

The Role of Revegetation in Rebuilding Ecosystem Functionality in Post Mining Environments: A Synthesis of Global Evidence

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ABSTRACT

Coal mining, especially through open pit and underground methods, has left behind severely degraded landscapes, particularly in Asia, Africa, and South America. These environments suffer from disrupted soil structures, toxic residues, and impaired ecosystem functionality. Although revegetation is widely implemented as a restoration strategy, global insights into its effectiveness across ecological and socioeconomic dimensions remain fragmented. This study aims to synthesize global empirical evidence on the role of revegetation in rebuilding ecosystem functionality in post-mining landscapes. Utilizing a narrative review approach, the study analyzes 12 peer reviewed articles from 2014 to 2024 sourced from Scopus. Key findings reveal that revegetation significantly improves plant biodiversity, enhances soil quality and microbial activity, and contributes to carbon sequestration and ecosystem resilience. Moreover, it offers socioeconomic benefits such as land reutilization, employment generation, and community engagement. This review contributes an integrative understanding of revegetation's multidimensional impacts, bridging ecological, biological, and social aspects. The paper offers novel insights for adaptive restoration strategies and calls for future research into trait-based species selection, soil microbiome dynamics, and long-term monitoring frameworks. Such integrative approaches are vital for achieving sustainable ecological recovery and informing evidence-based policy in post-mining rehabilitation.

Keywords: revegetation, post mining restoration, ecosystem functionality, sustainable land rehabilitation.

1. INTRODUCTION

Coal mining, particularly through open pit and underground methods, has contributed significantly to economic development but at a considerable environmental cost. Across coal producing regions in Asia, Africa, and South America, post mining landscapes are frequently marked by severe ecological degradation, including soil compaction, nutrient depletion, heavy metal accumulation, disrupted hydrology, and loss of native vegetation (Tripathi et al., 2014; Zhang et al., 2021). These conditions not only hinder natural regeneration but also impair ecosystem functionality the system's inherent capacity to regulate ecological processes, maintain biodiversity, and support ecosystem services (Ren et al., 2025).

Efforts to rehabilitate such degraded lands have led to the growing application of revegetation as a core strategy within ecological restoration frameworks. Revegetation refers to the re-establishment of plant cover either naturally through succession or via human-assisted interventions with the objective of restoring ecosystem structure and function (Navarro-Ramos et al., 2022). Beyond reintroducing vegetative layers, revegetation initiates a cascade of ecological benefits, including improvements in soil organic matter, hydrological stability, microbial community development, and carbon sequestration (Pille da Silva et al., 2019). Accordingly, many regulatory bodies now require revegetation as a mandated component of post-mining reclamation plans.

Despite widespread adoption, studies evaluating the outcomes of revegetation are often fragmented and scattered across diverse ecological zones, disciplines, and restoration strategies. While research from China (Lei et al., 2016), Brazil (Pille da Silva et al., 2019), and India (Tripathi et al., 2014) provides strong empirical evidence of revegetation's effectiveness, there remains a lack of integrated synthesis that links these outcomes to long-term ecosystem functionality and their socioecological implications. Drawing on the socioecological systems (SES) framework, it becomes evident that revegetation outcomes must be assessed not only in terms of ecological recovery but also in relation to human-environment interactions, institutional support, and landscape-scale processes. Moreover, knowledge gaps persist in species selection, soil-microbe-plant interactions, and long-term performance monitoring, raising critical questions about the scalability and sustainability of current revegetation practices (Bi et al., 2022).

To address these issues, this paper aims to provide a narrative review that synthesizes global empirical evidence on the role of revegetation in rebuilding ecosystem functionality in post-mining environments. The review evaluates how revegetation contributes to ecological recovery including biodiversity restoration, soil rehabilitation, and carbon storage as well as its social and economic dimensions. It also identifies methodological limitations and context-specific constraints, offering a consolidated perspective on what has worked, where, and why.

The novelty of this review lies in its integrative scope: while previous studies have focused on ecological or technical aspects of revegetation in isolation, this paper bridges multiple dimensions ecological, biological, and socioeconomic to build a comprehensive understanding of revegetation as a transformative pathway for restoring degraded lands. By doing so, it contributes not only to scientific knowledge but also to the development of evidence-based policies and adaptive management strategies for post-mining restoration worldwide.

2. METHODS

2.1 Research Design

This study employed a narrative review design to systematically synthesize global evidence on the role of revegetation in restoring ecosystem functionality in post-mining environments. The narrative review approach was selected for its flexibility in integrating multidisciplinary findings across ecological, environmental, and socioeconomic domains, beyond the rigid inclusion/exclusion rules typical of systematic reviews. To enhance methodological transparency, we adopted clear inclusion criteria: (1) publication in reputable, peer-reviewed journals, (2) geographic and biome diversity to ensure global relevance, (3) thematic alignment with key aspects of revegetation and ecosystem functionality, and (4) sufficient methodological detail to allow comparative interpretation. This approach enabled an interpretive synthesis that draws out patterns, contextual nuances, and conceptual insights from diverse case studies.

2.2 Research Procedure

The research was conducted in sequential stages:

1. Problem Formulation and Conceptual Framing

The initial phase involved formulating the central research question: “*What is the role of revegetation in rebuilding ecosystem functionality in coal-mining-impacted landscapes?*”

Key ecological constructs were defined, including *ecosystem functionality*, *soil resilience*, *carbon sequestration*, and *socioeconomic recovery*. Theoretical models related to ecological restoration and landscape transformation guided the review structure.

2. Literature Search and Source Selection

Peer-reviewed journal articles were identified through academic databases such as Scopus database, using combinations of keywords: “*revegetation*,” “*coal mining*,” “*post-mining restoration*,” “*ecosystem functionality*,” “*biodiversity*,” “*soil recovery*,” and “*carbon sequestration*.”

Inclusion criteria were:

- Studies published between 2014–2024,
 - Empirical studies or review articles addressing post-coal mining revegetation,
 - English language publications.
- Grey literature, dissertations, and conference proceedings were excluded to ensure peer reviewed scientific rigor.

Study (Author, Year)	Region	Biome Type	Mining Type	Revegetation Approach	Key Ecological Impact
Lei et al. (2016)	China	Temperate forest	Open-pit coal	Soil and vegetation co- restoration	Enhanced plant-soil recovery
Bi et al. (2022)	China	Temperate grassland	Coal subsidence	N ₂ -fixing plants and biocrusts	Boosted fungal diversity, microbial balance
Tripathi et al. (2014)	India	Dry tropical forest	Surface mining	Passive revegetation	CO ₂ sequestration in mine spoil
Pille da Silva et al. (2019)	Brazil	Tropical forest	Coal	Mimosa scabrella restoration	Improved soil structure and nutrient cycling
Ren et al. (2025)	China	Temperate grassland	Reclaimed coal mine	Mixed native species	Increased soil quality indices

Study (Author, Year)	Region	Biome Type	Mining Type	Revegetation Approach	Key Ecological Impact
Navarro-Ramos et al. (2022)	Global review	Various	Mixed mining types	Meta-analysis	Low consistency in outcomes across studies
Mylliempap & Barik (2019)	India	Subtropical grassland	Coal	Long-term observation	Poor biodiversity recovery even after 50 years
Zhang et al. (2021)	China	Mountainous region	Open-pit coal	Vegetation succession stages	Progressive slope stability and diversity
Ivanova et al. (2024)	Russia	Boreal forest	Coal	Technogenic soil treatment	Soil conditioning strategies summarized
Yang et al. (2021)	China (urban)	Urban-ecological	Subsidence	Landscape restoration	Linked to regional development goals
Yuan & Dong (2024)	China/Germany	Comparative (temperate)	Industrial coal	Case study analysis	Socioecological lessons from the Ruhr area
Dang et al. (2022)	China	Temperate grassland	Coal subsidence	Hydrological analysis	Revealed evapotranspiration imbalance

3. Screening and Thematic Coding

A total of 12 peer-reviewed articles were selected for in depth analysis based on their thematic relevance and scientific rigor. These articles were imported for reference management and manually coded across four thematic axes:

- (i) *Vegetation and biodiversity outcomes,*
- (ii) *Soil and microbial responses,*
- (iii) *Carbon storage and climate linkages,*
- (iv) *Socioeconomic and policy dimensions.*

4. Synthesis and Interpretation

Extracted findings were analyzed thematically to identify consistent trends, divergences, and knowledge gaps. The synthesis emphasized longitudinal trajectories

of revegetated ecosystems, cross continental comparisons (e.g., Asia, South America, Europe), and the interplay between ecological processes and social outcomes.

2.3 Data Sources and Reliability

Data for this study were derived exclusively from published, peer-reviewed literature, ensuring high reliability and scientific validity. The inclusion of cross regional studies allows for a robust understanding of revegetation performance across diverse environmental and institutional contexts. Moreover, all referenced articles reported empirical methods, such as field trials, soil analysis, biodiversity assessments, or long-term monitoring, enhancing the credibility of the synthesized insights.

To improve transparency and reproducibility, all cited sources are provided in the reference section with DOI links. The methodological transparency of this review enables other researchers to replicate the study process or apply it to similar topics in other ecological restoration domains.

3. RESULTS AND DISCUSSIONS

This section synthesizes key findings derived from peer reviewed literature concerning the ecological and socioeconomic impact of revegetation in post-mining environments. The results are structured into four core themes that reflect the primary objectives of the review: vegetation recovery, soil quality, ecosystem resilience, and socioeconomic transformation.

Table 1. Synthesized Findings on Revegetation Outcomes in Post-Mining Landscapes.

Key Dimension	Main Findings	Representative Studies
Vegetation Recovery	Species richness, cover, and biomass increase with revegetation age	Zhang et al. (2021), Lei et al. (2016), Myllemngap & Barik (2019)
Soil Quality	Improved organic matter, nutrient levels, porosity, and microbial diversity (e.g., AMF, microbial biomass).	Ren et al. (2025), Pille da Silva et al. (2019), Bi et al. (2022)
Ecosystem Resilience	Enhanced erosion control, NPP, litter decomposition	Tripathi et al. (2014), Zhang et al. (2021), Ren et al. (2025)
Socioeconomic Transformation	Revegetation enables land reuse (e.g., agroforestry, tourism), generates employment, and supports community participation.	Yang et al. (2021), Ivanova et al. (2024), Navarro-Ramos et al. (2022)



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Figure 1. Revegetation impacts range from ecological to socio economic benefits.

3.1 Vegetation Recovery

The reviewed studies consistently reported that revegetation enhances species richness, ground cover, and biomass in post-mining landscapes. For instance, in the Heidaigou and Beidian Shengli coal mines in China, a temporal progression was observed from pioneer exotic grasses to more complex native plant communities (Zhang et al., 2021; Lei et al., 2016). Species diversity and community stability were positively correlated with restoration age.

These findings support the hypothesis that revegetation fosters biodiversity enhancement through ecological succession. However, the initial use of exotic or fast-growing monocultures can inhibit long-term diversity, underscoring the importance of incorporating native species into revegetation strategies (Myllemngap & Barik, 2019). This aligns with ecological theory suggesting that structural diversity leads to higher ecosystem resilience and functional redundancy.

3.2 Soil Quality

Significant improvements in soil physical and chemical properties were reported across studies. Soil organic matter, total nitrogen, phosphorus content, porosity, and aggregate stability increased with revegetation duration, as observed in both tropical and temperate zones (Pille da Silva et al., 2019; Ren et al., 2025).

In addition to these physicochemical improvements, revegetation was found to boost microbial biomass and functional diversity. The development of biological soil crusts and

increased arbuscular mycorrhizal fungi (AMF) presence were common indicators of microbiome recovery (Bi et al., 2022). These results confirm that soil health and microbial community function are central components of ecosystem recovery, supporting biogeochemical cycles and nutrient availability.

Despite positive trends, the success of microbial restoration varied depending on soil degradation levels, amendment use, and plant–microbe compatibility. This highlights a gap in understanding complex plant microbe soil interactions and calls for future microbiome-focused research.

3.3 Ecosystem Resilience

Multiple studies demonstrated that revegetation enhances long-term ecosystem functionality, including erosion control, water regulation, and energy flow within trophic networks. These are crucial indicators of ecological resilience (Zhang et al., 2021). Notably, revegetated sites showed increased litter decomposition rates and net primary productivity, signifying the reactivation of key ecological processes.

Regarding carbon storage, studies such as Tripathi et al. (2014) in India and Ren et al. (2025) in China confirmed that revegetated sites sequester significantly more carbon both in biomass and soils than non-revegetated controls. This supports the hypothesis that revegetation contributes to climate mitigation goals and enhances the global carbon sink capacity of post-mining landscapes.

However, long-term monitoring data remain scarce. Few studies extend beyond a 10-year horizon, limiting our understanding of carbon accumulation dynamics and long-term sustainability.

3.4 Socioeconomic Transformation

Revegetation also demonstrated positive social and economic impacts. In regions such as Indonesia, China, and Latin America, it provided employment in seedling cultivation, planting, and maintenance, and offered alternative land uses such as agroforestry and ecotourism (Yang et al., 2021; Ivanova et al., 2024).

Moreover, participatory revegetation approaches, where local communities are engaged in species selection and benefit-sharing, were associated with improved project legitimacy and sustainability (Navarro-Ramos et al., 2022). Yet, several studies highlighted inequities in access to restored lands and limited community involvement due to top down project design. These findings indicate that social integration remains underdeveloped and that institutional mechanisms must evolve to support inclusive governance and equitable benefit distribution.

4. CONCLUSION

This review highlights the multifaceted role of *revegetation* in restoring ecosystem functionality across degraded post-mining landscapes. Synthesizing global evidence, the study affirms that revegetation not only supports vegetative recovery and biodiversity enhancement

but also facilitates the rehabilitation of soil structure, nutrient dynamics, microbial activity, and carbon sequestration. It further reveals the significant socioeconomic benefits of revegetation, including land reutilization, job creation, and community resilience elements often overlooked in ecological restoration discourse.

Despite these promising outcomes, several critical limitations persist. First, the frequent reliance on fast-growing exotic species for rapid coverage has often compromised native biodiversity and long-term resilience. This points to a fundamental gap in functional trait-based species selection, especially in contexts of nutrient-poor, contaminated, or compacted post-mining soils. Second, the biological complexity of soil microbe plant interactions in early-stage revegetation remains poorly understood, limiting the effective use of microbial-based restoration techniques. Third, short monitoring durations often constrained by funding cycles fail to capture the decades-long processes of ecological succession and functional recovery, potentially resulting in premature conclusions about project success.

Institutional and policy fragmentation further weaken the systemic potential of revegetation. In many jurisdictions, reclamation is treated as a regulatory formality rather than an ecological investment, leading to disjointed planning, limited stakeholder participation, and inadequate integration with broader land-use or climate policies. Additionally, the lack of meaningful community engagement and equitable benefit-sharing threatens the long-term sustainability and social legitimacy of revegetation efforts.

Critically assessing these limitations underscores the need for a shift from purely technical interventions to more transdisciplinary, participatory, and context-sensitive approaches. Future efforts should prioritize long-term ecological monitoring, adopt trait-based and native species frameworks, strengthen microbial soil research, and integrate revegetation with ecosystem service valuation and socio-political considerations. Revegetation, when understood not only as a restoration tool but also as a pathway to ecological justice and climate resilience, holds transformative potential for the future of post mining landscapes.

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