

Sustainable Transformation of Post-Mining Quarry Landscapes into Recreational and Tourism Destinations: A Conceptual Framework for Regional Development and Green Entrepreneurship

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Abstract

The revitalisation of post-mining landscapes represents a critical challenge for environmental sustainability, regional development, and the transition of post-industrial territories. Abandoned quarries, although often environmentally degraded, offer significant potential for adaptive reuse as recreational and tourism-oriented spaces. This study aims to analyse the possibilities for the sustainable transformation of post-mining quarries and to evaluate their potential for regional development and green entrepreneurship. The research combines a systematic literature review, a comparative analysis of international and Slovak case studies, and a multidimensional evaluation framework that integrates environmental, technical, socio-economic, and entrepreneurial factors. A site assessment was conducted using a set of criteria (K1–K9) to identify differences in transformation potential. The results reveal substantial disparities between international and Slovak sites. While international examples demonstrate advanced infrastructure and strong integration of entrepreneurial activities, Slovak sites show lower levels of planning and limited business development. This mismatch highlights an “implementation gap” in post-mining landscape transformation. The study identifies three transformation models and emphasises green entrepreneurship as a key driver of sustainable development. The proposed framework supports decision-making and provides a basis for future research on quantitative modelling and innovative entrepreneurial strategies.

Keywords

post-mining landscapes, quarry revitalisation, sustainable tourism, regional development, green entrepreneurship



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Introduction

Surface mining is one of the key methods of mineral resource extraction; however, it also leaves significant anthropogenic impacts on the landscape, including abandoned mining structures and degraded areas. These disturbances lead to biodiversity loss, habitat fragmentation, and disruption of hydrological regimes, resulting in long-term environmental and socio-economic consequences. Therefore, it is essential to address the subsequent use of post-mining areas, with contemporary approaches emphasising their revitalisation in accordance with the principles of sustainable development and the circular economy (Tibbett, 2024; Worlanyo & Jiangfeng, 2021). The concept of the circular economy represents a novel paradigm for sustainability, emphasising the closing of material loops and the efficient utilisation of resources (Geissdoerfer et al., 2017).

The revitalisation of mining areas is a multidisciplinary process integrating ecological, technical, and socio-economic aspects. Its objective is not only the stabilisation of the territory but also its reintegration into regional development, particularly through recreation and ecological tourism in line with sustainability principles (Turrión et al., 2021; Singh et al., 2024).

The transformation of post-mining areas involves new forms of economic and energy utilisation consistent with circular economy principles, which emphasise resource efficiency and waste minimisation (Prieto-Sandoval et al., 2018). The study by Ronyastru et al. (2024) highlights the potential of these areas for renewable energy applications. At the same time, the importance of recreational and tourism-oriented uses as instruments of regional development is increasing (Kurowska et al., 2023). Despite their significant environmental impacts, quarries have high potential to be transformed into ecologically and socially valuable spaces, a process that requires a multidisciplinary approach (Tibbett, 2024).

Over the past decade, scientific interest in transforming abandoned quarries into ecologically and socially valuable areas has increased significantly. Taranyan (2024) highlights their utilisation in urban parks and ecotourism, while Semeraro et al. (2019) emphasise the link between landscape restoration and economic development. Institutional instruments (Halevy et al., 2023) and urban planning solutions (Harchenko et al., 2021) also play an important role. Successful revitalisation additionally requires consideration of social factors, particularly the “sense of place” and public participation (Svobodová et al., 2023), while the integration of expert and local knowledge is essential for effective planning (Lee et al., 2024). Contemporary approaches to post-mining land revitalisation increasingly employ multicriteria decision-making models, enabling comprehensive evaluation of environmental, social, and economic factors. Singh et al. (2024) recommend using multicriteria analytical frameworks to assess alternative uses of abandoned mines, particularly in urbanised areas where diverse and often conflicting interests converge. Similarly, Deveci et al. (2022) propose fuzzy decision-making models that incorporate social impacts and promote greater transparency.

From an environmental perspective, the success of revitalisation projects is closely linked to the adaptation of restoration strategies to local landscape conditions. Turrión et al. (2021) emphasise the importance of geomorphological reconstruction and the appropriate selection of vegetation species in the restoration of mining areas in Mediterranean environments. Worlanyo & Jiangfeng (2021) further highlight the need to combine physical, chemical, and biological methods to restore soil productivity in post-mining landscapes.

Despite the growing number of studies and implemented projects, there is still no unified methodological framework to enable systematic evaluation of the revitalisation potential of abandoned quarries and to support decision-making regarding their future use. A comparative study by Cho, Lee, and Park (2021) demonstrates that countries adopt different approaches to post-mining land transformation, while a coordinated international framework to ensure the long-term sustainability of these sites remains lacking.

From the perspective of current research, a significant gap—referred to as the “entrepreneurship gap”—can be identified: the insufficient integration of post-mining landscape revitalisation with the theory and practice of entrepreneurship. Most existing studies focus on environmental restoration and the technical aspects of reclamation, whereas economic mechanisms, business models, and the potential for value creation within regional economies remain underexplored (Kurowska et al., 2023; Singh et al., 2024). In particular, there is a lack of systematic analysis of opportunities to develop small and medium-sized enterprises, innovative tourism services, and new forms of land use aligned with the principles of the green economy.

In this context, the revitalisation of abandoned quarries emerges not only as an environmental challenge but also as an opportunity to develop new economic activities grounded in sustainability principles. The transformation of post-mining landscapes into recreational and tourism spaces can spur new entrepreneurial opportunities in areas such as ecotourism, geotourism, environmental education, and outdoor activities, thereby diversifying regional economies and advancing green entrepreneurship.

The present study aims to analyse the possibilities for the sustainable transformation of former mining quarries into recreational and tourism spaces and to evaluate their potential from the perspective of regional development and green entrepreneurship. At the same time, the study proposes a conceptual framework for assessing the revitalisation potential of post-mining areas, reflecting the need to integrate environmental, social,

and economic factors and enabling the identification of promising directions for their future utilisation within the context of sustainable development.

Literature review

The importance and necessity of quarry revitalisation

Quarries represent a specific form of mining activity with pronounced and long-term impacts on the landscape, ecosystems, and human populations. Their presence is associated with the disruption of geological structures, alteration of hydrological regimes, habitat fragmentation, and visual degradation of the landscape. Despite these negative impacts, they have significant potential to be transformed into functional landscape elements that serve ecological, recreational, and educational purposes. Their revitalisation therefore requires a multidisciplinary approach integrating ecological, technical, social, and economic aspects of landscape planning (Tibbett, 2024).

Over the past decade, research on converting abandoned quarries into ecologically stable and socially beneficial areas has intensified significantly. Taranyan (2024) identified the potential to transform quarries in Yerevan into botanical gardens, urban parks, and ecotourism centres, while Semeraro et al. (2019) highlighted the possibility of linking environmental restoration with economic development through renewable energy sources. At the institutional level, Halevy et al. (2023) emphasise the importance of conservation easements as instruments supporting the sustainable use of land and biodiversity protection. Harchenko et al. (2021) analysed architectural and urban planning aspects of revitalisation, noting the potential to integrate former quarries into urban structures as multifunctional public spaces.

However, quarry revitalisation extends beyond the technical restoration of the landscape and encompasses significant social and cultural dimensions. Svobodová et al. (2023) emphasise the importance of the “sense of place” as a factor influencing the acceptance of projects by local communities. Public participation and the collective perception of the landscape are therefore essential for the long-term sustainable use of these areas. Lee et al. (2024) further highlight the need to integrate expert and local knowledge into the evaluation of ecosystem services, a crucial step for effective revitalisation planning.

The increasing complexity of decision-making has led to the adoption of multicriteria approaches. Singh et al. (2024) recommend applying multicriteria frameworks to evaluate environmental, social, and economic aspects of land use, while Deveci et al. (2022) propose fuzzy models that incorporate uncertainty and social impacts into decision-making processes. From an environmental perspective, adapting restoration strategies to local conditions is essential, including geomorphological reconstruction and the selection of appropriate species (Turrión et al., 2021), as well as integrating physical, chemical, and biological methods for soil restoration (Worlanyo & Jiangfeng, 2021). The practical applicability of integrated approaches is further demonstrated by Pawełczyk's (2018) study, which employed the AHP method to design sustainable quarry revitalisation.

Despite these advances, the absence of a unified institutional framework remains a significant challenge. Cho et al. (2021) point to differing approaches to post-mining land transformation across countries and the lack of a coordinated international strategy. At the same time, Damian et al. (2019) emphasise the need to consider ethical aspects and social responsibility when making decisions about the future of these areas. Quarry revitalisation thus represents not only a technical and environmental challenge but also a complex process that reflects broader societal values and the principles of sustainable development.

Context of environmental sustainability and legislation in relation to the revitalisation of mining areas

The mining industry is currently undergoing a significant transformation driven by growing environmental and societal demands. The sustainable revitalisation of mining areas is becoming essential not only for ecological reasons but also for legislative and strategic imperatives, with frameworks for these processes established by initiatives such as the Paris Agreement, Agenda 2030, and the European Green Deal. Despite some progress, the mining sector continues to lag in integrating sustainability principles into strategic management, underscoring the need to adopt the concept of “strong sustainability” and ensure the protection of natural capital (Tost et al., 2018).

Technological innovation and environmentally oriented solutions play a key role in this transformation, particularly in reducing energy intensity and implementing renewable energy sources. Research indicates a growing interest in sustainability within the mining sector; however, most innovations are concentrated in the extraction phase, whereas mine closure and reclamation remain underdeveloped (Aznar-Sánchez et al., 2019). Ensuring sustainable development requires balancing environmental, economic, and social dimensions throughout the entire mine life cycle, which necessitates clearly defined regulatory frameworks and interdisciplinary approaches (Pouresmaieli et al., 2023).

Indicator systems represent an important tool for evaluating revitalisation processes, enabling the monitoring of ecological restoration quality. Alves et al. (2024) highlight the use of regeneration indices based on vegetation and soil parameters to assess the effectiveness of revitalisation. In specific contexts, such as semiarid regions, the reconstruction of hydrological systems and landscape structures is essential, with the success of these processes

depending on high-quality planning and regulatory frameworks (Krzyszowska Waitkus, 2022). In the context of surface mine closure, methodological tools such as the combined use of SWOT and AHP analyses are increasingly applied, enabling transparent evaluation and selection of optimal transformation strategies (Spanidis et al., 2023).

At the operational level, optimisation and modelling approaches also play a significant role. Operations research tools, including linear programming and metaheuristic methods, enable the effective management of complex decision-making processes and the integration of environmental, economic, and social criteria (Aghdamigargari et al., 2024). At the same time, broader environmental challenges associated with mining—such as land degradation, pollution, biodiversity loss, and mining in environmentally sensitive areas—must be addressed, requiring a systemic approach that integrates legislation, technological innovation, and corporate social responsibility (Qarahasanlou et al., 2022).

It follows that the revitalisation of post-mining areas is a complex challenge that requires integrating legislative instruments, technological innovations, and interdisciplinary approaches. A key factor for success is systematic planning grounded in scientific knowledge and the active involvement of relevant stakeholders. Only a coordinated approach will enable the transformation of abandoned mining areas into ecologically stable, socially beneficial, and economically viable landscape elements.

Recreational reuse of quarries

The revitalisation of abandoned quarries is currently a significant research and practical topic in environmental management, landscape planning, and sustainable regional development. Surface extraction of mineral resources leaves pronounced geomorphological impacts on the landscape, often resulting in environmental degradation, habitat fragmentation, and alterations of hydrological regimes. Following the cessation of mining activities, extensive post-mining areas emerge, requiring a systematic approach to reclamation and subsequent utilisation. In recent decades, the academic literature has increasingly emphasised the potential of these areas for recreational and tourism-oriented uses, which enable the integration of ecological restoration with new socio-economic functions (Talento et al., 2020; Kurowska et al., 2023).

Abandoned quarries should not be perceived solely as degraded areas but may instead represent unique landscape environments with high aesthetic and geological value. Their characteristic morphology—rock faces, terraced structures, and newly formed water bodies—creates distinctive settings that can be attractive for recreation, tourism, and environmental education. Properly designed revitalisation thus enables the reintegration of these areas into the landscape system and their renewed utilisation for societal needs (Talento et al., 2020). Consequently, the recreational use of quarries is often regarded as one of the most effective forms of secondary utilisation of post-mining landscapes, delivering environmental, social, and economic benefits while simultaneously contributing to regional development (Orewere et al., 2021).

From the perspective of landscape planning, quarry revitalisation can be implemented through two principal approaches. The first involves reconstructing the original landscape character, i.e., restoring the area to its pre-mining condition. The second approach entails creating new functional landscape structures that reflect the site's anthropogenic character while integrating recreational, ecological, or tourism-related functions. In practice, the latter approach is increasingly applied, as it enables the adaptive utilisation of the specific morphological and landscape-aesthetic characteristics of quarries (Talento et al., 2020).

Green entrepreneurship and regional development

Green entrepreneurship represents a dynamic research domain situated at the intersection of environmental sustainability, economic development, and innovation systems. It is commonly defined as entrepreneurial activity that simultaneously generates economic value while contributing to environmental improvement, thereby supporting broader sustainable development goals (Kuckertz & Wagner, 2020; Dean & McMullen, 2007).

In recent years, increasing attention has been directed toward its role as a driver of regional economic transformation, particularly in structurally affected or post-industrial regions. These regions often face economic decline, unemployment, and environmental degradation, which create both constraints and opportunities for the emergence of sustainability-oriented entrepreneurial activities (Audretsch & Belitski, 2020). Within this context, post-mining landscapes represent territorially embedded resources that can be reconfigured into new economic assets through innovative and environmentally oriented business models.

From a theoretical perspective, green entrepreneurship is closely linked to the concept of entrepreneurial ecosystems, encompassing networks of actors, institutions, and resources that shape regional entrepreneurial dynamics (Stam & Van de Ven, 2021). The transformation of post-mining areas into recreational and tourism destinations can therefore be understood as part of broader regional innovation systems, where public policies, private investment, and local stakeholder engagement interact to generate new development trajectories.

The economic relevance of these transformations is particularly evident in the expansion of sustainable tourism activities, including ecotourism, geotourism, outdoor recreation, and environmental education. These activities contribute to diversifying regional economies, job creation, and increased competitiveness (Rasoolimanesh et al., 2020; Hall, 2020). Additionally, tourism-oriented reuse of post-mining sites generates

multiplier effects by stimulating demand for complementary services, including accommodation, gastronomy, transport, and cultural activities.

However, the development of green entrepreneurship in post-mining regions is shaped by structural and institutional factors, including access to financial resources, regulatory frameworks, land ownership arrangements, and levels of human capital. Entrepreneurial intentions oriented toward sustainability are influenced both by individual capabilities and the broader institutional environment (Kuckertz & Wagner, 2020). Furthermore, effective policy support, governance mechanisms, and cross-sectoral collaboration are essential for fostering green innovation and sustainable business models (Stam & Van de Ven, 2021).

Despite the growing body of research, a significant gap persists in integrating green entrepreneurship into the planning and evaluation of post-mining land use. Existing studies often address environmental restoration and economic development separately, while the explicit linkage between these dimensions through entrepreneurial processes remains underdeveloped (Kurowska et al., 2023; Singh et al., 2024). This highlights the need for conceptual frameworks that can systematically capture the entrepreneurial potential of post-mining landscapes.

In this context, the transformation of post-mining quarries into recreational and tourism spaces can be conceptualised as a hybrid development pathway combining ecological regeneration with the creation of new market opportunities. Such an approach aligns with contemporary trends in sustainable regional development, where value creation increasingly relies on the regeneration of existing resources. Consequently, green entrepreneurship emerges as a key mechanism for translating environmental assets into socio-economic benefits and enhancing long-term regional resilience and sustainability.

Methodology

Research focused on the potential transformation of post-mining landscapes into recreational and tourism spaces requires a multidisciplinary methodological approach that integrates environmental, economic, and socio-spatial dimensions of land use. Given the inherent complexity of quarry revitalisation processes, this study employs two complementary methodological approaches.

Research approach

This study adopts a conceptual and applied research design to analyse the potential of post-mining quarries to be transformed into recreational and tourism spaces within the context of sustainable regional development and green entrepreneurship.

Given the complexity of post-mining landscape revitalisation, the research is grounded in an interdisciplinary framework integrating environmental, socio-economic, and spatial planning perspectives. Such integrative approaches are increasingly emphasised in sustainability research, particularly in the context of post-industrial land transformation (Singh et al., 2024; Worlanyo & Jiangfeng, 2021).

The methodological approach combines qualitative analysis with structured comparative evaluation, enabling a comprehensive assessment of quarry transformation opportunities. This approach is consistent with recent studies highlighting the importance of combining qualitative insights with multidimensional evaluation in complex environmental systems (Lee et al., 2024).

To ensure methodological transparency and reproducibility, the research design follows a structured analytical procedure consisting of four sequential steps: (i) systematic data collection, (ii) selection and classification of case studies, (iii) evaluation based on predefined criteria, and (iv) comparative interpretation and identification of transformation patterns.

The research is based on two complementary approaches:

- comparative analysis of selected case studies, focusing on successful international examples and selected Slovak sites,
- conceptual multicriteria evaluation, applied to identify key factors influencing the suitability of quarries for recreational and entrepreneurial use (Singh et al., 2024).

Additionally, the methodological framework aims to identify typologies of quarry transformation models, thereby enabling the classification of post-mining sites by their level of development, functional diversification, and economic integration.

Comparative analysis of quarry revitalisation

Comparative analysis is a widely used method in the study of post-industrial landscape transformation, as it enables the identification of patterns, differences, and success factors across diverse geographical and institutional contexts (Talento et al., 2020; Kurowska et al., 2023).

In this study, the comparative analysis focuses on:

- selected international case studies representing successful transformations of post-mining quarries into recreational, tourism, or multifunctional spaces,

- selected Slovak quarries, representing either existing or potential examples of post-mining landscape reuse.

The study analyses a set of selected representative case studies (international and Slovak), chosen based on data availability, relevance to the research objective, and representativeness with respect to transformation type and development stage.

The selection of international case studies was based on:

- demonstrated success in post-mining revitalisation,
- integration of environmental, social, and economic functions,
- relevance for replication in Central European conditions (Kurowska et al., 2023).

Slovak case studies were selected to reflect the current state of post-mining landscape utilisation, including both systematically developed recreational areas and spontaneously emerging sites with latent development potential.

Comparative evaluation was conducted using qualitative dimensions commonly applied in sustainability and land-use studies, including:

- type and intensity of recreational use,
- level of ecological restoration,
- integration into regional tourism systems,
- involvement of local communities,
- contribution to local economic development.

These dimensions reflect the current research emphasis on multifunctional land use and the integration of ecosystem services (Lee et al., 2024; Singh et al., 2024).

Conceptual evaluation framework

To address the complexity of decision-making in post-mining land use, the study applies a conceptual multidimensional evaluation framework that integrates key sustainability and development factors.

The framework is based on the assumption that the interaction of four core dimensions determines the transformation potential of post-mining quarries:

Environmental dimension

- ecological condition of the site,
- biodiversity and ecosystem potential,
- water and landscape quality.

These factors are essential for long-term ecological restoration and are widely recognised in post-mining land reclamation research (Worlanyo & Jiangfeng, 2021).

Technical dimension

- physical stability and safety of the quarry,
- geomorphological characteristics,
- feasibility of spatial adaptation.

Technical feasibility remains a critical precondition for any form of post-mining land reuse (Singh et al., 2024).

Socio-economic dimension

- accessibility and usability for the public,
- social acceptance and community relevance,
- integration into regional development strategies.

Recent studies highlight the importance of participatory approaches and social acceptance in landscape transformation (Lee et al., 2024).

Entrepreneurial dimension

- potential for tourism-related services,
- opportunities for small and medium-sized enterprises (SMEs),
- attractiveness for investment and business development.

Entrepreneurial potential was operationalised through indicators reflecting the presence of tourism infrastructure, service diversification, and the degree of integration into local economic systems. The inclusion of this dimension reflects the growing importance of green entrepreneurship as a driver of sustainable regional development (Kurowska et al., 2023).

Evaluation criteria and procedure

Based on the conceptual framework, a set of evaluation criteria was identified to assess the suitability of post-mining quarries for recreational and tourism use.

The criteria were derived from:

- scientific literature on quarry revitalisation and land-use planning (Talento et al., 2020),
- empirical insights from case studies (Kurowska et al., 2023),
- sustainability-oriented evaluation frameworks (Singh et al., 2024).

The evaluation process involved:

- qualitative and semi-quantitative assessment of selected sites,
- comparative analysis across defined criteria,
- identification of strengths, limitations, and development potential.

Instead of applying a fully quantitative model, the study adopts a comparative interpretive approach, which is increasingly used in sustainability research to address complex, context-dependent systems (Lee et al., 2024).

Each criterion was assessed on a 5-point ordinal scale (1–5), with higher values indicating greater suitability. The scoring was based on predefined threshold values to ensure consistency and comparability across case studies.

To ensure a structured and transparent evaluation of post-mining sites, a set of criteria and indicators was developed based on existing literature and adapted to the specific context of quarry revitalisation. The criteria integrate environmental, technical, socio-economic, and functional dimensions of land use.

The evaluation results were not aggregated into a single composite index; instead, they were interpreted comparatively across criteria, allowing the identification of dominant patterns and transformation typologies.

Tab. 1 Evaluation criteria for assessing the recreational potential of post-mining sites

Group	Code	Criterion	Indicator / Measurement Method	Threshold Values (Scale 1–5)
Primary criteria	K1	Geotechnical stability and safety	Slope stability, occurrence of landslides, and safety of water access points	1 = unstable, high landslide risk; 3 = partially stable, limited access; 5 = stable, safe access points, presence of safety/rescue elements
	K2	Water quality	Microbiological parameters (E. coli, enterococci), water transparency (Secchi disk)	1 = poor quality, turbid water; 3 = conditionally acceptable, transparency 1–2 m; 5 = good quality, transparency >4 m
	K3	Depth and area of the water body	Maximum depth (m), surface area (ha)	1 = <2 m, <0.5 ha; 3 = 2–5 m, 0.5–2 ha; 5 = >5 m, >5 ha
	K4	Vegetation and ecological value	Vegetation cover (%), presence of autochthonous species	1 = degraded, invasive species; 3 = partial stabilisation; 5 = high biodiversity, native communities
	K5	Accessibility and infrastructure	Distance from settlements, transport accessibility	1 = >10 km, no access; 3 = 3–10 km, limited accessibility; 5 = <3 km, direct access (car, public transport, cycling)
Additional criteria	K6	Aesthetic and landscape value	Visibility of the water body, panoramic views	1 = low landscape value; 3 = moderate attractiveness; 5 = high aesthetic value, panoramic scenery
	K7	Recreational and sports opportunities	Number and diversity of possible activities	1 = basic swimming only; 3 = 2–3 activities (e.g., swimming + cycling); 5 = more than 5 different activities
	K8	Supporting infrastructure and services	Parking, sanitary facilities, information points, and catering services	1 = no services; 3 = basic infrastructure; 5 = comprehensive services
	K9	Social and community value	Use for events, cultural and educational activities	1 = unsuitable; 3 = occasional events; 5 = regular events, strong community integration

Data sources and case study selection

The research is grounded in a combination of secondary data sources and case study analysis, which is a standard methodological approach for investigating complex socio-environmental systems and the transformation of post-industrial landscapes (Singh et al., 2024; Lee et al., 2024).

The primary sources include:

- peer-reviewed scientific publications indexed in the Web of Science and Scopus databases,

- studies focused on post-mining land use and environmental restoration (Worlanyo & Jiangfeng, 2021; Turrión et al., 2021),
- research addressing sustainable tourism, geotourism, and landscape transformation (Kurowska et al., 2023; Taranyan, 2024),
- scholarly works dedicated to multicriteria evaluation and decision-making processes in land revitalisation (Deveci et al., 2022; Singh et al., 2024).

Additional data sources included publicly available institutional reports, regional development documents, and official information from site management authorities, thereby ensuring data triangulation. Such an approach enhances the validity and robustness of the findings and is widely recommended in sustainability and environmental planning research (Lee et al., 2024; Svobodová et al., 2023).

The international case studies represent well-established examples of successful quarry transformation, reflecting a high degree of integration of environmental, social, and economic functions. Their selection was guided by the principles of knowledge transferability and applicability within Central European conditions (Talento et al., 2020; Kurowska et al., 2023). In contrast, the Slovak cases capture the current state of post-mining landscape utilisation, including the identification of existing barriers and development potential within the national context.

This approach is consistent with contemporary methodological practices that combine evidence-based analysis with contextual interpretation and interdisciplinary evaluation of landscape systems (Singh et al., 2024; Lee et al., 2024; Tibbett, 2024).

Methodological limitations

The study is grounded in a conceptual and comparative approach, which inherently entails certain limitations.

First, the evaluation is not based on a fully quantitative decision-making model, which may limit the precision of comparative analyses. However, such approaches are widely accepted within sustainability research, where complex socio-environmental interactions are examined (Lee et al., 2024).

Second, the selection of case studies is constrained by data availability and the limited number of large-scale revitalisation projects in Slovakia, which may affect the representativeness of the findings.

Third, the semi-quantitative evaluation process may involve a certain degree of subjectivity. This was mitigated through the application of predefined evaluation thresholds, the consistent use of criteria across all analysed cases, and systematic cross-case comparison.

Fourth, the absence of primary field research may limit the depth of site-specific analysis; nevertheless, the use of multiple secondary data sources ensures sufficient analytical robustness and data triangulation.

Fifth, the results are predominantly exploratory, and their generalisability is constrained by the study's geographical and contextual scope. Despite this, they provide relevant insights for similar post-mining regions in Central Europe.

Notwithstanding these limitations, the applied methodology offers a robust foundation for identifying key factors influencing quarry transformation and for developing a conceptual framework applicable to comparable regional contexts. At the same time, it establishes an analytical basis for future research on quantitative modelling of revitalisation potential and the development of entrepreneurial strategies in sustainable tourism and green entrepreneurship.

Results

The evaluation of selected case studies was carried out using a set of criteria defined in Table 1, which integrates environmental (K2, K4), technical (K1, K3), socio-economic (K5, K9), and functional-operational (K6–K8) dimensions of post-mining land use. This framework enabled a systematic comparison of the analysed sites and the identification of differences in their transformation potential. The comparative tables for the international (Table 2) and Slovak (Table 3) case studies represent the operationalisation of the proposed evaluation model, with individual sites interpreted based on their dominant characteristics and the extent to which the defined criteria are met. The results indicate a pronounced differentiation between international and Slovak sites in terms of transformation complexity and utilisation levels.

International sites, such as Lausitzer Seenland, Cospudener See, and Quarry Park, achieve high scores across most of the evaluated criteria, particularly in infrastructure and accessibility (K5), supporting services (K8), and the diversity of recreational activities (K7). These sites are also characterised by a high level of functional integration, encompassing recreational, cultural, and entrepreneurial activities, which contribute to their economic sustainability and regional significance.

In contrast, Slovak sites exhibit greater variability and, in general, lower levels of fulfilment across several criteria, particularly in terms of infrastructure provision (K5), supporting services (K8), and entrepreneurial utilisation of the area (K9). Although several sites, such as Slnečné jazerá and Lake Košice, achieve relatively high

values for recreational functions (K7) and environmental attractiveness (K2, K6), their development is often constrained by the lack of systematic planning and comprehensive site management.

From the perspective of individual criteria, Slovak post-mining sites demonstrate relatively favourable performance primarily in the environmental and aesthetic dimensions (K2, K6). In contrast, the most significant deficiencies are observed in infrastructure, services, and entrepreneurial utilisation (K5, K8, K9). This imbalance highlights an insufficient link between environmental potential and the area's economic valorisation.

The integration of the results presented in the comparative tables with the evaluation framework further enables the identification of three principal types of transformation models: (i) fully developed recreational systems with a high degree of diversification (typical of international sites), (ii) partially developed urban recreational areas (e.g. Slovak gravel pits), and (iii) latent or spontaneously utilised sites with a low level of regulation (e.g. certain flooded quarries).

International Case Studies

The comparative analysis of international case studies confirms that post-mining areas represent a significant transformation potential for recreational, environmental, and economic uses, with the identified models exhibiting a high degree of variability depending on the type of mining, geomorphological characteristics, and the applied management approach (Talento et al., 2020; Kurowska et al., 2023).

In the European context, projects focused on transforming former lignite mining sites into water-based recreational landscapes predominate. Lausitzer Seenland (Germany) represents one of the most comprehensive transformation models, in which former lignite quarries are systematically flooded and interconnected to form a functional hydrological system. This process is implemented in phases, with recreational use introduced only after the required environmental and safety standards are met (Lausitzer Seenland, 2025). A similar yet more urban-integrated model is exemplified by the Cospudener See, where a former mining pit has been transformed into an intensively used recreational lake with high visitor numbers and strong integration into urban infrastructure (Stadt Leipzig, 2025).

In the Central European context, Lake Most (Czech Republic) represents a notable example demonstrating the importance of systematic monitoring of water quality and geotechnical stability as key prerequisites for the safe public use of such sites (Statutární město Most, 2025). Similarly, Lake Velenje (Slovenia) represents a model of an urban recreational system characterised by high accessibility, safety, and intensive use by the local population (Mestna občina Velenje, 2025; I Feel Slovenia, 2025).

Outside Europe, projects combining recreational and infrastructural interventions prevail. In Australia (Collier region), Lake Kepwari and Black Diamond Lake exemplify the transformation of former coal-mining pits into recreational lakes, with differences in regulation levels highlighting the importance of a managed approach to safety and site governance. While Lake Kepwari is the result of a planned transformation supported by infrastructure development, Black Diamond Lake represents a spontaneously utilised site that subsequently requires additional regulatory interventions (Department of Biodiversity, Conservation and Attractions, 2025; Government of Western Australia, 2025).

North American examples demonstrate a diversification of post-mining land-use functions. Quarry Park & Nature Preserve (USA) combines water-based recreation, climbing, and nature-based activities, with a strong emphasis on safety management (Stearns County, 2025; City of Waite Park, 2025). Brownstone Adventure Park represents a commercially oriented model based on adrenaline activities, thereby expanding the economic potential of such sites (Brownstone Exploration & Discovery Park, 2025; Portland Brownstone Quarries, 2025).

Projects with dominant aesthetic or cultural functions represent a specific category. The Butchart Gardens (Canada) demonstrate the long-term transformation of a former quarry into an iconic tourist destination with high aesthetic value (The Butchart Gardens, 2025; Parks Canada, 2025). Similarly, Fertőrákos Quarry (Hungary) exemplifies the cultural and social utilisation of a quarry as a natural amphitheatre (Fertőrákosi Kőfejtő és Barlangszínház, 2025). Rummu Quarry (Estonia) combines recreational use with industrial heritage, while the Kimberley “Big Hole” (South Africa) represents a model of industrial tourism (Rummu Quarry, 2025; Visit Estonia, 2025; The Big Hole, 2025).

An extreme example of innovative utilisation is the InterContinental Shanghai Wonderland (China), where recreational and accommodation functions are directly integrated into the quarry's geomorphology, demonstrating the potential of high-tech architectural solutions in post-mining environments (InterContinental Shanghai Wonderland, 2025; IHG Hotels & Resorts, 2025).

Synthesis of results – international context

1. Safety and infrastructure are decisive for public acceptance. Water bodies and significant depths (Quarry Park), as well as “wild” or unmanaged sites (Black Diamond), require clearly defined regulations, appropriate equipment, and effective supervision.

2. Phased development is essential. Many lakes are created progressively (filling, neutralisation, slope stabilisation), and recreational use is introduced only after the required environmental and safety parameters have been achieved (Altdöbern, Cospuden).
3. Product diversification enhances sustainability. The combination of swimming, sports, cultural activities, and educational functions (Lausitz, Fertőrákos, Brownstone) reduces seasonality and attracts diverse user segments.
4. Identity and heritage constitute valuable assets. The narratives associated with mining and quarrying sites (Butchart, Big Hole, Rummu) strengthen destination identity and branding, provided they are professionally interpreted and managed with adequate safety standards.
5. The comparative summary of the analysed sites is presented in Table 2, which systematises differences in site typology, functional utilisation, safety measures, and governance models.

Tab. 2 Comparative analysis of selected international post-mining sites and their transformation into recreational areas

Location (Country)	Type of Mining	Type of Site	Main Recreational Functions	Key Safety Measures	Governance Model	Transformation Model Type
Lausitzer Seenland (DE)	Lignite	Flooded pits interconnected by canals	Swimming, sailing, cycling, tourism, beaches, marinas	Slope stabilisation, water quality control, phased flooding	State reclamation agency LMBV + regional authorities	Fully developed, integrated recreational system
Cospudener See (DE)	Lignite	Flooded pit	Beach recreation, swimming, cycling/in- line circuit, boating	Water monitoring, safety zones, and developed infrastructure	City of Leipzig + regional associations	Urban-integrated recreational system
Lake Most (CZ)	Lignite	Flooded open-pit mine	Beach recreation, swimming, sports, and a circular trail	Slope stability, laboratory water monitoring	City of Most + state administration	Controlled post-mining lake redevelopment
Lake Velenje (SI)	Lignite	Flooded pit	Beach recreation, swimming, SUP, sailing, water park	Shoreline stabilisation, lifeguard supervision, hygiene monitoring	City of Velenje + partnerships	Urban recreational water system
Lake Kewari (AUS)	Lignite	Flooded quarry	Swimming, water skiing, camping	Artificial beaches, sanitary facilities, piers, and controlled access	DBCA (state agency)	Planned recreational lake transformation
Black Diamond Lake (AUS)	Lignite	Flooded pit	Informal swimming, paddleboarding	Warning systems, controlled access, safety signage	State authority (Abandoned Mines Program)	Spontaneous/unmanaged recreational site
Quarry Park (USA)	Granite	Flooded quarries + nature park	Swimming, climbing, hiking, diving	Jumping restrictions, patrols, marked trails	Stearns County administration	Multifunctional nature- based recreation system
Brownstone Park (USA)	Sandstone	Flooded quarry	Water-based adventure park, zip- line, wakeboarding	Organised activities, trained personnel, and insurance coverage	Private operator	Commercial adventure recreation model
Butchart Gardens (CAN)	Limestone	Former quarry pit	Garden tourism, cultural events	Slope stabilisation, landscape and horticultural management	Private foundation + heritage authority	Aesthetic-cultural transformation model
Fertőrákos Quarry (HU)	Limestone	Quarry – natural amphitheatre	Theatre and music performances, exhibitions	Structural adaptations, audience safety measures	Regional cultural institution	Cultural landscape reuse model
Rummu Quarry (EE)	Limestone + prison site	Flooded quarry	Swimming, diving, tourism, disc golf	Regulated diving, paid access, supervision	Private owner + tourism agency	Hybrid heritage- recreational model
Kimberley Big Hole (SA)	Diamonds	Open-pit mine	Museum, viewpoints, “Old Town” exhibition	Barriers, museum infrastructure, and visitor management system	De Beers + City of Kimberley	Industrial heritage tourism model
Shanghai Wonderland (CN)	Limestone	Quarry – “earthscraper” hotel	Accommodation, wellness, tourism attraction	Advanced geotechnical measures, high- end construction technologies	Private developer + hotel chain	High-tech architectural transformation model

source: own processing

The table indicates that water-based recreational areas constitute the dominant type of transformation, with the highest level of infrastructural readiness identified in cases characterised by institutionally managed governance models.

Quarry Revitalization Potential in Slovakia

The comparative analysis of Slovak case studies indicates that post-mining areas in Slovakia represent a significant, yet unevenly utilised, potential for recreational and tourism purposes. The identified sites primarily include gravel pits, flooded quarries, and historical mining water structures, with their transformation in most cases resulting from gradual development rather than systematic planning (Worlanyo & Jiangfeng, 2021; Pavolová et al., 2022).

Among the analysed examples, gravel pits dominate, representing the most common form of transformation of post-mining landscapes into recreational areas (Štrba et al., 2019; Pavolová et al., 2022). A representative example is the Slnčné jazerá in Senec, which were created by connecting several mining pits and have gradually transformed into a complex recreational zone with year-round use (Slnčné jazerá, 2024). The site currently integrates water sports, accommodation services, beaches, and recreational infrastructure, with its development largely driven by the gradual expansion of services, water quality monitoring, and the implementation of functional zoning (European Environment Agency, 2023).

A similar transformation model can also be identified in the case of Bratislava gravel pits (Kuchajda, Veľký Draždiak, Zlaté piesky, Rusovské jazero), which represent urban-integrated recreational spaces (Hofierka et al., 2020). These sites originated as by-products of sand and gravel extraction and now serve as natural bathing areas, leisure parks, and sports zones (Bratislava City, 2023). Their significance lies primarily in their accessibility, integration into urban infrastructure, and intensive use by residents. On the other hand, they are constrained by spatial and technical limitations, as well as by the need to systematically manage water quality and public spaces (EEA, 2023).

A specific example of an urban transformation model is Lake Košice (Nad jazerom district), which originated as a gravel pit and was subsequently adapted into a recreational water body (Košice Región, 2024). This site represents a typical example of brownfield conversion into an urban recreational park, with its success largely dependent on regular water-quality monitoring, available infrastructure, and strong local visitation (Štrba et al., 2019).

At the regional level, the Rudava site (Malé Leváre) is an example of a natural recreational area developed on a former mining site (Region Záhorie, 2023). This locality demonstrates the potential of regional gravel pits for tourism development, particularly when basic operational conditions such as water quality, accessibility, and basic infrastructure are ensured (Pavolová et al., 2022).

Another type of post-mining transformation is exemplified by flooded quarries, with the Beňatina quarry serving as a representative example (Košice Región, 2024). This site is distinguished primarily by its aesthetic and natural value, complemented by geological and palaeontological features. However, its recreational use is significantly influenced by the need for visitor regulation, safety measures, and nature conservation (Worlanyo & Jiangfeng, 2021).

In a broader spatial context, a system of gravel pits can be identified in the Danubian Lowland (for instance, Nové Košariská), where mining activities and progressive reclamation occur simultaneously (Hofierka et al., 2020). This model highlights the importance of a phased approach to land transformation, including technical reclamation, slope modelling, defining safety zones, and the gradual opening of sites to the public (Pavolová et al., 2022). At the same time, it emphasises the need for a clear separation between active mining areas and recreational zones (European Commission, 2020).

Synthesis of results – Slovak context

Based on the analysed case studies, several key characteristics of post-mining land transformation in Slovakia can be identified:

- The dominance of gravel pits as the primary form of recreational use, representing the most easily transformable type of post-mining landscape.
- A strong linkage to urban environments, where urban sites exhibit higher levels of utilisation due to accessibility and infrastructure availability.
- The absence of systematic planning, with most sites emerging through gradual adaptation rather than the implementation of comprehensive transformation models.
- The critical importance of water quality and safety, constitutes a fundamental prerequisite for the usability of these areas.
- The need for a phased approach to revitalisation, particularly in cases of active or recently terminated mining activities.

- Constraints arising from nature conservation requirements, which limit the development potential of certain sites, especially quarries with high ecological value.

To synthesise the results of the analysis of Slovak sites, a comparative table was constructed that summarises the key characteristics of the identified post-mining areas transformed for recreational purposes. Table 3 systematically compares individual sites by origin, site typology, current functional use, and governance/regulatory frameworks. Such a structured comparison enables the identification of dominant transformation models and key factors that influence their usability in the Slovak context.

Tab. 3 Comparative overview of selected post-mining sites transformed for recreational use in Slovakia

<i>Location</i>	<i>Origin</i>	<i>Type of Site</i>	<i>Current Functions</i>	<i>Governance / Notes</i>	<i>Transformation Model Type</i>
<i>Slnčné jazerá</i>	<i>Gravel extraction</i>	<i>Large water body</i>	<i>Beaches, sports, and accommodation</i>	<i>Municipal recreational area, water quality monitoring</i>	<i>Partially developed recreational system</i>
<i>Kuchajda (Bratislava)</i>	<i>Gravel extraction</i>	<i>Urban lake</i>	<i>Swimming, fishing, park recreation</i>	<i>Municipal management / recreational use</i>	<i>Urban-integrated recreational site</i>
<i>Veľký Draždiak (Bratislava)</i>	<i>Gravel pit</i>	<i>Urban lake</i>	<i>Swimming, sports, open access</i>	<i>Planned upgrades, presence of high-voltage lines</i>	<i>Urban recreational site with development potential</i>
<i>Rusovské jazero (Bratislava)</i>	<i>Gravel pit</i>	<i>Natural site</i>	<i>Beaches, cycling</i>	<i>Protected area (Danube Floodplains), public health authority supervision</i>	<i>Environmentally constrained recreational site</i>
<i>Lake Košice</i>	<i>Gravel pit</i>	<i>Urban reservoir</i>	<i>Beach recreation, sports, and fishing</i>	<i>Municipal district Nad jazerom</i>	<i>Urban recreational system (brownfield conversion)</i>
<i>Beňatina</i>	<i>Former quarry</i>	<i>Quarry lake</i>	<i>Walking, experiential activities</i>	<i>Natural monument, regulated access</i>	<i>Aesthetic-natural site with regulated access</i>
<i>Rudava (Malé Leváre)</i>	<i>Gravel pit</i>	<i>Natural bathing site</i>	<i>Beaches, swimming</i>	<i>Regional recreational area, water quality monitoring</i>	<i>Regional recreational site</i>

source: own processing

The comparative analysis indicates that the most common transformation of post-mining areas in Slovakia involves gravel pits adapted into recreational water bodies with varying levels of infrastructure provision. Urban sites (for instance, Kuchajda, Draždiak, Lake Košice) exhibit a higher intensity of use due to their accessibility and integration within the urban environment, whereas regional and natural sites (Rudava, Beňatina) are characterised by lower levels of regulation and a stronger emphasis on the natural character of the landscape.

At the same time, significant differences can be identified in governance and regulatory frameworks, ranging from formally managed urban recreational areas to less regulated or environmentally protected sites. The results highlight the absence of a unified approach to post-mining land revitalisation, as reflected in the heterogeneous quality of infrastructure, safety measures, and site management.

The identified differences between international and Slovak post-mining sites also reveal significant implications for economic utilisation and entrepreneurial development, which are discussed in the following section.

Discussion

The transformation of post-mining areas into recreational and tourism-oriented spaces represents not only an environmental and spatial-planning challenge but also a significant opportunity for economic diversification and the advancement of green entrepreneurship. As demonstrated by the comparative analysis, post-mining landscapes can function as platforms for the emergence of new business activities that integrate environmental regeneration with economic value creation (Szewczyk-Świątek, 2025; Wibowo et al., 2024).

From a sectoral perspective, the economic utilisation of post-mining areas is most commonly associated with the development of sustainable tourism segments, including geotourism, adventure tourism, wellness-oriented recreation, cultural events, and environmental education. These forms of tourism contribute to the diversification of regional economies and enhance their resilience, particularly in structurally disadvantaged or post-industrial regions (Saha, 2025; Manalu et al., 2024). Empirical evidence confirms that post-mining tourism can generate substantial socio-economic benefits, including job creation, increased visitor flows, and the revitalisation of local economies (Saha, 2025; Wibowo et al., 2024).

A key mechanism by which these transformations generate economic benefits is the development of micro, small, and medium-sized enterprises (SMEs), particularly within the creative economy and tourism sectors. SMEs play a critical role in post-mining regions by supporting local employment, fostering innovation, and enabling the diversification of economic activities beyond extractive industries (Manalu et al., 2024). Their contribution is particularly significant in tourism-related sectors such as gastronomy, accommodation services, guiding, and cultural production, where local knowledge and resources can be effectively valorised.

The concept of green entrepreneurship provides both a theoretical and practical framework for understanding these processes. Green entrepreneurship is characterised by the integration of economic and environmental objectives, with firms actively contributing to sustainability through innovative business models and environmentally oriented services (Ansari, 2025; Arora et al., 2023). Recent research highlights that green entrepreneurship catalyses sustainable development by promoting resource efficiency, innovation, and the adoption of environmentally friendly technologies (Ansari, 2025). At the same time, it contributes to the long-term competitiveness and resilience of regional economies (Arora et al., 2023).

In the context of post-mining transformation, different business models can be identified depending on the degree of institutional involvement and market orientation. International case studies demonstrate the existence of (i) publicly driven models, (ii) privately driven commercial models, and (iii) hybrid models combining public and private resources. These models enable the formation of diversified economic ecosystems integrating tourism, services, and cultural activities (Szewczyk-Świątek, 2025).

However, the comparative analysis also reveals a significant gap between international and Slovak post-mining sites regarding entrepreneurial utilisation. While international examples exhibit a high degree of business model diversification and integration into regional economic systems, Slovak sites remain predominantly oriented toward basic recreational functions with limited development of entrepreneurship-oriented services. This finding is consistent with broader research indicating that post-industrial regions often struggle to fully exploit their entrepreneurial potential due to institutional and structural constraints (Worlanyo & Jiangfeng, 2021).

The limited development of entrepreneurial activities in Slovak post-mining regions can be attributed to several structural factors, including insufficient investment support, fragmented governance, regulatory constraints, and the lack of strategic integration between environmental restoration and economic planning. At the same time, the results indicate that these regions possess environmental and spatial attributes comparable to those of successful international cases, suggesting that the primary barriers are institutional and economic rather than physical (Szewczyk-Świątek, 2025).

The findings further confirm the relevance of the applied multidimensional evaluation framework (K1–K9), which enabled the identification of discrepancies between sites' environmental potential and their actual entrepreneurial utilisation, particularly in infrastructure, service provision, and economic integration.

From a policy and strategic perspective, the results indicate the need to transition to more integrated development approaches that combine environmental restoration with support for local entrepreneurship, innovation ecosystems, and tourism development strategies. Key instruments include promoting SMEs, developing creative economy sectors, and implementing innovation-driven tourism models that enable the effective valorisation of post-mining landscapes (Manalu et al., 2024; Ansari, 2025). The findings have significant policy implications, particularly regarding the integration of environmental and economic objectives within regional development frameworks.

Despite these contributions, the study has several limitations. The analysis is primarily based on qualitative and semi-quantitative evaluation, which may limit the precision of cross-site comparisons. Furthermore, the availability of comparable data for Slovak post-mining sites remains limited, which may affect the generalisability of the findings.

This study contributes to the existing literature by linking post-mining land transformation to the concept of green entrepreneurship and offering an integrated perspective that combines environmental, socio-economic, and

entrepreneurial dimensions in the context of regional development. It also provides an analytical basis for identifying key factors that influence the successful transformation of post-mining landscapes into sustainable, economically viable spaces.

Overall, post-mining areas can be conceptualised as emerging entrepreneurial ecosystems in which natural resources, cultural heritage, and institutional frameworks interact to generate new economic opportunities. The transition from extraction-based economies to sustainability-oriented development pathways thus depends on the ability to transform these areas into multifunctional environments that support both ecological restoration and economic growth (Wibowo et al., 2024; Szewczyk-Świątek, 2025).

Conclusion

The present study focused on analysing the potential for sustainable transformation of post-mining quarries into recreational and tourism spaces, with particular emphasis on their role in regional development and green entrepreneurship. Based on a systematic literature review, comparative analysis of case studies, and the application of a multidimensional evaluation framework, it can be concluded that the revitalisation of post-mining landscapes represents a significant instrument of sustainable development capable of integrating environmental, social, and economic dimensions of land use.

The results confirm that post-mining areas possess substantial transformation potential; however, this potential is contingent on a comprehensive, systematic approach to their planning and management. International case studies demonstrate a high degree of functional integration of recreational, cultural, and entrepreneurial activities, with these sites achieving advanced levels of infrastructure, safety, and economic sustainability. In contrast, Slovak sites exhibit a lower degree of transformational complexity, with their utilisation often constrained by insufficient infrastructure, a lack of strategic planning, and weak integration with entrepreneurial activities. This disparity highlights an “implementation gap,” defined as the discrepancy between a site's environmental potential and its actual economic utilisation.

From a methodological perspective, the study confirms the relevance of the applied multidimensional evaluation framework (K1–K9), which enables a systematic assessment of quarries' revitalisation potential. This framework integrates environmental, technical, socio-economic, and entrepreneurial factors and serves as a suitable tool to support decision-making in post-mining land-use planning. The results further indicate that the most pronounced differences between analysed sites relate primarily to infrastructure, service accessibility, and the level of economic integration, underscoring the need to strengthen the entrepreneurial dimension of revitalisation processes.

From a regional development perspective, quarry transformation offers a significant opportunity to diversify the economy, particularly through sustainable tourism, geotourism, outdoor recreation, and environmental education. These activities can generate multiplier effects within regional economies and support job creation, especially in the small and medium-sized enterprise sector. In this context, the concept of green entrepreneurship emerges as a key mechanism for transforming environmental resources into economic value, enabling the development of innovative business models grounded in sustainability principles.

Based on the findings, several key implications for practice and policymaking can be formulated. First, it is essential to promote integrated planning approaches to post-mining land revitalisation that link environmental restoration with economic development and entrepreneurial activities. Equally important are the development of infrastructure, the assurance of environmental quality (particularly water quality and slope stability), and the creation of a favourable institutional environment for business development. At the same time, it is necessary to strengthen community participation and foster cooperation between public and private sectors, which is crucial for the long-term sustainability of revitalisation projects.

The study also identifies several research gaps that define directions for future research. These include the need for quantitative modelling of revitalisation potential, a deeper analysis of business models in post-mining regions, and the evaluation of the effectiveness of policy instruments supporting revitalisation. Future research should also focus on integrating digital technologies, intelligent monitoring systems, and the concept of ecosystem services into the planning and evaluation of revitalisation processes.

In conclusion, post-mining quarries represent a significant resource for the emergence of new forms of sustainable development, with their transformation into recreational and tourism spaces playing a crucial role in the transition from extraction-based economies to models grounded in knowledge, innovation, and sustainability. The success of this transformation process, however, depends on the ability to integrate environmental, social, and economic dimensions into a coherent strategic framework that reflects regional specificities while supporting the development of green entrepreneurship and long-term regional resilience.

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