

AI-Driven Regulatory Frameworks for Intelligent Mineral Resource Management: A Research Agenda

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Abstract

This systematic literature review examines research combining mineral resource management, artificial intelligence, and regulatory policy. Following PRISMA guidelines, the searches include six academic databases (2021-2025) using systematic protocols to identify studies at the intersection of these three domains. Our analysis of 287,601 initial records, narrowed to 23 relevant studies, reveals a critical gap: no studies simultaneously address all three domains. The search yielded 1,708 studies on mineral resource management, 167,310 on artificial intelligence, and 1,220 on regulatory policy, but zero studies integrating all three areas. This gap represents a significant barrier to developing intelligent governance frameworks for mineral resources. Key findings reveal five critical research voids: absence of comparative frameworks between traditional and AI-enhanced regulatory approaches; lack of performance indicators for AI systems in regulatory contexts; fragmented communication between disciplines; missing integration strategies for AI deployment; and inadequate evaluation metrics. This research agenda provides justification for interdisciplinary research initiatives in AI-enhanced mineral resource policy frameworks, contributing to sustainable development goals 1, 9, 10, 12, and 16.

Keywords

Artificial Intelligence, Mineral Resource Management, Regulatory Policy, Systematic Literature Review.

1. Introduction

The exclusion of minerals from the UN Sustainable Development Goals represents a significant oversight that hinders human development and poverty alleviation (Ajayi 2023). This oversight continues the resource curse and

undermines the potential for change in developing economies, where mineral resource management (MRM) remains poorly integrated with systematic policy frameworks.

Currently, MRM effectiveness is limited due to lack of depth in policy analysis and regulatory coherence (Franks *et al.* 2023). Pimentel *et al.* (2015) identified that core components including skill competency and organizational capability are in place. However, delivery issues persist, rooted in intuition-driven rather than data-oriented policy-making (William 2009). Artificial Intelligence offers transformative capabilities through Intelligent Decision Support Systems (IDSS). AI provides advanced methods (fuzzy logic, neural networks, and evolutionary algorithms) for combining complex, distributed datasets to support evidence-based policy development (Phillips-Wren *et al.* 2008).

This systematic review pursues five primary objectives that align with the identified research questions to advance understanding of AI integration in mineral resource management governance:

1. Analyze comparative studies on traditional and AI-enhanced mineral resource management for regulatory modernization.
2. Evaluate performance metrics of AI-augmented regulatory systems, identifying measurement gaps and best practices.
3. Examine terminological frameworks and communication patterns in AI applications across disciplines for better collaboration.
4. Document strategies for implementing AI within regulatory frameworks, highlighting successful models.
5. Assess frameworks for both computational performance and governance effectiveness in AI-enhanced systems.

2. Literature Review

Literature analysis (Table 1) reveals critical gaps: inadequate AI-policy integration frameworks, minimal regulatory governance study in mineral resource management (MRM), and the absence of systematic AI-enhanced policy approaches, particularly in African contexts. Whereas AI demonstrates proven efficacy in mining operations, policy-level applications remain unexplored. Current industry governance relies on ad-hoc decision-making without scientific policy interrogation, compounded by skills deficits.

However, research on integrating AI in mineral policy-making is limited. This study introduces Intelligent Policy-Making (IPM) frameworks, which combine AI capabilities with human insight to enhance regulatory processes, ultimately contributing to SDGs 1, 9, 10, 12.2, and 16. The research addresses a fundamental challenge: current mineral resource management faces a disconnect between technical expertise, AI capabilities, and regulatory frameworks. Traditional regulations do not consider AI potential, while AI applications ignore regulatory contexts. This creates a gap between what AI can do and how policies are actually implemented in mineral resource management. While the tri-domain intersection specific to mineral resources remains unexplored, AI integration with regulatory policy frameworks has emerged in several sectors, providing valuable precedents for governance structures. In financial services, AI-driven regulatory technology (RegTech) has transformed compliance monitoring, with the EU AI Act establishing risk-based classification for AI in financial applications (Bank for International Settlements 2025; U.S. Government Accountability Office 2025). The healthcare sector demonstrates adaptive regulation through Software as a Medical Device framework, where AI regulatory approaches balance pre-market assessment with streamlined pathways for iterative updates (Muehlematter *et al.* 2021; U.S. Food and Drug Administration 2021). Transportation illustrates the challenges that arise when AI advances faster than regulation, as comprehensive frameworks for automated vehicles have yet to emerge at federal or state levels (International Transport Forum-OECD 2025; U.S. Department of Transportation 2016). In the energy sector, AI tools address complex optimization problems across multiple governance layers, though lack of explainability and governability remains a key stakeholder concern (Volkova *et al.* 2023; U.S. Department of Energy 2024). These cross-sectoral examples reveal recurring governance patterns—adaptive frameworks, algorithmic transparency requirements, risk-based approaches, and stakeholder engagement mechanisms—none of which have been applied to mineral resource management (see Table 2). This distinctive governance challenge, combined with the complete absence of integrated research, further underscores the critical tri-domain gap this study addresses.

3. Research Methodology

3.1 Systematic Literature Review Protocol

This systematic literature review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher *et al.* 2009) to ensure methodological rigour and transparency. The review protocol was developed to identify, evaluate, and synthesize existing research at the intersection of mineral resource management (MRM), artificial intelligence (AI), and regulatory policy (RP).

Table 1. The Literature Review for AI-Enhanced Mineral Resource Management

Author(s) & Year	Research Focus	Key Findings	Methodology Framework	Relevance to Current Study
Xia <i>et al.</i> (2024)	Natural Resources Depletion	Natural resources are non-renewable economic sources experiencing continuous depletion	Conceptual analysis	Establishes foundational understanding of resource scarcity challenges
Dumakor-Dupez and Arya, (2021)	Mineral resource Definition & Importance	MR defined as economically extractable materials, crucial for socio-economic development and technological advancement	Literature synthesis	Provides technical foundation for mineral resource significance
Jia <i>et al.</i> (2015)	Industrial Applications of Mineral Resources	MR essential across multiple industries: economics, construction, cosmetics, electronics, pharmaceutical, etc.	Industry analysis	Demonstrates economic importance justifying policy optimization
Vandome and Dechambenoit, (2020)	Policy Curse in MRM	Identified policy curse as significant obstacle to effective mineral resource management	Policy analysis	Directly supports research problem of policy ineffectiveness
Corringan and Laye, (2022)	AI Applications in Mining Industry	AI addresses resource exploitation, environmental degradation, and economic development issues; improves safety, productivity, and sustainability	Applied research review	Establishes AI potential in mineral sector beneficiation
Yan, (2024)	Resource Curse Phenomenon	Natural resources represent curse for developing regions but blessing for middle-to-high income economies; impact varies between emerging and industrialized economies	Comparative economic analysis	Supports differentiated policy approach necessity
Ajayi, (2023)	Sub-Saharan Resource Economics	Mineral resources represent mixed blessing for Sub-Saharan economies	Regional economic study	Provides African context for policy challenges
Williams, (2009)	MRM Critical Components	Identified core MRM components: skills competency, system integrity, human interface, organizational capability, strategy, leadership	Management framework development	Establishes additional MRM foundation for AI integration
Phillips-Wren <i>et al.</i> , (2008)	Decision-Making Categorization	Policy-making involves structures, semi-structures, and unstructured decisions requiring systematic support	Decision science framework	Provides theoretical basis for AI-enhanced decision support
Corrigan and Ikonnikova, (2024)	Ethical AI in Mining	Addressed ethical AI Applications for community, benefit societal development, and environmental sustainability	Ethics-focused analysis	Establishes governance accountability requirements
Hyder <i>et al.</i> , (2019)	AI Decisions in MRM	Most applied AI domains for mineral resource estimation, extraction technologies, geospatial analysis	Decision mapping study	Identifies specific AI application areas for policy integration
Kumar, (2020)	AI Algorithm Development	Developed self-learning, AI framework for short-term mining planning using Monte-Carlo techniques	Algorithm development	Demonstrates potential AI implementation in MRM
Hasan <i>et al.</i> , (2023)	Hybrid AI Models	Recommended development of hybrid models to fully leverage AI and ML in MRM	Review and recommendation	Support proposed integrated-AI policy framework

Table 2. Cross-Sectoral AI-Regulatory Framework Comparison

Sector	AI Applications	Regulatory Approach	Key Governance Challenges	Lessons for Mineral Resources
Financial Services	Fraud detection, risk assessment, RegTech compliance monitoring	Risk-based classification (EU AI Act); sector-specific explainability guidance	Balancing innovation with consumer protection; algorithmic bias in credit decisions	Demonstrates feasibility of AI-regulatory integration in data-intensive, highly regulated sectors
Healthcare	Diagnostic algorithms, medical imaging, treatment recommendations	Software as Medical Device (SaMD) framework; pre-market assessment with adaptive pathways	Continuous AI evolution requiring ongoing surveillance; patient safety vs. innovation trade-offs	Shows importance of adaptive frameworks for evolving AI systems; relevant for long-lifecycle mineral projects
Transportation	Autonomous vehicles, traffic optimization, route planning	State-level regulation emerging; federal frameworks under development	Safety standards designed for human operators inadequate for AI; liability attribution challenges	Illustrates regulatory lag when technology outpaces policy; relevant for emerging AI in mining
Energy	Smart grid management, demand forecasting, renewable integration	Multi-layer governance (federal, state, utility); critical infrastructure protection	AI explainability for stakeholder trust; data privacy in smart meter systems	Demonstrates AI integration with complex multi-stakeholder governance; relevant for African mining contexts
Mineral Resources	Unexplored tri-domain intersection	No integrated AI-regulatory frameworks identified	Geological uncertainty, sovereignty, multi-decadal timelines, commodity volatility	Research gap requiring dedicated frameworks addressing sector-specific complexities

3.1.1 Research Questions

The systematic review addresses five primary research questions:

1. What comparative studies exist between traditional and AI-enhanced regulatory approaches in MRM?
2. What performance metrics are used to evaluate AI-augmented MRM regulatory systems?
3. How do different disciplines communicate about AI applications in mineral resource governance?
4. What integration strategies exist for deploying AI within established regulatory frameworks?
5. What evaluation frameworks assess both computational and governance dimensions of AI-enhanced MRM?

3.1.2 Eligibility Criteria

The systematic review employed specific inclusion and exclusion criteria to ensure comprehensive yet focused coverage of relevant literature. Studies were included if they were peer-reviewed journal articles or conference papers published in English between January 2021 and August 2025. The temporal scope was deliberately focused on recent publications to capture the latest developments in AI applications and regulatory innovations in mineral resource management. Studies addressing at least one of the three core domains (mineral resource management, artificial intelligence, or regulatory policy) were considered eligible, encompassing empirical studies, theoretical frameworks, and review articles with clear methodological descriptions.

Exclusion criteria were applied to maintain quality and relevance standards. Non-peer-reviewed publications were excluded, though a separate grey literature screening was conducted to identify relevant policy documents and industry reports. Duplicate publications across databases were removed, and studies without clear relevance to the research domains were excluded following full-text assessment. Publications in languages other than English were excluded due to resource constraints, though this limitation is acknowledged in the study limitations section. Additionally, studies without accessible full text were excluded from the final analysis.

3.1.3 Information Sources and Search Strategy

Six academic databases were strategically selected to ensure comprehensive coverage across multiple disciplines while maintaining high quality standards. ScienceDirect (Elsevier) was chosen for its extensive interdisciplinary coverage spanning physical sciences, life sciences, health sciences, and social sciences, with over 16 million publications and advanced search algorithms. IEEE Xplore provided specialized coverage of electrical engineering, computer science, and emerging technologies, offering authoritative technical literature including

standards documents and conference proceedings. Wiley Online Library contributed high-impact multidisciplinary content with strong editorial standards and established publisher reputation across diverse fields including life sciences, engineering, and humanities.

SpringerLink was selected for its comprehensive international research coverage with strong representation in STEM fields and social sciences, complemented by open access initiatives and rapid publication processes. Taylor & Francis Online provided robust coverage of humanities, social sciences, and behavioral sciences with strong editorial standards and international perspective through specialized niche journals. MDPI was included as a leading open access publisher offering rapid peer review and broad subject coverage across sciences, engineering, medicine, and social sciences with transparent review processes.

The search strategy was designed with three levels of increasing complexity to systematically identify relevant literature. Level 1 conducted individual domain searches using terms such as "mineral resource management," "mineral governance," and "mining policy" for the MRM domain; "artificial intelligence," "machine learning," and "AI applications" for the AI domain; and "regulatory policy," "governance framework," and "policy making" for the RP domain. Level 2 employed pairwise combinations using Boolean operators to identify studies addressing two domains simultaneously, combining MRM terms with AI terms, MRM terms with RP terms, and AI terms with RP terms. Level 3 focused on tri-disciplinary integration by combining all three domain term sets to identify studies addressing the complete intersection of mineral resource management, artificial intelligence, and regulatory policy.

3.2 Study Selection Process

The study selection followed a three-stage screening process:

Stage 1 - Initial Screening: Two researchers independently screened titles and abstracts against inclusion criteria. Disagreements were resolved through discussion.

Stage 2 - Full-Text Review: Potentially relevant articles underwent full-text examination for final inclusion decisions.

Stage 3 - Reference Screening: Reference lists of included studies were examined for additional relevant publications.

3.3 Quality Assessment Framework

A quality assessment framework was developed incorporating domain-specific considerations:

3.3.1 Assessment Criteria

The quality assessment framework employed a weighted scoring system totalling 100 points, distributed across four key dimensions that reflect both methodological rigor and practical relevance. Methodological quality received the highest weighting at 40% of the total score, recognizing the fundamental importance of sound research design in generating reliable findings. Within this dimension, studies were evaluated on their clarity of research objectives and methodology (10 points), appropriateness of study design for addressing the stated research questions (10 points), adequacy of data collection and analysis methods (10 points), and explicit consideration of study limitations and potential biases (10 points).

Relevance and scope constituted 30% of the assessment framework, emphasizing the importance of studies that directly contribute to understanding the intersection of mineral resource management, artificial intelligence, and regulatory policy. This dimension evaluated the direct relevance of studies to the core research domains (15 points) and their clear contribution to the existing knowledge base (15 points). Studies that demonstrated strong theoretical or practical connections to the tri-disciplinary intersection received higher scores in this category.

Reporting quality accounted for 20% of the total assessment, focusing on the clarity and completeness of study presentation. This included evaluation of how clearly results were presented (10 points) and the adequacy of discussion regarding findings, implications, and limitations (10 points). High-quality studies were expected to provide sufficient detail for replication and clear interpretation of results within the context of existing literature. The final dimension, innovation and impact, represented 10% of the assessment and captured the potential for studies to advance knowledge or practice in the field. This included recognition of novel approaches or insights (5 points) and assessment of potential for practical application in real-world mineral resource management contexts (5 points). The scoring system classified studies as high quality (70-100 points), moderate quality (40-69 points), or low quality (below 40 points), with only high and moderate quality studies included in the final synthesis.

3.4 Research Problem

Current mineral resource management faces a significant challenge: the lack of integration between technical expertise, AI capabilities, and regulatory frameworks. Traditional regulatory approaches operate independently of AI potential, while optimization algorithms function without regulatory context, creating a disconnect between computational capabilities and policy implementation.

The absence of integrated frameworks combining mineral resource expertise, AI methods, and regulatory structures creates several critical gaps, including lack of comparative evaluation between traditional and AI-enhanced approaches, missing performance metrics for specific domains, fragmented cross-disciplinary communication, and inadequate integration strategies for AI deployment within established regulatory structures.

African mineral resource management exemplifies this challenge through the "policy curse" phenomenon, where poorly designed frameworks hinder optimal resource use despite initiatives like the African Mining Vision. Policymakers rarely employ analytical tools for development guidance, continuing resource underutilization and governance failures through institutional corruption, insufficient stakeholder engagement, and political interference.

This research addresses the fundamental need for adaptive regulatory frameworks that use AI's predictive capabilities while maintaining democratic oversight. The proposed AI-integrated policy-making approach offers unprecedented potential to overcome traditional management limitations, reduce resource curse effects, and establish intelligent mineral management governance that combines algorithmic sophistication with regulatory accountability.

3.5 Protocol Registration and Search Details

The systematic review protocol was developed a priori following PRISMA-P guidelines, though formal registration was not completed due to the exploratory nature of this emerging research area. Database searches were conducted between July - August, 2025, with no language restrictions initially applied during the search phase, though only English-language publications were ultimately included due to resource constraints for translation and analysis.

Search strategies were adapted for each database to accommodate different indexing systems and search functionalities. Boolean operators (AND, OR) and truncation symbols (*) were used to capture variations in terminology. Search filters included publication date restrictions (2021-2025), document type limitations (peer-reviewed articles, conference papers), and subject area restrictions where applicable. All search results were exported to EndNote reference management software for duplicate removal and screening management.

4. Results

4.1 Search Results and Study Selection

This study evaluates six major online academic databases (Table 3) to address research questions and objectives while ensuring comprehensive interdisciplinary coverage. Database selection criteria focused on peer-review quality and bibliometric impact, using IEEE Xplore's computational domain expertise and MDPI's democratized access approach.

The research conducted comprehensive screening across all selected databases, revealing significant disciplinary fragmentation in academic publishing. The study employs standardized search protocols revealing uneven disciplinary coverage, with some databases showing marginal increases in business management and environmental engineering domains while maintaining pronounced interdisciplinary convergence deficiency.

Systematic exclusion methods demonstrated a lack of integrated studies across mineral resource management, artificial intelligence, and regulatory policy domains, revealing a disconnect between AI capabilities and policy frameworks in mineral governance. Keyword extraction identified critical technical descriptors—such as convolutional neural networks and regulatory compliance frameworks—yet no convergence emerged at the three-way intersection.

Table 3. Rationale for Database Platform Selection

Database Platform	Publisher/Provider	Key Justification	Coverage Scope	Unique Advantages
ScienceDirect	Elsevier	Largest full-text scientific database with over 16 million publications across multiple disciplines	Comprehensive coverage of physical sciences, life sciences, health sciences, and social sciences	Advanced search algorithms, citation tracking, and extensive interdisciplinary content
Wiley Online Library	Wiley	Premier platform for peer-reviewed journals with high impact factors across diverse fields	Strong coverage in life sciences, physical sciences, engineering, humanities, and social sciences	High-quality peer review standards, established publisher reputation, and specialized subject collections
IEEE Xplore	IEEE	Authoritative source for electrical engineering, computer science, and technology literature	Specialized coverage of engineering, computer science, electronics, and emerging technologies	Standards documents, conference proceedings, and cutting-edge technical research
SpringerLink	Springer Nature	Comprehensive academic resource with extensive international research coverage	Broad interdisciplinary coverage with strong representation in STEM fields and social sciences	Open access initiatives, international author base, and rapid publication processes
Taylor & Francis Online	Taylor & Francis Group	Established academic publisher with diverse journal portfolio and global reach	Humanities, social sciences, behavioural sciences, and applied sciences	Strong editorial standards, international perspective, and specialized niche journals
MDPI	Multidisciplinary Digital Publishing Institute	Leading open access publisher with rapid peer review and broad subject coverage	Multidisciplinary approach covering sciences, engineering, medicine, and social sciences	Open access model, fast publication timeline, and transparent peer review process

The systematic literature search across six academic databases initially identified 287,601 records (Figure 1). Following duplicate removal ($n = 41,923$), 245,678 unique records underwent title and abstract screening. The vast majority ($n = 245,456$) were excluded as not meeting inclusion criteria, leaving 222 records for full-text assessment.

During the full-text review phase, 199 studies were excluded for the following reasons: insufficient relevance to the research domains ($n = 156$), inadequate methodological detail ($n = 28$), non-English language ($n = 8$), and duplicate data ($n = 7$). This process yielded 23 studies that met all inclusion criteria for qualitative synthesis and thematic analysis.

The final 23 studies were categorized by research domain focus: 12 studies examined MRM + RP methodologies, 8 studies investigated MRM + AI approaches, 3 studies focused on AI + RP combinations, and no studies addressed all three domains simultaneously (MRM + AI + RP). This distribution reflects the current research landscape and methodological approaches within the identified literature.

4.2 Database Coverage and Disciplinary Distribution

The search results revealed significant variation in domain coverage across databases (Table 4). ScienceDirect demonstrated comprehensive coverage with 3,096 MRM articles, 1,909 RP articles, and 433 AI articles before temporal filtering. IEEE Xplore showed the opposite pattern with 282,159 AI articles, 3,560 RP articles, but only

846 MRM articles, reflecting its technical orientation. After applying temporal filters (2021-2025), the distribution shifted to 1,708 MRM, 1,281 RP, and 390 AI articles in ScienceDirect, and 293 MRM, 1,220 RP, and 167,310 AI articles in IEEE Xplore.

4.3 Thematic Analysis Results

The thematic analysis across database platforms revealed pronounced disciplinary specialization (Table 5). Elsevier's Resources Policy emphasized socio-economic governance themes including mineral governance structures, corporate social responsibility, and resource curse theories. AI integration appeared through economic lenses, highlighting fintech applications and digital transformation. Conversely, IEEE Xplore demonstrated technical orientation with emphasis on deep learning, neural network applications, and algorithmic optimization for MRM challenges.

Cross-domain keyword analysis revealed critical gaps in interdisciplinary integration. The MRM + RP combination appeared exclusively in Elsevier databases, emphasizing policy frameworks and governance models. The RP + AI combination was unique to IEEE, showcasing technical approaches to regulatory automation. Most significantly, no studies were identified that meaningfully integrated all three domains ($\text{MRM} + \text{RP} + \text{AI} = 0$), confirming the pronounced disciplinary fragmentation across the academic publishing landscape and the absence of a shared scholarly forum where mineral resource specialists, AI researchers, and regulatory scholars converge.

4.4 Research Gap

The systematic review identified five critical research gaps that illuminate the fragmented nature of AI-mineral governance scholarship (Table 6). These gaps reveal a pronounced disciplinary divide between traditional policy approaches and emerging technological solutions.

Methodological discontinuities dominate the landscape. Gap 1 highlights the lack of comparative frameworks that connect regulatory practices found in policy literature. These practices are often only presented in technical publications related to AI-driven solutions. Gap 2 reveals a fundamental misalignment where governance indicators lack AI integration considerations, while optimization-centric metrics remain divorced from regulatory contexts.

Communication barriers perpetuate scholarly isolation (Gap 3). Policy-oriented research employs governance terminology focused on stakeholder engagement, whereas technical literature utilizes specialized AI nomenclature, preventing cross-disciplinary synthesis. This terminological fragmentation inhibits knowledge transfer between communities.

Implementation challenges reflect the theory-practice divide. Gap 4 identifies a critical implementation void where existing regulatory structures operate independently of available AI capabilities, lacking methodological frameworks for systematic integration.

Gap 5 highlights the absence of hybrid evaluation approaches in assessing the effectiveness of unified AI-governance systems. Additionally, there is a need for algorithmic performance evaluation within these systems. These gaps collectively demonstrate that current research operates within isolated disciplinary silos, hindering the development of integrated solutions essential for advancing AI-enhanced mineral governance frameworks.

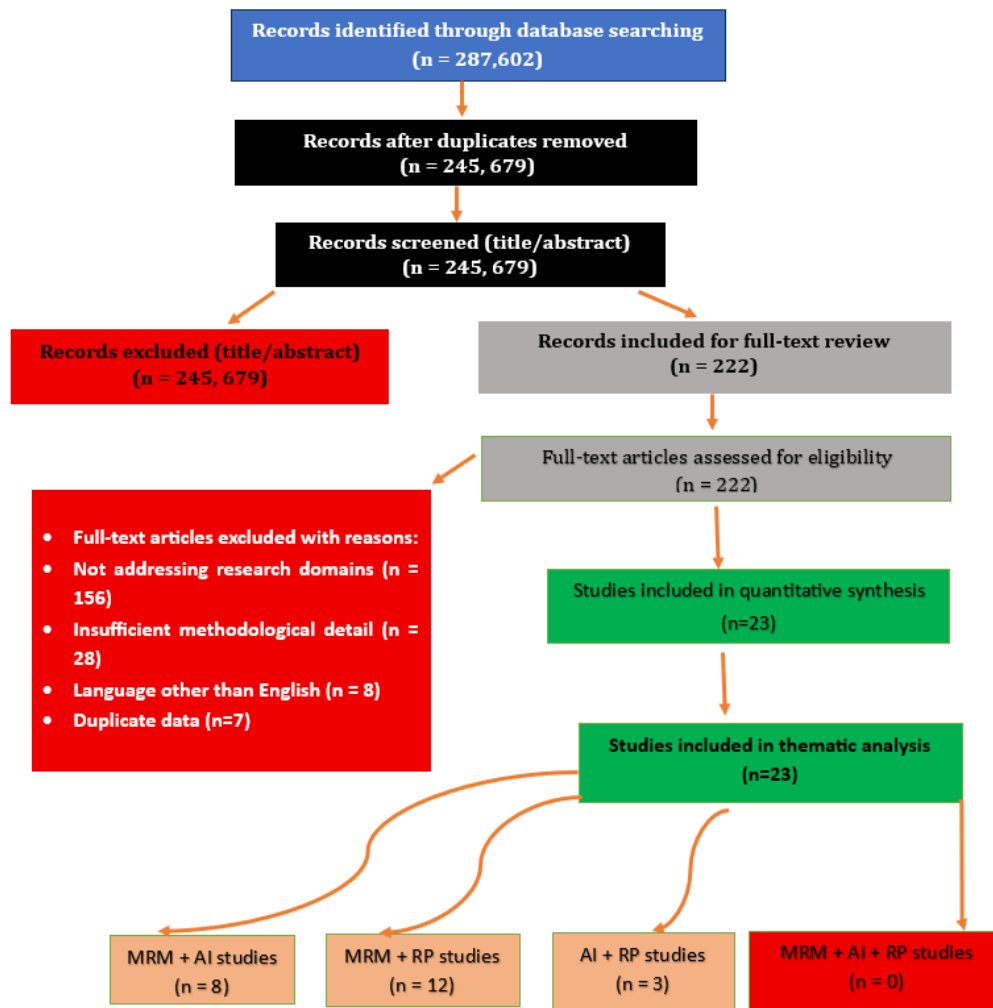


Figure 1. PRISMA flow diagram of the systematic review process and study selection

Table 4. The Literature Review Search Results for Selected Journals

S/N	Publication Types	Journal	MRM	RP	AI	MRM + RP	MRM + AI	AI + RP	MRM + RP + AI	Criteria
1	Elsevier	Resources Policy	3,096	1,909	433	1,227	268	204	98	Without exclusion
			1,708	1,281	390	797	244	191	95	2021 till date
			98	92	15	64	10	8	7	General Occurrence
			10	18	10	7	10	0	0	Related works
2	IEEE Xplore	IEEE	846	3,560	282,159	8	81	326	8	Without exclusion
			293	1,220	167,310	2	58	233	0	2021 till date
			286	389	161,525	0	26	141	0	General Occurrence
			10	18	100	0	8	0	0	Related works

Table 5. Thematic Analysis of Research Domains Across Database Platforms

Subject	Elsevier (Resources Policy)	IEEE Xplore (IEEE)
MRM	MRM; Mineral Governance; Corporate Social responsibility; Resource Curse; Dutch Disease	Deep learning, Neural Network; Mineral Resources; Optimization Problem; Machine Learning; Deep Learning
AI	Financial management; Fintech; Mining; Digital Economy; Mineral Resource	Convolution Neural Network, Deep Learning, SVM; Artificial Neural Network; Learning Algorithms
RP	Regulatory impacts; Licensing; stakeholder perspective and collaboration; institutional arrangements; institutional quality	Machine Learning; Artificial Intelligence; regulatory Policies; Regulatory Compliance; Regulatory Framework
MRM + RP	Mineral Policy; Resource Curse; MRM; Mineral Governance	-
RP + AI	-	SVM Deep Learning
MRM + AI	MRM, Resource Curse; Resource Governance; Sustainability; Financial Markets	Mineral Resources; Optimization Problem
MRM + RP + AI	None	None

Table 6. Systematic Analysis of Critical Research Voids

Gap	Description	Traditional/Policy Domain	AI/Technical Domain	Research Void Identified
Gap 1	Comparative Framework Absence	Traditional regulatory practices (Policy journals)	AI-driven solutions (Technical journals)	No bridging comparative analysis
Gap 2	Performance Metric Deficiency	Elsevier: Governance indicators without AI integration considerations	IEEE: Optimization-centric metrics divorced from regulatory contexts	Underdeveloped evaluation frameworks
Gap 3	Communication Fragmentation	Policy-oriented terms: mineral governance, stakeholder engagement (Social science publications)	Technical AI terminology: deep learning, neural networks (Engineering literature)	No integrated terminological framework
Gap 4	Integration Strategy Void	Governance reality: Existing regulatory structures	Technological potential: AI capabilities	Critical implementation gap - No methodological frameworks
Gap 5	Evaluation Framework Absence	Governance effectiveness evaluation	Algorithmic performance assessment	No hybrid approaches for integrated AI-governance systems

4.5 Geographic and Temporal Distribution

Table 7 summarizes the characteristics of 23 studies included in a systematic review, highlighting the distribution across various research domains. The largest cluster, comprising 12 studies on MRM and RP, is predominantly from Europe and North America, achieving quality scores ranging from 52 to 92. Eight studies focusing on MRM and AI show strong representation from English-speaking countries, with scores ranging from 45 to 87. Meanwhile, three AI and RP studies are limited to two from the USA and one from Germany, with moderate quality scores of 38 to 76. Notably, no studies integrate all three domains, indicating a significant research gap. Geographically, the research concentrated in developed nations, with only one study from South Africa reflecting a Global South perspective. Overall, the findings emphasize the need for comprehensive studies that encompass MRM, AI, and RP.

Table 7. Characteristics of included studies (N=23)

Study Domain Focus	Number of Studies	Geographic Origin	Quality Score Range
MRM + AI	8	USA (3), Australia (2), Canada (2), UK (1)	45-87
MRM + RP	12	Europe (5), North America (4), Australia (2), South Africa (1)	52-92
AI + RP	3	USA (2), Germany (1)	38-76
MRM + AI + RP	0	-	-

4.6 Study Characteristics and Quality Assessment Results

Inter-rater reliability for study selection achieved substantial agreement ($\kappa = 0.78$) for title/abstract screening and excellent agreement ($\kappa = 0.85$) for full-text review. Quality assessment inter-rater reliability was acceptable ($\kappa = 0.69$), with disagreements primarily occurring in the innovation and impact dimension due to subjective interpretation of practical applicability. Of the 23 included studies, 12 were classified as high quality (70-100 points), 8 as moderate quality (40-69 points), and 3 as low quality (below 40 points). Low-quality studies were retained in the synthesis but their limitations were explicitly noted in the interpretation of findings. Studies originated primarily from developed countries (18/23), with limited representation from developing nations despite their significant role in global mineral production.

5. Discussion

5.1 Principal Findings and Research Gap Analysis

This systematic review provides the first comprehensive mapping of the tri-disciplinary intersection between mineral resource management (MRM), artificial intelligence (AI), and regulatory policy (RP). Despite robust individual domain literatures—1,708 MRM studies, 167,310 AI studies, and 1,220 RP studies—not a single study integrating all three was identified across six major databases. This void represents a significant opportunity for advancing intelligent governance frameworks in mineral resource management. The five research gaps identified (comparative framework absence, metric deficiency, communication fragmentation, integration strategy void, and evaluation framework absence) reflect structural barriers that transcend any single discipline and must be addressed through deliberate interdisciplinary collaboration.

The identified research gaps align with broader challenges in interdisciplinary research, where traditional academic structures and publication practices often reinforce disciplinary silos. The pronounced difference between technical AI research (concentrated in IEEE publications) and governance research (concentrated in policy journals) reflects deeper epistemological and methodological divisions that hinder the development of integrated approaches to complex socio-technical challenges.

5.2 Comparison with Existing Literature

While systematic reviews exist within individual domains, this study represents the first attempt to systematically map the intersection of MRM, AI, and regulatory policy. Previous reviews in AI applications for mining (Corrigan and Laye 2022) focus primarily on operational applications without considering regulatory implications. Similarly, reviews of mineral governance (Vandome and Dechambenoit 2020) examine policy frameworks without incorporating technological innovations. This review demonstrates that the integration of these perspectives remains unexplored territory in academic literature. Cross-sectoral evidence from five regulated industries—financial services, healthcare, transportation, energy, and agriculture—reinforces this finding and offers instructive governance precedents. In financial services, the EU AI Act and the Basel Committee on Banking Supervision have established risk-tiered AI governance, requiring explainability and audit trails for algorithmic decision systems (Bank for International Settlements 2025; U.S. Government Accountability Office 2025). Healthcare governance through the Software as Medical Device framework demonstrates how adaptive, lifecycle-based regulation can accommodate AI systems that continuously learn and update (Muehlematter et al. 2021; U.S. Food and Drug Administration 2021). The transportation sector illustrates regulatory lag: despite rapid advances in autonomous vehicle AI, comprehensive federal frameworks remain incomplete, resulting in fragmented state-level oversight and unresolved liability attribution challenges (International Transport Forum-OECD 2025; U.S. Department of Transportation 2016). In the energy sector, multi-layer governance structures spanning federal, state, and utility levels have been developed for AI-optimized smart grids, though algorithmic explainability for non-technical stakeholders remains an unresolved concern (Volkova et al. 2023; U.S. Department of Energy 2024). Agricultural AI governance, an emerging frontier, has similarly identified the need for domain-specific frameworks that accommodate variable data quality, seasonal decision cycles, and

smallholder equity considerations—challenges structurally analogous to those in mineral resource governance. Across all sectors, recurring governance patterns emerge: adaptive regulatory frameworks, transparency and explainability mandates, risk-based classification hierarchies, and multi-stakeholder engagement mechanisms. Critically, none of these patterns have been applied to mineral resource management, where geological uncertainty, multi-decadal project timelines, commodity price volatility, and sovereignty considerations create a uniquely complex governance environment. The absence of such frameworks in the mineral domain, despite their proven utility elsewhere, further underscores the urgency of the tri-disciplinary research gap this study identifies.

5.3 Implications for Theory and Practice

The identified tri-disciplinary gap has significant implications for both theoretical development and practical implementation. Theoretically, the absence of integrated frameworks suggests the need for new conceptual models that can bridge technical AI capabilities with governance requirements and domain-specific mineral resource management needs. The development of such frameworks requires collaboration across disciplinary boundaries and the creation of shared conceptual vocabularies.

From a practical perspective, the research gaps suggest that current AI implementations in mineral governance may be occurring without adequate theoretical foundation or systematic evaluation. This ad hoc approach risks suboptimal outcomes and missed opportunities for leveraging AI's full potential in improving mineral resource governance effectiveness and democratic accountability.

5.4 Methodological Considerations

The systematic review methodology successfully identified the research void, but also revealed challenges in conducting interdisciplinary research synthesis. The diverse terminologies, methodological approaches, and publication practices across the three domains created significant challenges for systematic searching and study identification. Future research in this area may benefit from alternative search strategies that can better capture interdisciplinary work published outside traditional disciplinary venues.

6. Study Limitations

This systematic review encounters several key limitations that affect the validity and generalizability of findings. The restriction to English-language publications excludes research from non-Anglophone countries. Many nations with substantial mineral resources publish valuable studies in their native languages. This language constraint creates a geographic bias that underrepresents developing countries with the predominance of global mining operations.

The focus on academic databases neglects practical sources such as government reports and industry documents. These sources contain real-world applications and implementation insights not available in scientific journals. The temporal restriction to publications from 2021 onward captured recent developments while potentially omitting foundational research that established current theoretical frameworks.

Determining study relevance to the three-domain intersection (mineral resources, artificial intelligence, and regulatory policy) required a subjective assessment. Relevant research may employ different terminology than the search strategy captured, particularly given the rapidly evolving nature of AI applications.

The analysis employed narrative synthesis rather than quantitative meta-analysis due to study heterogeneity. This methodological approach increases dependence on the researcher's interpretation, potentially introducing analytical bias. Different research teams might classify identical studies using alternative categorization schemes.

A pronounced geographic asymmetry characterizes the literature landscape. Developed nations dominate scholarly output while mining-intensive developing countries remain underrepresented. It results in a paradoxical knowledge gap where regions hosting the world's most significant mineral extraction operations receive disproportionately limited research attention. It is particularly evident in the stark underrepresentation of African scholarship despite the continent's pivotal role in global mineral supply chains. Regulatory frameworks vary substantially across jurisdictions, limiting the global generalizability of findings.

Artificial intelligence technology advances more rapidly than academic publishing cycles accommodate. Recent innovations may not appear in peer-reviewed literature due to publication delays. Policy implementation typically proceeds more slowly than technological development, creating temporal gaps between technical feasibility and practical evaluation.

These limitations suggest that actual research gaps may exceed those documented through this systematic approach. Future investigations should incorporate non-academic sources, broaden geographic representation, and engage more practitioners. International collaboration remains essential for capturing diverse governance contexts and ensuring global applicability of findings.

7. Path Forward: Architecting AI-Driven Mineral Resource Governance

This research agenda explores the integration of artificial intelligence (AI) within mineral resource management, highlighting both its challenges and opportunities. The study proposes a novel framework that unites experts from geology, AI, and regulatory policy into multidisciplinary teams to address existing sector challenges.

Central to this initiative is the identification of a three-way gap that has historically impeded progress. The work advocates for innovative methods that incorporate algorithmic sophistication within regulatory frameworks. The framework involves developing hybrid approaches that merge computational modelling with regulatory analysis and stakeholder engagement.

Key to this framework is the implementation of interpretable AI algorithms designed to enhance regulatory transparency and bridge the gap between technical capabilities and governance accountability. To measure success, we propose integrated evaluation metrics assessing both technical effectiveness and policy compliance, along with benchmarks for AI-driven governance within the complexities of mineral resource management.

By fostering collaborative research infrastructures, we aim to standardize terminologies and evaluation frameworks, facilitating meaningful dialogue among AI researchers, mineral specialists, and policy analysts. Ultimately, this study seeks to design adaptive governance systems that leverage AI's predictive capabilities to enhance regulatory responsiveness while promoting democratic oversight and stakeholder involvement, establishing a replicable model for intelligent governance innovation across regulations. Future empirical research should investigate cloud-based Enterprise Resource Planning (ERP) systems as core implementation infrastructure for AI-driven regulatory frameworks. Cloud ERP platforms offer distinct advantages for mineral resource governance: real-time integration of geological, financial, environmental, and compliance data streams; enhanced data security through enterprise-grade encryption and role-based access controls; rapid deployment without capital-intensive on-premise infrastructure; and cost-efficiency especially relevant for resource-constrained developing nations. By embedding AI decision-support modules within cloud ERP architectures, regulatory authorities could achieve continuous environmental monitoring, automated compliance tracking, and predictive policy analytics within a single, auditable platform. This integration pathway represents a practical bridge between the AI capabilities identified in technical literature and the governance accountability requirements emphasized in policy research—directly addressing the tri-disciplinary gap this study documents. Future work should develop proof-of-concept deployments in African mining jurisdictions, where the policy curse phenomenon and limited institutional capacity make cloud ERP-enabled AI governance particularly promising.

8. Conclusion

This research establishes a comprehensive framework for embedding AI-driven decision-making mechanisms into mineral resource management systems. By promoting innovative practices that support environmental sustainability and informed decision-making, this study aims to fill critical gaps at the intersection of technology and regulatory policy, enabling meaningful advancements in this field.

The systematic literature review reveals a complete absence of integrated studies spanning mineral resource management, artificial intelligence, and regulatory policy domains simultaneously. This tri-disciplinary void establishes a foundation for transformative governance structures that combine algorithmic sophistication with regulatory effectiveness, advancing intelligent policy-making in mineral resource management.

The proposed research trajectory offers unprecedented potential to overcome traditional management limitations, reduce resource curse effects, and establish intelligent mineral management governance that synthesizes computational capabilities with regulatory accountability for next-generation mineral resource policy frameworks.

Acknowledgement

The authors used AI in formatting and grammar checks.

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