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Towards an Understanding of Project Finance in the Mining Sector in the Sustainability Context: A Scientometric Analysis

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Abstract: The purpose of this study is to analyze the extant literature on Project Finance (PF) with a comprehensive understanding of the status quo and research trends in the mining industry. Thus, this study utilizes a scientometric review of global trends and structure of PF and mining research from 1977 to 2020 using techniques such as co-author, co-word, co-citation, and cluster analyses. A total of 80 bibliographic records from the Scopus database were analyzed to generate the study's research through scientometric networks. The findings indicate a steady growth of the research field, which includes Environmental, Social, and Governance criteria. The most significant contributions have originated mainly from the United States, Australia, the United Kingdom, and South Africa. The main research trends identified several issues related to risk, management, and financing concerns. This study provides researchers and practitioners with a comprehensive understanding of the status quo and research trends of ontology research within PF in the mining context and promotes further studies in this domain.

Keywords: project finance; sustainability; mining projects; bibliometric analysis

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1. Introduction

Although the first appearance of Project Finance (PF) was many centuries back, when the British Crown financed silver mines through non-recourse loans from Italian merchant banks [1], nowadays, it has a pivotal role, especially for developing infrastructure systems [2]. The development of both public and private infrastructure systems is capital intensive [3]. Based on Global Infrastructure Outlook (2019) data, the World Economic Forum (2019) estimates that the world faces a $15 trillion infrastructure systems gap by 2040. It is mainly represented by Americas ($6.5 Trillion), Asia ($4.6 Trillion), Europe ($2 Trillion), Africa ($1.7 Trillion), and Oceania ($0.2 Trillion) [4,5].

In this regard, the growing demand for capital and infrastructure investment remains significant given the globalization of markets, new regulations in key industries, and privatization of public entities worldwide. In this way, in order to increase not only coverage but also improve the quality in the infrastructure systems both social and economic, sustainability issues have more importance than years ago [6]. Thus, infrastructure development is a proper way of achieving the Sustainable Development Goals (SDGs) [6–9].

PF is one of the most important techniques for developing infrastructure systems [10,11]. This has been widely used together with Public-Private Partnerships (PPPs) for encouraging private investors to participate in the development of both greenfield and brownfield projects, which include airports, hospitals, mining, highways, power generation, mines, sewage treatment, among others [12–14]. In this way, the recent growth of PPPs is closely related to PF, given the characteristics that make it suitable for developing infrastructure

systems [12,15]. Thus, given the limitations of public funds available for infrastructure investment, governments encourage private sector entities to enter into contractual agreements for the financing, development, and operation of capital-intensive projects [16], as are mining ones. Based on this issue, private investors and governments have used both PF as PPPs to raise financial resources and thus, close the coverage gap [14].

In this context, PF has had a fundamental role as an investment vehicle for developing infrastructure systems and as a mechanism for sharing and mitigating risk [17]. Thus, based on financial needs, sustainable financial mechanisms, particularly transition bonds (green bond's subset), play a pivotal role in developing sustainable mining projects. It is important to highlight that, in the short to medium term, all financial mechanisms should be aligned with the SDGs; this applies to all sectors and projects. Given the importance of the mining sector in different industries and sectors, research that allows for a better understanding of financing strategies is necessary. Thus, studies of how PF has been used in the mining sector and its relationship with the SDGs will improve project development standards.

Although PF is often compared to corporate finance, there is an essential difference between both. In PF, the debt is lent to the Special Purpose Vehicle (SPV), while in corporate finance, debt is taken over by company [18,19]. Consequently, corporate finance acquires the form of an on-balance sheet financing, whereas PF deals as off-balance-sheet financing as the contracted is not evident on the accounting statements of the sponsors [20]; thus, infrastructure systems are financed by non-recourse or limited recourse debt financing structure and focusing on one specific project [15]. In this way, PF appears as an opportunity for increasing the borrowing capacity of the sponsors, with insignificant repercussions on their credit metrics [20–22].

PF involves the structured financing of a specific economic entity, which is also known as an SPV [11]. This is created by sponsors using both equity and debt to finance the project's assets, being the two primary financing sources [23] with a more significant proportion in debt which leverage ratio could be between 70% and 100% approximately [21]. For that reason, cash flows generated by the SPV must be enough to cover operating expenses (Opex), debt service (interest plus principal), and return to equity [11,24]. In this regard, high leverage offers opportunities to incorporate debt aligned with the SDGs into the capital structure.

Similarly, ref. [25] defines the SPV as the creation of a legally independent project society financed with equity from one or more sponsors and non-recourse debt to invest in a capital asset. Therefore, both financial resources and assets must be managed by SPV, which allows the sponsors to be shielded against the risks inherent in the projects [22]. Hence, the SPV allows lenders to have a real and tangible guarantee, which they could require in case of project default on debt [19], and thus, lenders have no claim to any other assets than the project itself [26].

As is logical, there are companies of different sizes within the mining sector; they are also distributed in various activities within their value chain such as exploration, production, processing and/or transportation, which can be unique or multiple for certain companies. This profile size and activities are key to determining the financing possibilities, the difficulties faced, and the relationship between PF and SDGs.

In general terms, companies oriented towards production and processing, and larger, have multiple alternatives when it comes to obtaining funds. At the same time, small companies in exploration and prospecting work face considerable barriers to financing projects, depending to a greater extent on external financing. In the first case, large companies tend to prefer internally generated funds as financing, while small companies, with limited internal funds and viewed with suspicion by lenders for corporate debt, tend to use non-recourse schemes such as PF or other innovative mechanisms to ensure financing their projects.

As can be observed, given all these special features, PF has trends research in the existent literature, which has been diverse. It has ranged from studies in project management, finance, economics, strategic planning to sustainable development, particularly in

project management, risk, capital structure, contracts, PPPs, infrastructure, investment, and others, applied to both social and economic infrastructure systems. Consequently, the relationship between sustainability and PF is a broad and complex research field with several applications in different disciplines and industries, which has resulted in a considerable potential field for quantitative and descriptive research. Thus, going beyond this topic is encouraged by the potential for developing new financial theories, and therefore, publications on this topic in journals and textbooks have been increasing in the last years at an exponential pace.

Knowledge Gap, Objective, and Contributions

Despite this increase, applied research or related to the mining industry has been scarce. The studies prepared to date do not stand out for their volume or their impact, which is paradoxical given the potential and differentiating characteristics described of PF for infrastructure projects in the mining sector. The research focused on the relationship between PF and mining, although much more incipient, has also followed the growing trend in terms of publications in recent years. Likewise, the existing literature has addressed aspects ranging from the most technical aspects of mining activity, such as the discussion about mineral reserves and their calculation methods, to examinations closer to the financial field, such as comparing alternatives for financing mining projects. Despite this diversity of research approaches, the depth in each one has been reduced, which accounts for the unexplored and disjointed field, despite extensive PF research and mining. This situation does not mean in any way the non-existence or diffuse relationship between PF and mining. On the contrary, it is surprising because it contrasts with the wide range of this relationship in practice that has been recognized and applied for several decades now [27–31].

In order to gather researches on this topic, unlike PPPs, which has several review papers, very few review papers that have PF as core have been published. These have mainly focused on indicating the research progress draws from interdisciplinary perspectives, analyzing the relationship with PPPs, integrating project management and international business, financing, and contract design. For instance, ref. [32] provided an overview state of research in PF. This study reviewed the body of work published in scientific journals in 2009–2013 non indicating what database was used or how many papers were used for the analysis; however, 25 papers were cited. It concluded with four core research areas, namely, (1) contractual arrangements and the legal framework, (2) project risk measurement and project selection methods, (3) globalization of project development and public sector cooperation, and (4) projects under the SDGs.

Also, based on specialized journals categorized in the Journal Citation Reports (JCR), as well as publications of multilateral organizations related to infrastructure project development, ref. [33] carried out a characterization of stages, risks, control, and monitoring mechanisms explaining the difference with the traditional way of financing all kinds of infrastructure systems. Although this study also did not indicate how many papers and documents were used for the analysis, 95 were cited in total. Likewise, this concluded with four research trends: project management, contractual arrangements, financing, and environmental. Based on the review of specialized literature, the authors described further research. Some of the most important topics were real options, sustainable financing, capital structure, discount rate, among others.

Moreover, ref. [34] provided a review of the state-of-the-art indicating the main features to explain the role of the PF participants and the main contractual arrangements. This work analyzed 148 papers from Scopus covering the period 1969–2020. Unlike other literature reviews, this study analyzed empirical case studies from different perspectives, which included risk management, financial analysis, operational research, management, regional studies, and sectorial applications. Further research, which was based on innovative ways to fund projects, was indicated.

Similarly, ref. [35] undertook a bibliometric analysis of papers relating to PF and PPPs. Scopus was used and more than 600 papers published between 1990 and 2020

were examined. This work found that PF and all studies related to PPPs appear to have a steady momentum toward growth. Most of the current works focus on contract design, risk-sharing, and analyzing the contract performance and benefits, neglecting areas such as contract termination and renegotiation. The area of management is regarded as a leading field for further research for academics and professionals. Although this study is bibliometric, no analysis was carried out based on networks, maps, or clusters.

On the other hand, ref. [2] analyzed the global phenomenon of PF as both a management and finance instrument in the international context. The author summarized the main findings from an interdisciplinary perspective, particularly on the integration among finance, management, and international business, using 95 papers, almost all of them from Scopus. Also, it proposed a research agenda on the three most promising related to international business and management; thus, financial arrangements, transaction cost economics, and financing foreign investments in risky contexts.

From a financial perspective, ref. [36] performed a state-of-the-art of financial sustainability in PF, particularly for toll roads. This study reviewed 29 research papers and other documents among conference proceedings, presentation materials from industry, and master's and doctoral theses for 1999–2020 non indicating what database was used. As can be observed, although these literature reviews give insight on PF research, none have focused on the mining field, and almost all of them are qualitative that prone to subjectivity offering a non-holistic characterization of PF challenges, and thus, it is not just possible to capture more than single measures. Thus, there is a need for more in-depth analysis, which allows new ways for further research to extend the PF and mining literature towards an academic and practical approach.

To help bridge the identified knowledge gap, this research aims at undertaking an in-depth scientometric study of PF and mining to provide researchers and project managers with a comprehensive understanding of the status-quo and research trends to provide structure and direction to the existing and future research at a specific level.

To the best of the author's knowledge, no previous research on the body of knowledge in PF mapped out the linkage or working relationships employing networks. Also, no previous studies have analyzed in-depth aspects such as co-author, citation clusters, or research keywords clusters.

The findings of this study will allow to emphasize the trends and patterns and thus establishing the foundations of research processes in this field and outline strategies to provide insights that keep advancing in the knowledge frontier in the PF-mining domain. It is also expected that this study helps define policies and best practices to encourage private participation in the development of infrastructure systems and the creation of new financial mechanisms that allow having a broader source of financing resources.

To highlight the importance of research on PF, ref. [1] notes the academic and practical benefits obtained through the capacity to conduct research in a productive and informative environment. Thus, this paper endeavors to make three substantial contributions to the existing body of knowledge and practice. First, this study is the first to integrate a scientometric analysis that provides an appropriate setting for articulating the main issues this research addresses. Second, this study compiles, manages, structures, and classifies a wide-ranging PF research body within the project management and mining world. Third, it exemplifies how opportunities for further research can be detected by applying abductive reasoning to the networks and topic cluster reviews, and thus, it is possible to describe challenges from empirical and theoretical literature.

The rest of this paper is organized as follows. In Section 2, the research approach utilized and the literature search and indexing strategy are discussed. Section 3 presents the results of the different scientometric analyses with different knowledge graphs along with their discussion and interpretation. Section 4 outlines the conclusion and future directions. The findings in this research are expected to provide researchers and practitioners with a comprehensive understanding of the status quo and research trends of ontology research

within PF in the mining context and promote further studies in this domain. It will also serve as a consultation toolkit for policymaking for government agencies.

2. Materials and Methods

This study analyses the linkage and relationship among PF and mining research using network analysis based on diagrams and maps provided by scientometric techniques. The scientometric is a set of techniques that allows for a broader yet concise capturing and mapping of a scientific knowledge area by identifying structural patterns and tracing salient research frontiers using mathematical formulae and visualization [37].

This study employs four scientometric techniques which analysis: (1) co-author (2) co-word, (3) citation, (4) cluster. These analyses and their visualization have been performed using VosViewer software version 1.6.14. It was developed by Nees Jan van Eck and Ludo Waltman [38]. This has been used in several studies of diverse disciplines [39–45]. According to [41,44], given that scientometrics includes all quantitative aspects of scientific research, it has been widely used to measure the impact of scientific contributions as well as monitor scientific developments, identify emerging trends, and map science patterns that allow identifying the internal composition of a specific topic. Likewise, the scientometric review can solve the essential limitation of traditional review articles: the lack of rigor to some extent (e.g., subjective and impressionistic description) [45].

Therefore, to achieve the study aim, the four scientometric techniques which will be employed will be used to (i) track the evolution of the research field, (ii) identify the key researchers and institutions. Also, part of the objectives of this study is to (iii) identify the key subject categories, (iv) research keywords and co-citation clusters as well as (v) deduce the salient and emerging research themes. Meanwhile, a corpus of journal articles, conference proceedings, books, and other types of documents would be analyzed. As mentioned before, the study's findings are expected to contribute to the existing body of knowledge by highlighting the trend and pattern of PF-Mining research field, establishing its research themes and clusters, mapping the network of key researchers and institutions, and recommending areas for future studies.

Before determining the academic databases used for article search and selection, and as an initial screening process, pre-search was carried out to ensure that the selected academic databases were reasonable and had the most research papers published on PF concerning mining. Thus, this process was executed in Scopus and Web of Science (WoS) database. In both "Project Finance", "Project Financing", "Mining" and "Mines" were used as keywords. Finally, the Scopus database was chosen as the most appropriate option to carry out the study since it includes several more documents compared to WoS. In this way, a total of 80 documents were obtained in December 2020 using the following search equation: (TITLE-ABS-KEY "Project finance" OR "Project financing") AND TITLE-ABS-KEY ("Mining" OR "Mines"). After these, papers and all other articles were downloaded and indexed into Mendeley reference manager for its reading and content analysis. The overall methodology and literature search strategy are presented in Figure 1.

It is important to note that both Project Finance and Project Financing terms have been used from a practicing and academic perspective as the same [23,46–48]; indeed, there is no difference between both. In this way, as such a growing literature has begun to explore deeper, the significant researches conducted on this topic has used the Project Finance term [25,49,50]. Hence, in this study, this term is used given that it has had a substantial increase in the body of academic and practitioner literature and, thus, more relevant in the knowledge frontier [10,12,24,51,52]. However, concerning the bibliographic search strategy, both terms cover as many documents as possible and avoid missing valuable information. Besides, limitations should be acknowledged. The most significant limitation is the lack of primary and secondary information on subsectors in the mining industry and financing details of each mineral. In this sense, obtaining specific information that would allow for more robust analysis to compare different variables was not possible.

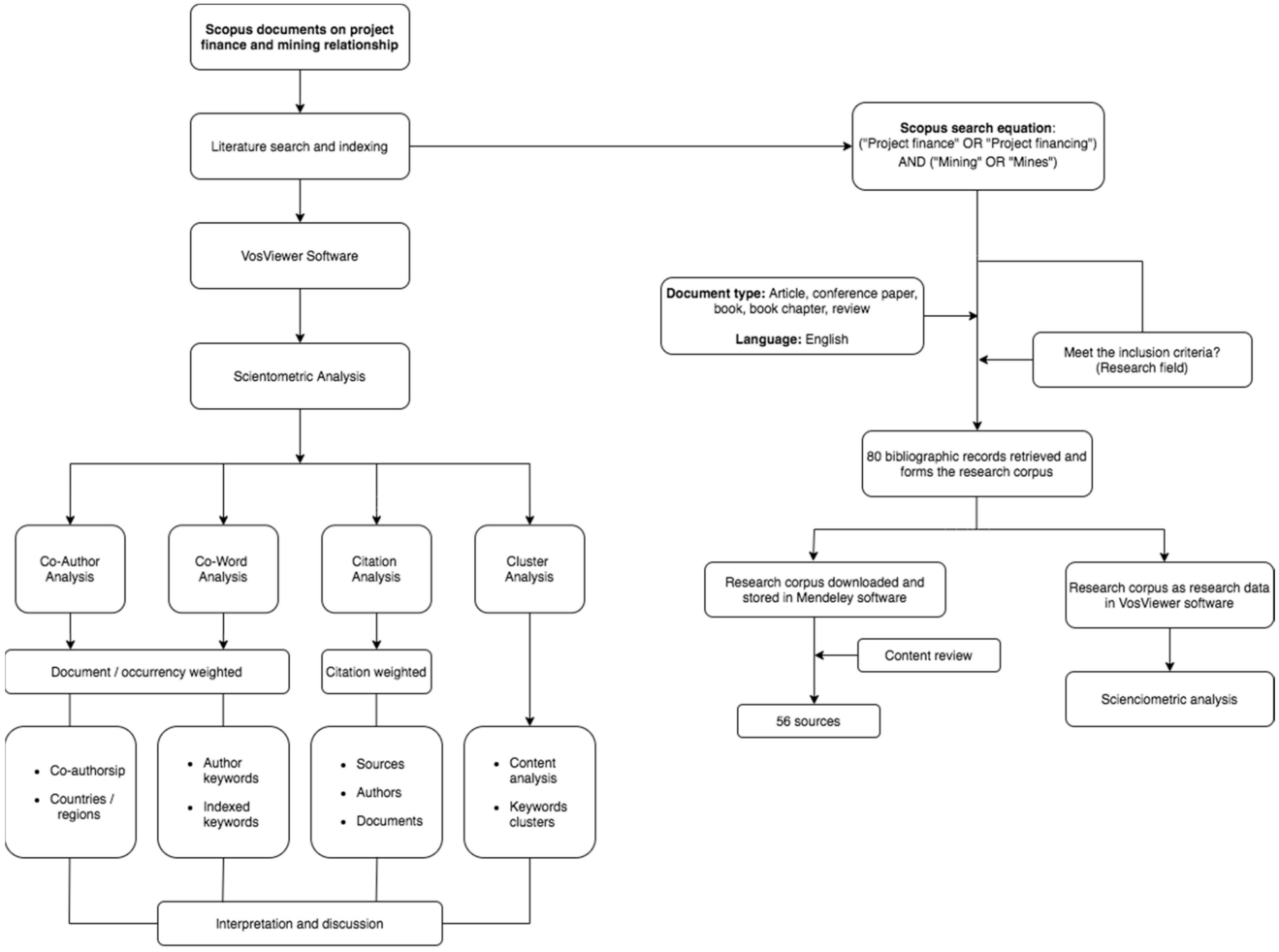

Figure 1. Methodology and literature search strategy.

3. Scientometric Analysis, Results, and Discussion

3.1. Co-Author Analysis

This type of scientometric analysis determines how related the items in question are according to the number of documents that have been jointly elaborated (co-authored). With the information and metadata of bibliographic records obtained from downloading search results from the Scopus database, it is possible to apply this analysis using the authors' and countries/regions units of analysis. It is necessary to mention the basic operation of this software. Here the concepts of items, links, weights, and clusters take on special relevance. Ref. [33,53] describe them as the basic building blocks of a network. Thus, an item is an object that one is interested in analyzing: researchers, publications, countries, and keywords. These items can be related to each other, giving rise to links, which are connections between two items. Examples of links in VosViewer are co-occurrence links between terms, bibliographic links between documents, or co-authorship links between researchers. Such links have associated with them a force depending on how marked this is between the elements. For example, in this analysis (co-author), the number of documents in which two researchers have been co-authors is given the strength. In the network visualization, the links are expressed as colored lines between the items.

Thus, the items and links generate a network. The attributes that an item can have, as well as clusters, still need to be mentioned. As for the attributes, these are varied, but we are interested in the "Weight" attribute. This is a positive numerical value that indicates the relative importance of an item. The greater or lesser importance is reflected in the network in the item's size.

Finally, the clusters are items grouped based on similarity according to the analysis carried out. It should be clarified that an item can be a cluster by itself in case not enough relationships with another or other items are identified. Their colors facilitate the visualization of the clusters since each cluster has a particular color. Thus, in sum, each analysis focuses on various items and privileges specific attributes, but for all of them, the closeness between items, their size, and the number of lines between them indicate their relevance within the set of bibliographic data contemplated.

3.1.1. Co-Authorship Network

As already mentioned, this analysis identifies the number of documents that have been prepared jointly and thus establishes the relationship between the items. In this case, Figure 2 presents the network using the researchers as the item or unit of analysis. That is, the relationships between researchers are shown according to the jointly elaborating works. Thus, it is intended to examine the existence and characteristics of collaboration networks and possible established groups of authors focused on PF-mining research. Besides, the weight attribute "Documents" was used to give preponderance to the items (researchers) according to the volume of works in which there is co-authorship.

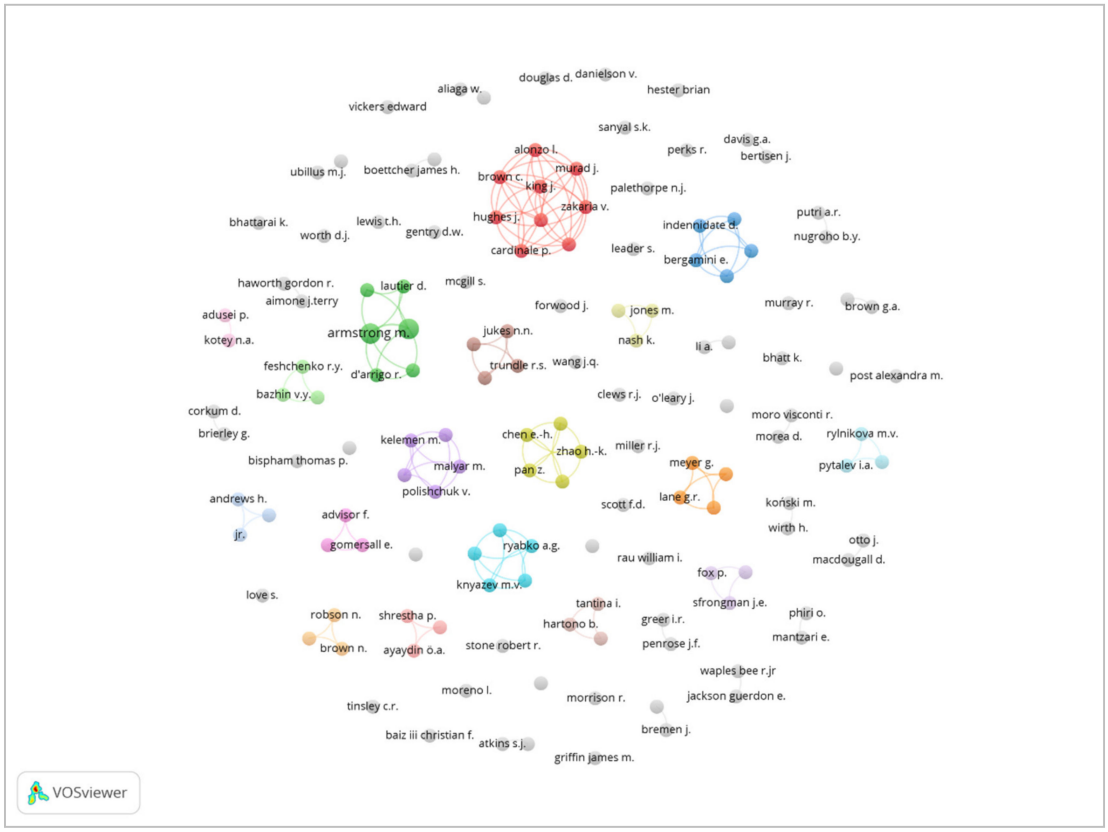

Figure 2. Co-authorship network. Source: Author's own research using VosViewer and Scopus database.

The resulting network reveals the existence of 143 authors and 144 links that are configured in 72 clusters. As shown in Figure 2, the clusters are very dispersed, and several sizes are reduced as they are made up of only one or two elements. In fact, it is observed that although there are some larger clusters, that is, documents prepared by a greater number of researchers, there is no relationship between clusters. This is consistent with the fact that all the authors have only one document within the selected registry base in which they have acted as co-authors. The only authors with more documents in the sample are Armstrong M. and Galli A., who have collaborated on two journal articles.

The co-authorship analysis results indicate synergies in the field of this study analyzed from collaborative networks between researchers [37]. In this case, the scarce number of works in which each researcher has been a co-author, in addition to the low number of authors per document, allows us to affirm that there are no established networks of collaborative work in the field of PF-Mining research. The structure of the network reveals the disjointed and low degree of depth among the participants in this area of study, researchers usually carry out their work alone or with few co-authors, and those who carry out studies addressing the relationship between PF and Mining do not perform subsequent studies that go deeper or suggest new topics.

3.1.2. Network of Countries and Regions

Here the analysis of co-authorship is applied to the item of countries which allows visualizing the distribution of knowledge in the field of study around the world, to identify the leading countries in the production of knowledge and collaboration networks between them. The network returns a result of 22 items and ten links. The number of clusters is 14. As in the analysis based on authors in the previous section and as seen in Figure 3, there is great dispersion between the items, and the non-unit clusters are few, only five exactly. The network shows a predominance in clusters highlighted in red and blue, concentrating six countries among them. The red cluster includes the United States, South Africa, Belgium, and Pakistan. Blue, for its part, includes the United Kingdom and Australia. These two clusters show a relationship between them represented in the figure by the link that goes from the node of Australia to that of the United States of America.

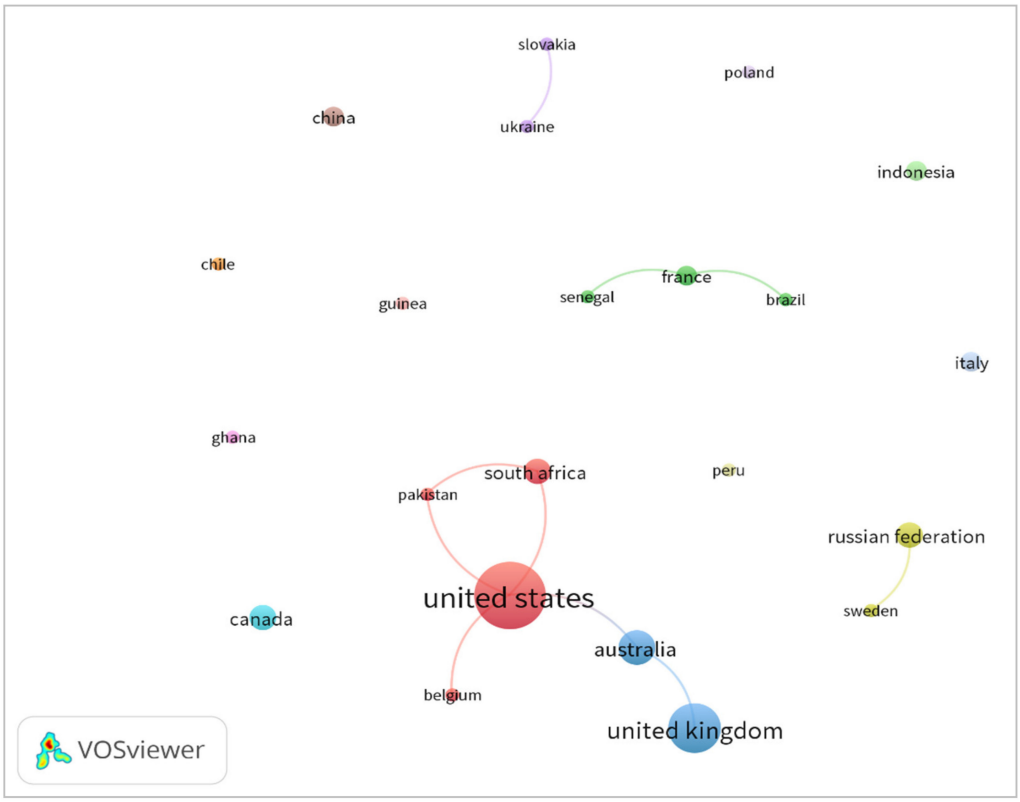

Figure 3. Network of countries. Source: Author's own research using VosViewer and Scopus database.

Thus, the United States of America, the United Kingdom, and Australia are the three countries from whose origin they are the authors with the largest number of documents they work together. The cluster made up of Russia and Sweden also stands out. For this network, the weight attribute used was also "Documents". Apart from these countries, there are no links between the rest of the countries. This suggests that the works in which researchers from these countries have been co-authors have been individual and isolated

investigations, no consistency translates into a greater number of co-authored documents or relationships with countries with greater production in the field of PF and mining.

On the contrary, a large concentration is observed in the clusters as mentioned earlier led by the United States of America and the United Kingdom, with the highest volume of co-authored documents with networks between them, although scarce, existing. This is not surprising and is in line with the fact that several of these countries belong to the top of the world's leading countries in mineral production.

Thus, there is a logical effort by researchers, governments, and institutions of such places to delve into the study of mining, within which financing is a fundamental concern and hence they are attributed the largest number of contributions in the study of the PF and mining relationship.

Regarding the evolution of literature published in PF and mining over time, this has been more or less consistent over time, with 32 years with at least one related document during the period considered, that is from 1977 to 2020. Furthermore, based on the 80 bibliographic records, an average number of 2.5 documents per year is estimated in said period without very significant variations from year to year. However, as shown in Figure 4, the number of documents published on PF-mining has experienced a mild growth since 2007. Thus, the accumulated percentage of publications reflects this momentum in scientific production and is verified by the average number of documents per year, which is 3.5 between 2007–2020 versus the general average of the sample of 2.5. Likewise, between 2007 and 2020, 45 articles have been published, representing 56.25% of the documents in the sample.

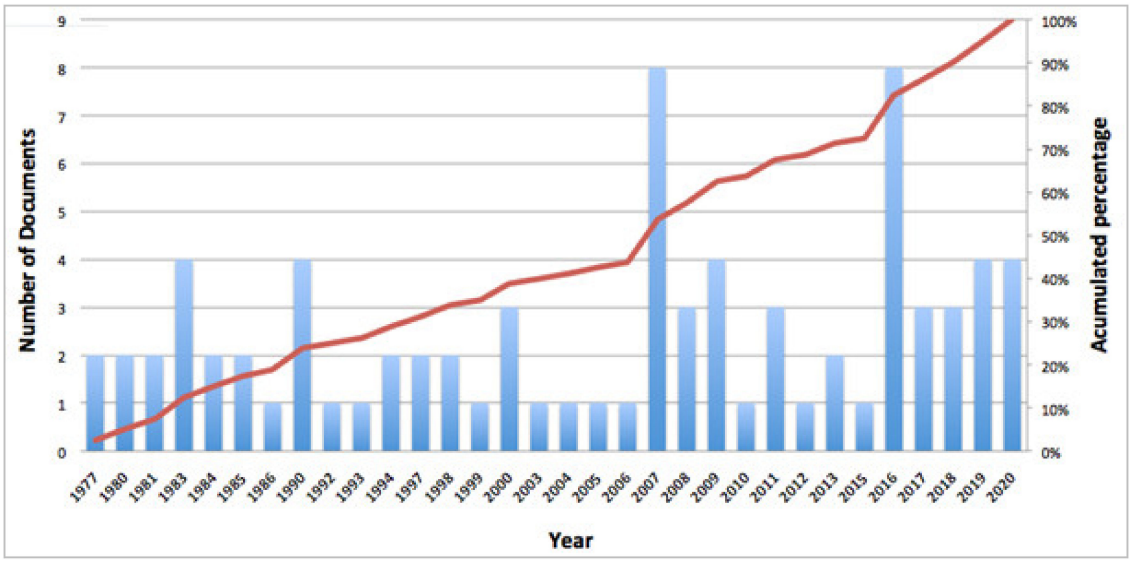

Figure 4. Distribution of the indexed research corpus from 1977 to 2020. Author's own research using VosViewer and Scopus database.

Besides, the median of the years of publication turns out to be 2003 and the years of most significant activity have been 2007 and 2016, both with eight publications. This increase is reasonable if one considers the transformation of the dynamics of the global mineral market experienced from the first decade of the 20th century. The insufficient global supply of minerals caused a significant increase in production and reversed this situation worldwide. From then on, the concern is to alleviate the excess supply. The doubling and tripling in the product of certain minerals since the 90s show the progressive preponderance of this economic sector [54,55].

It should also be mentioned that despite this global excess in the supply of minerals, the situation does not show signs that the increased research interest in the PF and mining relationship will subside in the coming years. The demand for minerals is expected to increase due to key migration towards sustainable development leveraged in a low-carbon

economy where clean energy technologies are both a cornerstone and highly mineral-intensive, with demand increases of up to 500% forecast for certain minerals [56,57].

3.1.3. Co-Word Analysis

The co-word analysis allows identifying the keywords present in the corpus of bibliographic records, and with this, it helps determine which concepts, topics, and categories of analysis are most relevant in the field of study, as shown in Figure 5. This analysis manages to see practically what the research has focused on since it only collects the most relevant words, those that best describe the content of the research results. In this case, the keywords used for the analysis are of two types.

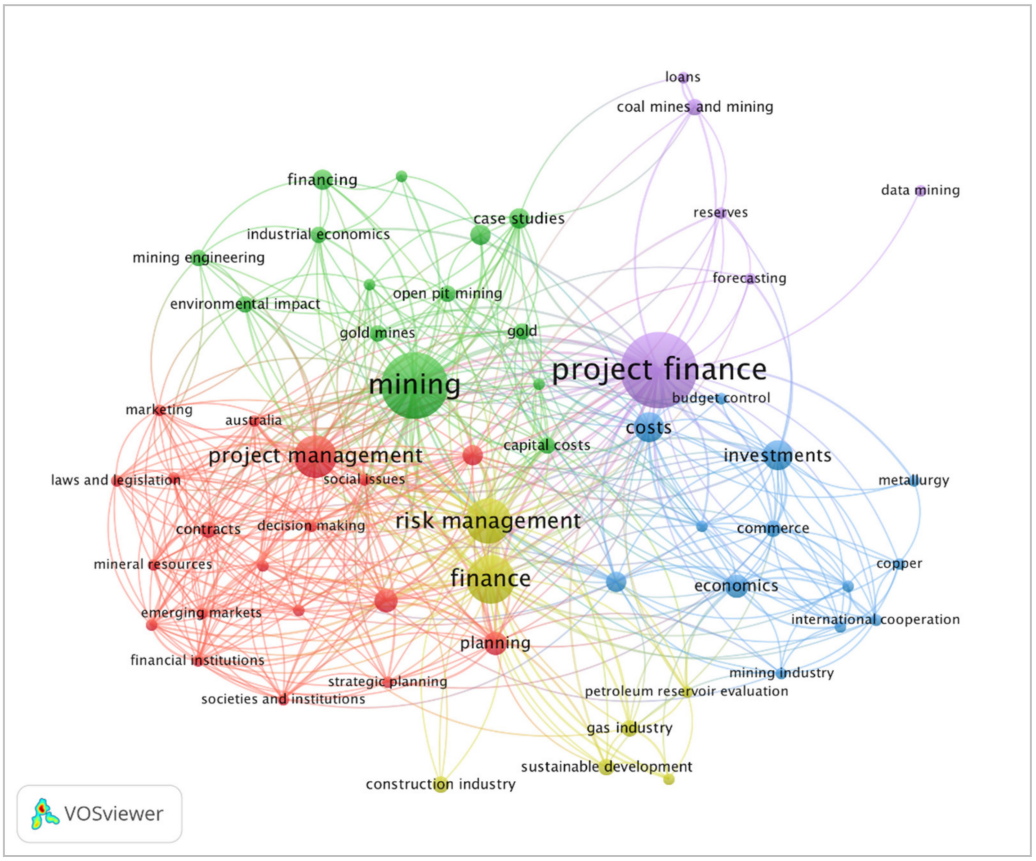

Figure 5. Network of co-occurring keywords. Source: Author's own research using VosViewer and Scopus database.

On the one hand, those established by the author or authors in each document, and on the other the "Index keywords", which are individual words or short phrases that, like those of the author, reflect what the document is about, but these are not provided by the authors but are selected by the database or the publisher. These can be controlled or uncontrolled keywords. The first ones are extracted from already established lists containing the main concepts of different study areas, assigned when adding the document to the database and facilitating searches. On the other hand, the latter are terms chosen by experts in the field based on the subject's content and have no word limit in terms of terminology [58]. Uncontrolled terms, as they are not removed from lists of controlled terms, allow reflecting concepts or trends of recent data not included in them.

The network obtained is made up of 59 items and 474 links. With the procedure mentioned above, the VosViewer software identified 513 keywords. However, for better visualization and obtaining words of greater significance, a minimum limit of two occurrences was imposed, with which the number of keywords was 59. Before obtaining the described result, the network was prune, unrelated terms were eliminated, and different

variants of the same term were merged, such as "Case histories" and "Case studies" or "Project financing" with "Project finance". This procedure was performed by including a thesaurus file as described in [44]. Besides, 5 clusters were obtained for the keywords. As can be seen in Figure 5, the keywords that occur the most are Project Finance, Mining, Finance, Risk Management, Project management, and Investments. Therefore, these words are the terms that concentrate most of the investigations and act as a bridge between the terms of lesser occurrence, as can be seen from the fact that they are the ones with the largest and strongest links.

Table 1 presents the main keywords with their statistics. Regarding the links, the resolution attribute (0.80) and a minimum cluster size of 6 items were adjusted to obtain significant and telling groupings of the research structure in the PF and mining field. As already mentioned, 5 clusters were obtained. However, a detailed analysis of the largest nodes and the entire network together with an exhaustive content review of the documents allows us to notice other words of relevance in the field and reveal relationships between clusters. Examples of these are "Reserves", "Feasibility studies", "Due diligence, "Contracts" or "Project sponsors". Based on this, as will be seen later, in the cluster analysis, only 3 clusters were considered indicative of the research trends in the domain in question.

Table 1. Top 15 keywords on the bibliographic records. Source: Author's own research using VosViewer and Scopus database.

Keyword	Occurrences	Links	Total Link Strength	Avg. Pub. Year
Project finance	24	50	92	2003
Mining	20	43	85	1995
Finance	23	39	69	2006
Risk Management	12	43	74	2007
Project management	11	35	67	2008
Investments	7	23	31	2013
Costs	7	24	30	2000
Planning	5	22	31	2009
Economics	5	21	28	2003
Mining companies	5	22	27	2011
Risk perception	4	24	30	2011
Case studies	4	18	22	1996
Developing countries	4	19	22	2005
Financing	4	8	9	2005
Mine Financing	4	6	8	1989

In addition to allowing the identification of research topics and interests, keywords allow us to analyze their evolution over time [53,59]. In this sense, Figure 6 shows the Overlay visualization of the keyword network. This form of visualization is precisely the same as the network visualization of Figure 4. The difference lies in the colors of the items determined by the "Score" attribute, in this case, this attribute corresponds to the average year of publication (Avg. Pub. Year). Thus, the older the document, the closer to the violet color, and the more recent its tonality will be close to yellow [53]. Some of the most recent terms are "International cooperation", "Commerce" and "Budget control", while among the oldest are "Industrial economics", "Mining" and "Mineral industry and resources".

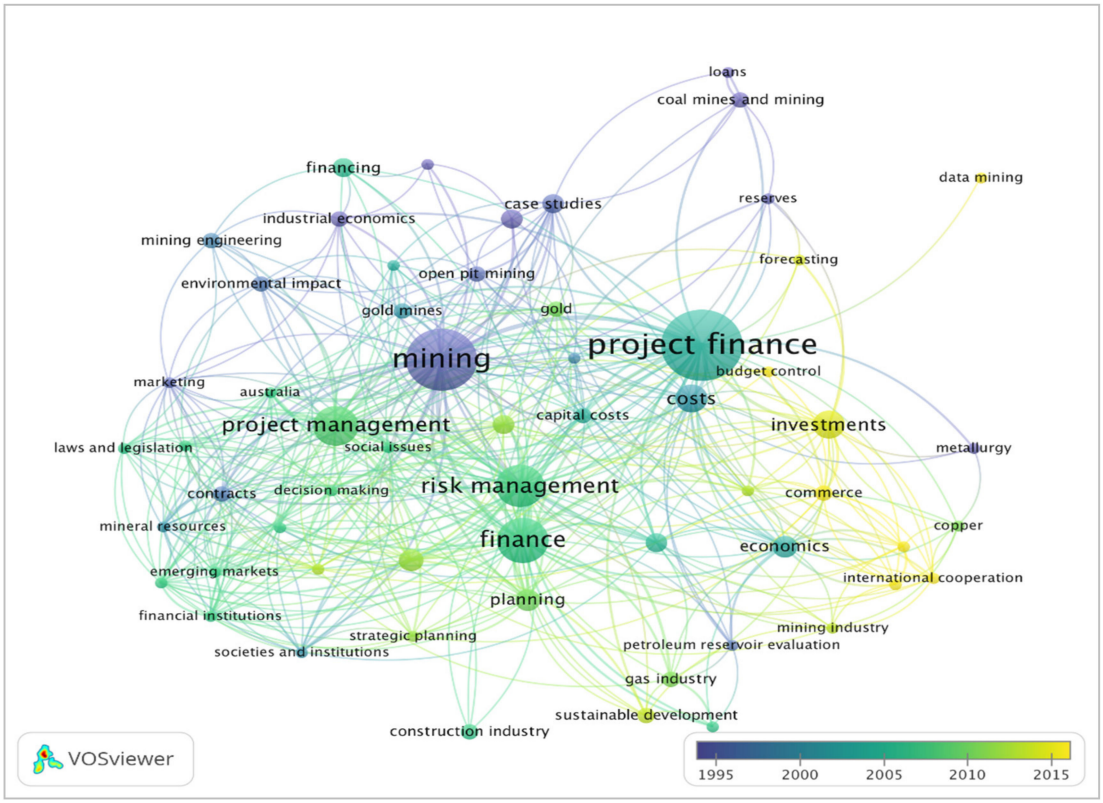

Figure 6. Overlay visualization of co-occurring keywords. Source: Author's own research using VosViewer and Scopus database.

Something interesting to highlight is what seems to be the migration from the concept of "Mine financing" to "Project financing" and that suggests the technification at all levels from the conception of a mine as a project. Another evolution that seems to occur is the specific term "loan" that has an Avg. Pub. Year of 1981, towards the more general term of "financing" that presents an Avg. Pub. Year of 2005 and that not only includes loans but several other forms of financing. Likewise, highlight the temporality of "Sustainable development" and "International cooperation" with Avg. Pub. Year of 2012 and 2016 respectively. Such temporality can be explained by the years in which sustainability studies experienced a greater boom worldwide. These fueled the discussions and helped to finalize the Paris agreement signed in 2015, adopted by 166 countries and where both terms are core elements [37].

3.2. Citation Analysis

The citation analysis determines the relationship between the items based on the number of times an item within the sample cites another. For these purposes, the software is indifferent if the citation is from A to B or vice versa. This analysis allows us to look at which articles and documents generally have the greatest impact on the academic community. Thus, by identifying the most cited documents, it is recognized which are the base articles within the field of study, which serve as references for current researchers and which should be considered in future research. Within the applicable units of analysis are the source, author, and document.

3.2.1. Journal Citation Network

Different sources were included in the analyzed corpus; among these are journal articles (35), conference papers (30), book chapters (7), books (5), conference reviews (2), and reviews (1). The network observed in Figure 6 obtained 56 items or sources, and no link was found between them. This disconnection due to the absence of links is reflected

in the number of clusters 56. That is, all the clusters are unitary. What is disjointed in the network is that within the corpus considered, no pair of the sources, regardless of their type, cite each other. Once again, as in the analysis of co-authorship, the fragmented and dispersed research in the field of PF and mining is evidenced as well as for co-authorship, there are no consolidated networks of sources. Especially of journals—because unlike the character unique in time of the rest of types of documents are those that last over time—that is concentrated and deepen in the field of research in such a way that the production of one serve as an input to that of others, or in other words, quote each other.

In the network shown in Figure 7, the weight attribute used was that of "Citations"; thus, each item's size indicates the number of cumulative citations of each source within the corpus. As can be seen on the web, the largest items correspond mainly to journals, among them "Engineering economist", "Eurasian Mining" and "Sustainability" stand out. Also important are the books "Surface Mining" and "Project finance for the international petroleum industry", as well as the series of publications of conference papers "Australasian Institute of Mining and Metallurgy Publication Series" which is by far the source with the largest number of documents with eight records in the corpus. Regarding the conference papers, their sources, the proceeding journals, although they are not usually cited much as reflected in their sizes on the network, they are also quite significant, representing 20 of the 56 items on the network.

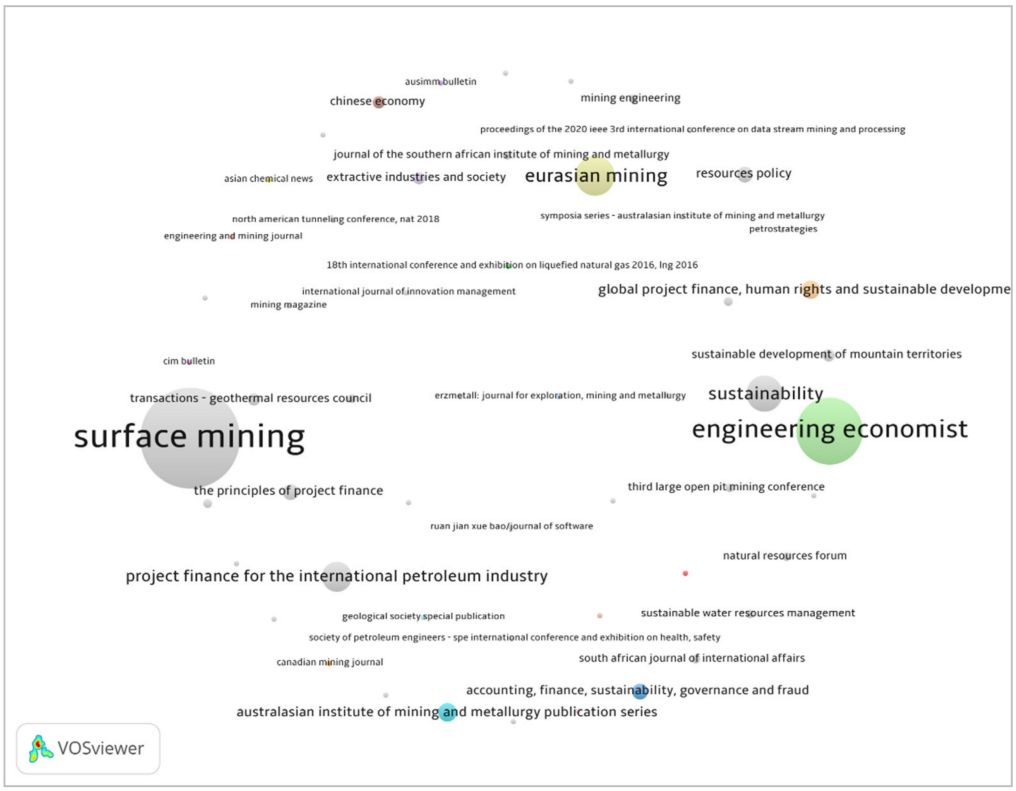

Figure 7. Source citation network. Source: Author's own research using VosViewer and Scopus database.

Table 2 shows the leading journals in the research corpus with the number of documents of each one, their accumulated citations, and the Scimago Journal Rank (SJR) impact factor. This factor gives a certain weight to the citations of a journal, depending on the scientific area and the relevance of the citing journals, this implies that each citation from a source with a high SJR has a higher value than a lower SJR. In this case, the journals with the greatest impact are "Eurasian Mining" and "Resources Policy", the one with the highest number of citations "Engineering Economist" and the one with the most documents "Mining Engineering".

Table 2. Top 10 source journals in the research corpus. Source: Author's own research using VosViewer and Scopus database.

S/N	Journal	Publisher	Documents Count	Citations	SJR
1	Mining Engineering	Society for Mining, Metallurgy and Exploration	5	2	0.136
2	Engineering and Mining Journal	Mining Media Inc.	3	0	0.102
3	Erzmetall: Journal for Exploration, Mining and Metallurgy	GDMB Informtionsgesellchaft	2	0	0.381
4	AusIMM Bulletin	Australasian Institute of Mining and Metallurgy	2	0	0.103
5	Engineering Economist	Taylor & Francis	1	39	0.286
6	Eurasian Mining	Ore & Metals Publishing House	1	15	1.347
7	Sustainability	Multidisciplinary Digital Publishing Institute (MDPI)	1	13	0.581
8	Asian Chemical News	Reed Business Information Ltd.	1	0	-
9	Resources Policy	Elsevier Ltd.	1	3	1.204
10	Sustainable Development of Mountain Territories	North Caucasian Institute of Mining and Metallurgy, State Technological University	1	2	0.207

3.2.2. Author Citation Network

The citation analysis applied to the authors shows the relationships based on the citations made between them. In Figure 8, the corresponding network is presented, it identifies 143 authors but does not detect any link or relationship between them, then no author cites another author within the corpus and corroborates what was observed in the previous analyzes on the disjointedness of the relative research field to PF and mining. Also, several clusters as items (143) were obtained.

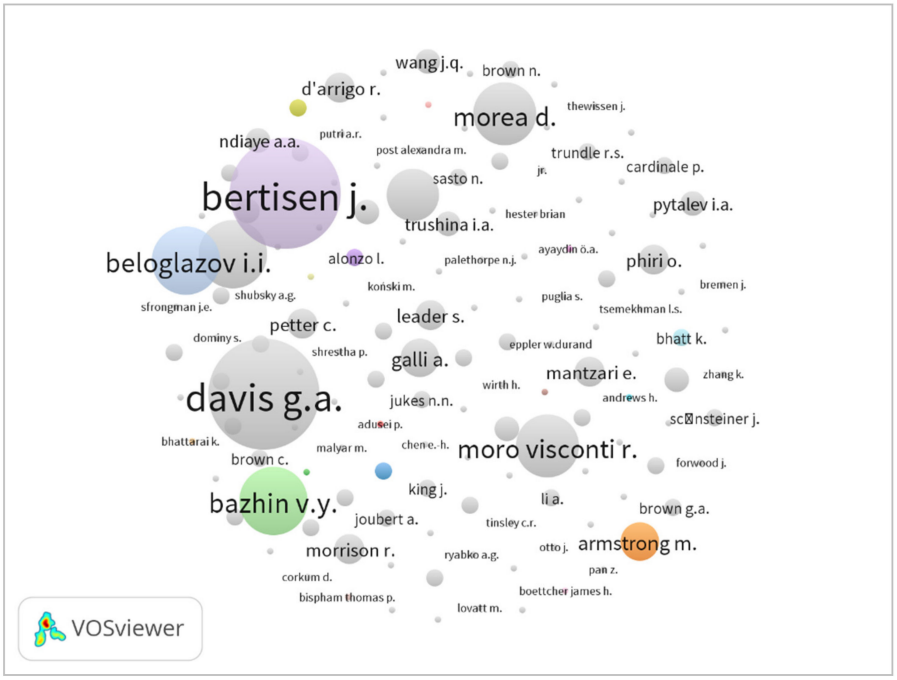

Figure 8. Author citation network. Source: Author's own research using VosViewer and Scopus database.

The used weight attribute used also corresponds to Citations. Of all the authors, only 58 have at least one citation within the bibliographic records contemplated. In Table 3, the main authors, their country of affiliation, and the h-index are detailed.

Table 3. Top 10 cited authors and documents on Scopus citation metric. Source: Author's own research using VosViewer and Scopus database.

S/N	Document	Afilliation Country	Total Citations	h-Index *
1	[60]	Indonesia	79	1
2	[61]	USA	39	1
3	[62]	Russia	14	8
4	[63]	Italy	12	9
5	[64]	USA	9	1
6	[65]	United Kingdom	3	2
7	[66]	United Kingdom	3	1
8	[67]	Chile	3	9
9	[68]	United Kingdom	3	5
10	[69]	USA	3	4

* h-index is based on Scopus calculations and as the affiliation country it corresponds to the main author of each document.

3.2.3. Document Citation Network

Finally, we find the one applied to documents as a unit of analysis within the analysis of citations. For this network, as in the previous two, the weight attribute used was "Citations", the same number of items and clusters (78) were obtained, and no links were identified between the items. In Figure 9, the corresponding network is shown. If compared with Figure 7, it is quite similar in terms of names and relative scale. The foregoing is consistent that only two authors within the corpus have more than one document, as mentioned in the co-authorship analysis. Therefore, the most cited documents are, in turn, those of the most cited authors. As will be seen in the following analysis, these most important documents in terms of citations are also the basis of the clusters considered.

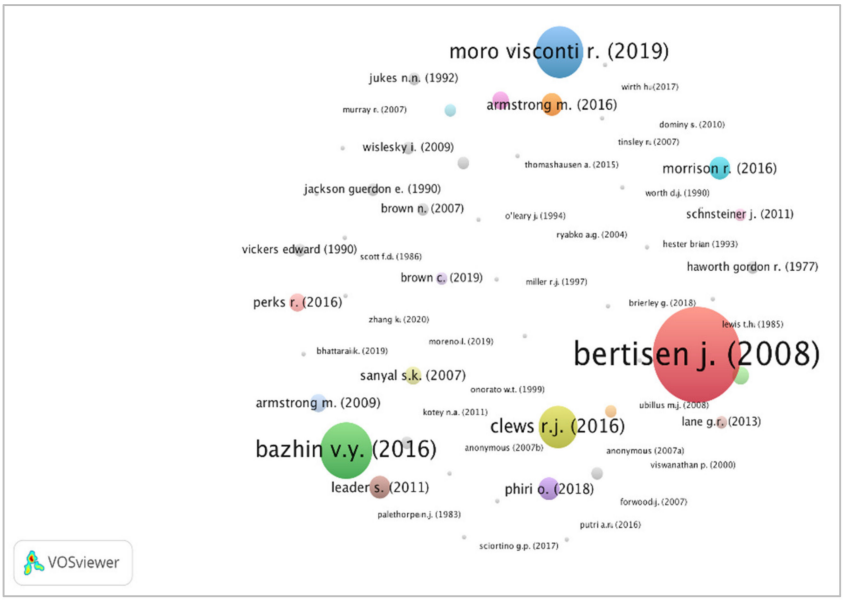

Figure 9. Document citation network. Source: Author's own research using VosViewer and Scopus database.

3.3. Cluster Analysis

From the content review and analysis of the articles and other documents resulting from the search in the Scopus database and keyword cluster analysis, it was possible to identify three large areas in which, despite being fragmented, extended over time and still relatively little research on PF in the mining industry the research efforts carried out so far in this field are framed. These three areas are understood by (1) Characteristics, dynamics of PF, mining and their potential applicability as a whole, (2) The gap and financing difficulties experienced in the mining industry and finally (3) The study, characteristics, and potential of PF in terms of risks in the mining sector.

This first trends deals on describing the main characteristics of PF in the face of critical and unique issues in the mining industry and examining the relevance of the PF-mining relationship. Here the contribution of [60] is especially relevant, which mentions the generalities of the project financing process of the mining industry, its particularities in terms of time and risks, outlines the main variables to take into account in the financing process, in addition to defining both PF and bank loans. Thus, it follows that the two main characteristics of mining versus other industries and of financial importance are the depletion nature of the resource and its very long periods of operation [60]. Likewise, ref. [44,45] agree that the mining industry's high risks and large capital expenditures make financial analysis key in resource development. This arises because, as stated [70], there is great overlap and interrelation between technical and non-technical areas in practice, which is why a close relationship between the various disciplines is desirable when developing a mining project. Then, financial risk is a cornerstone of the viability of mining projects in addition to operational/market [60,70–72].

Faced with the attractiveness of mining projects, it is highlighted that the attractiveness of these types of projects lies in its reflection of an expected return and the ability to pay the debt service [60]. As can be seen, these two determining factors of the attractiveness of a certain project in the mining sector will be determined in addition to the natural volume, quality, and compliance in the resource development plan, by the chosen financial structure [54,60]. A weak financial structure can result in the early failure of an otherwise sound and economically viable project [60,66,73,74]. As already mentioned, this industry is capital intensive, and therefore, investments are significant, inexorably leading to debt playing an essential role in any development in mining [74]. Thus, companies have various possibilities at their disposal when deciding their form of financing (capital structure), the main options being the corporate loan, the increase in capital stock via the issuance of shares, corporate bonds, or PF [54,73].

In this research trend, PF focuses on its differences, advantages, and disadvantages compared to the rest of funding alternatives. Thus, ref. [75] refers to this option as those financing whose source of repayment is limited to the income stream generated by a particular development. This structure exhibits several benefits that make it suitable as an existing alternative for project execution that is potentially unfeasible, not only financially but also environmentally or socially, in various scenarios [60,64,76–78]. On this, ref. [70] points out the high levels of debt, long terms, limited recourse from lenders to project sponsors, the extensive evaluation of the project, and the use of sophisticated prediction models as differentiating elements of PF compared to the more conventional forms. For example, in the energy industry, more precisely oil, which for financing purposes is essentially the same in terms of the general dynamics of its economy and operation, the ability to achieve high leverage, distribute risks, access specific sources and matching deadlines favor PF in said industry [64]. However, internally generated funds represent the most important source of financing.

In [75], it is argued that firms use PF to (1) raise capital, (2) reduce financial exposure, and (3) reduce capital costs. It happens that the link is interesting since there are properties especially useful when its application involves mining. Along these lines, ref. [78] argues the existence of risks that must be assumed in large-scale infrastructure investments such as mining, among these are the risk of asset specificity, high transaction costs, and progressive

expropriation that PF allows to manage notably, unlike other schemes such as the typical corporate finance for example. There are also general characteristics of PF that mitigate transaction costs in markets with concentrated buyers/sellers, solve agency problems and provide coverage for country risk [78], the latter, an increasingly relevant factor for mining developments as highlighted [73]. On the other hand, ref. [79] notes that PF is often used in sectors with captive markets, including mining and energy. Based on the above, and from the study of numerous infrastructure projects between 2007 and 2012 in Indonesia, it is concluded that there is a high and statistically significant propensity to use PF when there is a concentrated supplier/buyer on the project, and especially if said supplier/buyer is a state-owned (public) companies [78].

Faced with the relevance of the use of PF [63], he points out that the benefits of using it must outweigh the costs. Thus, ref. [80] highlights the usefulness of PF for mining projects to raise debt without the owners being directly responsible for the repayment because although it is more expensive and delayed (demanding due diligence) than the corporate loan based on the financial health of the company, it allows assets to be leveraged in ways that would not be possible [80]. The author also points out that under this structure (PF) the lenders normally assume the risk of force majeure, the final commercial risk, and the risk of minerals reserves legally. In the long run, a well-structured PF improves perceived solidity, improving terms (lower cost and required ratios) and therefore increasing the profitability and flexibility of the project sponsors.

As a result of the benefits mentioned above, there is a recent tendency to prefer PF over other financing alternatives [81], especially in large-scale mining and energy projects (oil, gas, coal, copper, aluminum) [53]. The differences between PF and the traditional corporate loan alternative are evident, but as [61] argues, whether one or the other is the key decision to obtain financing is a matter of cash flow. In general, what a bank tries to consider before financing a mining project are the bank documents (the final feasibility report and an information memorandum) and the location of the same [82]. This greater appetite for PF is not at all despised by banks, in the sense that interest margins can be three to four times higher than those of corporate loans, as it is logical when taking a risk not contemptible [83]. Another cause that has contributed to the progressive positioning of PF is the high capital costs and the low profitability achieved with financing through equity, which have caused a reduction in profits and the need for greater leverage [26].

Although this increase in the participation of PF in the financing of the mining sector versus the previously usual corporate loan [27] in general is recent, its discussion dates back some time. Already in the 80s, ref. [28] inquired about the role that commercial banks will assume in financing international mineral projects; various financing techniques were evaluated, among them PF. The recognition of financing via PF to Liquefied Natural Gas (LNG) projects [30] and a case study of the Ok Tedi Mine in 1983 by [31] are examples of this. In the latter, PF was proposed as "a logical innovation necessary to cope with the deployment of finance as more and more capital accumulates and concentrates" (p. 126) and highlights its usefulness insofar as it is aligned with the concern to limit financial exposure by governments in their resource development policy. Thus, PF, whose beginnings date back to 1970 specifically for infrastructure and privatization projects, is now used regularly to develop successful greenfield and brownfield mining projects [84]. This positioning of PF, although positive, is still precarious.

Thus, although the annual investment is enormous in the oil industry, the PF represents a relatively small source of capital for the industry. Oil and gas companies primarily use more conventional sources of corporate finance or internally generated funds [64]. This situation arises even knowing the PF's flexibility since the diversity of each project. PF schemes have been used successfully in the various phases of the industry value chain (up-mid-downstream). However, the investment volumes allocated there mean that the oil and gas industry represented around 30% of the global PF market in 2016 [64].

This situation highlights the need to continue research on PF and other innovative mechanisms to finance resource development, mainly due to the effects on the industry of

the 2008 financial crisis and the consequent decrease in production. This matter has become a challenge to obtain mining financing even in countries like China, with other sources such as private equity funds [70] becoming popular, and even Metal Streaming and Off-take agreement schemes that, contrary to what one might think, are not against PF. In fact, streaming favors it by reflecting on the bank's potential for a total or partial sale of their mineral production for the future [30,54], of course, depending on the buyer's credibility.

The second research trend deals with the financing gap and difficulties experienced in the mining industry. Here, the dynamics of the financing process and actors that make obtaining financing in this industry become increasingly complex, especially for certain types of companies and mining projects, are addressed in greater detail. Undoubtedly, the work that most faithfully reflects this trend is that of [61], there the bias in estimating the cost of capital in mining projects is studied, verifying its persistence, especially in small companies. This bias is explained by insufficient financing for these projects, leading to inflation and the persistence of cost overruns. With this, it is estimated that capital costs are on average 14% more than estimated in feasibility studies, a tendency to cost overruns that are reflected in the reliability normally estimated for such studies of between −5% and 15% [85]. While this is recognized, the reasons for its persistence are unknown.

However, ref. [61] states that in addition to the excess demand for financing in the mining industry, there are information asymmetries, direct and indirect incentives both in mining firms and in project consulting firms that lead to the bias emerging and persisting. Knowing that there is an excessive demand for financing, project sponsors are forced to undervalue the costs of their projects when they embark on the task of raising [64]. The foregoing is supported by [86], who, although focusing on the difference in real versus projected product in mining projects, affirms that the historical biases in the cost of capital have been due to the lack of financing. On the other hand, in line with the factors that promote this bias [66], it recognizes that high metal prices can be a red herring, they improve profitability projections and valuation models, making the projects more attractive for investors and lenders but ignore the time between project start and cash flow generation.

Thus, the difficulties of raising resources and achieving financial viability are seen. Difficulties that, however, are not generalized but are already expressed in [62] and it is widely recognized; they are concentrated in small and medium-sized mining companies [54,60,70,73,87]. In this regard [54,70] show insufficient financing for the prospecting and exploration stages compared to the others and the small ones compared to the large ones. In general, exploration companies have no income from mineral production and depend solely on external financing to advance their projects [70]. Added to this are the greater risks inherent to prospecting and exploration activities, key elements within the industry but with great uncertainty [60,64,70], as well as the fact of less operational flexibility, but above all financing of the smaller projects versus large-scale ones. This author also mentions the main aspects that determine the ability to obtain resources.

Against this background, novel schemes have emerged, such as metal streaming and Off-take agreements, which have been mentioned in the first research trend, that have helped these small and medium-sized companies to obtain financing. These mechanisms, as previously mentioned, do not conflict with PF, but even more, they share to a large extent the principle of PF on relying on future project flows and not so much on the company's supporting assets [54]. These alternative forms of financing that are being applied could also facilitate the process of formalizing artisanal and small-scale mining (ASM), ref. [54] analyzes this for the case of Rwanda. The author maintains that the formalization of mining titles, it is necessary to design adequate financing structures for this type of companies so that the benefits of such formalization can materialize since it is hardly possible to make a mining title bankable, only with exceptions, in which small exploration companies can secure long-term credit lines using the mineral deposit as collateral [73].

Its contribution is undoubtedly significant for industry and government since the formalization agenda is of global interest since it is recognized that "The growth and efficiency of small companies have been restricted by several factors, including access to

financing, the lack of technological and management capacity and the quality of the regulatory environment" (p.1) [88]. Even more important with the battered metals market since the 2008 crisis and which has great relevance in Latin America and countries like Colombia, which, as well as Rwanda, has marked social and security problems concerning mining.

The issue of the regularization of informal mining and other issues susceptible to reform in countries is supported by the World Bank Group. Through its various agencies, it offers financing schemes for subsidized and unsubsidized PF to the government or state companies [69]. Regarding the government interest and the existing financing gap [87] addresses the issue by emphasizing the greater control and balance granted by PF before (due-diligence) and during the agreement compared to direct state financing based on experiences in the sector miner in China. Hence, the PF is useful to governments that want to promote or strengthen the mining sector by injecting resources.

It follows from this trend that the general financing problem, exacerbated in small mining companies, could be lessened or partially resolved with the introduction of new schemes such as PF, in which the pressure on funds earmarked for traditional corporate loans is reduced. Something that would bring the preliminary decrease in the magnitude of the bias in the cost of capital. Furthermore, given that there is, deep down, a similarity between PF and Metal Streaming in terms of the principle under which they operate, based on the future performance of the project, PF's growth potential in the mining sector is notorious. It could alleviate several small companies with projects with potential (good and reliable flows) but without assets to support the loan and much less influence with the lenders. Under this scheme, obtaining resources from abroad with development banks is favored when firms or commercial banks are reluctant due to country risk [29,73].

The last of the trends in the existing literature refers to works focused on analyzing the characteristics and potential of PF in terms of risks in the mining sector. Mainly this trend is associated with the link between financing and mining activities with the general category of sustainability, of viable developments from the economic, social, and environmental aspects, usually associated with the Environmental, Social and Governance (ESG) concept. As can be seen in the first trend, the role of banks in the development of mineral resources has been seen for a long time under various financing schemes [28], among them PF. In this sense, despite the variety of options available for financing, the risk aspect is a critical element of whatever option is the chosen option, which is reflected in multiple investigations [28,72,74,83,89–94]. Thus, it is emphasized that it is of utmost importance to carry out proper due diligence since it allows controlling the cost of financing in PF by reducing the risk margin since it achieves an early identification and mitigation of risks [91]. The analysis of the due diligence process is recurrent, more precisely, the risk assessment and its overlap/interaction. In [45], they study two due diligence cases in mining projects and learn from them. For its part, ref. [33] explores the rationale, process, and results of an early-stage problem identification and management process applied to large-scale onshore oil development in Madagascar, highlighting the benefits for large-scale resource developments in general. Benefits include the fact that timely risk management can help companies improve impact assessments, manage non-technical risks, and thus align the project with the eventual requirements of a PF. Additionally, problem management can help companies align projects with international PF requirements and strengthen corporate and project risk management processes.

Hence the concern in [46,79] reveal the importance and diagnose the situation of risk coverage in mining projects. On the other hand, ref. [11] verifies the status of hedging practices in the mining industry in multinational mining groups, finding that, despite the perception, mining companies hedge their risks with increasing variety. This is a very revealing finding, but even more so what emerges when seeing that some risk hedges take place exclusively due to the fulfillment of financing requirements [95], then a possible effect of PF in increasing hedging practices is conjectured in mining companies.

In this trend, the study of risk, beyond its decomposition, is framed in the benefits that PF can bring for its treatment, either by reducing, mitigating, transferring or any

related strategy. Exactly, it is revealed that due to its characteristics, PF serves as a bastion to accelerate performance in terms of sustainability via risk management apart from the operational or financial traditionally involved in the disbursement of resources by a borrower [65,68,81,89,92,96–99]. What is being argued here is that more specialized funding such as PF can promote greater and faster adoption of ESG standards than other typical structures can force [90]. The author recognizes the management and adherence to environmental standards regarding disposal and management of waste in mines as a key to access financing, especially PF with signatory institutions of the Equator Principles (EQs). [99] makes arguments on the role and responsibility of banks in financing mining projects in environmental matters, an area often referred to more globally as Corporate Social Responsibility (CSR) but usually relegated in this industry. Against this [65] examines the disclosure practices and the related motivation to disclose or not the CSR activities in the mining industry of Zambia, finding that the scarce disclosure that exists is aimed at building public image or for project financing purposes. Then, the disruption of the PF as a more tailor-made financing structure, and above all because of its exhaustive evaluations, is that it increases the disclosure and commitment to CSR of mining companies, especially in developing countries.

This is consistent with [97] in that in PF, the great dependence of the sponsor (owner of the project) on the sales of the resource to meet the debt in PF leads to more and better commitments related to sustainability/ESG. In the same way, the allusion to the EQs is repeatedly noted because the EQs are strict in only granting loans to projects with good environmental, social, and human rights management. Also, more and more banks are joining for reputational reasons and risk management. It is estimated that in 2013 the banking institutions that signed the EQs represented 85% of the transnational PF [66]. More than enough reason for mining companies to be adopting voluntary Equator Principles guidance with looking to future funding. Then, given that several of the PF banks are signatories of the EQ, greater commitment to sustainability is expected. An example of this is the case presented by [96].

The mechanism by which PF financing improves projects' sustainability profile essentially consists of the financial institutions that provide PF, mostly the IFC and members of the EQ, oblige borrowers to include human rights and sustainable development standards [65,68,81,97]. Thus, the PF mechanism, especially those supported by the IFC or another international public institution, is better than other equity schemes by leading to better compliance with standards through greater scrutiny, transparency, and exposure to investors and borrowers [81]. With this in mind, and more towards the regulatory sphere, there are great benefits of the mining reforms regarding the inclusion of ESG aspects in obtaining financing, either incorporate or sustainable loans. Something should be emphatic, the changes made to mining regulations in social and environmental matters are not only for ethical/reputational purposes but also a commercial rationale, especially when favoring the financing of companies that apply such standards [97].

The political reforms of mining codes arise as a means to affect the entire industry in terms of improving its attractiveness when obtaining resources. The case of the mining code of Guinea is a demonstration of this and also a good reference for countries that have not yet addressed the social and/or environmental issues in their mining industries. The benefits of considering these risks not only fall on the sponsors but also on themselves as lenders, as [92] exposes the importance of evaluating ESG risks in PF by banks it allows either to achieve financial viability and sustainable development both of its activity as well as those financed, or incurring risk levels inconsistent with its policies.

Some contributions that are worth mentioning are that of [68], who analyzes the potential impact that calculations of risk distributions among the participants of a PF on projects such as mines or pipelines in their different stages can have on society in where the project is located, especially in the area of human rights. It states that what is sought is to reconcile the risks on returns with those of damage to the fundamental rights of third parties in the area of influence, a clear reflection of the movement towards more sustainable

projects, whatever their motivations. Also, the social sphere has been evaluated on the development of relations of mining companies with indigenous people. It is argued that such relationships are due to several factors, among them the growth in acceptance of the Equator Principles, a benchmark for determining the risk in PF, as well as the development of the UN Global Compact [98].

Similarly, interesting within this trend is the investigation into the existing tensions to prevent versus compensate for damages considered irreparable at the level of human rights in mining projects. This analysis is made by [89] especially in light of PF for its eagerness for reaching the stage without recourse, that is at operation phase. There, unlike [65,68,97] that expose PF as a vehicle towards better management and risk reduction in the socio-environmental arena, this postulates that it could promote it by its nature (without recourse to company assets). However, it is highlighted that this desire to complete the project's construction quickly is present in any form of financing.

In this regard, more research on the incentives that can lead sponsors to ignore prevention and adopt a compensation approach at all costs for damage caused is desirable. Finally, based on the above, there is a fairly close relationship between PF and ESG risk management, placing it one step higher than the other financing options. Thus, the natural question is whether this theoretical relationship has been materializing, an extremely little-explored question, but which preliminarily [81] helps to resolve. A joint case study analyzes whether PF in any way favors performance in human rights and SDGs compared to those who do not use PF. The result indicates that it does lead to better records. However, the best specific form of PF for this is unknown [81].

4. Conclusions

This study carried out a scientometric analysis that, through various techniques such as co-author, keyword, citation, and clusters analysis examined the existing frontier of knowledge in the field of PF and mining. This allowed to identify, describe, and analyze the patterns, structures, and configuration of the research carried out between 1977 and 2020. In total, 80 bibliography records from various sources extracted from the Scopus academic database that made up the corpus of the scientometric study were analyzed. In regard, researchers and practicing professionals may use this study's findings to broaden the central aspects of developing mining projects. Additionally, these findings can be incorporated into further research efforts to understand the mining industry and the SDGs better. Based on results, the co-authorship analysis indicates synergies in the field of the study analyzed from collaborative networks between researchers [37]. In this case, the scarce number of works in which each researcher has been a co-author, in addition to the low number of authors per document, allows us to affirm that there are no established networks of collaborative work in the field of PF-mining research. The network structure reveals the disjointed and low degree of depth among the participants in this study area. Researchers usually carry out their work alone or with few co-authors, and those who carry out studies addressing the relationship between PF and mining do not perform subsequent studies that go deeper or suggest new topics. This is a call for researchers to work together in groups.

The country network suggests that the works in which researchers from these countries have been co-authors have been individual and isolated investigations, no consistency translates into a greater number of co-authored documents or relationships with countries with greater production in the field of PF and mining. This is not surprising and is in line with the fact that several of these countries belong to the top of the world's leading countries in mineral production. Nonetheless, the number of documents published on PF-mining has experienced mild growth since 2007. It should also be mentioned that despite the current global excess in the supply of minerals, the situation does not show signs of increased research interest in the PF and mining. This relationship will subside in the coming years since the demand for minerals is expected to increase due to key migration

towards SDGs leveraged in a low-carbon economy where clean energy technologies are both a cornerstone and highly mineral-intensive.

For its part, the co-word analysis applied to keywords showed the keywords that occur the most are Project Finance, Mining, Finance, Risk Management, Project management, and Investments. Therefore, these words are the terms that concentrate most of the research and act as a bridge between the terms of lesser occurrence. Besides, five clusters were obtained. Other important words are "Reserves", "Feasibility studies", "Due diligence," Contracts "or" Project sponsors ". It was also shown its evolution over time, being some of the most recent terms are "International cooperation", "Commerce" and "Budget control", while the oldest include "Industrial economics", "Mining" and "Mineral industry and resources".

From a professional perspective, in the journal citation network, different types were analyzed. Here once again, as in the analysis of co-authorship, the fragmented and dispersed research in the field of PF and mining is evidenced, that is, as well as for co-authorship, there are no consolidated networks of sources. Likewise, it is identified that the journals with the most significant impact are "Eurasian Mining" and "Resources Policy", the one with the highest number of citations "Engineering Economist" and the one with the most documents "Mining Engineering". Concerning author citation analysis, it yielded 143 authors but does not detected any link or relationship between them, then no author cites another author within the corpus and corroborates what was observed in the previous analyzes on the disjointedness of the relative research field to PF and mining.

Finally, the document citation network highlighted [60–64] as the most cited documents, all of them are journal articles except the first one. It also revealed the lack of promptness in the research in PF and mining since only two authors within the corpus have more than 1 document; therefore, the most cited documents are, in turn, those of the most cited authors.

There are, therefore, no direct or indirect collaboration networks, only ten sources have more than one document, in terms of journals, only four of them exceed that limit, and of all the authors, only 58 have at least one citation. This leads to an inconsistency since the issue shows that it has been increasing in recent years and the demand for minerals calls for a deeper understanding of the financing mechanisms of these projects, then to increase knowledge in PF-mining, greater consistency and collaboration will be required between authors, journals and institutions from countries around the world.

The studies, although scarce, have been varied in covering several facets of the relationship between PF and mining. The comprehensive content review and keyword cluster analysis allowed to identify three main research trends. The first one focuses on describing the main characteristics of PF in the face of critical and unique issues in the mining industry and examining the relevance of the PF-mining relationship. Here it is mentioned the generalities of the project financing process of the mining industry, its particularities in terms of time and risks, and the main variables to consider in the financing process. Likewise, financial risk is recognized as a cornerstone of the viability of mining projects in addition to operational and market risks, and the advantages of PF versus alternative financing options such as high levels of debt, long terms, limited recourse from lenders to project sponsors, the extensive evaluation of the project are the subject of research. Finally, an increase is recognized in the proportion of PF in the financing of mining projects, although it continues to be reduced despite the proven flexibility of PF in all stages of the value chain in the mining industry.

The second research trend deals with the financing gap and difficulties experienced in the mining industry. Here, the dynamics of the financing process and actors that make obtaining financing in this industry become increasingly complex, especially for certain types of companies and mining projects, are addressed in greater detail. A key topic among researchers in this trend is the bias in estimating the cost of capital in mining projects, verifying its persistence, especially in small companies. It is explained that the bias is explained by insufficient financing for these projects, which therefore leads to inflation and the persistence of cost overruns. This addresses the obvious financing difficulties of mining

companies, especially critical in small and medium-sized mining companies dedicated to the exploration and prospecting stage compared to large companies dedicated to mineral exploitation and processing. This research trend also recognizes the emergence of schemes such as Metal streaming and Off-take agreements that have helped to mainly solve this problem, which does not quarrel with PF and instead are based mainly on the principle of PF on relying on future project flows and not so much on the company's supporting asset.

From a professional perspective, it follows from this trend that the general financing problem, exacerbated in small mining companies, could be lessened or partially resolved with the introduction of new schemes such as PF, in which the pressure on funds earmarked for traditional corporate loans is reduced. Something that would bring the preliminary decrease in the magnitude of the bias in the cost of capital. Furthermore, given that there is, deep down, a similarity between PF and metal streaming, PF's growth potential in the mining sector is notorious. It could alleviate several small companies with projects with potential (good and reliable flows) but without assets to support the loan and much less influence with the lenders.

The last research trend found in the existing literature of PF and mining refers to works focused on analyzing the characteristics and potential of PF in terms of risks in the mining sector. Mainly, this trend is associated with the link between financing and mining activities with the general category of sustainability, of viable developments from the economic, social, and environmental aspects, usually associated with the ESG concept. Outstanding this trend is examining hedging practices in the mining industry in multinational mining groups, finding that, despite the perception, mining companies hedge their risks with increasing variety. This is a very revealing finding, but even more so what emerges when seeing that some risk hedges occur exclusively due to the fulfillment of financing requirements [84], then a possible effect of PF in increasing hedging practices is conjectured in mining companies. What is being argued here is that more specialized funding such as PF can promote greater and faster adoption of ESG standards than other typical structures can abet [87].

Moreover, it is shown that the scarce disclosure that exists for certain jurisdictions is aimed at building a public image or for project financing purposes, especially in developing countries. Another crucial finding of this trend is that political reforms of mining codes arise to affect the entire industry to improve its attractiveness when obtaining resources; the case of the mining code of Guinea is an example of it. Also, the social sphere of the development of relations of mining companies with indigenous people has been evaluated. It is argued that such relationships are due to several factors, among them, the growth in acceptance of the Equator Principles, a widely recognized benchmark for determining the risk and according to existing evidence, driver of better sustainability profiles in mining companies.

The findings of this study will allow emphasizing the trends and patterns and thus establishing the foundations of research processes in this field and outlining strategies to provide insights that allow keeping advance in knowledge frontier in the PF-mining domain. These research processes should be understood as the processes to be taken into account by each one of the interested parties (stakeholders) in the PF processes, considering not only what is related to the permits for the exploitation of mineral resources but how they can be exploited, maximizing value for all stakeholders. The previous is done with adequate knowledge of the stages of exploitation of a mineral resource, from exploration to mining closure, through construction, assembly, exploitation, and mineral processing. It is also expected that this study helps define policies and best practices to encourage private participation in the development of mineral resources and the creation of new financial mechanisms that allow having a broader source of financing resources adjusted to the size and niche of the companies. From an academic, professional, and policy-maker perspective, further research topics worth exploring are as follows:

- Incentives that can lead sponsors to adopt a compensation approach at all costs for damages caused. This will allow a better understanding of how the variables E

(environmental) and S (social) impact financial results, mainly Return on Assets and Return on Equity.
- Comparative studies of PF application by minerals' class and companies' size. This will allow analyzing if there are specifics characteristics according to financial mechanisms used.
- The role of PF and mining industry on the considerable increase in the developing of renewable energy technologies and electric mobility. This will allow correlating ESG criteria in order to analyze the importance of the mining industry in the low carbon economy.
- According to type of mineral, carry out analyses on the main financial mechanisms used in PF schemes. This will allow identifying how transition bonds could boost the mining industry.

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