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Post-mining land uses in Germany: transforming mine and quarry sites into assets

Bernd Lottermoser [a,*]

[a] *Institute of Mineral Resources Engineering, RWTH Aachen University, Germany*

Abstract

Germany has a long-standing tradition of repurposing mine and quarry sites, with community efforts to rehabilitate mined land and spoil heaps for parkland dating back to the early 1800s. The objective of this study is to report on post-mining land uses of mine and quarry sites in Germany. To identify such transformation outcomes, co-word and keyword literature searches were applied, coupled with site visits to selected locations. Based on such an analysis, there are > 800 repurposed mine and quarry sites in Germany (605 closed historic and 201 currently operating mines and quarries). Many of the closed historic mine and quarry sites are used for cultural and heritage purposes (e.g. museums and heritage trails, 38%). Others have been repurposed for new infrastructures (e.g. science and technology [S&T] parks, 17%), leisure activities (e.g. concert halls and art exhibitions, 14%) and mining landscapes (11%). Less common repurposing (< 5%) is for forestry and agricultural uses and sports venues, followed by new natural habitats, renewable energy production, wildlife conservation, medicinal and therapy treatment, food production and catering, education and research, as well as waste disposal and storage. At these historic repurposed mine and quarry sites, non-profit organisations predominantly look after cultural and heritage venues, whereas > 120 for-profit companies pursue manufacturing activities. By contrast, at operating mines and quarries, the dominant repurposing has shifted to wildlife conservation (18%) and renewable energy production (15%). Evidently, in Germany there has been effective transformation of > 800 mines and quarries to innovative and beneficial post-mining land and infrastructure uses. The documented transformations offer transferable insights for mining-dependent economies, emphasising an appropriate regulatory regime, sufficient financial resourcing, early engagement of stakeholders and timely planning of integrated post-mining land uses to achieve sustainable repurposing of mines and quarries.

Keywords: *transformation, repurposing, post-mining, land use, Germany*

1 Introduction

1.1 Background and study aim

The repurposing of mine and quarry sites transforms former industrial land into productive, sustainable assets, moving beyond traditional closure rehabilitation methods like ecosystem restoration to provide long-term environmental, social and economic benefits to local communities. In fact, closed mines and quarries are increasingly transformed into novel post-mining land uses for agriculture, tourism, renewable energy, cultural places, preservation of heritage sites or industrial innovation (Whitbread-Abrutat 2024; Whitbread-Abrutat & Lowe 2024). This repurposing approach, often initiated through progressive transformation during the mine's operation, turns environmental liabilities into community resources, fostering a sustainable transition for mining regions, stimulating new local economies, generating employment opportunities and fostering community resilience. Successful projects like the Eden Project

* Corresponding author. Email address: Lottermoser@mre.rwth-aachen.de

(Pearman 2009) demonstrate that creative planning can also turn abandoned mines and quarries into new vibrant opportunities.

Germany is renowned for its massive efforts to repurpose its former lignite and uranium mines. Upon reunification of East and West Germany in 1990, federal and state governments inherited a legacy of industrial and military contamination from the former German Democratic Republic (GDR). Decades of prioritising production over environmental protection, particularly in the chemical, mining and energy sectors, left behind severe soil and groundwater pollution, often referred to as “hazardous landscapes” or “hazardscapes” (Corson 1999). Following 1990, 25 to 30 major open cast lignite mines in eastern Germany were closed and over 1,000 km² of land was rehabilitated and repurposed, transforming industrial “moonscapes” into recreational lakes, forests, vineyards, cultural places, tourist attractions and renewable energy sites (LMBV 2023). Also, the Wismut uranium mines in Saxony and Thuringia, formerly operated by the Soviet-German Wismut GmbH, were closed after 1990 and required extensive rehabilitation.

Despite these transformation successes, a comprehensive database of all closed and transformed German mine and quarry sites is still missing. The objective of this study is to report on successful post-mining land uses in Germany in their entirety, based on a comprehensive analysis of reported transformation outcomes. By providing such information, the study aids in offering insights to achieve effective post-mining transitions of mining-dependent economies, emphasising an appropriate regulatory and planning regime, sufficient financial resourcing, early engagement of local stakeholders and timely development of integrated post-mining land use planning to achieve benefits for local communities in the long term.

2 Data acquisition and methodology

To identify transformation outcomes of closed mines in Germany, co-word and keyword searches were applied to the World Wide Web and bibliographic databases. Sites associated with mining activities, such as metallurgical plants, saltworks, brick factories and coal-processing places, were excluded from the search. Transformed mine and quarry sites were searched for on a state-by-state basis and relevant information was documented in Excel files. This included: the original name of the mine; the location (state and town); its GPS coordinates and Google Maps location; the raw materials extracted; whether it was a surface mine or underground operation; its webpage; its present use; its economic use; newly established business activities; NACE Code 2025 (Nomenclature statistique des activités économiques dans la Communauté européenne, which is the European Union’s (EU) standard classification system for categorising companies according to their economic sector; European Commission 2026). Site visits were conducted to selected locations that demonstrate early site transformations achieved in the 19th century and multiple post-mining land uses.

Individual sites were then categorised according to their current use and transformation, i.e. cultural and heritage purposes (e.g. museums, heritage trails); infrastructure (e.g. science and technology [S&T] parks); mining landscapes as well as new landscapes (e.g. parklands, lakes, nature conservation, wilderness areas); leisure activities (e.g. concert halls, art exhibitions); sports venues; forestry and agricultural uses; wildlife conservation; renewable energy production; medicinal and therapy treatment; food production and catering; education and research; waste disposal and storage; and water management. Sites were classified according to their dominant new land use (e.g. forestry), even when other and multiple uses were obvious (e.g. forestry plus water management). As this approach was limited to documenting transformed sites identified via web-based and bibliographic sources, the resulting database represents a conservative, minimum count of repurposed mine and quarry sites in Germany, with the true figure likely being higher.

3 The German mining sector

3.1 Mining activities

Germany has a long tradition in the extraction and processing of raw materials, with industrial-scale mining being traced back to Neolithic times. Mining has evolved over millennia, starting with Stone Age flint extraction and progressing through Roman metal mining and stone quarrying, medieval silver and metal booms, industrial-scale salt and coal mining, and managing closed uranium, lignite and coal mine sites.

Germany is a leading industrial nation and therefore one of the major consumers of energy and mineral raw materials. Germany's supply of mineral raw materials is based on imports of mineral resources, domestic mining and circular economy products for selected raw materials. Globally, Germany is rich in mineral resources and an important mining country, with around 2,700 individual mine and quarry sites (BMWi 2021). In particular, building raw materials (sand and gravel, broken natural stone, limestone and marl) as well as various industrial minerals (especially rock salt, potash and quartz sand/gravel) are extracted from local deposits. At the same time, Germany is poor in some mineral resources because meeting demand for metals, individual industrial minerals and fossil fuels is very heavily or completely dependent on imports. This import dependency is only partially reduced through the recycling of metals (e.g. 46% crude steel, 41% copper, 62% lead, 72% aluminium) (BGR 2025). However, recycling quotas are not enough by far to replace domestic mining or the import of raw materials. In 2024 the domestic production of mineral and energy raw materials was valued at EUR 14 billion (BGR 2025). The output comprised roughly 475 Mt of industrial minerals and construction materials, 91.9 Mt of lignite, 1.6 Mt of crude oil, 4,700 Mm^3 of natural gas and associated petroleum gas, and 3.1 Mm^3 of peat (BGR 2025). By both volume and value, sands and gravels were the most important raw materials, representing well over one-third of total domestic production, with an exploitable amount of about 211 Mt. In terms of sheer volume, the second-largest domestic raw material was crushed natural stone (167 Mt), followed by lignite (91.9 Mt). Production of rock salt and industrial brine, as well as potassium and magnesium salts (18 Mt), was also notable (BGR 2025). In 2024 Germany was Europe's largest producer of lignite, kaolinite, rock salt and potash (BGR 2025). Among the raw materials that the EU designates as critical, Germany extracts fluorspar, baryte, feldspar, graphite, coarse-grained quartz and quartz gravel (BGR 2025). Currently, the primary focus of exploration in Germany is on lithium and copper. Altogether, around 150 projects that could secure future domestic supplies of raw materials for German industry are underway in the country (BGR 2025).

3.2 Environmental impacts of mining

Mining and quarrying interfere with the environment. However, active mining in Germany in its various forms causes only small overall environmental pressures, based on data from the Federal Statistical Office of Germany (Lottermoser 2023). This assessment is attributed to restricted land-use footprints, managed waste production, controlled water consumption, and limited particulate matter and greenhouse gas emissions (Lottermoser 2023). For example, the area required by German mining (mining operations, open cast mines, pits, quarries) is only a fraction of the entire land area (2024: 1,277 km^2, approximately 0.357%) (BGR 2025). This is a tiny fraction compared to the vast tracts of land used for agriculture (50%) and forestry (30%) (Destatis 2026). Mine-disturbed sites, on the other hand, are areas of temporary land use because closed and former mine and quarry sites become once again available for subsequent uses. Therefore, the area of currently disturbed land in Germany calculated annually by the Federal Statistical Office of Germany does not increase any further. In fact, it has been declining continuously for decades (1992: 1,878 km^2; 2000: 1,796 km^2; 2010: 1,623 km^2; 2021: 1,407 km^2; 2024: 1,277 km^2) (Lottermoser 2023; BGR 2025).

3.3 Statutory framework for mining, mine closure and mine transformation

Mineral raw materials are extracted in Germany under strict regulations and in compliance with high environmental and social standards. The extraction of mineral resources in Germany is governed by the relevant federal framework legislation and state laws. The exploration and extraction of all mineral resources not subject to mining rights are governed by the *Federal Mining Act* (BBergG 1980) (LMBV 2023). These include, for example, petroleum, natural gas, coal, metal ores, water-soluble salts, most industrial minerals, all marine mineral resources and all mineral resources extracted underground. The responsible licensing and supervisory authorities under the Federal Mining Act are the mining authorities in the individual federal states. The extraction of raw materials, which is not subject to the Federal Mining Act, is regulated by state laws, e.g. the *Mining Act* (in North Rhine-Westphalia and Bavaria) as well as the *Federal Nature Conservation*

Act (BNatSchG), the *Federal Immission Control Act* (BImSchG), the *Federal Soil Protection Act* (BBodSchG) and corresponding state soil protection laws (LBodSchG) (LMBV 2023). Relevant mineral resources include anhydrite and gypsum rock, pumice, limestone and other natural stones, gravel and sand, as well as peat. The Federal Mining Act came into force in 1982 and replaced the previous mining laws created and enforced by the individual states. Nowadays, the abovementioned federal and state laws also regulate site closure and rehabilitation as well as the repurposing of mines and quarries. According to German mining law, the operator of a mine or quarry is, in general, responsible for the remediation of hazards to both people and the environment (i.e. polluter pays principle). Moreover, the Federal Mining Act (BBergG) requires operators to design and get approval for a closure plan whereby "*the surface of the area used by the terminated operations is restored*" (BBerg §55(2)2.).

4 Results

4.1 Transformation of historic mines and quarries

In Germany, the effective transformation of closed mine and quarry sites to beneficial, innovative and productive post-mining land and infrastructure uses goes back at least 220 years. Near Aachen, for example, flint mining of the Lousberg hill likely started around 32,000 years before present and was then pursued on an industrial scale during Neolithic times (5,800 to 5,300 years ago), producing over 300,000 axe blades. Such large-scale mining also involved an early form of mountaintop removal and strip mining (Schyle 2006). Quarrying of the mountain ridge for limestone and sand continued during Roman times and the Middle Ages. The surface mining practices led to severe landscape modification, deforestation and ecological destruction of the hill (Figure 1a). During the Middle Ages, the barren quarry site served a variety of roles: as a venue for local festivals featuring illuminations, music and fireworks; as a strategic military position for bombarding the city; as a refuge during the city's fire in 1656; and, up until the early 19th century, as a sheep pasture and mass grave for thousands of French soldiers (Terhart 1988). At that time, the site was covered in 4 to 5 m-tall waste rock piles and lacked any trees or shrubs. In the late 18th century, French troops occupied the city of Aachen, which then became part of the French Republic. In 1804 Napoleon I ordered the beautification of occupied German cities and, in 1807, efforts began to transform Lousberg hill (Terhart 1988). With the support of the French governor of Aachen (Alexandre de Lameth), local citizens initiated the regreening of the barren hill by creating an association, a citizens' 'Committee of embellishments', whose purpose was to promote tourism, raise funds and oversee the Lousberg transformation. In 1807 the Aachen city council voted to rehabilitate the site. The initial site rehabilitation was financed through a substantial donation from Napoleon I, private donations and the city's tax income from the local casino. Following the defeat of Napoleon I in 1815, Aachen was transferred to the Kingdom of Prussia, and a German landscape architect (Maximilian Weyhe) drew up detailed plans for the development of a parkland. The local municipality led the environmental restoration project. The initiative involved importing 36,000 t of soil and earth, planting 25,000 selected trees, and building roads, tracks, trails, pavilions and a restaurant/casino (Terhart 1988). Early efforts focused on the construction of an English landscape garden. Consequently, one of the first landscape public parks in Europe was established by 1818 (Figure 1b). Today, Lousberg remains a substantial recreational wooded parkland and protected industrial heritage site, while also hosting modern infrastructure for drinking water storage. Lousberg park in Aachen may be one of the first examples of how citizens can initiate the transformation of mined land into valuable community assets.

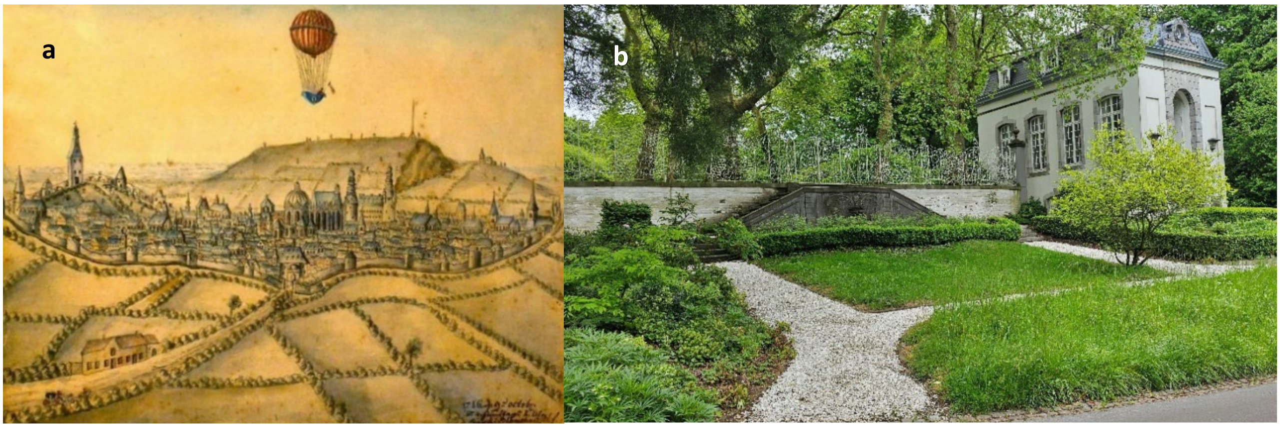

Figure 1 (a) A 1786 sketch of Aachen, North Rhine-Westphalia, featuring the mined, barren Lousberg hill in the distance; (b) Present-day view of the Lousberg hill, where reforestation, pioneered by local citizens, established one of Europe's first public parks in 1818

In the early 1900s, even larger-scale reforestation of waste heaps and mined out areas disturbed by open cast lignite mining was pursued in eastern Germany. Here, gardeners looked after mining settlements; professionals ('Kippenförster', or forest rangers of waste heaps) had to design and plan post-mining landscapes and were responsible for the reforestation of spoil heaps; and groups of workers planted saplings on waste dumps and barren areas (Meyer 2019; Knoche 2021). These reclamation procedures and their successes have been documented in some detail in the early mine site rehabilitation literature (Heusohn 1929).

Since the early 20th century, emphasis was also placed on the transformation of some closed historic mine and quarry sites to serve cultural and heritage roles. Since the 1920s there have been a number of mines and quarries that operated solely as educational and historic attractions for the German public. Consequently, today there are at least 170 historic mines and quarries in Germany, featuring walking trails, viewing areas, museums, heritage displays and guided mine tours, honouring the nation's industrial heritage (BGR 2017).

Until the 1960s the reuse of mine and quarry sites received little interest in Germany. Most of the aforementioned federal laws did not exist yet and the sole focus was the extraction of mineral raw materials for the reconstruction of a Germany devastated from World War II (BGR 2022). Mined-out quarries, gravel pits, underground workings and open pits were commonly abandoned or filled with construction debris or waste. However, in the 1960s and 1970s the growing environmental movement and general interest in the environment, including the consequences of raw material extraction, changed the perception of the mining industry. In the 1970s and 1980s the recultivation of former quarries and open pit lignite mines initially took place primarily by backfilling with overburden from subsequent open cast mining operations (UBA 2016). Also, closed open cast mines were recultivated using hydraulic engineering methods, resulting in pit lakes which were included in larger nature conservation areas.

For example, the Zukunft open cast mine produced 530 Mt of lignite between 1910 and 1987 (Blaustein-See 2026). However, this industrial activity profoundly altered the landscape and local communities, necessitating the relocation of villages. Following the closure of the lignite mine in 1987, the site underwent extensive reclamation and flooding, transforming into the Blaustein-See (Blue Stone Lake). Today this area serves as a recreational hub for hiking, water sports and culture – a powerful symbol of post-mining landscape transformation and ecological renewal (Figure 2).

Figure 2 View of the flooded and repurposed Zukunft lignite mine, North Rhine-Westphalia. The former open pit is now an approximately 100-hectare and up to 46 metres-deep artificial lake and recreational hub

The challenge of achieving beneficial post-mining land uses became of national significance upon German reunification in 1990. At that time, the mining sector in East Germany underwent a massive transformation, characterised by the immediate closure of unprofitable open cast lignite mines, the shutdown of all uranium mining, and a colossal environmental remediation and transformation effort of the former mine sites. To this date, rehabilitation and transformation of mining sites in the former GDR has been an extensive, decades-long process funded largely by the German federal and state governments, with costs for lignite remediation reaching over EUR 9.2 billion and uranium mine remediation EUR 6.4 billion (Harfst & Wirth 2011). These successful transformations of renowned locations have already been described in depth by numerous authors (e.g. Lersow & Schmidt 2006; Deshaies 2020; Schleußner & Mühlig 2025).

At the same time, mining companies discovered that animal and plant species found high-quality refuges in former as well as active mine and quarry sites (BGR 2022). Individual scientists and non-governmental nature conservation authorities had already realised decades before that almost every raw material extraction project is associated with environmental impacts but also offers considerable benefits for nature and the environment, especially in the context of post-use planning. This realisation has been particularly emphasised by the Nature and Biodiversity Conservation Union (Naturschutzbund Deutschland e. V. = NABU), which is Germany's oldest (founded in 1899) and largest environmental association (BGR 2022).

These historic mines and quarries are made accessible with great enthusiasm and dedication, often through volunteer work programs. The repurposing of mines and quarries is commonly initiated by grassroot volunteer movements of local citizens and young students/people as well as local governments and municipalities (e.g. EC 2025). In addition, over the last few decades these cultural and heritage sites have become embedded in geotourism regions, which have a strong focus on geology, historic mining practices, mining museums, technical monuments, trails and geoparks. Two major mining regions (Harz and Erzgebirge /Krušnohoří) date back to the Middles Ages and are UNESCO World Heritage Site-listed. The cultural and tourism significance has also been realised in the naming of hiking trails, cycle pathways, public roads and highways after waste materials and raw materials (e.g. Europe's Amber Road, Germany's Salt Road, Saarland's Waste Heap Trail [Saarländischer Haldenrundweg], Saxony's Silver Road, Bavaria's Ore Trail and Glass Road, Thuringia's Porcelain Road). The Rammelsberg mine is one of the high-profile examples of historic mines that have become major cultural heritage sites, nestled within a dense network of historic mining sites and industrial landscapes (Figure 3).

Figure 3 The historic Rammelsberg copper, lead, zinc, silver and gold mine operated for over 1,000 years (968 to 1988). It became a UNESCO World Heritage Site in 1992, and now attracts over 100,000 visitors per year

Today most transformed historic mines were originally coal mines (Figure 4), with metal (iron ore, base and precious metals) and industrial mineral operations the next most common mines (Table 1). Most historic mines, particularly underground mines, have found a new life as a cultural and heritage venue (e.g. museums, geoparks, heritage trails; Table 2, 38%). Others have been repurposed to serve as new infrastructures (e.g. S&T parks, 17%), leisure sites (e.g. concert halls, art exhibitions, 14%), and mining landscapes (11%) (Table 2). Less common repurposing (< 5%) is for forestry and agricultural uses and as a sports venue, followed by new habitats, renewable energy production, wildlife conservation, medicinal and therapy treatment, food production and catering, education and research, as well as waste disposal and storage (Table 2).

Underground mines are more often used for cultural and heritage purposes, new infrastructure, wildlife conservation, waste disposal and storage, medicinal and therapy treatment, food production, education and research (Table 2). By comparison, surface mines have predominantly been transformed to serve as new entertainment and leisure venues, mining landscapes, and agricultural and forestry uses (Figure 5; Dilly et al. 2007). At these repurposed mine and quarry sites, non-profit organisations predominantly look after cultural and heritage venues, whereas at least 120 different for-profit companies pursue new manufacturing activities (NACE codes: C13-C32, EC 2026).

Repurposing is also pursued to engage with the public and relevant stakeholders. For example, the German potash and rock salt mining companies K+S and GSES do not only produce mineral products; they also use their underground workings as repositories for municipal and industrial wastes. In addition, at their non-producing, shut-down mine sites, they offer tube slides, adventure courses and underground boat trips, and organise underground concerts, marathons and mountain bike tours.

Table 1 Transformed historic mines and quarries in Germany, listed by extracted resource

Previously mined resource	Number of transformed mines and quarries (n = 605)
Hard coal	167
Lignite	162
Metals	97
Iron	55
Sand and gravel	41
Natural stone (basalt, granite, sandstone etc.)	22
Limestone, marble, chalk	18
Salt	13
Clay	8
Uranium	8
Fluorite, baryte	8
Gypsum	2
Manganese	2
Opal, jasper, amethyst, agate	1
Graphite	1

Table 2 Transformations of historic mines and quarries in Germany, listed by category

Transformation category	All (n = 605)	Underground (n = 394)	Surface (n = 211)
Culture and heritage purposes	227	220	7
New infrastructure	103	95	8
Entertainment and leisure activities	83	18	65
Mining landscapes	68	10	58
Agricultural and forestry uses	34	0	34
Sports venues	32	17	15
New natural habitats	25	5	20
Renewable energy production	8	4	4
Wildlife conservation	7	7	0
Medicinal and therapy treatment	6	6	0
Food production and catering	5	5	0
Education and research	4	4	0
Waste disposal and storage	3	3	0

Figure 4 View from a coal spoil heap towards other revegetated coal waste dumps in the distance (Carl-Alexander waste dump, North Rhine-Westphalia). There are over 300 spoil heaps and landscape structures in North Rhine-Westphalia. Today, all sites have been closed and repurposed, and many of these landscapes now offer nature trails, magnificent views and landmark art on the summits of revegetated hills in the middle of the largest metropolitan region in Europe

Figure 5 The Wolkenberg vineyard (foreground) is established on the recultivated landscape of a former lignite open pit mine (Welzow Süd lignite mine, Brandenburg). The operating open pit is visible in the upper left-hand corner

4.2 Transformation of operating mines and quarries

A proactive approach of repurposing can be initiated through progressive, phased transformation while the mine is still operational. Currently in Germany, many operating mines, documenting their transformation activities, represent sand and gravel quarries, lignite pits and industrial mineral operations (Table 3). Surface-quarries, in particular, will be repurposed to serve wildlife conservation (18%), renewable energy production (15%), water management (13%), leisure activities (13%), the establishment of new natural habitats (8%), cultural and heritage purposes (8%), and agricultural and forestry uses (8%) (Table 4). The number of operating surface mines and quarries exceed the number of underground operations, principally because there are few underground mines currently active in Germany. Evidently, the repurposing of modern mines and quarries has now shifted to wildlife conservation and renewable energy production (Table 4). By contrast, it has become less common to reuse modern mine and quarry sites for cultural and heritage purposes (8%, Table 4) compared to historic mine sites (38%, Table 2). Temporary repurposing of sites is also pursued. For example, the German quarry company Mitteldeutsche Hartstein-Industrie AG not only produces mineral aggregates but also allows the use of its large basalt quarry for an international trade fair dedicated to the interactive demonstration of equipment used in the raw and construction materials industry (Figure 6).

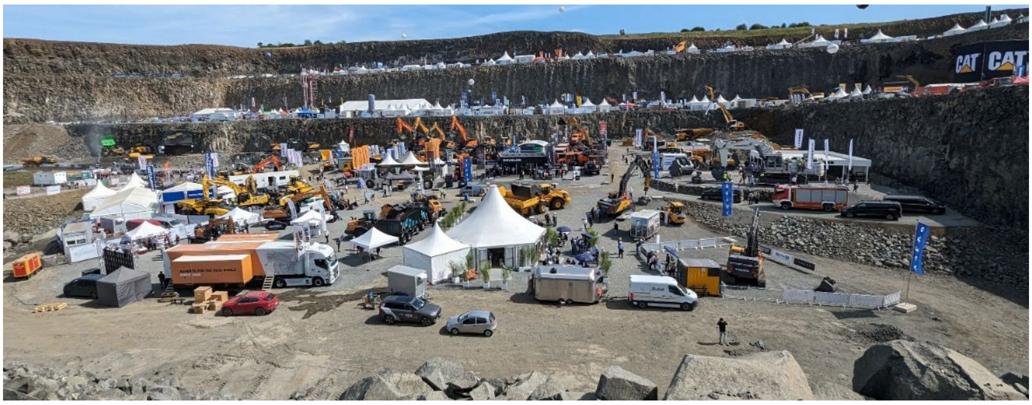

Figure 6 Europe's biggest basalt quarry, Hochberg, Nieder-Ofleiden is temporarily repurposed as a trade fair attracting > 300 exhibitors and hosting > 60,000 visitors experiencing mining and construction equipment in action

Table 3 Operating mines and quarries in Germany with planned transformations, listed according to the extracted resource

Mined resource	Number of operating mines and quarries (n = 201)
Sand and gravel	101
Lignite	48
Limestone, marble, chalk	17
Natural stone (basalt, granite, sandstone etc)	13
Quartz sand and gravel	9
Salt	8
Clay	3
Baryte, fluorite	1
Graphite	1

Table 4 Planned transformations of operating mines and quarries in Germany, listed by category

Transformation category	All (n = 201)	Underground (n = 10)	Surface (n = 191)
Wildlife conservation	37	0	37
Renewable energy production	30	0	30
Water management	26	0	26
Entertainment and leisure activities	26	0	26
New natural habitats	17	0	17
Culture and heritage purposes	17	5	12
Agricultural and forestry uses	16	0	16
Sports venues	14	0	14
Nature conservation	8	0	8
Education and research	5	0	5
Waste disposal and storage	4	4	0
New infrastructure	1	1	0

5 Discussion

Comprehensive databases on post-mining land uses remain scarce, with the literature dominated by individual case studies rather than broad overviews. While Keenan & Holcombe (2021) provide a notable exception with a database of 313 global cases, their tally likely underestimates the true scale of activity. This is highlighted by the discrepancy between their global figures and the > 800 individual sites identified by this study in Germany alone. This suggests that the actual number of global post-mining developments is likely in the thousands. The current study also demonstrates a shift in dominant post-mining land uses in Germany over time, from cultural and heritage purposes (Table 2) to wildlife conservation and renewable energy production categories (Table 4). Taking into account the relatively long lead times for new forms of land use to become established, it is likely that there will be further changes in future.

German post-mining success stories highlight that initiating redevelopment requires strong local stakeholder interests, clear aspirations and realistic planning. The enabling condition behind this success of transforming mines and quarries to new purposes appears to be the combination of the following factors ('the golden rules for mine and quarry transformation'):

1. define realistic post-mining land use plan. Planning of post-mining land uses and their possible economic or non-economic activities needs to consider the value to and aspirations of local stakeholders. Moreover, the post-mining value of a former mine site is driven by the real estate mantra 'location, location, location'. While initial challenges like contaminated land or removal of mining equipment and infrastructure can be overcome, post-mining developments remain inherently constrained by their location
2. have local participation. An early, inclusive dialogue of governments with local communities, non-government organisations and planners is considered a key success factor in transforming mine sites into vibrant community assets. For example, in the early 1800s the reforestation of the Lousberg hill mined land was driven by local citizens and open government community partnerships (Figure 1). Similarly, in the late 1990s, a grassroots movement by local citizens and young students laid the foundation for the Golpa-Nord lignite mine to become the renowned Ferropolis cultural centre for music festivals (EC 2025). Many historic mines and transformed sites are operated and made accessible with great enthusiasm and dedication through volunteers
3. pursue laws and regulations flexibly. Compliance with the German Federal Mining Act (BBergG 1980) is crucial and it stipulates that operators must design and receive approval for a closure plan whereby "*the surface of the area used by the terminated operations is restored*". This broad definition and a flexible interpretation of laws by the regulator allow for innovative post-mining land uses
4. ensure sufficient financial resources. Today's repurposing projects are supported by a mix of EU, federal, state, industry and private funding. For example, the RAG-Stiftung (RAG Foundation) was established by the former mine owners in 2007 with a massive portfolio (approximately EUR 17 to 18 billion) to manage and fund perpetual obligations of all closed hard coal mines – such as pit water management and subsidence repair – ensuring environmental safety long after mining ceases
5. follow high nature conservation/environmental standards. Mine rehabilitation in Germany involves both industrial stakeholders and NGOs, collaborating on sustainable raw material use and biodiversity preservation (BGR 2022). As a result, some rehabilitation activities and biodiversity enhancements have achieved world-class recognition (Figure 7). To support industry in its conservation efforts, best practice guidelines for the management and monitoring of biodiversity at mine and quarry sites have been established (Marken et al. 2025)
6. use relevant science and engineering. Mining and quarrying operations require best practice guidelines and industry handbooks to engage with possible transformation scenarios. For example, Germany aims to achieve net greenhouse gas neutrality by 2045, and a key element in achieving this goal is the large-scale expansion of photovoltaic (PV) systems (Figure 8). To accelerate the

deployment of PV capacity it is crucial to tap into previously unused land. Many mines and quarries have unused areas such as floors, slopes, conveyor belts, spoil heaps and lakes that are suitable for installing ground-mounted, floating or customised PV systems. However, significant hurdles at federal, state and municipal levels in approval procedures complicate the planning and installation of ground-mounted systems on sites. As a result, uncertainty and hesitation are common among companies, and the expansion has been slow. Recent industry guidelines and handbooks for the integration of PV systems should help to unlock more land for solar power generation and actively advance the repurposing of mined land (e.g. Lassen et al. 2025).

Figure 7 View of an active lignite open pit mine (Inden, North Rhine-Westphalia). In the distance a large artificial hill (16 km^2, 200 m tall), the so-called Sophienhöhe, is created by the disposal of 1,100 Mt spoil from the Hambach lignite mine. The mine opened in 1978, and the first tree was planted the same year. Since then, much of the spoil hill has been forested with 10 million trees, and the entire hill has become a recreational area with a > 120 km-long network of hiking trails. Such recultivation gained international recognition and was awarded in 2020 as part of the United Nations Decade on Biological Diversity

Figure 8 Solar park on a quartz sand-producing quarry (Nivelsteiner Sandwerke, North Rhine-Westphalia). The solar park currently produces renewable energy for around 5,000 homes nearby. The concept is to be expanded to include floating photovoltaic systems, wind turbines, batteries, combined heat and power plants, gas and steam power plants, and heat and hydrogen storage facilities to provide renewable energy to 50,000 people by 2030

6 Conclusion

Germany has a long-standing tradition of repurposing mine and quarry sites, with community efforts to rehabilitate mine waste heaps for parkland dating back to the early 1800s. These early initiatives focused on beautification and ecological restoration. Today over 800 mines and quarries have been or are in the process of being transformed into innovative, beneficial post-mining land uses and infrastructure projects. The enabling condition behind this success is early, active local community engagement as well as timely post-mining land use planning, an appropriately flexible regulatory regime, sufficient financial resourcing and high environmental standards. Such an approach ensures that post-mining land uses are sustainable and beneficial to local communities in the long term.

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