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RESEARCH ARTICLE

TOWARDS A METHODOLOGICAL FRAMEWORK FOR PATENT-BASED TECHNOLOGICAL PROSPECTING IN THE MINERAL SECTOR: A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Technological prospecting has become increasingly relevant for the mineral sector due to growing pressures related to sustainability, operational efficiency and the global energy transition. In this context, patent analysis constitutes an important source of technological intelligence for monitoring innovation trajectories and supporting strategic decision-making. However, the literature reveals substantial methodological fragmentation regarding search strategies, data treatment and analytical transparency in patent landscaping studies applied to mining and metallurgy. This study aims to identify and systematise the principal methodological practices employed in patent-based technological prospecting studies in the mineral sector and to propose a structured methodological framework. A systematic literature review inspired by PRISMA guidelines was conducted using the Web of Science and Scopus databases. After screening and snowballing procedures, eight studies were selected for in-depth analysis. The results revealed heterogeneous methodological approaches, with emphasis on hybrid search strategies, integration between patent and scientific databases, expert validation and advanced analytical techniques such as clustering, TRIZ, PCA and artificial intelligence-assisted foresight. Based on these findings, a five-phase methodological framework was developed to improve transparency, replicability and analytical consistency in mineral-sector patent landscaping studies. The proposed framework contributes to technological intelligence, innovation management and technology transfer practices within mining and metallurgy.

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INTRODUCTION

In the twenty-first century, the strategic relevance of the mineral sector has become increasingly evident as global megatrends such as urbanisation, digitalisation and the energy transition intensify the demand for mineral resources and advanced industrial materials (PwC, 2024; World Economic Forum, 2024). The expansion of renewable energy systems, battery technologies, electrified transport and smart industrial infrastructure has substantially increased dependence on critical minerals and metallurgical inputs, positioning mining and mineral processing industries at the centre of global industrial transformation. Simultaneously, the sector faces growing pressure to improve operational efficiency, environmental performance and regulatory compliance under conditions of technological uncertainty and rising sustainability expectations (Olvera, 2021). Despite its strategic importance, innovation dynamics within the mineral sector present distinctive structural characteristics. Unlike science-based industries in which innovation is predominantly generated internally, mining has historically been characterised as a supplier-dominated sector, where technological advances are largely introduced through equipment manufacturers, engineering firms and Mining Equipment, Technology and Services (METS) providers (World Economic Forum, 2024; Olvera, 2021). Consequently, mining firms frequently innovate through the acquisition, adaptation and integration of externally developed technologies rather than through endogenous R&D processes alone. This configuration increases the strategic importance of technological intelligence capabilities capable of monitoring external technological developments, identifying emerging solutions and reducing uncertainty associated with technological adoption. Within this context, technological prospecting emerges as a strategic instrument for supporting decision-making under conditions of industrial and technological complexity. Technological prospecting can be understood as a systematic process aimed at identifying, analysing and interpreting scientific and technological signals in order to anticipate innovation trajectories, support research and development (R&D)

planning and reduce uncertainty in strategic decision-making processes (Antunes *et al.*, 2018; Mayerhoff, 2008). More broadly, prospecting activities contribute to the construction of future-oriented technological visions, enabling organisations to transition from reactive innovation behaviour towards more proactive and anticipatory strategic positioning. Among the different approaches employed in technological prospecting, patent analysis has become one of the most robust and widely adopted methodologies due to the standardised, structured and legally validated nature of patent documents (Pires, Ribeiro and Quintella, 2020; Firat, Woon and Madnick, 2008). Patent databases contain detailed technical descriptions, technological classifications, ownership information and temporal records of inventive activity, thereby constituting valuable sources for mapping technological evolution, identifying innovation actors and detecting emerging technological domains. The World Intellectual Property Organization (WIPO) and several studies emphasise that a substantial proportion of global technological information is disclosed exclusively through patent systems, often remaining unavailable in scientific publications or other technical communication channels (Quintella *et al.*, 2018).

Nevertheless, despite the growing use of patent landscaping and technological intelligence studies, the literature reveals important methodological limitations associated with transparency, reproducibility and analytical consistency. Grant, Van den Hof and Gold (2014) argue that patent prospecting studies frequently suffer from methodological fragmentation due to the absence of consolidated reporting standards and the limited transparency of search protocols. Similarly, Smith *et al.* (2017), in a systematic assessment of patent landscape studies, identified substantial deficiencies regarding the description of search strategies, database selection criteria and data treatment procedures, compromising analytical replicability and the reliability of conclusions. These limitations become particularly critical in the mineral sector, where technological prospecting involves substantial semantic complexity, interdisciplinary technological domains and highly specialised industrial terminology. Terms such as mining, extraction and processing frequently overlap with unrelated technological fields, including data mining and digital analytics, generating significant semantic noise during patent retrieval procedures. Moreover, the absence of standardised methodological frameworks increases the risk of incomplete searches, inconsistent technological mapping and distorted interpretations of innovation trajectories. From a strategic perspective, these methodological weaknesses have important implications for industrial decision-making. In supplier-dominated industries such as mining, inaccurate or poorly structured technological intelligence studies may compromise investment decisions, technological partnerships and R&D prioritisation processes. Consequently, the absence of rigorous and replicable methodological procedures limits the capacity of mining firms, policymakers and Technology Transfer Offices (TTOs) to identify technological opportunities, evaluate competitive positioning and support innovation strategies grounded in reliable technological evidence. In response to these challenges, the present study seeks to contribute to the methodological consolidation of patent-based technological prospecting in the mineral sector. More specifically, the study aims to identify, analyse and systematise methodological practices employed in patent landscaping studies related to mining, metallurgy and extractive industries, ultimately proposing a structured and replicable methodological framework for technological prospecting in the mineral sector. Rather than focusing on the technological performance of specific minerals or firms, the study concentrates on the methodological architecture underlying patent intelligence processes, including search strategy construction, database selection, data treatment, analytical techniques and expert validation procedures. The justification for this investigation derives from both theoretical and practical considerations. From a theoretical perspective, the literature still lacks consolidated methodological protocols specifically adapted to the realities of the mineral sector, despite the growing strategic relevance of technological intelligence for mining innovation systems. Existing studies often employ heterogeneous search procedures, inconsistent classification criteria and limited methodological transparency, restricting analytical comparability and cumulative knowledge development. From a practical standpoint, the increasing technological complexity of mining operations and the accelerating pace of industrial transformation reinforce the need for more robust technological intelligence tools capable of supporting strategic planning, innovation management and technology transfer processes. Accordingly, this study contributes by proposing a methodological framework grounded in transparency, analytical rigour and sector-specific technological intelligence principles. The proposed framework seeks to reduce methodological fragmentation and provide operational guidance for researchers, mining companies, innovation agencies and TTOs interested in conducting patent-based technological prospecting studies in the mineral sector.

To achieve these objectives, the article is structured into five sections. Following this introduction, Section 2 presents the theoretical background concerning technological prospecting, patent analysis and systematic literature review methodologies. Section 3 describes the methodological procedures adopted in the systematic review, including eligibility criteria, search strategies, data extraction and analytical synthesis procedures. Section 4 presents and discusses the results, focusing on the methodological practices identified in the analysed studies and the development of the proposed framework. Finally, Section 5 presents the concluding remarks, highlighting the principal contributions, limitations and future research perspectives associated with patent-based technological prospecting in the mineral sector.

THEORETICAL BACKGROUND

Technological Prospecting and Patent Analysis: Technological prospecting and Competitive Technical Intelligence (CTI) have become central instruments for strategic decision-making under conditions of technological uncertainty and accelerated industrial transformation (Canongia *et al.*, 2004; Firat *et al.*, 2008; Antunes *et al.*, 2018). While technological prospecting is primarily oriented towards identifying long-term technological trajectories and anticipating future innovation scenarios, CTI focuses on the systematic monitoring of external scientific and technological signals capable of revealing immediate opportunities, risks and competitive movements (Mayerhoff, 2008). Despite differences in temporal orientation, both approaches converge in their capacity to transform dispersed information into strategic knowledge applicable to innovation management, research planning and technology transfer processes (Santos *et al.*, 2004). Within this context, patent documents constitute one of the most valuable sources of technological intelligence due to their standardised structure, legal nature and high informational density (Paranhos, 2019; Firat *et al*., 2008). Patents provide detailed technical descriptions, identify inventors and assignees, reveal technological trajectories and allow the monitoring of inventive activity across sectors and countries. The literature frequently emphasises that a substantial proportion of global technological knowledge is disclosed exclusively through patent systems, making patent databases indispensable for understanding the state of the art and avoiding duplication of technological efforts (Quintella *et al*., 2018). Beyond their legal function, patents operate as indicators of technological capability, innovative behaviour and industrial competitiveness (Pires, Ribeiro and Quintella, 2020). Their analytical value is particularly relevant in sectors characterised by intensive R&D investments, cumulative technological trajectories and strong dependence on specialised knowledge, such as mining and metallurgy. In these industries, patent analysis enables the identification of emerging technologies, dominant technological domains, innovation clusters and strategic positioning of firms, universities and research institutions.

However, the strategic use of patents as intelligence sources requires recognition of important methodological limitations. One major constraint concerns the 18-month confidentiality period between filing and publication, which creates a temporal blind spot in technological monitoring (Paranhos, 2019). Moreover, not all innovations are patented, as firms frequently rely on industrial secrecy and tacit knowledge protection strategies. Additional challenges arise from inconsistencies in patent classification systems and semantic ambiguities associated with technical terminology, particularly in interdisciplinary technological domains (Firat *et al*., 2008).
These limitations reinforce the need for rigorous methodological procedures in patent landscaping studies. The reliability of technological prospecting depends not only on the retrieval of patent documents, but also on data cleaning, classification consistency, semantic refinement and analytical interpretation. As emphasised by Dantas *et al*. (2026), patent intelligence in the mineral sector requires contextualised analytical frameworks capable of integrating technological, industrial and territorial dimensions rather than relying exclusively on automated retrieval procedures.

Once such methodological challenges are addressed, patent prospecting becomes a powerful instrument for technological foresight and innovation strategy. Indicators such as patent families, citation networks and technological co-occurrence patterns enable the identification of technological convergence, emerging trajectories and so-called “white spaces” — domains characterised by low technological occupation and potential innovation opportunities (Kim and Bae, 2017). Consequently, patent analysis supports strategic R&D decisions, investment prioritisation and partner selection processes (Quintella *et al*., 2018). Patent landscaping also plays a critical role in technology transfer and intellectual property management. Prior-art searches and freedom-to-operate analyses reduce legal uncertainty and mitigate risks associated with infringement of third-party rights (Paranhos, 2019). Furthermore, patent information contributes to the assessment of Technology Readiness Levels (TRLs), supporting the transition from laboratory-scale research to industrial and commercial application (Quintella *et al*., 2018). In this sense, technological prospecting transcends descriptive mapping exercises and becomes part of broader technological intelligence systems capable of supporting strategic and evidence-based decision-making.

Methodological Approaches to Technological Prospecting

Technological prospecting studies are increasingly characterised by the integration of quantitative and qualitative analytical approaches, particularly through bibliometrics, scientometrics and text-mining techniques capable of transforming large volumes of unstructured information into strategic intelligence (Firat *et al*., 2008; Amparo, Ribeiro and Guarieiro, 2012). In patent-based studies, however, the effectiveness of analytical outputs depends fundamentally on the precision of the retrieval strategy employed.

The literature consistently demonstrates that search procedures based exclusively on keywords tend to produce substantial semantic noise due to ambiguity and polysemy in technical terminology (Paranhos, 2019). This problem becomes particularly critical in mining-related studies because terms such as mining frequently appear in contexts unrelated to mineral extraction, including data mining and text mining. Consequently, many authors recommend the integration of keyword searches with International Patent Classification (IPC) and Cooperative Patent Classification (CPC) systems, which provide more standardised and technically precise delimitations of technological domains (Kim and Bae, 2017). The combined use of keywords and IPC/CPC classifications has therefore become one of the principal methodological practices in technological prospecting. IPC and CPC codes allow researchers to identify specific technological attributes independently of linguistic variation, while keyword strategies increase sensitivity and retrieval breadth. Complementarily, citation network analysis enables the evaluation of technological influence, knowledge diffusion and cumulative innovation processes (Alessandri, 2023).

Another central methodological decision concerns the selection of patent databases. Open-access platforms such as Espacenet offer extensive international coverage and are particularly useful for exploratory searches, although they present limitations regarding large-scale data export and integrated analytical tools (Paranhos, 2019). Commercial systems such as Orbit Intelligence and Derwent Innovation provide more advanced functionalities, including multilingual retrieval, patent family consolidation and large-scale analytics, facilitating global technological monitoring (Rocha, 2020). Hybrid platforms such as Lens have also gained relevance by integrating patent and scientific publication data within accessible visual interfaces (Pires, Ribeiro and Quintella, 2020). The transformation of patent data into interpretable technological intelligence increasingly depends on advanced analytical techniques associated with tech mining approaches (Firat *et al*., 2008). Statistical and computational methods such as clustering algorithms, co-occurrence analysis and multidimensional scaling enable the identification of technological proximity patterns and emerging innovation domains (Jeong and Yoon, 2015). These techniques support the construction of patent maps and technological portfolios capable of translating complex technological relationships into visual representations useful for strategic decision-making (Han *et al*., 2021). More recently, technological prospecting studies have incorporated artificial intelligence and predictive analytics techniques, including machine learning, neural networks and Principal Component Analysis (PCA), expanding the transition from descriptive patent statistics towards technological foresight systems (Dantas *et al*., 2026). These approaches enhance the capacity to detect technological convergence, estimate innovation trajectories and support long-term strategic planning. Despite these methodological advances, the literature still reveals substantial fragmentation and lack of standardisation in patent landscaping procedures. Grant, Van den Hof and Gold (2014) argue that the field continues to suffer from limited conceptual consolidation and insufficient methodological transparency, particularly regarding query construction, exclusion criteria and data-cleaning procedures. Similarly, Smith *et al*. (2017) emphasise that patent studies often fail to provide sufficient detail to ensure analytical replicability. For this reason, several authors highlight the importance of expert validation throughout technological prospecting processes. Automated analytical procedures remain highly dependent on specialist interpretation, particularly in complex industrial sectors characterised by tacit knowledge, interdisciplinary technologies and heterogeneous classification systems (Paranhos, 2019). In mining and metallurgy, expert participation becomes essential not only for search refinement and thematic validation, but also for interpreting technological trajectories and sector-specific innovation dynamics.

Systematic Literature Reviews in Technological Prospecting Studies: Systematic Literature Reviews (SLRs) have become increasingly relevant as rigorous methodological instruments for synthesising scientific knowledge and reducing subjectivity in evidence-based research (Tranfield *et al*., 2003; Sampaio and Mancini, 2007). Unlike traditional narrative reviews, which are often characterised by interpretative flexibility and absence of explicit selection criteria, SLRs are structured around transparent and replicable protocols designed to minimise bias and ensure methodological consistency (Rother, 2007). The methodological logic underlying SLRs is particularly relevant to technological prospecting studies because both approaches involve large-scale information retrieval, data curation and analytical synthesis. As argued by Smith *et al*. (2017), patent landscaping studies share important similarities with systematic reviews, differing primarily in the nature of the analysed documents: patents rather than scientific articles. Both approaches require rigorous search design, eligibility criteria, filtering procedures and analytical standardisation.

The operationalisation of SLRs generally begins with the formulation of a clearly defined research question followed by the establishment of eligibility criteria, database selection and search protocols (Galvão and Ricarte, 2019). These procedures ensure transparency and enable auditability of the analytical process. In addition, systematic reviews require explicit justification of inclusion and exclusion criteria, thereby reducing arbitrary selection decisions and strengthening scientific validity (Brasil, 2014). In technological prospecting research, the adoption of systematic review principles contributes directly to improving methodological transparency and replicability. This is particularly important because patent landscaping studies frequently exhibit insufficient reporting of search strategies, inconsistent treatment of patent families and limited explanation of data-cleaning procedures (Grant, Van den Hof and Gold, 2014). By incorporating SLR principles into patent analysis, researchers can establish more robust and reproducible technological intelligence frameworks.

Furthermore, the exponential growth of scientific and technological information reinforces the strategic relevance of systematic reviews as mechanisms for knowledge organisation and methodological consolidation. In this sense, SLRs operate not merely as bibliographic surveys, but as analytical instruments capable of identifying methodological patterns, theoretical gaps and emerging research trajectories (Cavalcanti, 2016). Accordingly, the present study adopts a systematic review approach not only to map patent prospecting practices in the mineral sector, but also to support the development of a structured methodological framework grounded in transparency, analytical rigour and technological intelligence principles.

MATERIALS AND METHODS

This study was conducted as a systematic literature review of a methodological nature aimed at identifying, analysing and synthesising patent-based technological prospecting practices applied to the mineral sector. A systematic review approach was adopted instead of a narrative review because it provides greater transparency in the definition of the research problem, eligibility criteria, search procedures and analytical stages, thereby reducing selection bias and increasing the reproducibility and scientific robustness of the investigation.

The overall review design was inspired by the PRISMA recommendations for systematic reviews, although adapted to the context of methodological investigations in technological intelligence and patent landscaping. Since the objective of the study was not to assess intervention effects or empirical performance outcomes, but rather to examine methodological approaches and analytical procedures, the review adopted a descriptive-comparative perspective focused on identifying recurrent practices, methodological divergences and levels of analytical sophistication within the selected studies. More specifically, the review sought to understand how technological prospecting studies in mining and metallurgy operationalise critical stages of patent landscaping, including the definition of technological scope, search strategy construction, database selection, patent retrieval, data cleaning and normalisation, integration with scientific databases and application of foresight techniques. The methodological emphasis adopted in this study reflects the understanding that the quality and strategic value of patent-based intelligence depend fundamentally on the transparency, coherence and replicability of the analytical procedures employed.

Research question: The review was guided by the following central research question:"What methodological practices and protocols are reported in the literature for conducting patent-based technological prospecting studies in the mineral sector, considering the stages of search, selection, treatment and analysis of technological data?". This question was designed not only to identify operational procedures adopted in patent landscaping studies, but also to understand the analytical rationale underlying technological intelligence practices in mining, metallurgy and related extractive industries.

Eligibility criteria: The selection of studies followed predefined inclusion and exclusion criteria intended to ensure thematic relevance, methodological consistency and analytical transparency.

Eligible studies comprised peer-reviewed scientific articles and full conference papers employing patent analysis, technological prospecting or patent landscaping as a central methodological approach applied to mining, mineral processing, extractive industries or closely related technological sectors, such as metallurgy and heavy industrial equipment. Only studies presenting explicit methodological information regarding search protocols, database selection, patent retrieval procedures or analytical treatment were included. The review considered publications written in English and published between January 2010 and January 2025. The temporal cut-off was established in order to capture the consolidation period of contemporary patent landscaping approaches following the expansion of digital patent databases, bibliometric software and AI-assisted analytical techniques. Editorials, technical notes, extended abstracts, institutional reports without peer review and purely narrative reviews lacking systematic search procedures were excluded. Bibliometric studies focused exclusively on scientific publications without incorporating patent data were also excluded, since the primary interest of the present research concerned methodologies for processing technological information contained in industrial property documents.

Information sources: The primary searches were conducted in the multidisciplinary databases Web of Science and Scopus due to their broad international coverage and their capacity to index journals relevant to mining engineering, technology management, scientometrics and information science. The combined use of both databases aimed to increase retrieval sensitivity and minimise database-specific bias, given that technological prospecting studies are frequently distributed across interdisciplinary domains and may not be comprehensively indexed within a single platform. As a complementary strategy, Google Scholar was employed to identify additional studies through title-, author- and reference-based searches derived from the initially selected papers. This procedure reduced the risk of omitting relevant methodological studies not adequately indexed using conventional patent-related descriptors. All retrieved records were exported to Zotero for organisation and duplicate removal. Both automatic and manual verification procedures were employed, including cross-checking of titles, authors, publication years and DOI identifiers. Additionally, a snowballing strategy was applied through the analysis of reference lists from the included studies. This procedure proved particularly important because methodological studies in technological intelligence are often inconsistently indexed and may employ highly heterogeneous terminology.

Search strategy: The search strategy was constructed through the combination of three principal groups of descriptors: terms related to patent analysis and technological prospecting; terms directly associated with patents and intellectual property; and descriptors linked to mining, metallurgy and extractive industries. An iterative refinement process was employed during query construction. Initial exploratory searches revealed substantial semantic ambiguity associated with the term *mining*, which frequently retrieved studies related to data mining, text mining and computational intelligence unrelated to mineral extraction. Consequently, the search strategy was progressively refined through the incorporation of additional sector-specific terminology, explicit patent-related descriptors and semantic exclusion logic designed to reduce thematic contamination and false-positive retrieval. The final search strings combined technological intelligence descriptors such as “technology foresight”, “patent landscape*”, “technology prospect*”, “patent analy*”, “scientometric*” and “technology map*” with patent-related expressions and detailed mineral-sector terminology including “mineral processing”, “ore processing”, “metallurgical industr*”, “mineral extraction”, “coal mining”, “gold mining”, “copper mining” and “iron ore”. In Scopus, the query was applied to the TITLE-ABS-KEY fields, whereas in Web of Science the TS field was employed. Equivalent strings were adapted according to the syntax requirements of each database platform. Language and temporal restrictions were applied during the screening stage rather than during the initial retrieval process in order to maximise sensitivity. The detailed search strings, execution dates and refinement adjustments may be presented in appendices to ensure procedural transparency and auditability.

Study selection process: The study selection process followed sequential screening stages aimed at progressively increasing thematic precision and methodological adherence. Initially, all retrieved records were screened based on titles and abstracts. At this stage, studies presenting clear thematic misalignment — particularly those related to data mining, healthcare technologies, information systems or unrelated engineering domains — were excluded. The remaining studies were subsequently evaluated according to the predefined eligibility criteria, focusing on the explicit use of patent analysis as a core methodological component, relevance to mining or metallurgy and minimum methodological transparency concerning search procedures and analytical techniques. Studies meeting these conditions were selected for full-text assessment. The full-text analysis examined search protocols, database selection procedures, treatment and cleaning of patent data, analytical indicators employed, integration with scientific databases and the use of advanced foresight approaches. Finally, the corpus was complemented through snowballing procedures, enabling the inclusion of additional methodologically relevant studies not identified during the initial electronic search.

Data extraction: Data extraction was conducted using a standardised analytical spreadsheet specifically developed for the review. The extraction protocol was initially tested on a pilot sample of studies and subsequently refined to ensure consistency, comparability and analytical reliability. For each included study, bibliographic information and methodological variables related to patent prospecting procedures were systematically recorded. Special attention was given to the identification of methodological transparency indicators, replicability practices and procedures related to specialist validation and technological interpretation.

Data synthesis and analysis: Data synthesis was conducted through a descriptive-comparative analytical approach, since the heterogeneity of objectives, technological domains and analytical techniques rendered traditional quantitative meta-analysis inappropriate. The studies were initially grouped according to application domain, scope of technological prospecting and level of methodological sophistication. Subsequently, a cross-sectional comparative analysis was performed in order to identify recurrent methodological practices, convergences and divergences in search strategies, patterns of analytical sophistication, data treatment standards and the role of specialist validation throughout the prospecting process.

Particular emphasis was placed on identifying methodological practices associated with hybrid search strategies, patent family treatment, semantic exclusion filters, integration between scientific and patent information, advanced foresight approaches and expert-assisted analytical validation. Based on this synthesis, a structured methodological framework for patent-based technological prospecting in the mineral sector was proposed. The framework was organised into sequential phases encompassing definition of technological scope, identification of Key Intelligence Topics (KITs), database selection, construction of hybrid search strategies, data collection and normalisation, indicator generation, network analysis and technological foresight. The proposed framework was constructed from the most recurrent and methodologically consistent practices identified in the literature, combined with principles of transparency, replicability and strategic technological intelligence. Accordingly, the model seeks to provide a practical and adaptable methodological guide for researchers, Technology Transfer Offices (TTOs), mining companies and organisations interested in employing patent landscaping as a strategic instrument for innovation management, technology transfer and technological intelligence in the mineral sector.

RESULTS

Characterisation of the analysed corpus: The review began with an expanded retrieval strategy combining descriptors related to patent analysis and technological prospecting with broad mineral-sector terminology. Initial searches employed expressions such as “patent analysis”, “patent landscaping”, “technology foresight”, “technology mapping” and “tech mining” associated with descriptors including “mining”, “mineral processing”, “ore processing”, “metallurgy”, “mineral extraction” and “extractive industry”. In Web of Science, the preliminary strategy retrieved 414 records, subsequently reduced to 409 following document-type filtering and to 399 after language restrictions. In Scopus, the equivalent search logic retrieved 699 records, of which 652 remained after the application of similar filters. However, exploratory examination of the results revealed substantial semantic ambiguity, particularly due to the widespread use of the term *mining* in unrelated contexts such as data mining, text mining and computational intelligence. This thematic contamination generated a large number of false positives and reduced the alignment of the retrieved corpus with the objectives of the study.

In response, the search strategy was refined through the incorporation of additional technological intelligence descriptors, explicit patent-related terminology and more specific mineral-sector expressions. The revised query substantially increased thematic precision and reduced semantic noise.Following refinement, 38 potentially relevant studies were identified across both databases. After duplicate removal, the corpus was reduced to 29 studies. Application of the temporal filter retained 26 publications from 2010 onwards. Title and abstract screening conducted according to the predefined eligibility criteria resulted in the exclusion of studies that merely mentioned intellectual property tangentially or discussed mining innovation without effectively employing patent analysis as a central methodological procedure. Nineteen studies were subsequently selected for full-text analysis. Nevertheless, practical limitations related to access to complete documents reduced the number of studies available for in-depth assessment. Following all retrieval attempts, seven studies were fully obtained and analysed. An additional study was identified through snowballing procedures, resulting in a final analytical corpus composed of eight studies.

Rather than representing a methodological weakness, the limited size of the final corpus reflects an important characteristic of the field itself: the low level of methodological standardisation and transparency within patent landscaping studies applied to mining and metallurgy. A substantial portion of the literature mentions patents only superficially, without adequately describing search protocols, data treatment procedures, classification criteria or analytical methods. Despite these limitations, the progressive refinement of search queries, systematic filtering procedures, critical screening and complementary snowballing ensured the construction of a methodologically coherent and analytically robust corpus aligned with the objectives of the review. The selection process additionally suggests that technological prospecting in the mineral sector remains at an intermediate stage of methodological maturity. Although the use of patents as strategic intelligence tools has expanded significantly in recent decades, the analysed studies still reveal considerable heterogeneity in search procedures, analytical sophistication and reporting transparency, limiting comparability and replicability across investigations.

Methodological practices and best practices identified in the analysed studies: The analysis of the selected studies revealed the absence of a single consolidated protocol for conducting patent landscaping in the mineral sector. Instead, a heterogeneous set of methodological approaches was identified, varying according to analytical objectives, technological scope, data availability and levels of analytical sophistication. Nevertheless, recurrent methodological patterns emerged regarding search strategy construction, integration between patent and scientific databases, treatment and normalisation of patent data, specialist participation and the progressive incorporation of advanced foresight techniques. Three principal search approaches were identified. The first consisted of hybrid strategies combining IPC classifications, keywords and company names in order to capture both technological domains and industrial actors. This approach proved particularly effective for identifying innovation ecosystems involving mining firms, equipment manufacturers and Mining Equipment, Technology and Services (METS) companies. A second group of studies employed exclusionary semantic logic through the use of negative Boolean operators and exclusion dictionaries aimed at eliminating thematic contamination associated with adjacent sectors such as oil, gas and computational data mining. These procedures significantly improved semantic precision and reduced false-positive retrieval. The third approach was based primarily on firm-centred searches focused on the patent portfolios of specific mining or metallurgical companies. Although particularly useful for competitive intelligence and analysis of internal R&D capabilities, this strategy presented limitations for identifying emerging technologies developed by universities, start-ups or external innovation networks. Another important finding concerned the increasing integration between patent databases and scientific publication databases.

Table 1. Data extraction protocol adopted in the review

Category	Variables / Elements Extracted	Analytical Purpose
General bibliographic information	Authors; publication year; journal or conference title; country or principal institutional affiliation	Identification of temporal, geographical and institutional patterns in the literature
Patent and bibliographic databases	Patent databases and scientific databases employed	Identification of information sources and technological intelligence infrastructures
Search strategy	Keywords; IPC/CPC codes; search fields; exclusion filters and Boolean operators	Analysis of retrieval logic and thematic delimitation procedures
Temporal scope	Timeframe adopted in the technological analysis	Identification of longitudinal and retrospective analytical approaches
Data treatment procedures	Duplicate removal; assignee name normalisation; patent family counting; legal status filtering; ownership verification	Evaluation of data cleaning, standardisation and analytical reliability
Analytical indicators and techniques	Temporal evolution analysis; leading assignees; geographical distribution; technological classifications; citation networks; co-occurrence analysis; text mining; clustering; AI-assisted approaches	Identification of analytical sophistication levels and technological intelligence practices
Software and analytical tools	Bibliometric software; spreadsheet analysis; network visualisation tools; statistical applications; text-mining software	Identification of computational and analytical infrastructures employed

Source: Authors' own elaboration.

Table 2. Methodological characteristics of the analysed studies

Study	Objective	Databases used	Search strategy	Analytical techniques	Role of experts
Daly, Valacchi and Raffo (2019)	Mapping innovation in mining	WIPO, Orbit	IPC + keywords + firms	Patent statistics	Sectoral validation
Chen et al. (2024)	Smart mining analysis	Incopat + WoS	Keywords + exclusion filters	Clustering and co-occurrence analysis	Cluster validation
Ruiz-Coupeau et al. (2020)	Mineral technological intelligence	Orbit + WoS	KITs + patents + articles	Integrated bibliometrics	Experts define topics
Savchenkov et al. (2020)	Steel-industry patent strategies	Russian patent databases	Firm-centred searches	Patent portfolio analysis	Strategic interpretation
Nikulin et al. (2013)	Technological evolution in mining	Patents + TRIZ	Technological searches	TRIZ and S-curves	Expert classification
Romanova and Sirotin (2017)	Metallurgical foresight	Regional patent databases	Technological keywords	PCA and neural networks	Scenario interpretation
Baglaeva et al. (2019)	Science–technology integration	WoS + Derwent	Hybrid searches	Comparative bibliometrics	Thematic assessment
Snowballing-derived study	Methodological complement	Multiple sources	Reference-based searches	Qualitative synthesis	Methodological curation

Source: Authors' ownelaboration.

Studies combining patent information from systems such as Orbit, Derwent and Incopat with bibliographic data from Web of Science demonstrated the analytical advantages of integrating scientific and technological trajectories. Such integration enabled the identification of emerging technological domains, gaps between academic research and industrial application and technologies transitioning from science to market deployment. The review also demonstrated that specialist participation remains fundamental throughout all stages of technological prospecting. Experts contributed not only to the definition of Key Intelligence Topics (KITs) and search strategies, but also to the validation of clustering procedures, technological interpretation and foresight analysis. These findings suggest that, within mining and metallurgy, purely automated approaches remain insufficient due to the complexity, tacit knowledge requirements and sector-specific interpretation demands associated with technological intelligence. Data treatment and normalisation procedures also emerged as critical components of methodological robustness. Best practices identified in the literature included patent family counting to avoid multiple counting of the same invention, assignee-name disambiguation, filtering according to legal status and exclusion of patents acquired from third parties when the objective was to measure endogenous innovation capabilities. The studies additionally revealed a clear transition from descriptive patent statistics towards more advanced technological foresight approaches. Earlier investigations concentrated primarily on indicators such as patent counts, leading countries, applicant firms and IPC distributions. More recent studies, however, increasingly incorporated clustering techniques, text mining, co-occurrence analysis, network visualisation, artificial intelligence, Principal Component Analysis (PCA), TRIZ methodologies and neural networks. This methodological evolution indicates that patent landscaping in the mineral sector is progressively shifting from static descriptive mapping towards integrated systems of technological intelligence and strategic foresight capable of supporting innovation management and long-term technological planning. Based on the comparative analysis, four broad methodological profiles were identified: technology-driven approaches centred on IPC codes and keywords; firm-centred approaches focused on corporate patent portfolios; hybrid intelligence models integrating patents, firms and scientific publications; and AI-assisted foresight approaches employing predictive and computational intelligence techniques. Despite these advances, important methodological limitations remain evident across the literature, including low transparency in query construction, limited standardisation of protocols, restricted replicability and strong dependence on proprietary patent databases. These characteristics suggest that patent landscaping applied to mining and metallurgy remains a field undergoing methodological consolidation. The findings of the review provided the empirical basis for the development of a structured methodological framework integrating the principal best practices identified throughout the literature.

The proposed framework incorporates hybrid query construction, integration between patents and scientific publications, data normalisation procedures, specialist validation and foresight-oriented analytical techniques within a coherent and replicable sequence of technological intelligence activities.

FINAL CONSIDERATIONS: The systematisation of the methodological practices identified in the literature enabled the consolidation of a five-phase framework that operationally synthesises the current state of the art in patent-based technological prospecting applied to the mineral sector. The proposed framework is grounded in the recognition that mining and metallurgy are highly context-dependent industries shaped by technological, geological, economic and regulatory specificities that cannot be adequately captured through generic or purely automated patent retrieval approaches. Unlike conventional patent landscaping models that begin directly with database searches, the framework proposed in this study emphasises the importance of strategic problem definition and specialist participation from the outset.

The initial phase focuses on the identification of Key Intelligence Topics (KITs) and the mapping of innovation ecosystems involving mining firms, universities, suppliers and Mining Equipment, Technology and Services (METS) companies. This approach reflects the understanding that technological intelligence in mining depends not only on technological descriptors, but also on the institutional and industrial configuration surrounding innovation processes. Subsequent stages integrate hybrid search strategies combining IPC/CPC classifications, keywords, firm-based searches and semantic exclusion filters designed to reduce thematic contamination and improve retrieval precision. The framework also incorporates rigorous data treatment procedures, including patent family counting, assignee-name disambiguation and filtering according to legal status and ownership structure, thereby improving the analytical reliability of patent indicators.

The final stages of the framework guide the transition from descriptive patent analysis towards broader technological foresight approaches integrating bibliometric analysis, co-occurrence networks, clustering techniques, TRIZ methodologies, S-curves, PCA and AI-assisted analytical tools. Consistent with the studies analysed throughout the review, the framework additionally emphasises continuous expert validation during all analytical stages, recognising that technological interpretation in mining and metallurgy requires substantial tacit and sector-specific knowledge.

Accordingly, the proposed framework does not seek to replace existing methodologies,but rather to integrate dispersed methodological contributions into a coherent, transparent and replicable analytical structure adaptable to different mineral segments and national contexts. The study therefore contributes both methodologically and practically by offering guidance for researchers, Technology Transfer Offices (TTOs), mining companies and policymakers interested in employing patent landscaping as a strategic instrument for technological intelligence, innovation management and technology transfer.
More broadly, the findings indicate that patent landscaping in the mineral sector remains an evolving field characterised by substantial methodological heterogeneity and limited standardisation. By comparatively systematising the principal methodological approaches identified in the literature and proposing an integrated analytical framework, the present study contributes to advancing the methodological maturity, transparency and replicability of technological prospecting studies in mining and metallurgy.

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