of the most important touristic destinations in Romania. This vision consists of multifaceted development plans such as the conversion of the former coal mine, the construction of a mining museum and the headquarters of the local town hall, the use of the site for industrial research and development, (re)connection to the city, new public spaces and restoration of the river shores. 2030 is foreseen as the estimated deadline for the urban regeneration project with a total budget of over €30 million[125]. The authority supervising, managing and implementing the urban regeneration project is the Planeta Petrila Association, which consists of City Hall Petrila - local public authorities, former miners, professionals and the local NGOs. The Planeta Petrila project combines interdisciplinary techniques to evaluate the existing potential of the region and to mobilise the local community around the process of regeneration through culture[126].

4.2 Recreational activities

Retrieved from Tracer H2020, https://bit.ly/3xkh1L2

Lusatian Tourist Lakes (Germany)

The project entails the rehabilitation of the former state-owned mining areas in the region of Lusatia, in Germany. Initially, following the cease of operation of old coal mines, the "Lausitz and Middle Germany Mining Administrative Company" was set up by the German Government in 1994 in order to flood the mines with water, thus creating 24 artificial lakes. In 2000 a new phase that lasted for 11 years was launched aiming at the transformation of the area. More than 30 projects were implemented in order to complete the landscape transformation, building marinas as well as creating beaches[127,128]. Today, the area offers opportunities for boat rides and water sports, whereas a former power plant was restored to host art exhibitions and events, and several towers offer unique viewpoints of the area. One former mine was left –on purpose– untouched to allow for nature restoration and, indeed, it was retaken by grass, marshland, insects, and birds. Additional leisure opportunities are offered by hotels, campsites, restaurants and theaters, while tour guides offer a tour of an industrial heritage site, showcasing the huge factory in Knappenrode and an 11,000-ton deck at nearby Lichterfeld[129]. The so-called horizontal Eiffel Tower of Lusatia is one of the main attractions of the area with a former overburden conveyor bridge, weighing 13,500 tons[130].

The projects were financed by several sources, including EU funds and €7.3 million from the Federal Ministry for Economic Affairs and Energy, the free State of Saxony and the federal state of Brandenburg. In addition, there is an additional and quite considerable support of landscape restoration and engineering of €1.23 billion up to the year 2022[131].

Landek Park (Czechia)

The former coal mine Anselm now houses the Landek Park and a Mining Museum. The 35 hectares park is a natural area hosting a variety of plants and animals and offering recreational opportunities with sports activities and a camp with a capacity of up to 2,000 people. The mine contained the oldest mining well in the city of Ostrava (Moravia-Silesia) and was converted into the largest mining museum in the Czech Republic more than 25 years ago. Visitors can enjoy tours that highlight the history of coal mining between 1782 and 1990, following a miner's typical day, and observe a demonstration of the operation of mining equipment. Visitors can also go down to the mining shaft, to the special miners' cloakroom, and through to the exhibition of mining rescue services, one of the largest collections in the world, with one of the oldest existing breathing equipment from 1884 and Siebe-Gorman diving equipment from 1920. They can also board an old mining train from the 1960s and learn about the history of mine transport[132]. The project won the Henry Ford Award in recognition of the revitalization of degraded areas, respect for the environment and cultural heritage[5].

Most (Czechia)

At the inactive surface coal mines near the city of Most, in North Bohemia, Czech Republic, museums and touring routes have been created. In particular, three routes are available to visitors: one focusing on restoration activities in Most whereas the other two, allow visitors to experience the open-cast ČSA and Vršany mines up close and see the technical work and the giant machinery, during what is referred to as the "Coal Safari". Close to the town of Most, there is the Podkrušnohorské Technical Museum, which displays the history of coal mining and processing in the central area of the Brown-Coal Basin of North Bohemia, while also presenting information on other industrial activities developed in the area. Visitors can also learn about the mining heritage in the wider Krušné Mountains area through two galleries (Sightseeing Gallery of Lehnschafter in Mikulov & Starý Martin Gallery)[133,134]. In addition, the companies Vršanska Uhelna and Severni Energeticka have built the Most Hippodrome, which includes, among others, a racetrack (horse racing and demonstration races), a 3km long skating track, sports facilities (e.g. golf) and picnic areas[5].

As Pontes (Spain)

The old open cast hard coal mine "As Pontes" was operated by the Spanish energy company, Endesa, until 2008[135,104]. As part of the rehabilitation of the 2,400 hectares area, the mine shaft has been inundated to create the largest artificial lake in Spain – with a perimeter of 18km and a depth of 205 m. The 865 and 547 cubic meters of water that were required to create the lake respectively came from the Eume and Meidelo rivers. Today it contains facilities for water sports, as well as beaches for swimming and recreation areas. The artificial lake is located 20 km from the Atlantic Ocean and at an altitude of 330m, offering Endesa the opportunity to develop a hydropower project with a capacity of up to 600 MW[5]. This project could also be potentially transformed to al pump-hydro energy storage facility[136].

Rother Valley Country Park (United Kingdom)

The Rother Valley Country Park, in England, UK was created, as part of the rehabilitation of the Meadowgate open pit coal mine which operated between 1976 and 1982. Planning for the Park had begun by the Rotherham Borough Metropolitan Council and the Sheffield City Council during the 1960s. The plans were reconsidered following the closure of the mine. A Joint Committee consisting of institutional bodies and local residents was set up to review the planning for the rehabilitation and closure of the site, and monitor the progressive rehabilitation process at the site. By 1978, the Final Development Options Report was published - four years before the closure of the mine - and formed the basis for the final design of the mine site. In the end, the open pit coal mine site was transformed into a successful recreational park that attracts over 800,000 visitors per year. The Park includes a series of recreational lakes and wetlands as well as facilities to support the visitors, such as car parks and access roads, while also offering guided walks and nature trails. Other recreational facilities developed include an 18 hole golf course, four soccer pitches, riding trail, a camping and caravan facility, an education center, a grass skiing slope, and a visitor Information Center at a 17th century mill that was redeveloped as part of the mine rehabilitation[137].

Rio Tinto Mining Park (Spain)

The Rio Tinto[138] area of Huelva boasts 3,000 years of mining history up to the 1990s. Since 1994, the "Parque Minero Riotinto" (Rio Tinto Mining Park) hosts various activities, such as the mining and railways museum, with its detailed history of mining in Rio Tinto, the Roman mine reconstruction and the Maharajah's railway carriage and steam engine. At the Peña del Hierro open-cast mine an actual mining gallery is hosted. At Bella Vista, today's living community of an English barrio, a restored Victorian engineer's house (Casa 21) can be visited. Visitors can also travel along the banks for the red Rio Tinto, to see the old mines and machinery and the extraordinary landscapes on a train trip in an original wooden carriage. Additionally, Rio Tinto Mining Park is a place for those with interest in history, geology, chemistry, metallurgy and/or engineering, and it offers an enjoyable and educational experience for all ages[139].

Phönix See (Germany)

Following 160 years of industrial history in the district of Hörde in Dortmund Germany, the closure of the blast furnace and steel plant site of ThyssenKrupp in 2001 led to a new beginning. In particular, the area was rehabilitated with the creation of an artificial lake – the Phoenix See. The project was implemented between 2005 and 2011 by a subsidiary of the Stadtwerke AG, with the inundation of the area taking place in 2010. The Phoenix See is a shallow water lake with a depth of 3 to 4 meters, a water volume of around 600,000 cubic meters and water surface area of 9,72 hectares. The perimeter of the lake is 3,2 km and the lake is fed primarily by groundwater[140]. The new lake is inviting for walking, jogging, cycling or skating. The 3,2 km long pedestrian and bicycle paths invite visitors to relax, as well as to sporting activities. Besides sports the shores of the lake offer high-end residential units, commercial offices, a floating stage with a marina and a promenade with restaurants.

116. Ministry of Landscaping, Innovation, Digitalization and Energy of the Lands NRW (2018), "Strategies and Plans in North Rhine Westphalia (Germany)", Presentation at the 3rd Working Group Meeting of the Coal in Transition Platform, https://bit.ly/3N0NrAm

117. Metropol Ruhr Tourismus, UNESCO World Heritage Zollverein – a highlight of industrial heritage", https://bit.ly/37yjjgC

118. NordRhein-Westfalen, "Ruhr Museum at the Zollverein World Heritage Site in Essen", https://bit.ly/3LYzgM9

119. Museum Wales, "Big Pit National Coal Museum",https://bit.ly/3ss1yHj

120. Museo Minero de Escucha, https://bit.ly/3srdWap

121. CHM-Lewarde, "France's largest mining museum", https://bit.ly/3PpTmkL

122. Tracer H2020 (April 2020), "Fact Sheet:Guido Coal Mine and Queen Louise Adit", https://bit.ly/3M79hST

123. UNESCO, "Tarnowskie Góry Lead-Silver-Zinc Mine and its Underground Water Management System", https://bit.ly/3M3tx7D

124. The initiative was organized by ADERF - the Association of Romanian Students and PhD students in France and the Cultural Association "CondițiaRomână.

125. Politehnica University Timișoar (2019), "Planeta Petrila: a post-mining community regeneration project", Presentation at the 4th Working Group Meeting of the Coal Regions in Transition Platform, https://bit.ly/3wlwYjr

126. Tracer H2020 (September 2019), "Fact Sheet: Petrila Planet-steps towards reactive art, Jiu Valley, Romania", https://bit.ly/3FzJEYg

127. The transformation project of Lusatia was supported by Internationale Bauausstellung (IBA, International Building Exhibition) which is an instrument of structural policy. IBA Fürst-Pückler-Land took place in Lusatia from 2000 to 2010 and has developed a new type of cultural landscape. Since late 1980s IBAs broke new ground with their state of the art architecture and through the years have evolved to today's living experiment in urban and regional planning incorporating complex social, economic and ecological aspects with the help of design, communication and participation. (IBA-SEE, "History of the 'Internationale Bauausstellung'", https://bit.ly/3M0uNIO

128. Lausitzer Perspektiven e.V (2018), "Accompanying the transition involving the community: proposals from Lusatia", Presentation at the 3rd Working Group Meeting of the Coal Regions in Transition Platform, https://bit.ly/3FBKuUv

129. The Guardian (10.9.2014), "Life after lignite: how Lusatia has returned to nature", https://bit.ly/3M96tVe

130. Tracer H2020 (September 2019), "Fact Sheet: The horizontal Eiffel Tower of Lusatia, Germany", https://bit.ly/38pExxA

131. Tracer H2020 (September 2019), "Fact Sheet: From mining to dream vacation 'Lusatian Lake District', Germany", https://bit.ly/3N5hNls

132. Vítkovice, "Mining Museum in Landek Park", https://bit.ly/3srQ32k

133. i:Mostecko, "The town of Most", https://bit.ly/3L97Vp7

134. i:Mostecko, "The official tourist portal for the region of Most and its surroundings", https://bit.ly/3N9KsWC

135. In the four mining centers of Andorra, As Pontes, Peñarroya and Puertollano in Spain, the company Endesa has recovered 5,000 hectares, mainly from open coal mines with an investment of more than €100 million. Part of the recovery projects is also the case of Puertollano, where mining land transformed to agricultural and livestock use, as described before iin the Primary sector chapter.

136. European Commission Joint Research Center (2013), "Assessment of the European potential for pumped hydropower energy storage", https://bit.ly/3suazzn

137. ReviRIS, "Inventory of global best practice scenarios for mine-closure and related social strategies", https://bit.ly/3yqO3vf

138. Andalucia.com, "Rio Tinto Mines", https://bit.ly/39SMFY1

139. Tracer H2020 (September 2019), "Fact Sheet: Green ideas for creative leisure time of Rio Tinto Mining Park, Huelva, Spain", https://bit.ly/3ypYSxz

140. Dortmund.de, "Phoenix See - Dortmund", https://bit.ly/3KYqBb7

5. Sustainable Mobility

Sustainable mobility constitutes a significant investment and policy pillar for the transition of coal regions. Such projects foster technology progress in electromobility, hydrogen mobility as well as relevant supporting infrastructure which are absolutely essential for the decarbonization of the transport sector and the achievement of the EU climate targets.

Table 5: Summary of sustainable mobility projects in coal mining regions

Project name	Country	Region	Description	Status	Year	Additional information
Clean mobility	CZ	Ústí nad Labem, Moravian-Silesian and Karlovy Vary	Purchase of hydrogen buses, construction of hydrogen filling stations linked to existing hydrogen production facilities.	Planning	2020-2025	Estimated budget: €60 million
Silesian Mobility Clusters	PL	Silesian	Support for the purchase of electric vehicles and promotion for the development electromobility industry;	Operating	2018	In cooperation with Katowice Special Economic Zone.

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Clean mobility -use of hydrogen (fuel-cells) in urban public transport and other applications (Czechia)

The project, implemented in the context of the Re:Start program and the Strategy of economic restructuring of Usti, Moravian- Silecian and Karlovy Vary regions, aims at using available EU funds to finance the purchase of hydrogen buses by the city/county urban transport operators in transition regions. It also includes the construction of hydrogen filling stations linked to existing hydrogen production facilities. The project is in line with the goals of the Czech clean mobility policy. Its estimated budget of €60million[141] is co-financed by EU funds as well as the state and the municipalities involved, and is planned to be implemented during the period 2020-2025.

Silesian Mobility Clusters (Poland)

The Silesia Automotive & Advanced Manufacturing cluster is an initiative of the Katowice Special Economic Zone, which was developed as the result of the restructuring of the Katowice coal region in Poland[142]. The specific mobility cluster aims at supporting research and development in the automotive and advanced manufacturing industry and at creating a strong platform of exchange and cooperation between companies, science and education institutions. One of the areas of focus is electromobility. Hence, a €100 million project will be implemented jointly by entrepreneurs and scientific teams, in order to provide support for the installation of electromobility infrastructure in the Metropolis GZM (Electric Vehicle car-sharing, scooter sharing, electric bikes) and promote the concept of mobility as a service (MaaS) for the Metropolis GZM[143].

141. Strategy of Economic Restructuring of Usti, Moravian-Silesian and Karlovy Vary Regions (2018), "Priority projects in Coal Regions in Transition in Czech Republic", Presentation at the 2nd Working Group of the Coal Regions in Transition Platform, https://bit.ly/3N2Upow

142. Katowice Special Economic Zone, "Information, Silesia Automotive & Advanced Manufacturing", https://bit.ly/3yC3lNw

143. Silesian Voivodship Regional Development Department Marshal Office (2018), "Silesian Voivodship - Coal Region in Transition: Strategic Projects", Presentation at the 1st Working Group of the Coal Regions in Transition Platform, https://bit.ly/3kZXYQl

6. Reskilling

The creation of new jobs for the people in the regions that are most affected by the transition is one of the biggest concerns in the Just Transition process. While experienced workers in the coal and lignite industries can be useful for other industrial and industrial sectors, it is often the case that new economic activities require the development of new skills. Hence, reskilling, upskilling, vocational training and capacity building projects and initiatives constitute basic pillars of Just Transition policies and plans. Moreover, young people in local communities need support in order to tackle the transition challenges and stay in the coal regions while new economic activities are developed.

Table 6: Summary of reskilling projects in coal mining regions

Project name	Country	Region	Description	Status	Year	Additional information
Cooperative Training Program at Coal Sites	DE	North Rhine-Westphalia	Out-of-school training for young people.	Operating	2008	Co-financing scheme: European Social Fund, governmental and non - governmental funds, and local budget.
Successor campus	DE	Brandenburg & Saxony	Acquisition, training, and coaching of potential employees for company succession.	Planning	2018	With the cooperation of the Cottbus Chamber of Crafts and Lusatian companies.
"Competence region Lusatia"	DE	Brandenburg & Saxony	Education and training center for children and young adults to demonstrate employment and career opportunities for young workers.	Planning	2018	Estimated investments: €35 million
Silesian Treasury	PL	Silesian	Scholarships for learning achievements to most talented pupils, students and Ph.D students.	Planning	2018	Estimated budget : €75 million

Project name	Country	Region	Description	Status	Year	Additional information
Mitigation of transformation impacts through targeted training measures	SK	Trenčín	Direct support to the workers education, training and re-training, mentoring and coaching, entrepreneurship and business development.	Operating	2019	Funded from European funds.
Silesian Professionals	PL	Silesian	Internships, additional courses, training, social campaign regarding vocational education and professional lessons in enterprises.	Planning	2019	Estimated budget: €4.2 million
Lethans Wind Farm - East Ayrshire training programme	UK	Scotland	60 new paid traineeships at the proposed Lethans Wind Farm.	Planning	-	-
Apprenticeship in Ebbw Vale Enterprise Zone	UK	Wales	SAS - Shared Apprenticeship Scheme: apprentices move between different employers to share responsibility for on-site training goals.	Operating	2021	Timeline: 2020-2023; estimated budget: €107 million
OAED program	EL	Western Macedonia and Peloponnese	Employment support programs for job creation, youth work experience, relocation grants, counseling, training and employment.	Operating	2021	Timeline: 2020-2023; estimated budget: €107 million

Cooperative Training Program at Coal Sites (Germany)

The Cooperative Training Program at Coal Sites in North Rhine-Westphalia, Germany aims to provide training opportunities so as to address the significant decline in jobs related to the lignite industry of the region. It was estimated that phasing out coal would affect directly 8,961 people working in the lignite mines and power plants of the Rhenish district as well as 14,338 jobs that were directly or indirectly linked to the lignite sector. The out-of-school training program found different traineeship positions for members of the local youth, who had not found a position already. In the second year of training, the apprentices participated in an additional company training. The project implementation was supported by GIB, a state-owned company working with the state government of North Rhine-Westphalia to combat unemployment. GIB supported the identification of training providers and small and medium-sized enterprises, while also offering external training[144,145]. The program is being implemented in the state of North Rhine-Westphalia in the Ruhr area since 2008. It is financed with funds from the European Social Fund, governmental and non-governmental funds, as well as local funds.

Successor campus (Germany)

The opportunities of company succession as an alternative to start-ups are emphasized by "Successor campus", an upskilling project in the region of Lusatia. The project was supported by the Cottbus Chamber of Crafts and Companies from Lusatia. The project targets 300 craft companies in Southern Brandenburg (25% of all companies) which face the challenge of shaping the generation change as the business owners are over 60 years old. The project aims at finding and training employees as successors, which shall systematically be acquired by the companies, further trained, coached and prepared for company succession. One main focus is the coaching of innovation-oriented company successors. The estimated budget for this project is €931,000[146].

Development of the innovative "competence region Lusatia" (Germany)

The project concept aims at creating an education and training center for children and adults in the region of Lusatia, in the State of Brandenburg, Germany. It is part of a flagship initiative titled "Innovating Learning Center Lusatia" (ILL), which has a total budget of €35 million. The project aims at securing young skilled workers in Lusatia, in an effort to hold back the outflow of young workers from the rural regions of Brandenburg by demonstrating employment and career opportunities in the region[146].

Silesian Treasury (Poland)

This project concept titled "Silesian Treasury" aims to create an incentive program for young pupils and students from the region of Silesia in Poland. It foresees granting scholarships for learning achievements of the most talented pupils, students and Ph.D students aiming at fostering excellence. The estimated budget is €75 million[143].

Mitigation of transformation impacts through targeted measures of EGF and complementary measures of ESF (Slovakia)

The project aims to provide education, training and re-training, mentoring and coaching opportunities on entrepreneurship and business development to the workers linked to the coal industry in the region of Upper Nitra in Slovakia. The project also aims to cover training, mobility, relocation, as well as subsistence allowances, with funding from European funds (European Structural and Investment Fund, ESIF /European Guarantee Fund, EGF) and in accordance with the regional integrated territorial strategy[147].

Silesian Professionals (Poland)

This project is included in the Regional Transformation Action Plan of Silesia in Poland that was adopted in 2019. It aims to support the adaptation of educational opportunities of vocational schools to the key needs of the changing local economy, by developing and building lasting mechanisms and networks of cooperation between schools and employers, as well as increasing students' access to internships and apprenticeships in Silesia[148]. Indicative planned activities include additional courses, training and classes for students of vocational education schools, courses and training for teachers, the possibility of practical preparation of the future staff, and internships. In addition, in order to create a positive image of vocational education it aims at supporting a social campaign regarding vocational education and demonstration and professional lessons in enterprises. The estimated budget is €4.2 million from the European Social Fund (€3.57 million), the state budget (€420,000) and only €210,000 as own contribution. It will be implemented under the 2014-2020 Regional Operational Program of the Silesian Voivodship which is the beneficiary, in partnership with the Chamber of Commerce and Industry in Katowice, the Katowice Special Economic Zone and the Chamber of Crafts and Small and Medium Enterprises in Katowice[149].

Lethans Wind Farm - East Ayrshire training programme (United Kingdom)

In the former coal mining area of East Ayrshire (UK) a wind farm developer has proposed a training program for 60 new paid traineeships at the proposed Lethans Community Wind Farm, which consists of 22 wind turbines. The Banks Renewables, as is the name of the wind farm developed, has signed an agreement with Netherthird Community Action Training (NCAT), a local social enterprise that provides a range of traineeships to 17-24 year olds, which would result in a five-year contract creating 60 new paid traineeships for local people, ranging from 4-8 week courses to year-long placements. The trainees would undertake landscape management, habitat creation, general groundworks and land management duties on Banks Renewables' proposed Lethans Wind Farm, should the plans be given the go ahead[150].

Apprenticeship in Ebbw Vale Enterprise Zone (United Kingdom)

In the Enterprise Zone in Ebbw Vale in Wales, a former tinplate producer region, 7,000 jobs were created to revitalize the area via a model that could also be applied to coal mining regions. Job creation in Ebbw Vale was supported by a successful on-site training program which enhanced local skills, especially of youth. The "SAS - Shared Apprenticeship Scheme", which is an apprenticeship model and a protocol for apprenticeship programs, allows apprentices to rotate between different employers, which means that businesses share the cost and responsibility of a long-term commitment. To date, this scheme has been implemented mostly in the construction and engineering industry, but is becoming increasingly popular in other priority sectors, such as tourism. One of the projects developed with support from the "Apprenticeship budget" is the Aspire Blaenau Gwent project. Specifically, in July 2015, the Ebbw Vale Enterprise Zone Board in conjunction with Blaenau Gwent Council received approval from Welsh Government to develop a Manufacturing/ Engineering Shared Apprenticeship Scheme under the SAS protocol and the Aspire project. The scheme involved apprentices aged 16-24 years old that after a selection process and interview were placed in a manufacturing company for 2-3 years and were paid above minimum apprenticeship wage. From 2015 to 2019, Aspire has cooperated with 50 manufacturing employers across the region. In 2019, all apprentices were hired at the end of their program, with 64% retained by their initial host company. By 2021, the program had supported more than 100 apprentices, placing them in 25 manufacturing companies with 51% of apprentices continuing their studies in higher education institutions. The practice of rotating apprentices amongst host employers is now well-established and proves to be beneficial for the most impoverished areas of Wales[151,152].

OAED programs (Greece)

Four Employment Support Programs in Greek lignite areas have been approved and started being implemented in 2021[153] by OAED (Greece's national employment agency). They are part of a 2020-2023 Special Transition Program[154] designed by the Steering Committee of Greece's Just Development Transition (SDAM) and its Technical Secretariat, aiming at jump-starting the transition process in Greece's two lignite regions (Western Macedo-

nia and Megalopolis). Specifically, the four programs have the following features:

1. Creation of new jobs: businesses will be supported to recruit unemployed in new full-time positions with attractive terms and conditions, such as increased wage and contribution subsidies, simplified terms of participation for the companies and faster than the current payment procedures.
2. Youth Work Experience: 100% coverage of salary and social benefits for young unemployed aged 18 to 29 years for their employment in local businesses.
3. Relocation Grant: Grants to local companies to cover relocation and accommodation costs if unemployed from the wider area are recruited.
4. Counseling, Training and Employment: Counseling services for the unemployed, (e.g. vocational guidance, development and upgrading skills through training) as well as business grants for their recruitment. Implementation of this program is undertaken by OAED in collaboration with the municipalities of lignite regions.

The four programs, with a total estimated budget of €107 million (€50 million for 2021 and € 56.9 million for 2022) is co-financed by Greece's 2014-2020 Cohesion Funds, the national Green Fund and other financial sources such as the EU Recovery and Resilience Fund and implemented by OAED.

144. Tracer H2020 (January 2020), “Best practice report on labour markets, social issues and tourism”, https://bit.ly/398D2UD

145. Tracer H2020 (September 2019), “Fact Sheet: Cooperative Training Program at Coal Sites, North Rhine-Westphalia, Germany”, https://bit.ly/3N5A0PQ

146. Presentation at the 1st Working Group of the Coal Regions in Transition Platform, https://bit.ly/3wnZUr0

147. Office of the Deputy Prime Minister for Investment and Informatization (2018), “Basic strategy, priorities and possibilities of financing the transformation projects within Upper Nitra From the Structural Funds”, Presentation at the 1st Working Group of the Coal Regions in Transition Platform, https://bit.ly/3yuRroU

148. European Commission (2020), “Region Profile: Silesia”, https://bit.ly/3L4HiBN

149. Department of European Social Fund Marshal’s Office of the Silesian Voivodship (2019), “Silesian Professional Employees”, Presentation at the 4th Working Group of the Coal Regions in Transition Platform, https://bit.ly/3Pc73Ua

150. Global Renewables News (7.3.2017), “East Ayrshire Wind Farm to Bring Winds of Change for 60 Out of Work Youngsters”, https://bit.ly/3l3KrHD

151. Tracer H2020 (September 2019),”Fact Sheet: Apprenticeship in Ebbw Vale Enterprise Zone, Wales, UK”, https://bit.ly/3L2CiOg

152. Blaenau-Gwent, “ASPIRE - support for employees”, https://bit.ly/39en9w4

153. Greek Ministry of Labour and Social Affairs (17.11.2021), Press Release “The ‘social package’ of OAED actions is implemented to support employment in Western Macedonia-Peloponnese and their transition to the post-lignite era”, https://bit.ly/3PbvgK9

154. SDAM, “Special Transitional Programme for the Just Development Transition-EmePDAM for the period 2020-2023”, https://bit.ly/3whvW8o

7. Economic Zones – Innovation

The economic transformation of the former lignite regions is most effective and efficient when the privileged location, experienced workers and existing infrastructure can be utilized in renewed ways. These parameters drive the change in the regions in transition through the materialization of new economic opportunities. Economic zones constitute a framework for organizing such new economic activities and contribute to the economic regeneration of the transition regions. Such zones include new energy or other industrial zones and logistics centers, especially near borders or along highways. Economic zones contribute to job creation, and sectoral specialization, by supporting research and technology development, smart and sustainable innovation with the creation of research and scientific centers as well as innovation and technology hubs.

Table 7: Summary of economic zones projects in coal mining regions

Project name	Country	Region	Description	Status	Year	Additional information
Industrial zones						
Tatabanya case	HU	Komárom -Esztergom	Activities in the fields of engineering, chemical industry, production of medical instruments, electronics and environmental engineering (including R&D).	Operating	1990s	The largest public industrial park in Hungary; local leadership and institutional learning played a substantial role for the economic recovery of the region.
Katowice Special Economic Zone	PL	Silesian and Opole	Industrial activities, new jobs, regional development through corporate tax reliefs granted to businesses within the zone, industry clustering and development of dual education.	Operating	1996	350 industrial companies; 600 industrial projects; over 90,000 new jobs; over €7.3 billion of investments.
Żory	PL	Silesian	40 ha industrial park	Operating	1997	12 investors, over 2000 new jobs and €750,000 of annual income from property tax.
Industrial Park Schwarze Pumpe	DE	Brandenburg	Financial center of the region; focus on innovative energy investments.	Operating	1990s	125 companies established since 2013; 4,500 employees.

Project name	Country	Region	Description	Status	Year	Additional information
Frantisek Industrial Zone	CZ	Moravian -Silesian	Industrial park	Operating	2009	Houses 25 companies, employing more than 300 people.
Freiheit Emscher	DE	North Rhine - Westphalia	Model for the development of the former mining areas and the surrounding districts according to a holistic urban development.	In progress	2017	Feasibility study of the project started at the beginning of 2017
Science - Technology - Innovation						
Thor Park	BE	Limburg	Hotspot for smart and sustainable innovation with a focus on energy transition, smart manufacturing and smart cities.	Operating	-	93ha total surface, houses 40 organizations, more than 400 employees and 2000 daily visitors.
Mont-Cenis Academy	DE	North Rhine-Westphalia	Intelligent building; houses education academy, hotel, library, town hall and open spaces.	Operating	2019	-
Schwarzheide Chemistry Park	DE	Brandenburg	Industrial and commercial facilities; main production: polyurethane, technical plastics, foam materials, coatings, dispersions, carbon nanomaterials, agricultural chemicals.	Operating	2017	Houses more than 40 companies; a good example of cooperation between private companies and various universities.

Project name	Country	Region	Description	Status	Year	Additional information
Glasgow Geothermal Energy Research Field	UK	Scotland	Investigates the use of coal mine water for geothermal energy production; aims to become an international-class research field attracting leading scientists and engineers worldwide.	In progress	2017	€10 million fund as part of the UK Geoenergy Observatories Project.
Gelsenkirchen Science Park	DE	North Rhine -Westphalia	51 companies and research institutes housed, along with shops and municipal buildings.	Operating	1995	-
FAB-Lab Cottbus	DE	Brandenburg	Fabrication laboratory; offers room and technical equipment for small and larger technical projects; allows on-site technical exchange of knowledge and experience.	Operating - Extension of existing program	-	Estimated budget: €4.1 million
Unmanned aerial vehicle hub	PL	Silesian	Develops the drone market in the area of legislation, education, production and services.	In progress	2018	Estimated budget: €40 million
Min Gen Tech	DE	Various	Promotes innovations in the field of mining and energy industry; supports companies in bringing know-how and new technologies into new markets.	In progress	2017	Funded by the Federal Ministry for Economic Affairs and Energy.

7.1 Industrial Zones

Tatabanya case (Hungary)

Tatabanya is a city in the capital of Komárom-Esztergom County in northwestern Hungary. It was established as a socialist city in the 1940s to serve the coal mining activities in the region and it developed into a complex industrial center (the 7th largest in Hungary by the early 1960s) of heavy industries such as mining, energy, chemicals, metallurgy, machinery, and construction. When the coal mines started closing in the 1980s and 1990s, there was a need for development of new activities. Since the late 1990s, with support from the local government, which in 1996 established the Economic Development Organization to coordinate the settlement of new companies and plan the necessary developments, Tatabanya grew as a 'model city' of export-based industrial recovery. Companies were supported to create a one-stop shop to manage their affairs and the Industrial Park was constructed. Today, it is the largest public industrial park in the country[155].

Today, the local economy relies on engineering, the chemical industry, the production of medical instruments, electronics and environmental engineering (including R&D activities). Local leadership and institutional learning - among other factors- had a substantial role in the economic recovery that was promoted directly by local government through infrastructure schemes, industrial park development along with the rehabilitation of environmentally damaged areas, and efficient city marketing to support foreign direct investment and employment. The municipality took the responsibility for property management, city marketing and acted as a mediator between state administration, local agents and investors, while also coordinating vocational training in the city. The semi-private

College of Modern Business Studies (now, Edutus University) supported the municipality in institutional innovations. Recently, a new actor, owned and managed by a central governmental agency, has entered the local industrial property market cooperating with local institutions to channel private capital, EU cohesion funds and social capital to the creation of a new industrial park[156].

Katowice Special Economic Zone (Poland)

Katowice Special Economic Zone (KSEZ) was established in 1996 with the State Treasury and the local municipalities as its main stakeholders. KSEZ occupies an area of 2614 hectares, covering the whole of the Silesian Voivodship and six districts in the Opole Voivodship. It was granted the legal status of economic zone, which led to the creation of four subzones within KSEZ. The entire economic zone was mainly self-financed by the stakeholders. Through granting corporate tax reliefs to business operating within the zone, promoting industry clustering and supporting the development of dual education[157], KSEZ aims to support the growth in industrial activities, and hence promote regional development and the creation of new jobs.

Furthermore, enterprises in the Katowice Special Economic Zone have easier access in cooperation with the government, municipalities and business environment in general and benefit from the sale of land (both greenfield and brownfield), the revitalisation processes and the co-financing of infrastructure development[158]. KSEZ was recognized as the best free economic zone in Europe in 2015-2017 and in 2019 was recognized by FDI Business Financial Times[159] as the 2nd best such zone globally. Over 540 business entities are currently operating in the zone. So far, they have invested approximately €9.6 billion and created more than 90,000 new jobs in the region[160].

Żory (Poland)

The Zory economic zone was developed in an abandoned mining region. It covers an area of about 40 hectares, which has the advantage of being close to a highway. Zory was granted the legal status of an economic zone, identical to the one of the Katowice Special Economic Zone. A non-formal public-private partnership was established between local investors, the Katowice Special Economic Zone and the municipalities, leading to the first non-formal investor: LakmaStrefa in 1997. In 2018, Zory hosted 12 investors, had created over 2,000 new jobs and generated an annual income from property tax alone of €750,000[158].

Industrial Park Schwarze Pumpe (Germany)

The Schwarze Pumpe industrial complex, in the Lusatia lignite district, Spremberg, Brandenburg, Germany the industrial complex was founded in the 1950s and developed into a large-scale mining processing center. Lignite from the area's lignite mines was used primarily for generating electricity, but also for other uses (briquettes, pulverised lignite, high-temperature lignite cokes for steel industry and town gas). The restructuring of the industrial complex

began in the 1990s. In the period between 2013 and 2018, approximately 125 new companies employing about 4500 individuals have been established on the site of the former lignite processing and refining plant. Among the investments bringing in innovative projects to the area, is one of Enertag AG (Dauerthal), on the design of a regenerating storage power plant at Schwarze Pumpe in 2022, where greenhydrogen will be produced by renewable energy via electrolysis[161]. With such a momentum, the Schwarze Pumpe Industrial Park is becoming a financial and transition driving force for the region.

Frantisek Industrial Zone (Czechia)

In the municipality of Horní Suchá, Moravia-Silesia, Czech Republic, the Frantisek coal mine has been converted into an industrial park, housing 25 companies and employing more than 300 people[5] (2015 data). Once the mine closed in 1999 and the associated metallurgy activities declined, the local municipality wanted to address the severe unemployment issues created by developing, in its own territory, alternative business activities to be hosted in a new industrial park[162]. After the mine closed, in 2002, the state-owned Diamo company undertook demolition and construction works in order to create the industrial park. Ownership of the area was transferred to the municipality from the private coal mining company OKD in 2005 at the symbolic price of CZK1. Financing of the revitalization plan was secured by the country's Ministry of Finance, while resources from the EU Structural Funds were used for the reconstruction of buildings[163]. In 2009, the industrial zone was recognized as the "Brownfield of the Year 2009". Between 2002 and 2008 unemployment fell from 24% to 13% and between 500 and 1000 jobs were created in the park[164]. The original 14-hectare area has since expanded by the Asental Group, in collaboration with the municipality of Horní Suchá, adding 30 hectares of adjacent land to create the current František II development area[162].

Freiheit Emscher (Germany)

This Freiheit Emscher project is a holistic spatial planning and urban development zone, which was formed in the responses to the progressive coal mine closures connected to the restructuring of the coal industry in North Rhine-Westphalia, in Germany. The project aims to create a new urban center with commercial and modern industry, housing, green spaces and leisure activities on the water. It comprises 20 brownfield sites of the former mining areas and the surrounding districts, which were identified as most suited for development purposes. In particular, the plan covers a development area of 1,700 hectares, north and south of the Rhine-Herne Canal and the Emscher river, which is divided into five main development sites (150 hectares each), one central new quarter at the Rhein Herne Canal, a mobility concept comprising the "Eco Line", a new motorway junction and the Industry Boulevard, while also foreseeing cross linked green spaces and attractive waterfronts. The Freiheit Emscher project is the result of an inter-municipal cooperation between 17 municipalities, 4 districts, the State North Rhine-Westphalia and the private owner RAG and was established in 2008[165]. The feasibility study of the project started at the beginning of 2017 with funding from the state of North Rhine-Westphalia[166].

7.2 Science – Technology – Innovation

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Thor Park (Belgium)

Thor Park in Genk is a transformation project of the former coal mining site of Waterschei, one of the seven former coal mines in the 'Belgian Kempen' into a smart and sustainable innovation hotspot, focusing on energy transition, smart manufacturing and smart cities. Its development is driven by the Limburg Investment Company 'LRM', the city of Genk and the KU Leuven[167]. The Thor Park has a total surface of 93 hectares, it unifies several buildings of the city, hosting 40 organizations, more than 400 employees and 2,000 visitors on a daily basis. Thor Park gives access to the expertise and infrastructure of the various entities on site and also to financial resources (financial partners, R&D projects, public funding). It is a public domain that gives companies the space through the oPEN Thor Living Lab to test their technologies and carry out experiments on a real-life scale and showcase them. In addition, they can access the expertise and infrastructure of other companies and entities on site, through hubs such as EnergyVille, T2-campus, IncubaThor, FacThory and Thor Central. Indicatively, EnergyVille is a collaboration between the Belgian research partners KU Leuven, VITO, imec and UHasselt on sustainable energy and intelligent energy systems. It develops technology and knowledge to support public and private stakeholders in the transition to an energy efficient, decarbonized and sustainable urban environment[168]. Typical projects include deep geothermal usage of warm and cold water from the abandoned coal mines (Mine Water 2.0), smart districts, building-integrated photovoltaics, microgrids, multi-energy districts, and energy harbors[169].

Mont-Cenis Academy (Germany)

The former coal mine area of Herne Sodingen in North Rhine-Westphalia was transformed in 1999 in the education academy Mont-Cenis of the government of North Rhine-Westphalia[116]. It is a building of special architecture designed by Lyon architects Jourda and Perraudin. Apart from the academy the building houses a hotel, a library, a town hall and open spaces. It is an intelligent building that uses waste heat, stores warmth, and generates energy[170].

Schwarzheide Chemistry Park (Germany)

The chemistry park "Schwarzheide" is situated in the central area of the Lusatian Lignite District, between the cities Schwarzheide and Senftenberg in a former lignite-based refinery, which has been converted into a park of industrial and commercial facilities. It occupies an area of 246 hectares with 180 hectares of usable space for industrial and commercial facilities. More than 40 companies and 30 relevant service providers and partners are based in the industrial complex which belongs to the BASF Schwarzheide GmbH. The main production lines established include polyurethane, technical plastics, foam materials, coatings, dispersions, carbon nanomaterials and different agricultural chemicals. Among the companies based in the industrial complex are 11 manufacturing companies and service providers and partners[171]. Inaugurated in 2017, in 2018 alone BASF invested €149 million and planned further investments of over €150 million in 2019, creating more than 100 new industrial jobs. In addition, it pioneered the project-based cooperation between private companies and universities in Germany[172].

Glasgow Geothermal Energy Research Field (United Kingdom)

The Geothermal Energy Research Field in Glasgow, United Kingdom aims to become an international-class research field that attracts leading scientists and engineers worldwide to investigate the use of coal mine water for geothermal energy production. It was launched in 2017 and was funded with €10 million as part of the UK Geoenergy Observatories Project led by the Natural Resources Research Council (NERC) and the British Geological Survey (BGS)[5].

Gelsenkirchen Science Park (Germany)

The Gelsenkirchen Science Park opened on the site of a former coal-fired steel plant in the area of North Rhine-Westphalia in 1995[173]. Today it houses 51 companies and research institutes with 900 solar panels installed, which focus on energy technology, information and communication technology as well as health management. Science Park is one of the largest solar rooftop systems, and aims, apart from generating power, to demonstrate that the generation of solar power is possible in metropolitan areas without destroying large areas of land. The Park houses companies and research institutes, shops, as well

as municipal services (Department of Economic Development, History). The Institute of Labor and Technology at the Gelsenkirchen University of Applied Sciences is also based in the Science Park. Various commercial and non-commercial exhibitions and events are hosted throughout the year[174].

FAB-Lab Cottbus (Germany)

The FAB-Lab[175], which stands for fabrication laboratory, is a non-profit operated space established in 2014 in Cottbus. It belongs to the wider lignite area of Lusatia (Lausitz) and the former Cottbus-Nord opencast mine was converted into an artificial lake, called Cottbuser Ostsee, after its closure. The FAB-Lab Cottbus project is included in the actions to develop entrepreneurship in the former lignite areas. The FAB-Lab hosts workshops, and contains infrastructure and facilities for materials processing and prototype construction as a means to support local entrepreneurship. It is located in the Brandenburgische Technische Universität (BTU) campus in Cottbus with good technical equipment including a 3D plastic printer. The space and technical equipment are used by students as well as the local community and start-ups for their small and larger technical projects, thus also providing the opportunity for exchange of knowledge and expertise. The Brandenburgische Technische Universität Cottbus-Senftenberg and start-up companies are partners of the FAB-Lab Cottbus, while the State of Brandenburg and Saxony plans to finance the extension and professionalization of the FAB-Lab as a service provider and "academy" for the region with an additional €4.1 million[146].

Unmanned aerial vehicle hub (Poland)

This project aims at forming a testing zone for drones and unmanned aerial vehicles (UAVs) as well as at addressing issues of legislation, education, production and services in the Metropolis GZM (formally Górnośląsko-Zagłębiowska Metropolia) in the Silesian Voivodship in the Katowice region, in Poland. The Central-European Drone Demonstrator (CEDD) in the lignite region of Metropolis GZM is the result of the collaboration of the Metropolis GZM, the Civil Aviation Authority (ULC) and the Polish Air Navigation Services Agency (PAŻP). Drone applications to be tested include blood transport, fight against smog, infrastructure monitoring, education and others[143]. The Polish Development Fund (PFR), JSW Group, Hawk-e, Drone Radar and the Institute of Aviation have already declared their willingness to become partners of the project[176]. The consortium for this project was established in 2018 under the coordination of GZM Metropolis and its estimated budget is €40 million.

Min Gen Tech Project (Germany)

The Min Gen Tech network aims to promote innovation in the mining and energy industries and to support the companies in bringing their know-how and their technologies into new markets in the former lignite region of Lusatia[146].The Min GenTech network (Min-

ing & Generation Technology – Made in Germany), is an initiative of the Cottbus Chamber of Industry and Commerce (IHK Cottbus), the Brandenburg Economic Development Corporation (Wirtschaftsförderung Land Brandenburg GmbH, WFBB), the Dresden Chamber of Industry and Commerce (IHK Dresden) and the Saxony Economic Development Corporation (Wirtschaftsförderung Sachsen GmbH, WFS), funded by the Federal Ministry for Economic Affairs and Energy as part of the federal model project 'Unternehmen Revier' (Project Coal District).

155. Pangea (20.5.2015), “Bányászvárosok metamorfózisa”, https://bit.ly/3srT96s

156. Acore-Project, “Hungary- Case study 1: Tatabanya”, https://bit.ly/3yu1sT3

157. The dual education system refers to the combination of apprenticeships in a company and vocational education at a vocational school in one course. Companies usually bear part of the educational costs and benefit from the skills of the trained professionals.

158. Katowice Special Economic Zone (2018), “Post-industrial sites: Termination or determination?, Lessons from Poland”, Presentation at the 2nd Working Group Meeting of the Coal Regions in Transition Platform, https://bit.ly/3yyl4FI

159. fDi Magazine (2019), “Global Free Zones of the Year 2019”, https://bit.ly/3l1aWxq

160. Katowice Special Economic Zone, “About us”, https://bit.ly/3wgNtNX

161. Tracer H2020 (September 2019), “Fact Sheet: Industrial park “Schwarze Pumpe” Conversion of a lignite processing industrial site”, https://bit.ly/3N3RM5V

162. Asental Group, “František II”, https://bit.ly/3ypZYtb

163. Horní Suchá Oficiální stránky obce, “Industrial Zone Frantisek”, https://bit.ly/37zNGU7

164. Daniela Vojkovska et al. (2013), “Underused land, brownfields, future use and effects: Browntrans Project output”, https://bit.ly/3PfJHga

165. RAG (2018), “The Ruhr in Transition: Examples of a policy instrument and a current development project”, Presentation at the 3rd Working Group Meeting of the Coal Regions in Transition Platform, https://bit.ly/3M5BTMe

166. Freiheit Emscher, “Chance für die Region”, https://bit.ly/3FCSDrz

167. Thor Park, “Thor Park, access to the smart world of today and tomorrow”, https://bit.ly/3srQZng

168. EnergyVille, “Who we are & what we do”, https://bit.ly/38iD2kM

169. EnergyVille (2018), “EnergyVille in the center of the EU”, Presentation at the 1st Working Group Meeting of the Coal Regions in Transition Platform, https://bit.ly/3PfdPbC

170. European Garden Heritage Network, “Akademie Mont Cenis”, https://bit.ly/39blyH3

171. Specifically: Chemical Company, Air Liquide GmbH, Huntsman Pigments, SDC Materials GmbH, IQ Tec Germany, Petopur GmbH, Styrolution Schwarzheide GmbH, Zeppoil Schwarzheide GmbH, BASF Business Services GmbH, DHL, Remondis Industrie Service GmbH & Co. KG, BIS Arnold GmbH, Bilfinger HSG Facility-management GmbH, IMO Industrieservice, Rösberg Engineering, Waury Fördertechnik, Alfred Talke Logistic Services or Waggonwerk Brühl GmbH.

172. Tracer H2020 (September 2019), “Fact Sheet: Chemistry park “Schwarzheide” Conversion of a lignite-based refinery into a showcase for industrial transition”, https://bit.ly/3MkLAqp

173. Wissenschaftspark Gelsenkirchen, https://bit.ly/3N5q3ls

174. Science Park Gelsenkirchen, https://bit.ly/3wjonho

175. fablab-cottbus.de, “Eine offene Werkstatt für Cottbus und Umgebung”, https://bit.ly/3l0l2hZ

176. mpactCEE, “GZM Will Become The Testing Zone For The Emerging Drone Market”, https://bit.ly/39b8EsE

Epilogue

This review did not aim to exhaustively list projects, but rather highlight the potential for equitable and sustainable development in regions facing an unprecedented and urgent need to transform their entire economic and social structure. Although each case presented here was unique, it also contained elements and features that can prove to be useful for other regions as well. As a result, this review essentially constitutes a pool of examples, good practices and valuable experiences, from which the regions and interested investors can draw ideas, adapt and develop their design according to the special characteristics of each region. In this way, use of available resources will be improved and valuable time will be saved in the course of a truly Just Transition for Europe's coal regions.

Map of sustainable projects in coal regions

Legend

1. Renewable Energy
Wind energy
Solar energy
Geothermal energy
Small scale renewables

2. Energy storage
Thermal storage
Batteries
Pump-hydro energy storage
Hydrogen

3. Primary sector
Agricultural projects
Agrivoltaics

4. Tourism
Industrial heritage
Recreational Activities

5. Sustainable Mobility

6. Reskilling

7. Economic Zones – Innovation
Industrial Zones
Science – Technology – Innovation

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Zeche Zollverein (Germany, North Rhine-Westphalia)
Location: **Former coal mines in Ruhr area, on the site of the Zeche Zollverein coal mine**
Description: **Transformation of coal mines to cultural hub, hosting music concerts and festivals**
Status: **Operating**
Year: **2001**
Additional Information: **UNESCO World Heritage Site since 2001; more than 250,000 visitors per year.**

ETES - Energy Thermal Power Storage (Germany, Hamburg)
Location: **Hamburg-Altenwerder**
Description: **Volcanic rocks as storage medium**
Status: **In progress**
Year: **2019**
Additional Information: **Siemens-Gamesa; 100 MW discharge capacity by 2022; efficiency ~44%.**

Big Battery Lausitz (Germany, Lusatia, Brandenburg)
Location: **Schwarze Pumpe industrial park, Lusatian lignite district**
Description: **50 MW short-term storage battery system; 13 containers housing the batteries; 110x62 m2.**
Status: **Operating**
Year: **2020**
Additional Information: **€25 million; operated by LEAG.**

Klettwitz wind park complex (Germany, Brandenburg)
Location: **Former opencast Klettwitz lignite mine**
Description: **89 MW, 58 turbines (2019), in two sections of restored lands.**
Status: **Operating**
Year: **1999**
Additional Information: **497 ha; 120 jobs inconstruction phase; European Route of Industrial Heritage.**

Clean mobility (Czechia, Ústí nad Labem, Moravian-Silesian & Karlovy Vary)
Description: **Purchase of hydrogen buses, construction of hydrogen filling stations linked to existing hydrogen production facilities.**
Status: **Planning**
Year: **2020-2025**

Silvermines pump-hydro project (Ireland, Tipperary County)
Location: **Former opencast barite Silverimines mine**
Description: **360 MW**
Status: **Pre-development**
Year: **2022**
Additional Information: **€650 million; 400 jobs in construction jobs; 50 jobs in O&M; to start operation in 2029.**

Lusatia reference power plant (Germany, Brandenburg, Lusatia)
Location: **Schwarze Pumpe industrial park, Lusatian lignite district**
Description: **10 MW for electricity & transport applications**
Status: **Planning**
Year: **2022**
Additional Information: **€67 million; construction between 2023 and 2024, to start operation by 2025.**

Green to Households (Slovakia, Bratislava)
Location: **Bratislava self-governing region**
Description: **83 MW of small-scale PV, heat pumps, high efficiency devices, biomass boilers.**
Status: **Operating**
Year: **2015**
Additional Information: **€115 million; €45 million in 1st phase (2015-2018) from national funds & ERDF.**

Thor Park (Belgium, Limburg, Genk)
Location: **Former coal mining site of Waterschei**
Description: **Hotspot for smart and sustainable innovation with a focus on energy transition, smart manufacturing and smart cities.**
Status: **Operating**
Additional Information: **93 ha total surface, houses 40 organizations, more than 400 employees and 2000 daily visitors.**

Cooperative Training Program at Coal Sites (Germany, North Rhine-Westphalia)
Location: **Rhenish mining district**
Description: **Out-of-school training for young people**
Status: **Operating**
Year: **2008**
Additional Information: **Co-financing scheme: European Social Fund, governmental and non- governmental funds, and local budget.**

Tatabanya case (Hungary, Komárom-Esztergom)
Location: **Former industrial center of heavy industries (e.g. mining, energy, chemicals, metallurgy, machinery, constructions).**
Description: **The largest public industrial park in Hungary.**
Status: **Operating**
Year: **1990s**
Additional Information: **Local leadership and institutional learning playd a substantial role in economic recovery of the region.**

Lusatian Tourist Lakes (Germany, Brandenburg & Saxony)
Location: **Former coal mines in Lusatian lignite district**
Description: **24 artificial lakes in Lusatia by flooding old coal mines. Activities: leisure, sports, marinas, beaches, hotels, campsites, restaurants and theaters, tour guides at industrial heritage site**
Status: **Operating**
Year: **2000**
Additional Information: **€7.3 million: Federal Ministry for Economic Affairs and Energy, the Free State of Saxony and the Federal State of Brandenburg; €1.23 billion for landscape restoration and engineering until 2022.**

Kozani solar park (Greece,Western Macedonia, Kozani)
Location: **Wider area of retired Kardia lignite-fired power plant**
Description: **204.3 MW (509.000 PV panels), covering the needs of 75,000 households.**
Status: **Operating**
Year: **2022**
Additional Information: **438 ha; €130 million; 350 jobs in construction phase.**

Puertollano case (Spain, Castile-La Mancha, Ciudad Real)
Location: **Former opencast coal mine in Puertollano**
Description: **908 ha have returned to agricultural and livestock use after their restoration.**
Status: **Operating**
Year: **2016**
Additional Information: **28,000 olive trees, 250,000 kg of olives annually.**

Pozo Barredo geothermal project (Spain, Asturias, Mieres)
Location: **Former underground Pozo Barredo coal mines**
Description: **6 MW in abandoned flooded coal mines used for heating and cooling various types of buildings.**
Status: **Operating**
Year: **2019**
Additional Information: **Two phases (4 MW in 2016 and 2 MW in 2019); €3 million (€500,000 from ERDF)**

Ermakia project (Greece, Western Macedonia, Ptolemaida)
Location: **Eordaia**
Description: **Combination of farming with electricity production**
Status: **Permitting**
Year: **2022**
Additional Information: **80 MW PV on a 125.8 ha plot of land in combination with grazing activities.**

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