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Utilising blockchain technology for managing natural resources: A case study of Reko Diq copper-gold project, Pakistan

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ABSTRACT

The mining industry is a key driver of the global economy, with many other industries relying on the mining sector for their growth. Despite its importance, the mining industry is mired with challenges of supply chain traceability, transparency, corruption, inefficiencies, data loss, etc., all of which create the need for innovative solutions involving emerging technologies that can streamline these processes and enhance their reliability. Blockchain is an emerging technology that has the potential to address most of these challenges in an effective manner. This study looks at the feasibility of utilising Blockchain technology for the management of Reko Diq copper-gold project in Pakistan, which faces similar issues, including lack of trust between stakeholders, corruption, sustainability problems, environmental degradation, and a legal battle. This qualitative study used six semi-structured interviews of stakeholders in Pakistan who had knowledge of the potential of Blockchain technology for the management of the Reko Diq project. The key themes that were identified in the study include Relations between Stakeholders, Environmental and Economic Sustainability, and Infrastructure Limitations. The Technology Acceptance Model was applied to the study, and the findings of the study support one tenet of the model - perceived usefulness; however, perceived ease of use was not supported. The Blockchain Screening Tool was also used to assess the feasibility of Blockchain implementation for the Reko Diq project. The findings indicate that the Reko Diq project is an ideal candidate for Blockchain implementation to enhance trust, transparency and credibility of the project.

1. Introduction

The mineral industry is critical to the achievement of strategic outcomes for successful clean energy transition, economic development, and ensuring national security. Demand for minerals is expected to grow over the coming decades, with the mining industry becoming a key player in the international development debate. Estimates suggest that demand for the five most critical minerals; lithium, cobalt, nickel, copper, and neodymium; is likely to increase between 1.5 and 7 times by 2030 (IEA, 2023). Many of these minerals are found in areas that are environmentally sensitive, and problems of biodiversity and water sources need to be addressed. It is also crucial that mining in these areas is carried out in a way that the natural resources are not exploited, and the local communities are empowered as a result of these operations. This means that all existing operations in mining need to be upgraded

and upscaled to ensure that this demand is met in ways that is sustainable, and incorporates the concerns of all stakeholders. Environmental, Social and Governance (ESG) concerns are therefore paramount (Bandura and Hardman, 2023).

The mining industry is also crucial to the achievement of multiple Sustainable Development Goals, including Goal 1 (No poverty; as it provides economic opportunities), which directly impacts Goals 2 and 3 (Zero hunger, and Good Health and Well-being). Goal 6 (Clean water and Sanitation) is relevant as the mining industry is heavily dependent on sources of water as well as wastewater management. Goal 7 (Affordable and Clean Energy) is relevant here as many mining operations support the world's transition to clean energy solutions. Goal 9 (Industry, Innovation and Infrastructure) remains an important component of the mining industry, particularly as it undergoes upscaling to incorporate new technologies. This also links to Goal 11 (Sustainable

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Cities and Communities). Goal 13 (Climate Action) assumes a central focus here as the mining industry is a key contributor to environmental concerns. Goal 16 (Peace and Justice, and Strong Institutions) is critical in managing the competing interests of stakeholders in the mining industry, which also links to Goal 17 (Partnerships for the goals). This paper contributes significantly to an understanding of these SDGs from the specific lens of a developing country like Pakistan, mired with problems of weak institutions, environmental degradation, competing stakeholder interests, poor economic outcomes, providing an overall context of why and how the multiple partners in this case can work together to achieve holistic outcomes that serve the interests of most stakeholders.

The mining sector, crucial for global development, is notorious for significant ethical and human rights challenges, including lack of transparency in sourcing, forced labor, harsh working conditions, pollution, and wars in some regions. Implementation of strict regulations with the use of Blockchain is paramount to ensure that the mineral resource industry operates in an ethical and sustainable manner (Tiron-Tudor et al., 2021). Blockchain technology holds significant potential to enhance the management of mineral resource industry (Jha et al., 2023). The capabilities of Blockchain technology can be leveraged in various ways to offer promising solutions in the supply chain of mining industry; this particularly implies when the sector is undergoing a digital transformation. Enhancing traceability and transparency in the supply chain processes can lead to more streamlined operations and ensure compliance with the environmental standards (Ma and Li, 2022). The integration of Blockchain platforms with IoT devices provides enhanced security framework by tracking the supply chain of minerals, and thus mitigates the risk of fraud. By offering a tamper-proof record of regulatory filings, environmental impact assessments, and efficient data management, Blockchain helps expedite compliance procedures (Calvão and Archer, 2021). This lessens the administrative load on businesses while simultaneously improving accountability and transparency to stakeholders, including governments, local communities, corporations, and NGOs.

The Reko Diq project is a massive copper-gold mining operation situated in Pakistan's isolated Chagai area of Baluchistan (Hasan et al., 2023). Reko Diq is estimated to contain about 16,098 thousand ounces of gold and 27,173 million pounds of copper, with a 40–45-year mine life expectancy. By 2032, Reko Diq is expected to produce 80 million metric tons annually, putting Pakistan's copper reservoirs in a position to supply a sizable amount of the world's copper needs for many years to come (The Express Tribune, 2024). It is expected that the Reko Diq project will increase Baluchistan's growth prospects and have a significant positive impact on Pakistan's economy. This entails generating jobs, supporting the regional economy, and encouraging investments in important fields like clean water supply, healthcare, education, and vocational training, all of which can be linked to SDGs. The project is expected to employ 7500 people during the construction phase, and it will create around 4000 regular employment opportunities once fully functionalized (Hasan et al., 2023). Reko Diq will have a significant positive economic influence on Pakistan, particularly on the underdeveloped province of Baluchistan. In addition to the economic benefits, the project will create jobs, promote regional economic growth, and invest in development programs. Baluchistan will be able to enjoy the profits, royalties, and other related benefits of its 25 percent participation in the mine without having to contribute financially to its development or management once the province's share of the mine is fully funded. The degree to which Reko Diq succeeds economically or encounters obstacles that prevent it from realizing its revolutionary

potential will depend on how ethically and efficiently this large project is managed. The subsequent stages, which involve addressing facility requirements and overcoming logistical challenges, will be crucial in crafting the story of Reko Diq's economic impact in Pakistan.

Tethyan Copper Company (TCC) Limited initiated the exploration of the Reko Diq mineral resources in 2000; however, the project faced numerous legal and regulatory challenges (Zürcher et al., 2019). The provincial government of Baluchistan terminated the mining license of TCC in 2011 on grounds of violating exploration agreements and concerns over the sharing of economic benefits. This led to the international arbitration, where in 2019, the World Bank's International Centre for Settlement of Investment Disputes imposed a penalty of \$5.8 billion on Pakistan to deny the mining license illegally (Barrick Gold Corporation, 2020). The conflict attracted a lot of attention because it could have an impact on foreign investment in Pakistan's mining sector and because there are problems with governance and transparency in the country's natural resource management. The latest developments in the Reko Diq affairs raised complex logistical issues, and the success of Reko Diq's project is seemingly constrained by several challenges. A recent development, revealed in mainstream media publications, has raised questions on the project's expansive transportation plans where a Federal Government commission has requested Reko Diq Mining Company (RDMC) to disclose its technical needs. The resistance of RDMC to utilize Gwadar Port adds another level of complexity and calls into question the viability and effectiveness of the selected modes of transportation.

Despite the importance of the mining industry for the global economy, the industry is dealing with several problems, including fierce competition, environmental concerns, government legislation and regulatory constrictions, rising costs, and lack of transparency and information sharing. There is thus a need for urgent innovative solutions to overcome these problems. The case of Reko Diq copper-gold project is suited for a feasibility study for the applicability of Blockchain because of the scale of the project and the potential for optimal outcome for all stakeholders.

Therefore, the objective for this study is to establish the feasibility of applying Blockchain technology to the Reko Diq copper-gold project to address problems of trust, lack of transparency, environmental degradation and infrastructure development. This study is novel as there is no study that has researched the combination of Reko Diq and Blockchain technology to enhance the quality of the project.

2. Literature review

The mining sector is one of the most important sectors the global economy. Most industries that fuel global growth, such as iron, steel, petroleum, natural gas, cement, etc. Depend on the mining sector for basic raw materials provision. However, the mining sector is facing unprecedented challenges due to increased competition, environmental concerns, as well as government legislation and regulations. Rising energy costs, increased demand, increased social and geopolitical risks, strict labour laws, cost control challenges, etc. are some of the major challenges that the mining industry is facing today. These require innovative solutions to be reconciled in a manner that is competitive as well as transparent and ethical (Kunhabamed and Rajak, 2023). Given the critical nature of the mining industry in the global economy, the inefficiency and antiquated nature of operation and commercial practices is a significant problem which leads to data loss and omission, security vulnerabilities, and widespread corruption. Mining supply chains also face challenges of traceability, transparency, and interoperability, which are directly linked to sustainability (Mann et al., 2018).

The primary sources of conflict in mining projects come from insufficient consultation with affected communities, inequitable distribution of socio-economic benefits, and environmental objections. It is interesting that the communities that live nearest to the mining operations are often the poorest, and often because of being in the vicinity of mining projects, have unique socio-economic and health related problems. Information transmission remains a key concern here as well, and is a core reason for insufficient planning and consistent setbacks (Kakran et al., 2023). Even when sufficient goals are established, adherence is usually weak, leading to conflict, malpractice and missed opportunities at almost all stages of the mining value chain. Participation of both the public and the private sector is critical to the success of several existing and emerging industries, and commercial pressure remains significant to the success of any initiative taken (Bird and Swezey, 2005). These conflicts can be managed appropriately by a combination of initiatives taken by the mining industry, public sentiment, and empowered regulatory institutions. The institutional capacity for these regulatory bodies is also important as it varies significantly in the impact and control that they are able to exercise in different communities around the world. This creates the scope for structural reforms that can feed into effective operational capacities (Dagher et al., 2020). Countries experiencing less democratic practises and a higher degree of control are usually able to exercise influence over these regulatory institutions, thereby swaying the interests of the industry towards a small minority of people without ensuring that these solutions and actions are acceptable to everyone affected. This creates a power tilt and undermines the environmental, societal and governance (ESG) guidelines that could be instrumental in keeping mining operations sustainable, transparent, and fair to all. Adherence to ESG goals has been shown to be positively linked to financial performance as well (Rao et al., 2023). The technical capability and capacity of the industry also differs across the world, and links to the availability of personnel and budgets to address the problems faced by the mining industry in terms of law enforcement and community development. A devolution of power is also necessary at this point so that the laws that are formulated at the federal government level can be implemented at local body level to ensure compliance, and to also create a two-way system of communication where the concerns of the grassroots stakeholders are communicated to those making these regulations. An absence of these measures leads to land grabbing, illegal mining operations, exploitation of local communities, environmental degradation, and the development of sentiments of alienation and distrust between the multiple stakeholders that are affected by the operations of the mining industry (Bandura and Hardman, 2023).

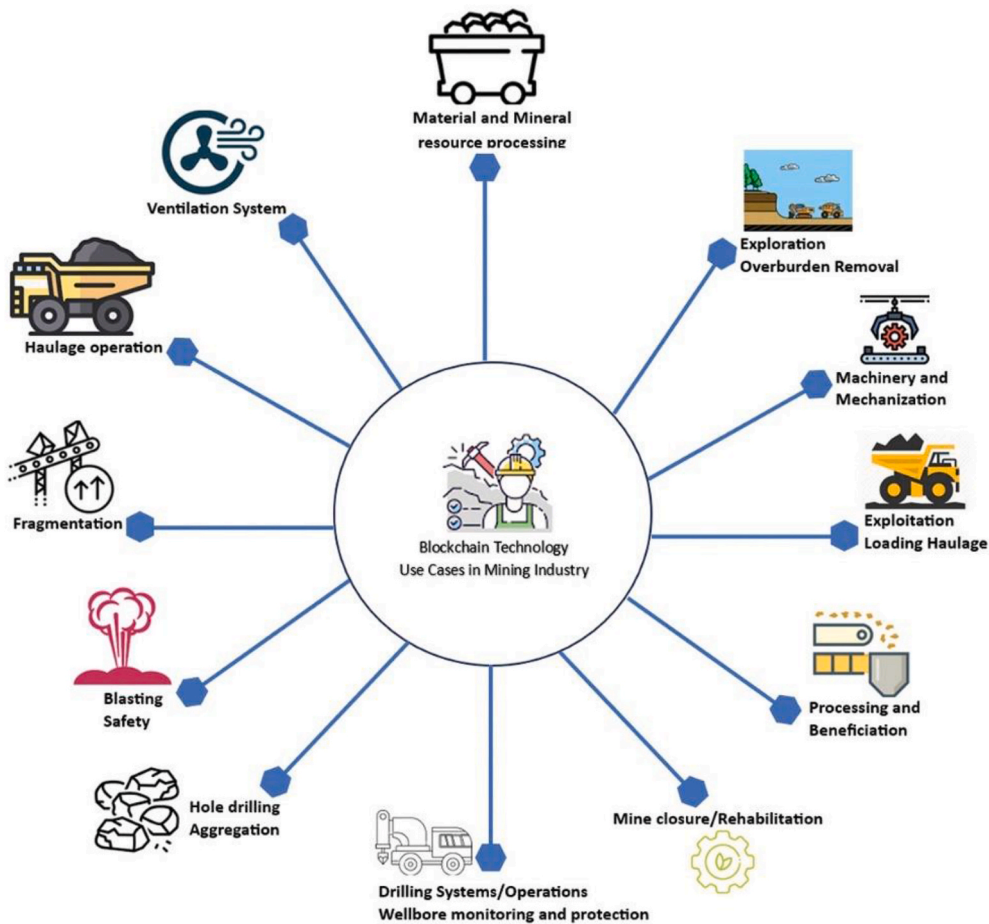
These challenges lend themselves to the adoption of emerging technologies, such as Artificial Intelligence, Blockchain, and FinTech, to address these challenges and increase the efficiency, transparency, and sustainability of mining operations globally. The fundamental tenets of Blockchain technology can be used to transform various mining sector processes like smart contracts, data management and traceability of the whole supply chain operation (Yousefi and Mohamadpour Tosarkani, 2022). Natural resource management is the responsibility of various government departments. A lack of trust among the departments can cause information islands to emerge, which hinders business cooperation and decreases productivity (Jha et al., 2023). These issues can be resolved by Blockchain technology that unifies processes and data to enhance data dependability and transmission efficiency (Sababuddin et al., 2023). Every group or individual could join the consensus process and view the public chain, where they can also record transactions that are verified by the Blockchain. Creating digital simulations of mining operations makes it easier to simulate, plan scenarios, and optimize production processes, which leads to effective resource optimization.

These technologies provide immersive training simulations and interactive safety processes, thereby enhancing worker training, awareness, and response to safety dangers.

Blockchain stands out as a disruptive innovation among the unique developments brought about by the advancements in information technologies. It has received a great deal of attention from domestic and international sources in a range of industries since 2013. Blockchain technology, in financial systems, functions by means of a distributed ledger system, in which information utilized for transactions or communication is kept in an open network of digital blocks (Tijan et al., 2019). Since every block has a date and time stamp and a unique digital signature, they are essentially unchangeable (Tan et al., 2023). These digital blocks are arranged following a complex mathematical logic, a process known as 'hashing' (Nakamoto, 2008), to form a chain of blocks, hence named as Blockchain (Li et al., 2023). Blockchain applications are being developed based on peer-to-peer logic, enabling organizations to exchange goods, services, and information without the need for central bodies to verify identity, validate transactions, or enforce commitments, eventually reducing the need for several intermediaries as seen nowadays. Initially, this can lead to operational efficiency and cost reductions for business enterprises by facilitating faster transactions that are digitally disseminated and synchronized across fewer parties (Munir et al., 2022). The fundamental principle of Blockchain technology is to enable digital asset transactions between system participants via a peer-to-peer network that distributes and maintains these transactions over the network, but the usage of Blockchain technology in preserving natural resource is rare in research.

There has been an increase in modern technology adoption in the mining sector, spurred by calls across different industries for improved environmental performance, enhanced supply chain management, and transparency (Fraga-Lamas and Fernández-Caramés, 2019). Additionally, businesses in the mining industry also consider the use of modern technology to increase productivity, improve record-keeping, reduce security flaws, and minimize corruption (Aleshi et al., 2019). There is also an increasing focus on portraying the mining industry as a modern, forward-thinking industry that is at the forefront of the development of a more sustainable economy. It is also one of the industries that is subject to stringent inspections for mining assets as well as worker safety, which is usually done through antiquated and inadequately digitalized processes, which can be significantly improved through the adoption of modern technology. Simultaneously, it is also one of the most difficult industries when it comes to the application of modern technology because of issues like lack of connectivity, dust, humidity, noise, underground activities, temperature, remote locations, and difficult meteorological conditions.

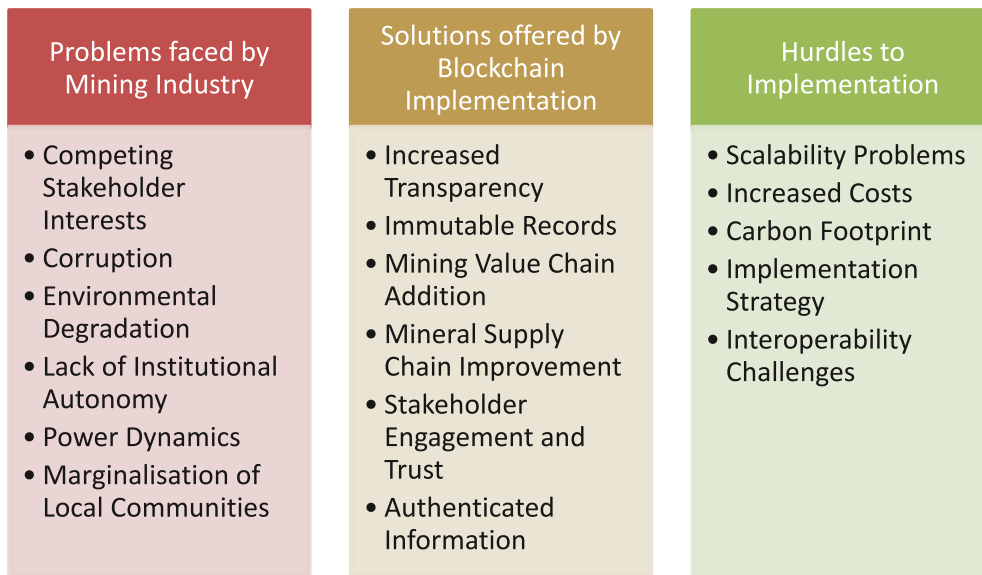
Mining companies have begun to use Blockchain technology for its inherent transparency. It is used throughout the mining value chain to trace, document, and certify the life cycle of minerals including the traceability of emissions (Onifade et al., 2024). Blockchain technology allows the exchange of important trade documents by using smart contracts instead of relying on paper copies. This allows users to feel secure when evaluating the authenticity of the information provided on the Blockchain (Atzei et al., 2017). Another layer of insurance is added to the documentation with proof that they have been approved by recognised authorities. The time stamp on transactions and transfers takes place immediately as well, thus improving the integrity of the mining supply chain (Gatteschi et al., 2018). This also supports the concept of ethical mining by enabling importers to track the history of the mineral's life cycle through the digitally tracked non-fungible tokens (Calvão and Archer, 2021).



Blockchain technology in mining industry.
 Source: Onifade, Adebisi & Zvarivadza (2024).

However, it is important that certain limitations are anticipated here. Because of the complexity of Blockchain technology, scalability is a critical hurdle, particularly as the volume of transactions increases, it also might cause a slowing down of the Blockchain processing of this information, which defeats the purpose of installing the technology in the first place. Increased costs during periods of high demand on public Blockchains are also a concern as this adds to the cost of running a mining project (Farahani et al., 2021). There are also concerns about the carbon footprint of the Blockchain technology when compared to conventional systems in terms of its impact on the environment. The decentralization advantage offered by Blockchain relies on consensus mechanisms like Proof of Work (PoW) or Proof of Stake (PoS), and Proof of Work is an energy intensive process, whereas traditional database systems in the mining industry with centralized structures require less energy for transaction validation (Mulligan et al., 2023). The complexity involved in the implementation of the Blockchain technology also means

that there needs to be a strategic approach to its implementation, incorporating change management and stakeholder engagement during the process to overcome the industry’s slow adoption rate of modern technology. Failure to do this might derail the process or lead to slow uptake, all of which can defeat the purpose of the technology and increase costs. Interoperability also remains a challenge because it requires the ability of different Blockchains in the mining industry to communicate and operate cohesively with each other, incorporating multiple stakeholders. These different Blockchains may employ different data structures and smart contract languages, which might make data exchange more complex across these multiple systems. There is therefore a need to ensure consistency across Blockchain to reap its rewards (Pradip et al., 2019).



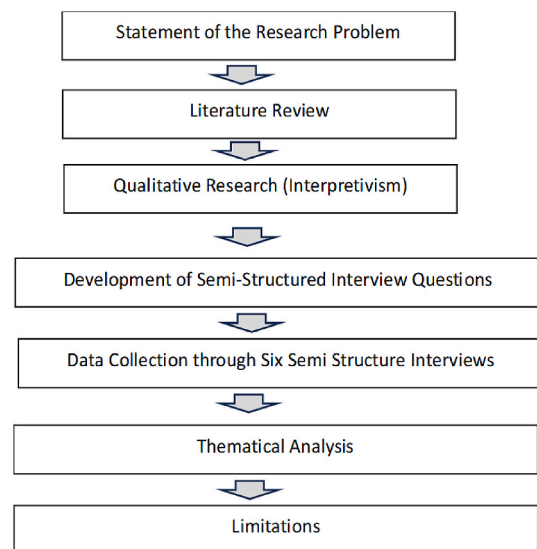
2.1. Research gap

While there has been a lot of focus on the problems faced by the mining industry and the potential of Blockchain technology to address these problems, we have not found a study that focuses on Pakistan, which is a country rich in natural resources, but strapped for resources in their exploration. The existing literature on the Reko Diq project itself is very minimal, and focuses more on the problems that the project faces, with little exploration of innovative solutions and their potential to solve these problems. This gap is addressed through this research paper that looks at the feasibility of the Blockchain technology in the specific context of Pakistan and the Reko Diq project, and how this can offer a solution for the problems identified.

2.2. Theoretical framework

The Technology Acceptance Model (TAM), (Davis, 1986) proposes that the acceptance of any new technology depends on two factors: (a) *perceived usefulness*, and (b) *perceived ease of use*. As per TAM, these two factors predict whether new technology would be accepted by its users or not. The literature has proposed the perceived usefulness of Blockchain technology in the context of project management in general, and in the utilization of natural resources where multiple stakeholders are involved, in particular. The problems identified with the Reko Diq case also lend themselves to the adoption of Blockchain technology. However, this technology is still a new concept, with very few people having a deep understanding of how it works. It also needs a significant investment in infrastructure to be installed, and further investment into training and developing people in its use as well as the responsibility of information management the information that this technology gives people access to. Given these factors, the Technology Acceptance Model has been chosen as the theoretical framework for this study to suggest whether the findings of the study support the perceived usefulness and perceived ease of use of Blockchain for the management of the Reko Diq project.

3. Research methodology



The present study employed a broad range of data collection techniques as part of its research approach to encompass the complex dynamics and multiple stakeholders associated with digital extraction. To maintain the data's authenticity and integrity, the researchers developed a set of preliminary questions that centered on developments in traceability technology and the application of Blockchain in the context of the Reko Diq project. These inquiries were iteratively refined throughout the data gathering phases. Data regarding the influence of Blockchain technology on Reko Diq project and natural resources of Pakistan was collected through semi-structured interviews of 6 high-

profile professionals having knowledge of the project and the technology. This exploratory approach to the study was chosen since little is known about Reko Diq other than the bad press that the legal battle has generated. The researchers had anticipated that they would be able to secure 12–15 interviews; however, the number of participants was significantly reduced due to the difficult combination of Blockchain technology and its application to the Reko Diq copper-gold project. At least 30 potential participants were approached using the snowball sampling technique. However, participants either did not have command over Blockchain technology, with it still being in its infancy in Pakistan, or did not have sufficient knowledge of the Reko Diq project beyond the legal case surrounding the project which has dominated mainstream media. As a result, 6 interviews could be conducted, each of which lasted 35–45 min. While the sample size remains small by qualitative study standards, the fact that these individuals are some of the handful of people who have knowledge of both Blockchain and Reko Diq makes the study’s contributions significant despite the small sample size.

It is anticipated that this study and its findings would have significant societal impact on the mining industry in general, and the Reko Diq project in particular. The study identifies issues that have been the core cause of conflict, and understands that this conflict has not been limited to the Reko Diq project only. There has been a general feeling of dissent in Baluchistan over the last several decades because of the impoverishment of the province despite being rich in mineral resources. This has also led to frequent unrest in the province, with one currently ongoing. By using the recommendations made in this study, it is anticipated that stakeholders in the project would see their concerns addressed, leading to stronger ties being generated in other areas as well between the local population, provincial government and federal government, and mining companies.

4. Findings and discussion

Participants of the study discussed several challenges faced by the Reko Diq project in the Baluchistan province of Pakistan. These include the relations between the stakeholders harmed because of tensions stemming between the stakeholders from longstanding grievances and trust and traceability issues, which can lead to security risks and operational disruptions. Similarly, disputes over resource ownership and control and regulatory uncertainties pose legal and regulatory challenges for the project. Environmental sustainability concerns, such as water usage, pollution, habitat destruction, and economic sustainability

concerns, such as the paradox of poverty in the midst of plenty, also present significant hurdles that require careful mitigation strategies. Likewise, infrastructure limitations in Baluchistan, including inadequate transportation networks and power supply shortages, hinder the project’s logistical operations and increase operational costs. Effective community engagement is essential yet complex due to historical grievances and socio-economic disparities. As a result of the interviews with the participants, it was seen that the impact of the Blockchain application, including its challenges and benefits on the Reko Diq project, was discussed under three key themes: The Relations between Stakeholders, Environmental & Economic Sustainability, and Infrastructure Limitations.

4.1. The relations between stakeholders: trust, transparency, traceability and corruption

The relations between the stakeholders are dominated by a lack of trust since the province has a long-standing dispute regarding its share of the natural resources extracted from there. Moreover, the tribes that claim ownership over the land maintain that the government did not consult with them before awarding the mining contract, and term the whole issue illegal and illegitimate. According to official sources, Baluchistan, the largest province in terms of area in the country, has a variety of sizable and valuable mineral deposits, including gold, silver, copper, iron, chromite and lithium in more than 1600 mines (Narratives, 2023), and most of these contracts have been given to foreign companies in the past, with the locals getting next to nothing from the proceeds. Reko Diq represents one of the largest copper and gold reserves in the world, having estimated reserves of 5.9 billion tons of ore grading, 0.41% copper and gold reserves amounting to 41.5 million ounces, and a mining life of at least 40 years (Narratives, 2023). The province is backwards regarding infrastructure, and the public does not really trust the government and other agencies. There is a long-standing history of law-and-order problems, and international actors have been behind them as well, supporting local dissent and local ‘freedom fighters’. BNP-M President Sardar Akhtar Mengal (2022) supported the local people by saying, “The owners of the resources of Baluchistan are its people.” According to the Constitution, the first right belongs to the locals wherever natural resources are discovered. This situation lends itself ideally to the implementation of technological solutions in general, and Blockchain in particular.

In recent years, with the increasing acceptance of Blockchain technologies, in the relevant literature, it is claimed that the application of

Table 1
Blockchain governance models and characteristics.

No.	Governance Model	Characteristics
1.	Novel multi-supervised permissioned blockchain (MSPB) governance model [56]	Supports auditing and eliminates centralized entities in the system, and avoids information security threats caused by centralized management entities.
2.	A novel on-chain governance model [57]	Blockchain cannot tolerate service interruptions for any reason. Thus, interruptions caused by hard forks or soft forks should be avoided. To this end, PBM has the ability to change the behaviour of a blockchain node or even smart contracts without stopping them. PBM fits better with the governance of private or permissioned blockchain networks, which are a class closer to legacy information systems. Policy-based governance deploys updates immediately after the end of the voting period
3.	Federated permissioned model [44]	Accelerates the transactions, so they are used in e-government systems by many users and operators. The use of smart contracts to manage data in administrative processes automatically and avoid corrupt practices in the administration through enhanced security and traceability.
4.	Blockchain-based governance model in the supply chain [41]	Mitigates the fear of stakeholders of sharing their sensitive data. The private ledger protects sensitive data through selective permissions. Communication and consensus mechanisms ensure that all participating nodes jointly ensure the safety and authenticity of data stored on the blockchain and collectively maintain the openness and transparency of the data in the blockchain.
5.	Blockchain Based Identity Verification Model[37]	Improves the efficiency of the document verification and issuing process drastically and achieves security, reliability, and transparency
6.	DLT based model (D- IACS) [58]	Supports and facilitates the conventional transformation of existing systems toward DLT systems based on the fourth industrial revolution (4IR) that accommodate smooth communication between legacy systems and the latest systems
7.	Blockchain-based e-participation model of Omani citizens[59]	Enhance citizen engagement, reduce costs, and increase the level of trust. Address scalability, minimize system complexity, and increase transparency to generate greater user interest in e-participation.

Source: Ibrahimy, Norta & Normak (2023; pg. 14)

Blockchain technologies increases society's trust in institutions in terms of transparency, data management and data protection, and has the potential to change the rules of the game in anti-corruption efforts. Sarker et al. (2021) described it as a game-changing tool in the fight against corruption. It reduces uncertainty and distrust in transactions by providing full transactional disclosure with the power and capacity of Blockchain. They found that Blockchain reduces process and document-related corruption in the global maritime industry. Besides this, decentralization facilitated by Blockchain technology could indeed benefit the project in several ways.

Ibrahimy et al. (2023) searched 45 primary and supporting studies, comprising peer-reviewed journals, proceedings, and book chapters, published between 2012 and 2023 with a systematic literature review (SLR) approach. They discovered seven Blockchain-based governance models with their characteristics and primary components shown in Table 1.

The Table indicates that in all of the governance models, Blockchain promises to be transparent, traceable, and auditable, which helps to avoid corruption and build trust between the stakeholders. Similar to these findings, participants of this research all agreed that the use of Blockchain would create better relations between the project's stakeholders by eliminating the issues related to corruption malpractices. They emphasize that due to the decentralized nature of the Blockchain, which is based on mathematical concepts, most of the problems will be solved among the stakeholders, and there will be a situation that no one can tamper with.

Participant Three stated that given the transparency issues involved in the actual worth of the project, as well as total extraction and monetization, the application of Blockchain technology will enhance the project's transparency and accountability. **Participant One** drew attention to the legal problems brought to court by the Pakistani government, the people of Baluchistan and a Canadian company, and the corruption in which stakeholders were abused, and stated that Blockchain could be utilized to re-establish trust between stakeholders. **Participant Four** also highlighted that by decentralizing decision-making processes and governance structures with the help of Blockchain, the project could distribute power more equitably among stakeholders, including local communities, government agencies, and investors. This decentralized approach promotes transparency, accountability, and inclusivity in project management, enabling greater participation and representation from all stakeholders. Furthermore, decentralization can enhance resilience against single points of failure or corruption, as decision-making authority is distributed across a network of participants rather than concentrated in a central entity. Similarly, **Participant Two** argued that Blockchain reduces centralized risk by distributing control and data, and with its decentralized nature, minimizes the risk of single central authority mistakes in malicious actions which affect the project life and their outcome.

This factor is particularly important given the fact that this case has drawn all sorts of attention. On one hand, some people agree that the initial agreement has been flawed and against public interests (Hassan, 2015), with Jeffrey Sachs maintaining that the award in the case was unjustifiable (Sachs, 2019). On the other hand, the case and its ruling has affected the image of Pakistan at the international level by building a negative perception of the country. Some even call it an attack on the sovereignty of the country, as the international arbitral tribunal declared the Supreme Court of Pakistan's decision ineffective in the case. This has resulted in a wrong impression being floated in the mining world, that investing in Pakistan is not safe as these may be revoked by the judiciary at any time. Such a perception can harm the potential for investment in the Pakistan's mining sector in the future as well. The economic impact of such a reputation is likely to harm Pakistan's economic growth and stability significantly.

Participant Two noted that Blockchain improves decision-making through analytics and can help build trust among stakeholders by providing transparent and traceable records. In this way, technology

resolves many controversial legal issues in real time. Similarly, **Participant Four** highlighted Blockchain's transparent and immutable ledger system, which can provide a reliable mechanism for tracking transactions, ensuring integrity, and fostering stakeholder trust to avoid concerns over resource ownership, regulatory compliance, and socio-political tensions. They stated, "By reducing the risk of fraud, corruption, and data manipulation, Blockchain can address critical challenges faced by the project, promoting fair resource management, efficient governance, and sustainable development in the region. So, integrating Blockchain technology aligns with the project's need for robust mechanisms to enhance transparency and accountability, ultimately contributing to its long-term success and socio-economic impact."

4.2. Environmental & Economic Sustainability

It is evident that the province's economic future is linked to the mines, minerals and fisheries sectors as stated by acting governor Baluchistan, Mir Jan Muhammad Jamali (The Express Tribune, 2022). The positive and negative effects of the mining industry on the economic and environmental sustainability are still arguable. As with all mining projects, the Reko Diq project has the potential to negatively impact environmental sustainability, such as deforestation, pollution, and degradation of local ecosystems. This would primarily lead to environmental degradation and potential health hazards for local communities. In 2022, the Supreme Court (SC) questioned whether Reko Diq's mining and gold exploration project was environmentally friendly, and directed the Federal Government to submit a comprehensive report on the measures taken to protect the environment (The Express Tribune, 2024).

Blockchain technology can support sustainability efforts by enabling traceability and verification of transactions and products, reducing waste and unethical practices in supply chains (Dasaklis et al., 2022). Although Blockchain does not directly offer a solution to the mentioned problems, Rana et al. (2019) stated that it is also represented by carbon offset trading in information, documents and money transactions, especially for mitigating climate change.

Similar to the related literature findings, while discussing the effects of Blockchain on supply chain management, **Participant Two** emphasized that it increases security and efficiency by facilitating customer relations and inventory management through transparency and traceability, as well as real-time updates. "As I mentioned, it is a cryptographic. So between the two parties, no one can hack this information, so it's also increased security and improved supply chain management definitely and some practically we are seeing that it has solved many complex supply chain problems because it connects suppliers, manufacturers, logistic providers". **Participant One** stated that "Sustainable practices can improve the project efficiency and delivering Blockchain can help monitor and verify sustainable practice, such as environmentally friendly production method and fair labour condition responsible for resource usage."

Participant Five called attention to the project's impacts on economic and social sustainability goals by saying, "Any mining is very capital intensive, and employment is very skill-intensive, which is lacking not only in Baluchistan but Pakistan as well for this particular project. In the Thar coal mining, which started about 20 years ago, there were no skills, and the local population had a very poor skill level, but the company there made it a point to reach out to the people. Train them, even send them abroad for training, and now there is a fairly large percentage of them. And you know about a quarter of these truck drivers are women." On the other hand, many academics argue the unethical issues in the mining industry via the paradox of 'poverty in the midst of plenty', which means the proceeds of the precious metals, diamonds and minerals sales go to benefit only a few, leaving the greater populace in abject poverty, creating what is often referred to as the resource curse. Onifade et al. (2024), advocated that Blockchain technology can be used as a tool against blood diamonds, a term that represents conflict and slave labour in the diamond supply chain process, leading to the underdevelopment of mineral-rich countries. A lot of startups and companies have already implemented

blockchain-based solutions for blood diamond problems, such as Everledger, IBM and Tracr, developed by De Beers. Similarly, the findings of Calvão and Archer (2021), addressed the use of Blockchain initiatives and distributed ledger technologies in the mining industry to help sustainable development in Africa by addressing the problem of conflict minerals, ensuring respect for due diligence standards, and improving supply chain management and traceability. **Participant Four** presented blockchain, which enables tracking as a solution to these problems. “With Blockchain technology, stakeholders can verify the origin of resources, monitor compliance with ethical standards, and ensure adherence to sustainability protocols throughout the supply chain. This level of transparency enhances accountability, builds trust among stakeholders, and supports efforts to promote ethical sourcing and sustainable practices within the project. Therefore, while ethical sourcing and sustainability may present challenges for the project, Blockchain technology offers a viable solution to address these issues and uphold responsible practices in resource extraction and management.”

4.3. Infrastructure limitations

There are infrastructure limitations in Baluchistan, including inadequate transportation and communication networks, and power supply shortages. There are two sides to the coin regarding the impact of the Reko Diq project on the region’s infrastructure. Previously, the mining company defended the project’s positive effects on the regional infrastructure with new railways, pipelines, and communication networks (Barrick Gold Corporation, 2022). Prime Minister Muhammad Shahbaz Sharif informed that “the Reko Diq project would prove to be a game changer for the development of Baluchistan and the region and planning would be made regarding communication infrastructure, especially railway lines, to take full advantage of minerals in Baluchistan” (The Express Tribune, 2024). However, according to Profit Pakistan Today (2024), the project, once again, seems to be marred by logistical and infrastructural shortcomings, a concern that has always been there to hinder the project’s logistical operations and increase operational costs. The company emphasizes that they question the cost incurred by the lack of infrastructure in the region regarding road and railway connectivity, access to the shipping and water and electricity supply, and whether it is possible to extract gold from these mines (Shanaz, 2024). This is not the first incidence of this kind in Baluchistan. Even with the Saindak gold project, a key grievance by the locals was that the infrastructure has been developed only to facilitate the extraction and not necessarily to benefit the people. For e.g., they maintained that the Chinese company mining in Saindak had constructed roads leading to company sites, but

the villages still remained without. Similarly, locals argue that most well-paying jobs in these mining projects are not provided to locals, who are relegated to low-paying jobs in security and labour.

The relevant literature points out that the use of Blockchain-based systems can be beneficial in developing better transportation, transactions, and inspection infrastructure. Blockchain-based Intelligent/Smart Transportation Systems can create a safe, reliable, decentralized, autonomous, intelligent transportation ecosystem and ensure better use of old transportation infrastructure and resources (Abdel-Basset et al., 2021; Jabbar et al., 2022). “Blockchain is believed by IBM to be an elegant solution to IoT, and the integrated “Blockchain of things” technology can be used to collect real-world transportation data and build the physical part of the parallel transportation management system” (Yuan and Wang, 2016, pg. 2663). Besides this, Blockchain-based cryptocurrencies offer an alternative way to conduct transactions securely and efficiently without the need for traditional banking infrastructure (Ngoga, 2023). Pincheria et al. (2022) mentioned that adopting Blockchain can be a useful tool to make inspection procedures more automated, reliable, and simple. Similarly, Onifade et al. (2024) revealed that Blockchain technology could be relied upon to develop the infrastructure necessary for mining safety and health in the region. Experts on the subject point out that Blockchain can be used to record all data related to rock mechanics and rock engineering designs, as well as the effectiveness of monitoring tools. Data regarding changes in rock from monitoring tools such as mapping of mines, ground motion sensors, stability, vibrations or gas concentrations are recorded in real-time on the Blockchain. They can be stored securely.

The participants’ opinions regarding the use of Blockchain technology in Reko Diq focused on Blockchain’s impact on infrastructure, mostly on the necessary actions needed to deploy Blockchain technology in the region’s current infrastructure. **Participant Four** stated that technical complexity and scalability issues might pose hurdles, requiring significant investment in infrastructure and expertise to deploy and maintain Blockchain networks effectively. **Participant Three** mentioned that Reko Diq’s site is in a remote area of Baluchistan, where there is no solid communication network. To trace raw and refined materials transfer from Reko Diq and other required inputs transferred from the port cities of Gwadar and Karachi to Reko Diq as required by the Blockchain system, besides the

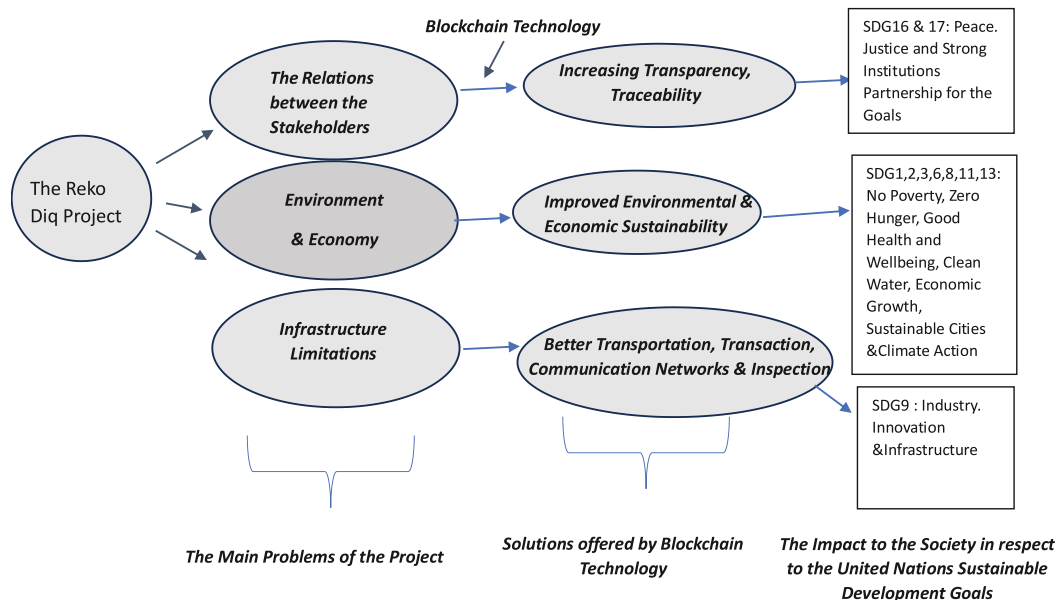
transportation infrastructure, the communication infrastructure connecting the area to Karachi, Quetta and Gwadar needs to be improved as well. He also mentioned that other social and economic infrastructures should be built that can benefit the people living in the region as well as the people working on the project. **Participant Five**

Table 2
Blockchain screening tool.

Utilising Blockchain Technology for Management of Reko Diq Copper-Gold Project in Pakistan		
Question	Explanation	Yes/No
Is there a need for shared access?	If there are few parties involved within the project scope, Blockchain is probably unsuited	Yes; Multiple stakeholders are involved
Is there need for regular access to records?	This is usually a vital requirement	Yes
Is there a need for transparency and accuracy?	This is likely to be yes in most cases	Yes
Are the parties trustworthy?	This is imperative, especially for the choice of nodes or validators	Yes; the parties involved are provincial and federal governments and internationally renowned companies in the mining sector
Is there a need for data permanence and immutability?	May not be essential in some contexts	Yes; particularly since the project has already been marred by legal rows and dispute with competing viewpoints on the strength of the outcomes
Can the physical item be easily converted to a digital asset?	NFT projects only	Most likely Yes
Can the problem be solved by a fractional ownership token	Only applicable to a small number of projects	Likely Yes, given the dispute on ownership of the reserves between the different stakeholders
Is there an opportunity for disintermediation? Cost reductions? Efficiencies?	This will be key in many cases. Further checks should be made to ensure disintermediation delivers benefits such as cost savings and improved timelines/lead times	Yes; this is a significant benefit of Blockchain utilization for the project as established through the findings of the study

mentioned the possible use of pipelines, liquidizing the metal and transferring it in liquid form, which might serve as a better option for a transparent and trackable environment in the Blockchain system.

extraction of the copper and gold from the mine has been awarded, leading to a general sense of distrust, and an emergence of power dynamics and weak institutional control in the region. The study has



These findings support the Technology Acceptance Model on one of its aspects; the findings unilaterally support the *perceived usefulness* of Blockchain technology for the effective management of the Reko Diq project. However, the second aspect of the Technology Acceptance Model, *perceived ease of use*, has not been established. In fact, the findings of the study suggest that there is a lack of skills in Blockchain technology use in Pakistan, which would make it difficult to implement and use without significant investment into infrastructure development and training of individuals in skills, as well as breaking down the psychological barriers against the use of technology in an otherwise traditionally-run-and-operated sector. While there is work being done on digitalization in various aspects, the *perceived ease of use* has not been well established. More work needs to be done on this aspect.

The *perceived usefulness* aspect of technology acceptance model can be further substantiated with the use of the Blockchain Screening Tool, which establishes the suitability of Blockchain technology for any project. This is shown in Table 2, and establishes the fact that nearly all elements of the Blockchain Screening Tool support the installation of Blockchain technology for the management of Reko Diq project.

The key objective of this study was to assess the feasibility of the Reko Diq project in Baluchistan for the implementation of Blockchain technology. The project is currently under a lot of scrutiny because of the bad press that it has received, as well as because of the lack of amicable relations between the different stakeholders, primarily between the Federal and provincial governments and the local population. There are also reports of corruption regarding the project, as well as concerns of environmental degradation. While Pakistan’s Supreme Court has intervened in the dispute between the different stakeholders in the project, the ruling was set aside by the international courts. A combination of these factors has led to a general sentiment that the Reko Diq project, despite having a significant economic and strategic role to play in Pakistan’s development, is being held back because of these problems. The local population is also not happy with how the award for the

established through the literature review as well as the participants’ responses that Blockchain technology has the potential to resolve all of these problems by offering solutions of traceability. Transparency. financial information sharing, stakeholder engagement, and overall improvement in the mining value chain as well as the mineral supply chain. However, infrastructure limitations, requirements for investment into the implementation of the technology, as well as the training and development of people in the use of the technology are some of the hurdles that are currently being faced in this context. The application of the Technology Acceptance Model has shown that there is no doubt as to the perceived usefulness of the Blockchain technology when it comes to its implementation in Reko Diq project. However, the hurdles identified in terms of infrastructure limitations and investment required undermine the perceived ease of use and more work needs to be done to address these issues before such a move towards implementation can be made. This paper has made some theoretical conclusions about these aspects, and suggests that the implementation of modern technologies in the mining industry is something that is happening all over the world, albeit with its own hurdles and limitations. Therefore, Reko Diq project is not going to be the only project that faces these problems, and lessons from around the world can be learnt so as not to reinvent the wheel and to use case studies from across the world to see how modern technologies like Blockchain can be implemented for better management of mining projects like Reko Diq.

5. Conclusion and recommendations

Based on the study findings and the application of the TAM and Blockchain Screening Tool, it can be safely assumed that implementing Blockchain technology for the management of Reko Diq project would go a long way in producing much better and desired outcomes. The Reko Diq project can benefit from transparent and immutable records of agreements and transactions thanks to distributed ledger technology

built on Blockchain (Karim et al., 2023; Khan et al., 2021; Rowan et al., 2006). Blockchain technology would allow for the tracking of the whole supply chain for the minerals removed from the Reko Diq, right from the point of extraction to the stages of processing and distribution. This can enhance traceability and ensure that minerals are supplied ethically and in compliance with the environmental standards. Smart contracts can automate the government's royalty payments based on predetermined standards, reducing the potential disagreements, and increasing process efficiency. The tokenization of assets, made possible by Blockchain technology, can enable fractional ownership of mining project shares or mineral rights (Hasan et al., 2023). This could open investment opportunities for smaller investors in the Reko Diq project, and potentially lead to the creation of new funding sources. By offering a decentralized, unchangeable repository for recording geological data, exploratory findings, and other pertinent information about the Reko Diq project, Blockchain can enhance data management and security. As Pakistan explores the complex nature of Reko Diq's logistical issues, it is critical to remember Pakistan's troubled history of badly completed projects, dishonesty, and inefficiencies. Blockchain can improve data management and security by providing a decentralized, immutable repository for storing geological data, exploratory results, and other relevant information concerning the Reko Diq project.

This study has certain limitations which need to be kept in mind. Firstly, this is a feasibility study and therefore, it is a provisional research in the application of Blockchain technology to the Reko Diq project. Future studies might apply the technology to an actual project and compare the outcome to the theoretical conclusions made in this study. This study has shown the potential for the use of Blockchain technology to projects in Pakistan, and in that respect, has provided a framework for the application of Blockchain and similar technological innovations. Secondly, there were very few people in Pakistan who had the combined knowledge of Blockchain technology and Reko Diq project. The Blockchain technology is in its infancy in Pakistan, and therefore, only a handful of people know about its potential or limitations when it comes to application to actual project. Also, Reko Diq is a government-run-and-controlled project which is shrouded in secrecy and lack of information. This meant that the few people who had information about the project were not forthcoming in talking about it, particularly the problems. Finding a combination of people who had knowledge of both Blockchain and Reko Diq was even more difficult. Future studies may want to include a larger sample size, hopefully with people who have a better grasp of Blockchain Technology as it grows in Pakistan, and the potential for its application to government projects. Thirdly, this study discussed the impact of Blockchain on emerging economies. In developed economies, the outcomes may be different. Future studies might compare the application of Blockchain in emerging and developed economies.

CRedit authorship contribution statement

Iram Tahir: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Khuram Shahzad:** Writing – original draft. **M. Sebnem Ensari:** Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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