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Knowledge Gaps in Mining Operations: Empirical Evidence from the Greek Lignite Mining Industry †

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Abstract: The objective of the paper is an introductory discussion on the knowledge gaps (KGs) observed in mining operations. A qualitative research (QLR) methodology, based on empirical evidence from the Greek mining industry, is discussed to identify the KGs appearing in mining operations and investigate the cause and criticality of each KG. Recommendations for the extension and integration of the methodology as a tool appropriate for introducing knowledge management (KM) in Greek mining organizations are provided.

Keywords: experts; knowledge management; mining systems; post-mining

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1. Introduction

In the entire life of a mining system, a vast amount of scientific and technological knowledge is acquired and accumulated [1]. However, practice shows that mining operations, especially in Greece, face dysfunctionalities and performance limitations, on how and to which extent this knowledge can be effectively managed [2]. In contemporary businesses and industries, this type of dysfunctionality is referred to as *knowledge gaps* (KGs) or *knowledge management gaps* [3,4]. The term KG describes '*the difference between knowledge that an organization needs to perform a certain project or program or to take crucial decisions, and knowledge that an organization possesses for this purpose*' [5,6]. This paper presents a methodology based on the principles of qualitative research (QLR), which has been applied to the preliminary investigation of the main KGs identified in Greek lignite mining operations. The primary data are collected via semi-structured interviews that are carried out in collaboration with Subject Matter Experts (SMEs) working in the local coal industry. The research results focus on a preliminary analysis of the content, the description of problems, and a semi-quantitative evaluation of the KGs' criticality. A discussion on the methodology application and the outlined results of and views on the extension of methodology towards a more detailed, quantitative, and mathematically and statistically consistent framework of analysis is provided.

2. Problems and Research Questions

In academia and industry, the term '*knowledge*' has several definitions, depending on the theoretical basis in which the term is interpreted. From the epistemological viewpoint, knowledge is divided into two (2) types [7]: tacit and explicit. Tacit knowledge is subjective, experience-based, and shared via interpersonal reactions and social interactions. Explicit knowledge is objective, recordable, formal, patterned, and easily transferable [8–10].

Knowledge is also understood as an entity or as a function. As an entity, knowledge has an ontological purpose, and it is represented in patterns/forms processable and manageable by means of information and communication technologies (ICT). As a function, knowledge is meant to be a constituent element of an organization's cross-functional and cross-disciplinary process [11,12]. Other approaches suggest knowledge to be the ultimate stage of the evolutionary scheme of data–information–knowledge, where data are sets of primary elements conveying single values of entities, information reflects data sets structured in attributes and patterns, and knowledge represents advanced structures of information enabling interrelationships, logical combinations, and options for inference to support decisions and actions of higher complexity [13–15]. The definition suggested by Davenport and Prusak [10] for the term 'knowledge', '*a fluid mix of framed experience, contextual information, values and expert insight that provides a framework for evaluating and incorporating new experiences and information*', is the most acceptable and widely referred in the literature.

The above approaches constitute the theoretical background for the analysis, design, and implementation of knowledge management (KM) systems in contemporary organizations. The practices and the type of tools required for the development of a KM system are organization oriented and depend on the business strategy, the functional structure, the available technology, the capabilities of personnel, and the infrastructure(s) that each company maintains for the management of knowledge it possesses.

In mining, tacit knowledge refers to the know-how and expertise acquired, shared, and applied by the personnel of a mining company (managers, operators, engineers, inspectors, etc.) during and because of the execution of extractive processes [1] and other relevant activities, such as waste management, environmental restoration, logistics, etc. Sources of tacit knowledge are subcontractors, consultants, suppliers of equipment (mining shovels, belt conveyors, bucket wheel excavators, drilling machines, etc.), synergies for knowledge and technology transfer (KTT), R&D programs in cooperation with higher education institutions (HEIs) and research and technology organizations (RTOs), and the interaction of the company's personnel with various stakeholders (central government, universities, public authorities, municipalities, welfare organizations, NGOs, labors, unions, etc.). Sources of explicit knowledge are the standards and regulations of the mining industry, best industry practices and methods, procurement campaigns, engineering and geotechnical investigations, environmental and social aspects, and documentation stored in the technical archives and libraries of mines.

The literature has limited references on the role of KM in mining operations. Boikanyo et al. [16] describe technical, administrative, and policy-making problems of high criticality acting as source stoppers in the introduction of KM in mining organizations based on data collected from 300 mines in Africa and elsewhere. Tones et al. [17] suggest a system for the organization and optimization of knowledge acquired during the life cycle of a mine related to terrain and landform management, geology, ecology, climate, social, financial, and other factors, and storage of this knowledge in a database, which may prove useful in projects of mines' closure and sustainable transformation/repurposing. Both works report that, in several cases, the management of mining companies is skeptical, if not reluctant, to introduce KM in mining operations. On the other hand, Young and Baretto [18] claimed that knowledge is considered a tool critical in establishing synergies/initiatives for the transformation of the mining sector to a 'greener' and socio-environmentally friendly industry in the 21st century.

The situation described above presents similarities with the Greek mining companies, as derived from discussions with experts in the local industry. Provided that many countries are progressively focused on '*zero carbon*' energy policies, the KM situation becomes an issue of lower priority, as numerous lignite mines will downscale their operations worldwide while others will be decommissioned. The problems associated with dysfunctionality can be assumed to be as follows:

1. Lack of KM culture and systems, which has an effect on the performance, functionality, and cost of extractive activities.
2. Limitations of personnel availability that create dysfunctions when the SMEs undertake new duties (internal rotation) or are on the way to retirement.
3. The quality of documentation and technical information is poor, and the relevant material is outdated and/or inappropriate for use.
4. The lack of life long training (LLT) in equipment technology, industry automation, new legislation for sustainability, ecological restoration, land use repurposing, etc., also has negative performance effects on mining activities.
5. The differences in understanding the terms and vocabularies of mining domain knowledge lead to (a) dysfunctionalities in the communication with external stakeholders and (b) intradisciplinary misalignments.

The above problems, among others, are shaping the context of the appearance of critical KGs that affect, in multiple ways, the mining operations and the mine transformations to achieve sustainability, as the latter are resource-demanding and knowledge-intensive frameworks of high complexity. In these frameworks, many experts from various disciplines of science and technology take intensive efforts to leverage the knowledge they have gained, aiming at the successful planning and execution of transformation initiatives. This effort is becoming more intensive, especially in the aging/closing/decommissioning phase [19], where projects for the transition of mines towards sustainability and CE are in the process of being launched.

From the above discussion, some research questions (RQs) are raised. The identification of the content and the classification of the fundamental KGs observed in mining operations constitute the first research question (RQ1). The second research question (RQ2) is about understanding the causes of KGs and the pre-evaluation of KGs criticality. The third research question (RQ3) is how and to what extent the methodology suggested in the present work can be integrated with a quantitative analysis allowing in-depth investigation of the KM landscape in Greek lignite mining companies and operations.

3. Materials and Methods

3.1. Suggested Methodology

The methodology suggested in the present work is empirical and follows the principles of QLR [20,21] and provides a substantial basis for understanding and analyzing the content and the context of the KGs in terms of their critical influence on the performance of mining operations. As the QLR is based on social interactions, the methodology requires cooperation from SMEs from the Greek mining industry and from other areas and domains of knowledge, such as environmentalists, geologists, ecologists, engineers, socioeconomic specialists, sustainability and land-use planners, legislation and permitting experts, etc. Thus, data and information can be collected, reported, evaluated, and recomposed in patterns and forms, enabling the better understanding of the influence and criticality of KGs in mining operations. The steps of the applied methodology are in line with the QLR principles and in particular the following principles:

S1. Definition of the Research Problem: The research problem is defined as *the 'Investigation of main KGs in mining companies and operations'*.
S2. Literature Review: It includes analysis and review of the existing literature. This step aims to understand how knowledge, KM, and KGs interact in the environment of mining organizations.
S3. Research Organization and Planning: It involves performing semi-structured interviews organized in two workshops (WS). WS1 aims to introduce a team of three SMEs (interviewees) to the research methodology and agenda. WS2 aims to collect primary data for the observed KGs by asking and recording the opinions and perceptions of SMEs.
S4. Data Collection: In WS1, brainstorming on the research concept and context and the sequence of research tasks is conducted, while the identification and preliminary

analysis of main KGs are also performed. In WS2, KGs are grouped into two groups, i.e., *internal* and *external*, and the cause of each KG is discussed and explained. Also, the criticality and relative significance of each KG is roughly estimated in terms of numerical values.

S5. Data Analysis: The data collected for the KGs, their causes, and the criticality rating of each KG are displayed in the form of a table. Statistical analysis for the frequency and criticality of the identified KGs is performed.

S6. Discussion: The outcome of WS1 and WS2 is presented. Based on the interpretations of the outlined statistical parameters, an analysis of the SME's perceptions of the identified main KGs is reported.

S7. Proposals for Further Research: The perspectives on how far and to which level of detail the QLR methodology could be extended and integrated are provided. Some viewpoints for the adaptability of the performed QLR, along with a proposal for a further, more detailed quantitative analysis of the KGs, are presented.

3.2. Application and Results

The methodology was applied by involving three SMEs with long-term experience in mining: (a) a Mining Operations Manager; (b) a University Professor in Mining Science; and (c) a Project and Risk Manager Expert. The outcome of WS1 and WS2 was the identification and taxonomy of Nos.24 KGs (see Figure A1 in Appendix A): (a) the section on internal KGs refers to Nos.13 KGs, which are associated with dysfunctions of knowledge flows and performance limitations within a mining organization, and reflects the introspective purpose of the research and (b) the section on external KGs refers to Nos.11 KGs, which are associated with the poor interchange of knowledge between external sources of knowledge and the mining organization, and reflects the extrospective purpose of the research. The first column of Figure A1 reflects the identification number (K-Ids) of each KG in increasing order. The second column concisely describes the internal and external KGs. The third column concisely describes the main causes of KGs. The last column shows the numerical estimation of the criticality of each KG criticality using a 1–5 rating scale, where 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high. By considering the statistical analysis results of the reflected data (both descriptive and numerical), the assumptions made are follows (Figure A1):

1. Grouping of Main Causes:

- Knowledge management: 41.67% (10 of 24) of KGs relate to the lack of KM policy, strategy, culture, and process and the absence of learning culture;
- Human resources: 37.50% (9 of 24) of KGs relate to the substitution or retirement of SMEs, the hiring of inexperienced personnel, the poor and/or ineffective nature of training, and the rotation of personnel with poor training;
- Technical management and Complexity: 33.33% (8 of 24) of KGs relate to complexity, low awareness of sustainability and CE, misuse of mining terms and technological vocabularies, etc.;
- ICT Systems: 25.00% (6 of 24) of KGs relate to the deficiencies of ICT systems and inter-disciplinary and cross-disciplinary communication(s);
- Company's internal (corporate) management: 20.83% (5 of 24) of KGs relate to organizational changes and their resetting, business processes reengineering (BPR), downsizing, cost cutting, de-escalating of business, etc.;

Note: the main causes, noted above, are linked with and derived from the company's management. If the management does not set the continuous learning and the reskilling and upskilling of the company's personnel as a priority, then the consequences of KGs will definitely occur.

2. Criticality Analysis:

General Evaluation of KGs criticality:

- 16.67% (4 of 24) of KGs in total = VL to LO criticality;
- 83.33% (20 of 24) of KGs: MO to VH criticality;
- 37.50% (9 of 24) of KGs: HI to VH criticality
- 46.15% (6 of 13) of internal KGs: HI to VH criticality;
- Average criticality of internal KGs (13 of 24) = 3.39: MO to HI;
- 27.30% (3 of 11) of external KGs: HI to VH criticality;
- Average criticality of External KGs (11 of 24) = 3.27: MO and HI;
- Average criticality of all KGs (Nos.24) = 3.33: MO to HI.

Evaluation of KGs' criticality per group of main causes:

- Human resources group's average criticality = 3.67: MO to HI;
- Company (corporate) Management's average criticality = 3.40: MO to HI;
- Knowledge management's average criticality = 3.20: MO to HI;
- ICT systems' average criticality = 3.00: MO;
- Technical management's average criticality = 2.75: LO to MO;
- Main causes' (total) average criticality = 3.20: MO to HI.

4. Discussion

The advantages of the QLR methodology are simplicity, quick performance, low complexity statistics, effective cooperation with SMEs (interviewees), low cost, and quick data collection. The disadvantages are limitations associated with the quality and quantity of the data collected, subjectivity, and diversification or misalignments of SMEs' opinions.

It was found that the content of the term KG presents some flexibility in how it is interpreted and used. Therefore, words, or synonymous expressions, matching the KG content, such as *unawareness*, *unavailability of SMEs, and knowledge limitations*, etc., were adopted to define the meaning of KGs in the research. Another important point was the distinction between internal and external KGs. This distinction demonstrates which KGs internally (*introspective analysis*) or externally (*extrospective analysis*) affect the (re)usability of knowledge in mining organizations.

The statistical analysis shows that the main causes of KGs are as follows: (a) lack of an effective/efficient KM system (41.67%), (b) dysfunctions of human resources management (37.50%), and (c) technical and managerial complexities of mining processes (33.33%). This sequence shows that the mitigation, filling, and shortening of KGs is an issue that can be resolved at a strategic level, via decisions on introducing a KM system. In addition, the ICT (25.00%) and the company's management deficiencies (20.83%) are shown to be significant but are causes of second priority, being considered more manageable as soon as an effective KM system is planned and established by the company's management. Other results obtained from the statistical analysis are mentioned below.

The average (overall) criticality for all (Nos.24) KGs is from MO to HI level (3.33). The average criticality for internal and external KGs is from MO to HI level (3.39 and 3.27, respectively). The internal KGs are shown to be of increased urgency since 46.15% of them are evaluated from HI to VH criticality level, while the external KGs are shown to be of decreased urgency since 27.30% of them are evaluated from HI to VH level of criticality. The average criticality for all KGs is calculated based on five categories of main causes from MO to HI level (3.20). The criticality of KGs is calculated for the group of (a) Human Resources, (b) Organization's management, (c) the absence of KM system, and (d) the ICT deficiencies that are evaluated from MO to HI level (3.67, 3.40, 3.20, and 3.00, respectively). The KGs of lower criticality are those related to technical management, which is evaluated to be close to the MO level of criticality (2.75).

5. Conclusions and Further Research

The QLR methodology is a low-cost, easy, and quick application tool appropriate for the preliminary investigation of KGs in organizations/operations of the Greek lignite mining industry. It provides a substantial basis for understanding the content and extent of KGs and their causes. The results of this research show that the main KGs are knowledge losses that are incurred due to the mobility of expert personnel, lack of knowledge on critical domains, managerial and technical dysfunctions, deficiencies of ICT systems, and the absence of KM culture and practices. The research methodology can be integrated at a more detailed level with a statistical analysis of data collected via structured questionnaires from an increased number of SMEs. The steps to be taken for the introduction of KM in mining organizations can become more substantial to the perspective of bridging the KGs and for the introduction of KM in Greek mining organizations. Finally, it is pointed out that the controlling of risks, caused by KM's introduction, requires special attention and appropriate measures that must be adopted as early as possible.

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Appendix A

KG-Ids	Knowledge Gaps (KGs)	Main Causes of KGs	KGs Criticality Rating
Internal KGs (introspective analysis)			
KG-I-01	Lack of subject matter experts (SMEs);	Retirement of SMEs; substitution with inexperienced	5
KG-I-02	Unavailability of experienced personnel to support the company's know-how	Organizational changes/resettings; BPR*; rotation of personnel	4
KG-I-03	Lack of resources required for the company's knowledge development	Downsizing; cost cutting; de-escalating of business	3
KG-I-04	Unawareness of recent updates in mining science and technology	Poor and/or ineffective training	3
KG-I-05	Dysfunctionalities in knowledge development/sharing	Cross-functional 'inertia'; lack of KM culture; complexity	2
KG-I-06	Absence of knowledge (data)base for the mining industry and science	ICT system deficiencies; lack of KM strategy/policy	3
KG-I-07	Obsolesce and/or outdating of company's data/information/documentation	ICT system deficiencies; lack of KM strategy/policy	4
KG-I-08	Poor organization, updating and reuse of company's knowledge	ICT system deficiencies; lack of KM strategy/policy	4
KG-I-09	Misconception of mining activities content, scope and requirements	Misuse of mining terms & technological vocabularies	3
KG-I-10	Lack of knowledge for the sustainable transformation of mines	Low awareness of Sustainability and Circular Economy (CE)	3
KG-I-11	Poor delivery of technical information/data within the company	Deficiencies of ICT & inter-/cross-disciplinary communication	2
KG-I-12	Low quality experts' judgement in decision making frameworks	Substitution or retirement of SMEs; inexperienced personnel	4
KG-I-13	Lack of (in-house) lessons learned workshops	Absence of learning and KM culture;	4
External KGs (extrospective analysis)			
KG-E-01	Limited access and communication with e-libraries	Networking limitations; ICT system deficiencies	2
KG-E-02	Ineffective knowledge acquisition from consultants and subcontractors	Lack of KM strategy for outsourcing management	3
KG-E-03	Ineffective knowledge acquisition from stakeholders & public consultations	Lack of KM strategy on stakeholders management	3
KG-E-04	Ineffective knowledge acquisition from suppliers/vendors/manufacturers	Lack of KM strategy on procurement management	3
KG-E-05	Absence of R&D and knowledge & technology transfer (KTT) partnerships	Ineffective policy for connecting knowledge & production	3
KG-E-06	Poor knowledge exchange with partners and cooperating organizations	Absence of learning culture; lack of KM processes	3
KG-E-07	Poor empirical evidence for problem solving methods, tools and decisions	Substitution or retirement of SMEs; inexperienced personnel	5
KG-E-08	Limitations on the knowledge required for the mines transformation	Complexity & multidisciplinary nature of long term-projects	2
KG-E-09	Changes in governmental policies, legislation, and regulations	Substitution or retirement of SMEs; inexperienced personnel	5
KG-E-10	Changes in funding practices, and financial frameworks/procedures	Substitution or retirement of SMEs; inexperienced personnel	4
KG-E-11	Poor understanding of the mines' transformation effects on society/economy	Substitution or retirement of SMEs; inexperienced personnel	3

Criticaly Rating Scale (1-5):

Very Low	1	Low	2	Medium	3	High	4	Very High	5

Figure A1. Knowledge Gaps (KGs) in Mining Organizations and Operations.

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