# Using blockchain technology for transparency in mining: a strategy to reduce corruption and increase accountability

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**Abstract**

The application of blockchain technology and the implementation of synthetic diamond production represent innovative strategies to transform the mineral resources sector in Angola, with a specific focus on the province of Lunda Sul, where the Catoca mine is located. Blockchain technology aims to improve the governance model and promote greater transparency and traceability in mining operations, a factor that contributes to the mitigation of corrupt practices and the strengthening of corporate responsibility. In addition, the production of synthetic diamonds emerges as a sustainable alternative, capable of reducing the environmental impact associated with traditional mining, and at the same time increasing the competitiveness of the sector in the global market. To support this work, an exploratory and explanatory methodology was adopted, including interviews with key stakeholders, such as two mining companies and the Department of Mines at the Faculty of Engineering of Agostinho Neto University. The referenced interviews enabled a detailed analysis of the current challenges of the sector and the opportunities related to the integration of disruptive technologies, such as blockchain technology, and sustainable practices, such as diamond synthesis. Therefore, the combination of such approaches can transform the Angolan mineral sector, aligning it with contemporary demands for transparency, sustainability, and operational efficiency.

**Keywords:** blockchain technology, transparency, responsibility, mineral resources, chain of value.

# Usando a tecnologia blockchain para transparência na mineração: uma estratégia para reduzir a corrupção e aumentar a responsabilização

**Resumo**

A aplicação da tecnologia blockchain e a implementação da produção de diamantes sintéticos representam estratégias inovadoras para transformar o setor de recursos minerais em Angola, com foco específico na província da Lunda Sul, onde está localizada a mina de Catoca. A tecnologia blockchain visa aprimorar o modelo de governança e promover maior transparência e rastreabilidade nas operações de mineração. Esse fator contribui para a mitigação de práticas corruptas e o fortalecimento da responsabilidade corporativa. Além disso, a produção de diamantes sintéticos surge como uma alternativa sustentável, capaz de reduzir o impacto ambiental associado à mineração tradicional e, ao mesmo tempo, aumentar a competitividade do setor no mercado global. Para embasar este trabalho, foi adotada uma metodologia exploratória e explicativa, incluindo entrevistas com partes interessadas chave, como duas empresas de mineração e o Departamento de Minas da Faculdade de Engenharia da Universidade Agostinho Neto. As entrevistas realizadas permitiram uma análise detalhada dos desafios atuais do setor e das oportunidades relacionadas à integração de tecnologias disruptivas, como a blockchain, e de práticas sustentáveis, como a síntese de diamantes. Portanto, a combinação dessas abordagens pode transformar o setor mineral angolano, alinhando-o às demandas contemporâneas por transparência, sustentabilidade e eficiência operacional.

**Palavras-chave:** tecnologia blockchain, transparência, responsabilidade, recursos minerais, cadeia de valor.

## 1. Introduction

Blockchain technology—based on principles such as decentralization, transparency, and auditability—represents a disruptive paradigm with the potential to revolutionize various sectors, including the diamond industry (Souza, 2021). Its distributed and immutable architecture enables the creation of transparent and verifiable records that can be used to track the entire diamond supply chain, from extraction to the final consumer. This traceability is critical for ensuring the ethical provenance of diamonds, combating the trade in so-called "blood diamonds," and promoting socio-environmental sustainability.

In Angola, particularly in the province of Lunda Sul, the implementation of blockchain in the diamond sector has the potential to enhance transparency, ethics, and sustainability. By recording each stage of extraction, transport, and commercialization on a distributed ledger, the technology reduces reliance on intermediaries and mitigates risks of fraud and corruption.

Furthermore, blockchain technology can strengthen consumer and investor trust, boosting the sector's competitiveness in the global market. Despite its potential, the adoption of blockchain technology requires overcoming challenges. These include developing robust technological infrastructure, investing in the training of qualified human resources, and formulating public policies that support innovation and digital governance (Nakamoto, 2008).

The integration of blockchain with other emerging technologies, such as artificial intelligence and the Internet of Things (IoT), can further expand its impact, enabling real-time data collection and advanced process automation. Thus, blockchain technology offers a unique opportunity to transform Angola's diamond industry by aligning it with international standards for transparency, ethics, and sustainability. Its successful implementation depends on strategic planning, including investments in infrastructure, capacity-building, and innovation-oriented public policies, to ensure a more inclusive and prosperous future for the country's mineral sector.

### *1.1 Blockchain technology*

Blockchain technology originates from a decentralized transaction protocol that operates on a peer-to-peer (P2P) network, allowing participants, who may not trust each other, to interact without relying on a central authority (Nakamoto, 2008). This architecture enables the secure and decentralized exchange of information, effectively eliminating the need for intermediaries.

The conceptual foundation of blockchain can be traced back to the double-entry bookkeeping system introduced by Luca Pacioli in 1494. This system, which required each transaction to be recorded as both a debit and a credit, introduced principles of balance, traceability, and accountability—concepts that remain central to modern financial governance (Itforum, 2022). The term "ledger," used in both accounting and blockchain contexts, originates from this historical method of organizing financial records.

Blockchain builds upon these foundations by employing a decentralized and immutable ledger. Each block in the chain contains the hash of the previous block, forming an interdependent structure that ensures the immutability of the record (Lima, 2022). As Lima explains, any attempt to modify a single transaction would require the alteration of all subsequent blocks—an action that is computationally infeasible. This chaining mechanism, combined with consensus algorithms like Proof-of-Work (PoW), ensures the security and integrity of the data stored within the system (Aitzhan & Svetinovic, 2018).

According to Bezerra (2010), one of the fundamental pillars of blockchain is cryptology—the science of encoding and decoding information. Techniques such as hashing and digital signatures reinforce the authenticity, integrity, and confidentiality of transactions (Figure 1). These cryptographic foundations are what allow blockchain to become a trusted infrastructure for both private and public sector applications.

In this sense, blockchain technology represents more than a digital innovation—it is a technological evolution that combines historical accounting concepts with modern advances in cryptography and distributed computing. Its ability to create immutable, auditable, and transparent records opens new possibilities across various sectors, from finance to supply chain management, redefining how organizations approach governance, accountability, and operational efficiency.

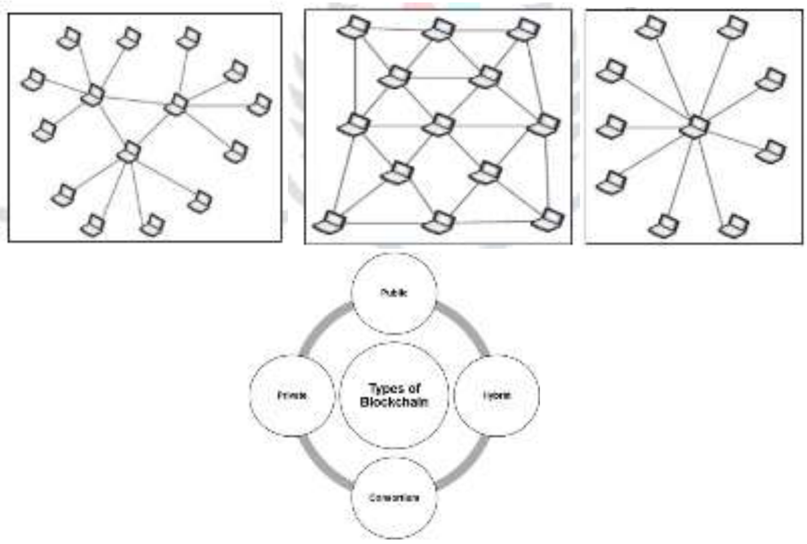


Figure 1. Private, consortium, and public blockchain technology types (Kibet et al., 2019).

The rapid technological advancements of the 21st century have reshaped how societies and industries operate, fostering an environment increasingly receptive to innovation. Among these emerging technologies, blockchain has garnered significant attention due to its capacity to address long-standing challenges in data integrity, transparency, and decentralized governance.

Fundamentally, blockchain is a distributed ledger system designed to securely record transactions through cryptographic mechanisms and consensus algorithms. Each transaction is authenticated with a digital signature, ensuring its legitimacy, and once recorded, data becomes immutable, resistant to unauthorized modifications (Cointelegraph, 2021). This architectural structure underpins blockchain's ability to offer a tamper-proof system for data management.

Before the advent of blockchain, financial and operational records were traditionally maintained in centralized and often opaque systems. These centralized models necessitated a high degree of trust in intermediaries to ensure data fidelity and prevent fraudulent alterations. Blockchain technology redefines this paradigm by distributing data across multiple nodes—network participants that collectively validate and store identical copies of the ledger. This decentralization enhances transparency, reduces the reliance on central authorities, and significantly mitigates the risk of fraud (Simply, 2022).

Particularly in sectors susceptible to corruption and opacity, such as the mining industry, blockchain offers a compelling solution. By creating a transparent and immutable digital trail of transactions and operational events, blockchain can help address critical issues like traceability gaps, illicit trade, and socio-environmental mismanagement (Ferreira, 2020). The shared ledger ensures that all stakeholders—from governments and companies to consumers and regulators—operate from a single, verifiable source of truth, thus reinforcing accountability and ethical compliance.

In this context, blockchain technology represents a paradigm shift in how data is stored, verified, and shared (Figure 2). Its robust security model and decentralized architecture position it as a transformative tool capable of fostering more ethical, transparent, and sustainable practices in complex and high-risk industries.

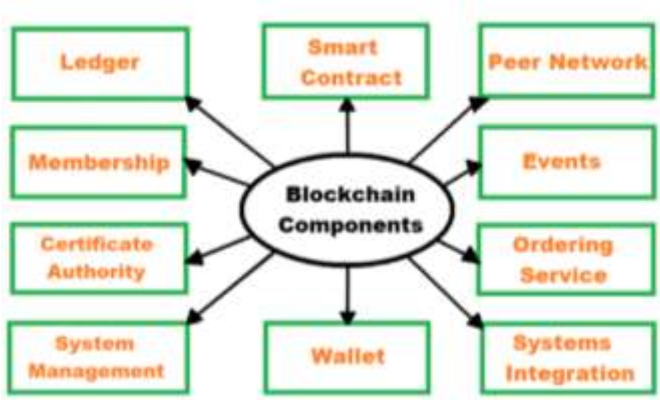


Figure 2. Components of block blockchain technology (www.TheEngineeringProjects.com).

Blockchain technology enables the execution of permanent and unique transactions through a structure composed of interconnected data blocks. At the core of this system lies encryption, which plays a crucial role in safeguarding information and encoding messages, irrespective of data variability, volume, or type. These cryptographic protocols ensure advanced levels of security throughout the transaction process (Escobar, 2021).

Transactions are recorded immutably within a sequential chain of blocks, each authenticated by participants in the network, referred to as nodes. These nodes are responsible for validating the integrity and accuracy of the data, collectively upholding the reliability of the blockchain system.

This decentralized and tamper-resistant architecture obviates the need for traditional intermediaries, such as banks or central authorities, to verify transactions. Instead, trust is established through consensus mechanisms, such as Proof-of-Work (PoW) and Proof-of-Stake (PoS), which govern the validation process and ensure that all transactions are securely and transparently recorded on the ledger.

The distributed nature of blockchain further enhances its resilience against systemic failure and cyberattacks. With every node maintaining a full copy of the ledger, any attempt to tamper with the data would require the simultaneous alteration of all subsequent blocks across every instance of the ledger—a task rendered practically infeasible due to the immense computational effort required.

As an emergent and transformative technology, blockchain integrates cryptographic techniques, decentralization, and consensus algorithms to establish a secure, transparent, and efficient infrastructure for transaction validation. Its application spans a wide range of sectors—including finance, logistics, and supply chain management—offering the potential to foster increased trust, operational efficiency, and data integrity across diverse domains.

### *1.2 Geology of diamond deposits*

Diamond deposits can be classified into two main types: primary and secondary. Primary deposits are associated with cratonic areas, particularly Precambrian cratons of the Archaean, as established by Clifford's Rule (Clifford, 1966; Jennings, 1995). These areas are geologically favorable for the preservation of diamonds, since they present stable and deep conditions necessary for the formation and maintenance of these minerals. Diamonds are transported to the surface through explosive volcanic episodes, associated with rocks of magmatic origin, such as kimberlites and lamproites (Mitchell; Bergman, 1991). These rocks result from eruptions that bring material originating in the Earth's mantle, which are products of intraplate magmatism (Figure 3).

Primary deposits are formed at depths ranging from 150 to 200 km, at temperatures ranging from 1100 to 1500 °C, in geological processes dating back to periods beginning around 3.3 billion years ago (Mitchell, 1986). Kimberlites, in particular, are extremely rare rocks, with an abundance in the Earth's crust of less than 1%. They occur in craton zones in the form of chimneys, dikes, and sills (Sêco, 2009; Fipke et al., 1995). However, not all kimberlites are mineralized with diamonds. Globally, less than 1% of these rocks contain diamonds in economically viable quantities, and only about fifteen deposits are considered world-class mines (Fipke et al., 1995).

It is worth noting that kimberlite magma has no direct genetic relationship with diamonds, as it acts only as a means of transport and allows diamonds, formed under extreme conditions in the Earth's mantle, to rise to the surface (Mitchell, 1986; Kjarsgaard et al., 2022). This ascension process is fundamental for the formation of primary deposits, which are economically exploited in various parts of the world.

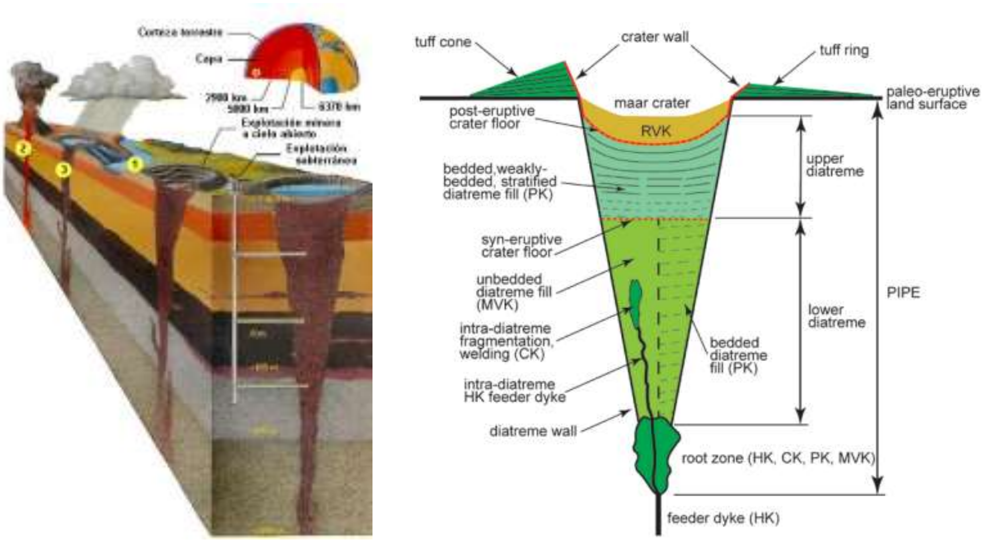


Figure 3. Cross-section (highly schematic composite, no scale implied) of a kimberlite maar-diatreme volcano, at the post-eruptive stage in which the maar-crater has been partially in-filled, illustrating the key terms used in this chapter. RVK = resedimented volcaniclastic kimberlite; PK = pyroclastic kimberlite; MVK = massive volcaniclastic kimberlite; HK = hypabyssal kimberlite; CK = coherent kimberlite. Source: Authors, 2025.

The terminology of this non-genetic maar-diatreme volcano, as well as the associated lithofacies, can be equally applied to olivine lamproite or CROL. Modified after Kurszlaukis (written communication 2003, 2020), Kjarsgaard (2007a, b), and White and Ross (2011), Kjarsgaard et al (2022).

Therefore, primary diamond deposits are intrinsically linked to specific geological contexts and involve deep magmatic processes and extreme thermodynamic conditions, the understanding of which is essential for the efficient prospecting and exploration of diamonds, given the importance of geology in the mineral resources sector.

1.2.1 Minerals

According to the definition of Latas (2016), diamond is a mineral composed exclusively of carbon, whose atoms are organized in a cubic lattice crystal structure. This atomic arrangement gives diamond its unique physical and optical properties. Diamonds can present different crystal habits, with octahedral being the most common, followed by dodecahedral, tetrahedral, and, very rarely, cubic (Figure 4).

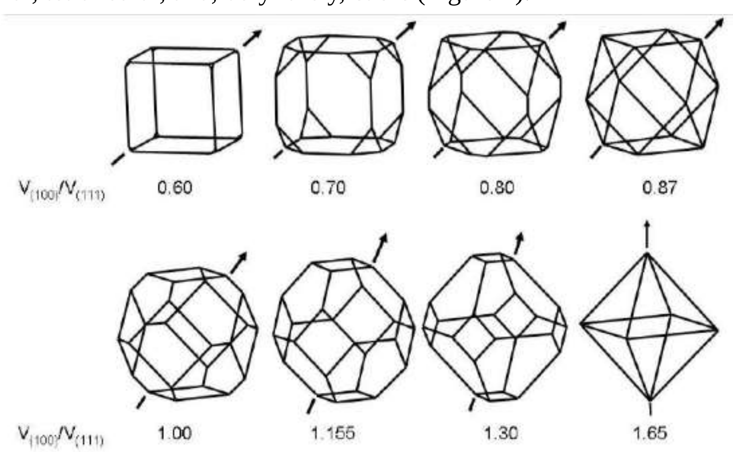


Figure 4. Variation in the crystal shape by the growth ratio of (100) face to (111) face (Gracio et al., 2010).

Among the physical characteristics, diamond exhibits perfect cleavage in four directions, conchoidal fracture, and a distinctive adamantine luster, which contributes to its aesthetic appeal. On the Mohs scale, diamond has the maximum hardness, corresponding to the value 10, which makes it the hardest natural material known. In terms of coloration, diamonds are generally colorless, but can present soft shades of yellow or gray.

The unit of mass used to measure diamonds, adopted in 1907 at the Fourth General Conference on Weights and Measures, is the carat, which is equivalent to 200 milligrams (0.2 grams), whose standardization allows for the accurate assessment of the weight of diamonds, a critical factor in determining commercial value.

Thus, diamond is a remarkable mineral, both for its exceptional physical properties and for its simple chemical composition, whose cubic structure, extreme hardness, and characteristic shine make this mineral one of the most valuable and coveted materials in the world, both for industrial applications and for use in jewelry.

Angola is widely recognized for its diamond potential, as it has favorable geology and a long history of diamond exploration (Figure 5). The country is located in the central region of the Congo Platform, a stable cratonic area that is home to some of the richest diamond reserves on the planet. Diamond exploration in Angola dates back to the early 20th century, with the discovery of alluvium deposits in the Lunda Norte and Lunda Sul regions, the region where the Catoca mine, one of the largest open-pit diamond mines in the world (Fipke et al., 1995; Jennings, 1995).


Figure 5. Angolan map with the concession’s miners object of the Contest Public International, 2019.

Angolan diamonds are mainly associated with kimberlite rocks, which are Igneous rocks formed in the Earth's mantle and are transported to the surface by deep volcanic eruptions (Mitchell, 1986). Such rocks occur in stable cratonic zones, such as the provinces of Lunda Norte and Lunda Sul, which are part of the Congo Craton. Clifford's Rule (Clifford, 1966) establishes that primary diamond deposits are associated with archaic cratons, which explains the concentration of kimberlites in these regions. In addition to primary deposits, Angola has vast secondary deposits - alluvial and eluvial - formed through erosional and transport processes of kimberlitic material over millions of years, which are mined in riverbeds and adjacent areas, and are responsible for a portion of the country's diamond production (Sêco, 2009).

Angola (Figure 5) ranks among the world's largest diamond producers, with an annual production exceeding 8 million carats (Ministry of Mineral Resources and Petroleum, 2021). The Catoca mine (Figure 6), which is operated in partnership with international companies, accounts for more than 70% of the national production. In addition to Catoca, there are other projects under development, such as Luaxe and Chiri, which promise to further increase the country's production capacity.

Therefore, diamond mining plays a crucial role in Angola's economy, as it plays a strategic role in Angola's economy and the development of infrastructure in mining regions. However, the sector faces technological modernization challenges, the formalization of artisanal mining, and the mitigation of socio-environmental impacts (Ferreira, 2020).

Figure 6. Catoca diamond mine (Mining.com, 2025, March 29).

Sustainable diamond mining in Angola requires the adoption of practices that balance economic growth with environmental preservation and social development. The implementation of advanced technologies, such as blockchain technology, can enhance the traceability of diamonds, ensuring that they come from ethical and conflict-free sources (Escobar, 2021; Wilson et al., 2006). In addition, public policies that promote the training of local labor and the diversification of the economy are essential to maximize the benefits of the diamond industry.

Therefore, the potential for diamond exploration in Angola is vast, supported by favorable geology and expanding infrastructure, whose long-term success depends on the adoption of practices that balance economic growth with environmental preservation and social development, investment in technology, and policies that promote social inclusion and environmental protection. With proper management, the diamond industry can continue to be a fundamental pillar for Angola’s economic and social development.

## 2. Materials and Methods

The methodology adopted in this study was structured based on rigorous scientific principles, aligned with the idea that "any knowledge is an answer to a question" (Japiassú, 1999). To this end, a mixed methods approach was used to produce empirically supported findings that apply to the topic in question: Application of blockchain technologies to improve transparency in the extractive sector: a case study on how blockchain technology can reduce corruption and increase accountability in the mining industry.

*a) Problem immersion*

- The study employed the Problem Immersion technique, which involved the following steps:
- Identification of challenges related to transparency, corruption, environmental impact, and competitiveness in the diamond mining sector in Angola.
- In-depth analysis of the causes and effects of such problems, focusing on the province of Lunda Sul, where the Catoca mine is located.
- Confirmation of the importance and relevance of the topic, based on scientific literature and sectoral data.
- Clear definition of the problem and objectives of the study, which include the characterization of blockchain technology, application of the technology to the mining sector, and assessment of its impact on data and security.

*a) Methodological approach*

The study was based on an exploratory and explanatory approach, using bibliographic review methods. The research was divided into three main stages:

a) Analysis of scientific literature and technical reports on blockchain technology, diamond mining, and governance in the extractive sector.

b) Interviews were conducted with 23 industry professionals, including representatives from mining companies, academic institutions, and government agencies. The interviews were conducted in person and via digital platforms (WhatsApp), following a questionnaire divided into three sections:

- Questions about management practices and challenges related to corruption.
- Analysis of the effects of mining on local communities and the national economy.
- Perspectives on the adoption of innovative technologies such as blockchain technology and synthetic diamonds.

c) The collected data were analyzed thematically and represented graphically using the Excel tool, which made it possible to identify patterns and trends.

*a) Implementation and validation*

Based on the research results, an activity plan was drawn up for the implementation of blockchain technology in the diamond mining sector in Angola. The plan includes:

a) Detailed description of decentralized architecture, security, and data.

a) Analysis of the potential benefits of blockchain technology in reducing corruption, increasing transparency, and improving operational efficiency.

b) Suggestions for integrating blockchain technology into specific processes, such as diamond traceability and supply chain management.

*a) Study Limitations*

During the research, the following limitations were identified:

a) Some mining companies have restricted access to their facilities, requiring formal documentation.

b) Few national studies that directly address the application of blockchain technology in the mining sector.

c) Some of the professionals indicated for the interviews withdrew from the process during the study.

*b) Description of the Instrument Used to Conduct the Interviews*

The instrument used for data collection in this work included a semi-structured questionnaire, organized into three main sections, each focused on a specific aspect of the diamond sector and the application of blockchain technology. The questions were designed based on the research objectives and the gaps identified in the literature review to obtain detailed and relevant information from the interviewees.

*c) Governance and Transparency Model*

Issues related to governance, transparency, and regulation of the diamond sector in Angola were raised, from the perspective of interviewees' perception of the effectiveness of current policies and the need for improvements, based on the following questions:

a) GT 01: In your opinion, is it essential that there are clear and specific laws that criminalize acts such as diamond smuggling and tax evasion in the diamond sector?

b) GT 02: Is there a need to review the social obligations of exploration companies, requiring investments in infrastructure, education, and health in the communities where they operate?

c) GT 03: Are tax residents and the lack of expertise to deal with the complexity of inventory assessment operations the main tax gaps in the diamond sector?

d) GT 04: Does the presence of state-owned companies in the diamond sector stabilize the diamond market and ensure the maximization of benefits for the country?

e) GT 05: Will the implementation of corporate governance mechanisms promote the improvement of regulation of the diamond sector in Angola?

f) GT 06: Has the Kimberley Process, together with other national and international initiatives, played a crucial role in promoting transparency and combating the illicit diamond trade in Angola?

*i. Socioeconomic impacts*

This section explores the socioeconomic and environmental impacts of diamond mining, with a focus on transparency, job creation, and mitigation of negative impacts.

a) IS 01: Can the lack of transparency in the results of mining operations and the absence of adequate local development plans limit the benefits of mining to the communities where mining projects are located?

b) IS 02: Do direct and indirect jobs generated by diamond mining contribute to poverty reduction in Angola?

c) IS 03: Does the Kimberley Process and the publication of all contracts between the government and mining companies increase transparency and prevent conflict diamonds from entering the legal market?

d) IS 04: Can the involvement of local communities in the recovery of degraded areas through revegetation techniques, soil rehabilitation, and treatment of water contaminated by the mining process constitute measures to mitigate environmental impacts?

*ii. Future of the industry (Applying blockchain technology)*

This section focuses on the application of blockchain technology in the production of synthetic diamonds and explores its potential impact on increasing transparency, traceability, and sustainability in the sector.

a) B01: Has blockchain technology increased consumer confidence, transparency, and traceability of diamonds in Angola?

b) B02: Can international cooperation support Angola in developing a more sustainable and transparent diamond sector?

c) B03: Does the production of synthetic diamonds drive the development of new technologies and materials, with applications beyond jewelry, such as the electronics industry?

d) B04: Have companies implemented corporate policies to ensure the periodic updating of their employees' skills?

## 3. Results

Based on the literature review, which addressed the mining subsector, the challenges and benefits of using blockchain technology, and the data collected through an interview, it was possible to structure the results and discussion presented in this scientific article. According to Diaz et al. (2013), the combination of theoretical and empirical information ensures consistency and relevance in the results. This approach allows for the incorporation of essential elements related to the research topic.

The literature review aimed to contextualize the mining subsector and highlight its main challenges, such as a lack of transparency, corruption, environmental impacts, and the need for technological modernization. It also explored the benefits of blockchain technology, including data, transaction transparency, reduction of intermediaries, and increased trust in operations. These aspects were fundamental in supporting the analysis and interpretation of the collected data.

### *3.1 Interviews*

During the interviews conducted for this study, detailed and specific data related to the extractive industry were collected, with an emphasis on the diamond exploration segment, mainly the largest diamond mines in Angola. Catoca was selected as the central focus due to its national and international relevance. It accounts for a portion of the country's diamond production and plays a crucial role in the economy of both Lunda Sul province and Angola overall.

The interview participants were carefully selected to ensure a multidisciplinary and comprehensive perspective. They included professionals and experts from diverse backgrounds, whose insights enriched the analysis and provided a holistic view of the sector. The group comprised mining specialists, economists, sociologists, government representatives, private-sector professionals, and civil society organizations.

Mining experts with extensive technical and operational experience contributed valuable insights into the geological, logistical, and technological challenges faced by the industry. Economists provided data and analysis on the sector’s contribution to Angola’s GDP, tax revenues, and regional economic development. Sociologists examined the social effects of mining, such as its impact on local communities, migration patterns, employment generation, and issues related to inclusion and poverty reduction.

Government representatives involved in regulating and promoting the mining sector shared information on public policies, institutional challenges, and oversight mechanisms. Private companies, including managers and technicians, shared practical experiences, operational challenges, and strategies for enhancing efficiency and sustainability. Meanwhile, civil society organizations offered independent, critical views on the environmental and social impacts of mining and advocated for greater transparency, sustainability, and human rights in the extractive sector.

The interviews followed a semi-structured format using a questionnaire divided into three main sections: governance and transparency, socio-economic impacts, and the future of the sector (with a focus on blockchain technology). This approach allowed flexibility to delve deeper into interviewees' specific areas of knowledge while ensuring consistent coverage of the study's core themes.

The collected data were analyzed thematically, with graphs and tables generated using Excel to help visualize emerging patterns and trends. The analysis combined quantitative data (e.g., response frequencies) and qualitative interpretations of interviewee opinions, ensuring a balanced and comprehensive understanding of the sector's challenges and opportunities.

The diversity of the interviewees enabled a multidimensional view of the diamond mining sector in Angola. By incorporating technical, economic, social, and political perspectives, the research findings were strengthened in terms of relevance, applicability, and alignment with the study's goals. The methodology, based on semi-structured interviews and thematic analysis, was essential to providing practical recommendations for enhancing governance, transparency, and sustainability.

During data collection, some limitations were encountered, particularly regarding access to information and institutional cooperation. One of the main obstacles stemmed from bureaucratic procedures that complicated direct communication with key stakeholders.

Conversely, several institutions were more receptive. One company, for instance, demonstrated openness and actively contributed valuable insights on governance and sustainability. Another company initially posed challenges, but eventually facilitated productive interviews. However, it was noted that many interviewees had limited familiarity with the research topic, requiring additional explanation of the study's objectives and relevance.

Lastly, the Department of Mining at the Faculty of Engineering of Agostinho Neto University (FE-UAN) saw strong participation from both students and faculty, particularly women. This highlights the increasing presence of women in mining engineering, signaling positive strides in gender diversity and inclusion. The collaboration of these students brought a valuable academic and youthful perspective to the discussion on the mining sector's future in Angola.

### *3.2 Characterization of interviews*

Table 1 presents the results of the interviews conducted with four key institutions: two minerals companies and Universidade Agostinho Neto (UAN), organized into three main categories: Governance and Transparency, Socioeconomic Impacts, and Blockchain Technology. Each category was evaluated based on the answers "Yes", "No", and "Other", which represent, respectively, agreement, disagreement, and neutral or undefined responses.

a) Governance and transparency

This category assesses institutions' perception of the effectiveness of governance and transparency policies in the mining sector. In Company 1, the majority of interviewees (22) agreed that good governance and transparency practices exist, while 4 disagreed and 4 provided neutral responses. Company 2 registered the highest proportion of positive responses (27), indicating a generally favorable perception, though 5 interviewees disagreed and 4 remained neutral. Among UAN students, 11 agreed with the statement, 2 disagreed, and 1 gave a neutral response. This distribution reflects a moderately positive overall view. Overall, most institutions acknowledge progress in governance and transparency; however, there is still room for improvement, particularly at the companies, where some disagreements and neutral responses were noted.

b) Socioeconomic impacts

This category examines perceptions of the socioeconomic impacts of mining, including its benefits to communities and the economy. In Company 1, 18 interviewees expressed a positive view ("yes"), with only 2 disagreements and no neutral responses. Company 2 recorded 14 positive responses, indicating a generally favorable perception, though several disagreements (8) and 2 neutral responses suggest some concerns. Among UAN students, 9 interviewees had a positive view, while 2 disagreed and 1 remained neutral. Overall, the analysis indicates that most interviewees recognize the positive impacts of mining; however, Company 1 stands out for having more disagreements, which may be attributed to perceived inequalities in benefit distribution and reported adverse effects on surrounding communities.

c) Blockchain technology

This category evaluates perceptions of blockchain technology's potential to enhance transparency in the sector. In Company 1, 15 interviewees expressed interest in the technology ("yes"), while 3 disagreed and 2 provided neutral responses. Company 2 registered the highest proportion of positive responses (20), indicating strong interest in adopting blockchain technology, with only 3 disagreements and 1 neutral response. Among UAN students, 5 agreed, 1 disagreed, and 6 remained neutral, suggesting limited familiarity and some uncertainty regarding the technology.

Thus, blockchain technology is seen as a promising solution, especially for companies. However, the lack of familiarity with the topic among UAN students suggests the need for greater dissemination and training on such technology.

Overall, Company 1 stood out with the highest number of positive responses (61 Yes), but also with a considerable number of disagreements (16 No), which may indicate internal challenges or differences of opinion. Company 2 presented a balance between positive (55 Yes) and critical (9 No) responses, reflecting a generally favorable view, but with room for improvement. UAN showed moderate participation, with 25 “yes” responses, but several neutral responses (8 Other), suggesting the need for greater involvement and knowledge on the topics addressed.

Table 1. Data according to the Institution consulted.

| Companies | Governance and Transparency | | | Impacts Socioeconomic | | | Blockchain Technology | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yes | No | Other | Yes | No | Other | Yes | No | Other | Yes | No | Other |
| Company 1 | 22 | 4 | 4 | 18 | 2 | 0 | 15 | 3 | 2 | 55 | 9 | 6 |
| Company 2 | 27 | 5 | 4 | 14 | 8 | 2 | 20 | 3 | 1 | 61 | 16 | 7 |
| UAN | 11 | 2 | 1 | 9 | 2 | 1 | 5 | 1 | 6 | 25 | 5 | 8 |
| Total | 60 | 11 | 9 | 41 | 12 | 3 | 40 | 7 | 9 | | | |

Source: Authors, 2025.

The results contained in Table 1 reveal a generally positive perception regarding governance, socioeconomic impacts, and the potential of using blockchain technology in the diamond mining sector in Angola. However, disagreements and neutral responses, especially in Company 1 and among UAN students, highlight the need for improvements in transparency, benefit distribution, and training on innovative technologies.

## 4. Discussion

### *4.1 Governance and transparency analysis*

The results presented in Table 1 show perceptions about transparency, governance, and the impacts of mining on local communities. In this case, 75% of respondents state that the lack of transparency in the results of mining operations and the absence of adequate local development plans can limit the benefits of mining for the communities where the projects are located. A majority indicate a general concern about how profits and benefits from mining are distributed (Figure 7).

The lack of transparency can result in communities’ distrust of companies and the government, while the absence of adequate local development plans can result in limited or unequal socioeconomic impacts. To this end, the results highlight the need to implement policies and practices that promote greater transparency in mining operations and the implementation of local development plans that meet the needs of affected communities.

On the other hand, 13.8% of interviewees agree with the existing governance model in the mining sector and support the current model, which may reflect a positive view of current policies and regulations, or a lack of knowledge about more effective alternatives. Therefore, although it is a small percentage, this positive view suggests that there are aspects of the current model that can be maintained or improved, rather than completely overhauled.


Figure 7. Interview results in the context of governance. (Source: Authors, 2025).

Finally, 10.5% of interviewees said they were indifferent to the existing governance model, characterized by a lack of involvement or knowledge about governance policies, or even a perception that these policies have no direct impact on their lives or activities. For this group, the need for greater engagement and awareness about the importance of governance in the mining sector stands out, both for communities and for professionals in the sector.

Therefore, the results in Table 1 and Figure 7 show that the lack of transparency and the absence of local development plans are the main challenges perceived by the interviewees, with 75% highlighting these factors as limiting the benefits of mining for communities. Meanwhile, only 13.8% express agreement with the existing governance model, and 10.5% are indifferent.

### *4.2 Socioeconomic impact analysis*

The application of blockchain technology and the production of synthetic diamonds in Angola's mineral resources sector, with a focus on the Lunda Sul province and the Catoca mine, has the potential to generate socioeconomic impacts (Figure 8). The analysis of the interviewees' responses, particularly about questions IS 02 and IS 04, reveals relevant data that allows a better understanding of such impacts.

Regarding the generation of direct and indirect jobs, 74.44% of interviewees confirmed that projects related to the implementation of blockchain technology and the production of synthetic diamonds have a positive impact. The introduction of new technologies, such as blockchain technology, can create employment opportunities in areas such as data management, IT, and supply chain auditing, which are essential to ensure the transparency and traceability of mining operations. On the other hand, the production of synthetic diamonds can generate jobs in research and development laboratories, as well as in industrial production units, factors that can contribute to the diversification of the local economy. However, it is important to consider that the transition to more sustainable and technologically advanced practices may require the retraining of the existing workforce, which represents an initial challenge that needs to be addressed.

In the context of sustainability and corporate responsibility, the implementation of technologies such as blockchain technology and the production of synthetic diamonds are seen as strategies that promote more ethical and environmentally responsible practices. Blockchain technology allows for greater transparency in mining operations, which can reduce corrupt practices and improve governance in the sector. This strategy can increase investor and consumer confidence, both nationally and internationally. The production of synthetic diamonds, in turn, reduces the environmental impact associated with traditional mining, such as soil degradation, water contamination, and greenhouse gas emissions. This shift aligns the sector with global demands for more sustainable practices and can improve Angola's image in the international diamond market. In addition, the adoption of sustainable practices can attract investment from companies and organizations that prioritize social and environmental responsibility, boosting the region's economic development.

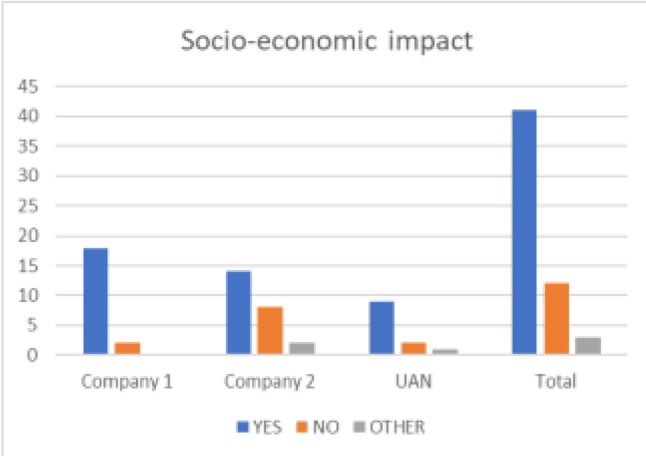


Figure 8. Interview results regarding socioeconomic impact. Source: Authors, 2025.

The combination of transparency, guaranteed by blockchain technology, and sustainability, provided by the production of synthetic diamonds, can increase the competitiveness of the Angolan mineral sector in the global market. The traceability of Angolan diamonds, ensured by blockchain technology, can make them more attractive to consumers concerned about the ethical origin of the products. At the same time, the production of synthetic diamonds can position Angola as an innovative player in the gemstone market, especially in a context where the demand for sustainable alternatives is growing.

However, while the socio-economic impacts are predominantly positive, it is important to consider the challenges associated with implementing blockchain technology and practices. Reskilling the workforce and adapting to new technologies may require more investments in education and vocational training. Furthermore, the transition to synthetic diamond production may face resistance from traditional industry players, who may view such a shift as a threat to their intrinsic interests.

Therefore, the analysis of the interviewees' responses, particularly about questions IS 02 and IS 04, indicates that the application of blockchain technology and the production of synthetic diamonds have the potential to transform the Angolan mineral sector and generate positive socio-economic impacts. These innovations can promote job creation, transparency, sustainability, and competitiveness of the sector, aligning it with contemporary demands for more ethical and efficient practices. However, the successful implementation of such strategies will require careful planning, investment in capacity building, and overcoming challenges related to adapting to new technologies and practices.

### *4.3 Future of the sector*

In the last section of the survey, dedicated to the Future of the Sector, it was found that the interviewees, mainly students from the Faculty of Mining Engineering, demonstrated a lack of knowledge about blockchain technology (Figure 9). This lack of knowledge led to doubts and a weak understanding (41.6%) of issues related to the technology. In addition, there was a 50% abstention in the responses related to the topic, which indicates a lack of familiarity or adequate information on the subject among the participants.

This scenario reflects the need for investment in education and training regarding disruptive technologies, such as blockchain technology, which have the potential to transform the Angolan mining sector. A lack of knowledge about these innovations can hinder implementation and limit the intrinsic benefits, both in terms of transparency and operational efficiency, as well as sustainability. Therefore, it is essential that educational institutions, such as the Faculty of Mining Engineering, integrate content on emerging technologies into their curricula to promote the training of professionals prepared for the challenges of the future.

On the other hand, in terms of socioeconomic impact, interviewees acknowledged that direct and indirect jobs generated by mining-related projects can contribute to poverty reduction in Angola. Furthermore, the involvement of local communities in initiatives to restore degraded areas through techniques such as revegetation, soil rehabilitation, and treatment of water contaminated by the mining process was seen as an important measure to mitigate environmental impact. These practices enable ecosystem restoration and promote the active participation of communities, strengthening the sector's role in the sustainable management of natural resources.

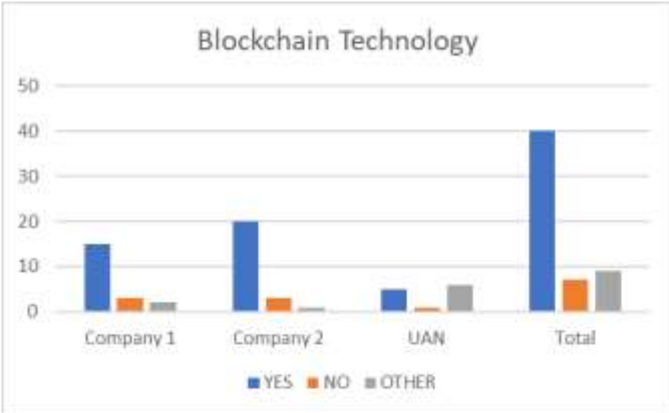


Figure 9. Results of the interview on the future of the sector. Source: Authors, 2025.

However, despite these positive perspectives, 20% of interviewees denied that these measures have an impact, while 5.54% abstained from responding. This divergence of opinions may be related to a lack of information or the perception that environmental mitigation efforts and community involvement are not yet sufficiently effective, a factor that reinforces the need for greater dissemination and awareness of the benefits of these practices, as well as greater transparency in the implementation of environmental recovery projects.

In this context, the survey results highlight the importance of investing in the education and training of students and professionals in the mining sector, especially in the area of innovative technologies such as blockchain technology. Furthermore, it is essential to promote sustainable practices, such as the recovery of degraded areas and the involvement of local communities, to ensure that the development of the Angolan mining sector is inclusive, transparent, and environmentally responsible. Overcoming the challenges identified, such as technological ignorance and lack of trust in environmental mitigation measures, is crucial to achieving the objectives and transforming the sector into a model of sustainability and innovation.

### 4.3.1 Implementation of technological innovations for the mining industry

The growing need to achieve productivity gains and competitiveness in the global market with products with higher added value and a higher degree of innovation has driven the adoption of innovative technologies, both in the field of substantial innovation, such as the application of blockchain technology, and in the field of disruptive innovation, such as the production of synthetic diamonds. The production of synthetic diamonds, in particular, represents a change in the diamond mining and processing sector, with the potential to increase efficiency, reduce costs, and improve global competitiveness. The production of synthetic diamonds is an industrial process that replicates the extreme conditions under which diamonds form naturally on Earth. While natural diamonds are formed over millions of years, under extremely high pressure and temperature deep within the planet, modern technology makes it possible to create identical diamonds in a laboratory in a matter of weeks. This technological advance not only offers a sustainable alternative to traditional mining but also opens up new opportunities for the industrial use of diamonds, ranging from the manufacture of cutting tools to applications in electronics and cutting-edge technology.

Thus, the adoption of new technologies in diamond mining and processing can bring benefits, such as increased efficiency, cost reduction, sustainability, and global competitiveness. More advanced industrial processes allow the production of high-quality synthetic diamonds consistently and on a large scale, eliminating many of the costs associated with traditional mining, such as excavation, transportation, and environmental impacts. In addition, the production of synthetic diamonds reduces the environmental impact, since it does not involve the degradation of ecosystems or the emission of polluting gases associated with mining. With a cheaper and more sustainable alternative, synthetic diamonds can position Angola as an innovative player in the global market for gemstones and industrial materials.

However, the production and marketing of synthetic diamonds also present challenges, especially in terms of consumer confidence and the differentiation between synthetic and natural diamonds. The provision of synthetic gemological material as a substitute for natural diamonds can generate distrust among consumers, especially when there is a lack of transparency and clarity about the origin of the diamonds. This situation requires the development of accurate, easy-to-use, and widely available identification and detection tools. The challenge for the gemological and mining sector is to keep up with technological innovations and ensure that professionals, such as gemologists, laboratories, and dealers, are trained to perform accurate tests and differentiate between natural and synthetic diamonds. Awareness and ongoing training of these professionals are essential to maintain market integrity and consumer confidence.

Therefore, the production of synthetic diamonds represents a positive point in the application of the concept of sustainability in the mining sector. By reducing dependence on traditional mining, this technology contributes to the preservation of the environment and the reduction of negative impacts associated with the extraction of natural resources. In addition, the adoption of sustainable practices can attract investment from companies and consumers who value environmental and social responsibility. The combination of innovation, sustainability, and transparency can position Angola as a leader in the global diamond market, both natural and synthetic, ensuring the country's economic development responsibly and inclusively.

In this way, the production of synthetic diamonds (Figure 10), combined with innovative technologies such as blockchain technology, can transform the Angolan mineral sector, making it more competitive, sustainable and aligned with global demands. However, to fully take advantage of these opportunities, it is necessary to overcome challenges such as technological ignorance, the differentiation between natural and synthetic diamonds, and the training of qualified professionals. The combination of innovation, sustainability, and transparency can position Angola as a leader in the global diamond market, both natural and synthetic, ensuring the country's economic development responsibly and inclusively.

According to Mendes (2010), synthetic diamonds can be produced using two main methods: High Pressure, High Temperature (HPHT) and Chemical Vapor Deposition (CVD). The HPHT method simulates the natural conditions in which diamonds are formed by subjecting graphite, a less organized form of carbon, to extremely high pressures and temperatures, above 50,000 atmospheres and 1,500 °C, in a special press. Under these conditions, the carbon atoms rearrange themselves into a diamond crystalline structure. The CVD method involves the decomposition of a carbon-containing gas, such as methane, in a vacuum environment. The released carbon atoms are deposited on a diamond seed, forming a new crystalline layer. This method allows diamonds to be grown in different shapes and sizes, and offers greater flexibility in the production process.

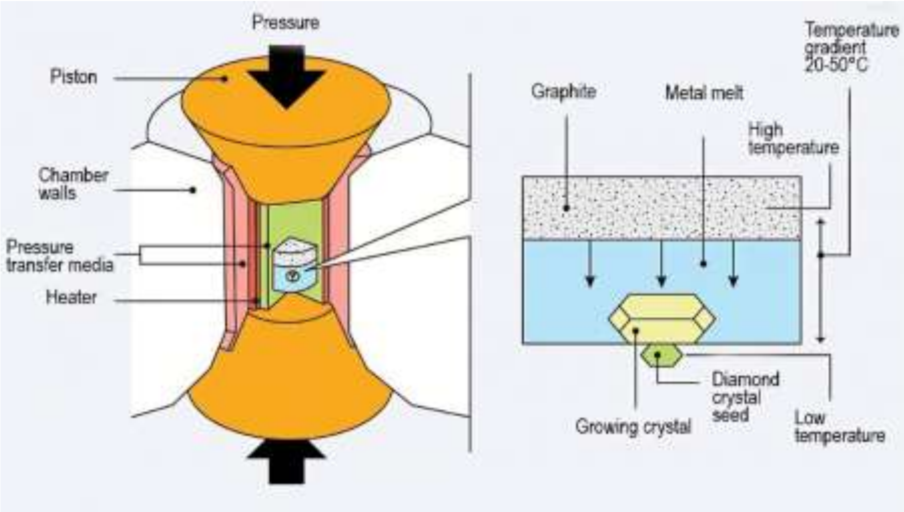


Figure 10. Schematic diagram of diamond growth using the temperature gradient method (Zhang et al., 2024).

The evolution of referenced production methods has made synthetic diamonds increasingly similar to natural diamonds, both in terms of physical and chemical properties. This increasing similarity presents a challenge for the accurate identification of synthetic diamonds, requiring the use of specialized equipment such as gemological microscopes, spectrophotometers, and thermal conductivity meters. These instruments are essential for distinguishing between natural and synthetic diamonds, since the differences can be extremely subtle and imperceptible to the naked eye or with conventional equipment.

The need for advanced equipment to identify synthetic diamonds reflects the sophistication of production methods, which have evolved rapidly over the years. This technological evolution not only increases the quality and variety of synthetic diamonds available on the market but also places pressure on gemologists, laboratories, and dealers to remain up-to-date and capable of performing accurate tests. The awareness and ongoing training of these professionals are essential to ensuring the integrity of the market and the confidence of consumers who depend on transparency and accuracy in gemstone identification

Along these lines, synthetic diamonds are widely used in industry in cutting tools, sandpaper, drill bits and electronic components due to their hardness and thermal conductivity, in jewelry offering a more affordable and ethical alternative compared to natural diamonds, and in various areas of research, such as physics, chemistry and materials science.

The main advantage is that it eliminates the need for mining, which causes environmental damage such as deforestation, soil erosion, water pollution, and displacement of communities. Although the production process requires energy, the total consumption is generally less than that required for the mining, transportation, and processing of natural diamonds. The production of synthetic diamonds generates less solid and liquid waste compared to mining. The production of synthetic diamonds is more sustainable than the mining of natural diamonds, as it does not cause the same environmental and social damage (claiming rights to benefits derived from mining). The production of synthetic diamonds does not involve the social and environmental problems associated with the mining of natural diamonds. Synthetic diamonds are generally more affordable than natural diamonds, which makes them an attractive option for many consumers. Technology has advanced and has allowed the production of synthetic diamonds with gemological quality indistinguishable from natural ones. The growing demand for diamonds, both for jewelry and industrial applications, is driving the growth of the synthetic diamond market.

### *4.4 Macro-environmental analysis*

In a mining panel held in New York, USA, focusing on internationally accepted best practices implemented in the diamond production chain, Benedito Paulo Manuel, General Director of Sociedade Mineira de Catoca, highlighted the intention to ensure that the development of mining is accompanied by the improvement of the social conditions of the population. The speaker emphasized the importance of a strong investment in areas such as education, health, sports, and culture, underlining Catoca's economic and social commitment to the development of Angola. As a result of this commitment, Sociedade Mineira de Catoca is proud to be a catalyst for the development of local communities and the country in general, through a vast portfolio of social programs that positively impact the lives of thousands of families. This approach reflects the adoption of responsible and sustainable practices, aligned with international standards of corporate social responsibility.

In the competitive context of the diamond mining and production sector, it is relevant to consider the barriers to entry for new competitors, as identified by Porter (1986). Porter lists seven barriers that hinder the entry of new players into the market, the first of which is economies of scale. In sectors such as mining, large companies have an advantage, since the unit cost of production decreases as the absolute volume of production increases. This means that a new competitor must either operate on a large scale from the beginning, which requires high investment, or accept a cost disadvantage as a small start-up. Porter notes that economies of scale in production, research, marketing, and services are particularly relevant barriers in capital and technology-intensive sectors such as diamond mining and processing.

In addition to economies of scale, Porter highlights other barriers such as product differentiation, capital requirements, switching costs, access to distribution channels, disadvantages of independent costs of scale, and government policies. In the case of diamond mining, product differentiation is crucial, especially with the emergence of synthetic diamonds, which require a clear distinction from natural diamonds to maintain consumer confidence. Capital requirements are also a barrier, given the high investment required to explore, extract, and process diamonds. In addition, access to distribution channels and government regulation can make it difficult for new competitors to enter the market, especially in countries with highly regulated industries.

From the inbound logistics of the inputs needed for mining to the operations of transforming rough diamonds into finished products, the company seeks efficiency and quality. External logistics ensures that diamonds reach international markets safely and efficiently, while marketing and sales work to position Angolan diamonds as high-value and trustworthy products. Finally, associated services, such as certification and guarantee of ethical origin, reinforce the company's reputation in the global market.

Therefore, the Companies (1 and 2) combine good social practices and efficient value chain management that can transform the company into an agent of economic and social development. At the same time, the barriers to entry identified by Porter highlight the challenges that new competitors face in a highly competitive and regulated sector. The adoption of strategies that integrate social responsibility, technological innovation, and operational efficiency is essential to maintain competitiveness and sustainability in the diamond mining sector. By aligning itself with these practices, Company 1 not only strengthens its position in the global market but also contributes to the sustainable development of Angola, benefiting local communities and the country as a whole.

### *4.5 Competitive value chain analysis*

The competitive value chain analysis proposed by Porter (1986) is essential to understanding how companies create and maintain competitive advantages (Figure 11). The value chain divides a company's activities into five primary activities (inbound logistics, operations, outbound logistics, marketing and sales, and services) and four supporting activities (infrastructure, human resource management, technology development, and acquisitions). These activities, when managed efficiently, allow the company to offer superior value to customers, either through cost strategies (reducing operating costs) or differentiation (offering unique or higher quality products) (Figure 11).


Figure 11. Porter's value chain model (Porter, 1986).

In the diamond mining sector, value chain implementation is crucial to address challenges such as global competition and the need for sustainability (Kumar; Rajeev, 2016). For example, efficient inbound logistics and operations reduce costs and increase productivity, while marketing and sales enhance brand reputation, especially in markets that value ethical diamond sourcing. Support activities such as technology development and human resource management are key to innovating and maintaining a skilled workforce.

Furthermore, Porter highlights barriers to entry that protect established companies, such as economies of scale, product differentiation, and capital requirements. In the case of diamond mining, such barriers are particularly relevant, as the sector requires high investments in technology and infrastructure, as well as a strong reputation to compete in the global market. Company 1 uses the value chain to strengthen its competitive position, aligning operational efficiency with responsible social and environmental practices.

Therefore, competitive value chain analysis enables companies to identify opportunities for improvement and build sustainable competitive advantages (Silva et al., 2025). In the diamond sector, the integration of primary and support activities, combined with overcoming barriers to entry, is essential to compete in a globalized and constantly evolving market.

## 4. Conclusions

With the results presented here, we can conclude that:

i. The implementation of blockchain technology and innovation initiatives is crucial to transforming the diamond mining sector. These tools promote a collaborative and transparent approach to resource management.

ii. To maximize these benefits, it is essential that the National Agency for Mineral Resources (ANRM), particularly Company 1, enhance its technical and institutional capacities, such as data governance, regulatory oversight, and digital infrastructure.

iii. The automation of critical processes, such as payments, monitoring, security, and data management, through the use of smart contracts (self-executing agreements with terms embedded in code) reduces bureaucracy and mitigates corruption risks. This approach improves operational efficiency and builds trust among stakeholders.

iv. State-owned entities can serve as key instruments in ensuring greater state participation in the profits from diamond mining, which contributes to national development. However, for this to be effective, these organizations must operate under strict regulatory oversight, with accountability and sound governance.

v. Blockchain technology is a powerful tool for achieving these goals. It enables more secure and traceable asset and transaction management. Additionally, blockchain facilitates new forms of collaboration between entities, increasing confidence in data transfer and processing.
This is particularly valuable in complex value chains, such as the diamond industry, where asset and transaction management require high levels of accuracy and security.

vi. By integrating blockchain technology into their operations, organizations can not only improve performance but also position themselves as leaders in innovation and sustainability.

vii. Thus, the combination of blockchain technology, smart contracts, and accountable governance can transform Angola's diamond mining sector. It aligns the industry with global demands for transparency, sustainability, and operational excellence.

viii. The adoption of these practices benefits both the State and private entities, while contributing to the country's socio-economic development. This ensures that mineral resources are managed responsibly and inclusively.

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## 7. Authors' Contributions

The authors of this article contributed proportionally, engaged in the development of this work, with greater responsibility given to the students involved in the proposed studies, within the scope of the master's Course in Innovation and Engineering of Cyber Physical Systems, associated with the innovation technologies.

## 8. Conflicts of Interest

The authors declare that there are no competing interests related to the research, authorship, or publication of this manuscript. No financial, personal, or professional relationships, whether direct or indirect, exist that could inappropriately influence the work presented in this study. The authors further confirm that they have adhered to ethical guidelines in conducting and presenting the research, ensuring that the results and conclusions drawn are unbiased and free from any conflict of interest.

## 9. Ethics Approval

Not applicable.

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