Technology as a Double-Edged Sword: A Socio-Technical Grounded Theory of 4IR Adoption for Sustainability Compliance in Namibia's Mining Industry

Mr Felix Mutau*[1], Jacob Segale (PhD)[2]

[1]PhD Candidate, Africa Research University (ARU), Lusaka, Zambia

[2]Africa Research University (ARU), Lusaka, Zambia

***Corresponding Author**

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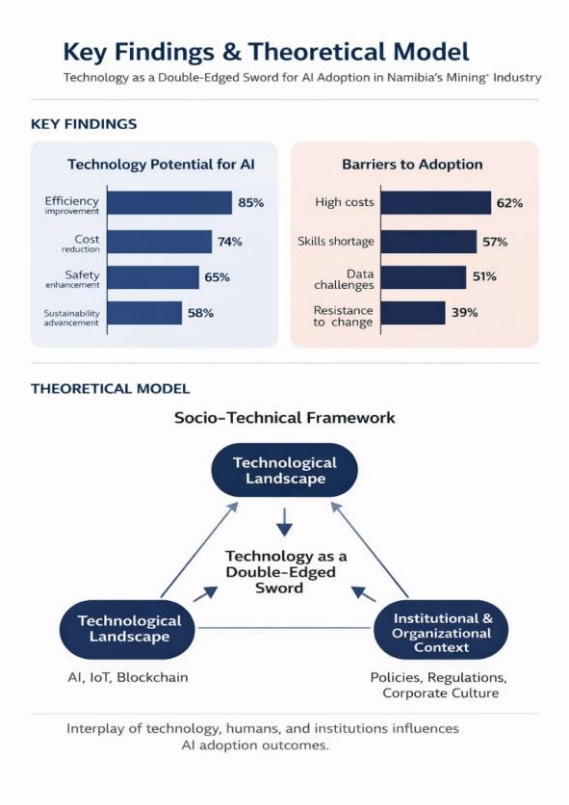
ABSTRACT

Context and Gap: The mining industry in Namibia has struggled with sustainability compliance. Although sustainability has been proposed as a solution to the current problem, there remains a research gap regarding the practical application of Fourth Industrial Revolution (4IR) technologies and the barriers to their implementation, particularly in Namibia. Purpose: This paper sought to determine how the main 4IR technologies, in particular the Internet of Things (IoT), Artificial Intelligence (AI), and blockchain, could be applied to these long-standing sustainability issues in Namibia's mining industry. Methods: A pragmatic, socio-technical grounded theory approach was used in the study with a sequential explanatory design. The first step was a survey of 179 stakeholders in the industry, followed by 14 face-to-face interviews. Critical Quantitative Results: The survey indicated high stakeholder confidence in the use of these technologies to achieve regulatory compliance, with AI viewed as most helpful (31%), followed by blockchain (26%) and IoT (25%). However, the survey also identified serious obstacles: lack of technical expertise (28%), prohibitive implementation costs (26%), management resistance (24%), and uncertainties regarding the regulatory guidelines (19%). Qualitative Theme and Contribution: The interviews identified a socio-technical tension, the phenomenon of the Technology as a Double-Edged Sword, in which interviewees expressed a sincere interest in the process of technological change but faced real fears of employment displacement and increased digital gaps. The principal contribution of the study is the introduction of a new socio-technical framework that offers evidence-based guidance to policymakers and leaders in industries to control digital transformation in an equitable manner in the extractive industries.



Keywords: Sustainable Mining, Fourth Industrial Revolution (4IR), Internet of Things (IoT), Artificial Intelligence (AI), Blockchain, Namibia, Regulatory Compliance, Socio-Technical Systems, Digital Disparity, Pragmatic Grounded Theory.

INTRODUCTION

The mining industry of the world is undergoing a major change that is commonly known as Mining 4.0. The fourth industrial revolution (4IR) is a new technological shift that drives this new age and includes the Internet of Things (IoT), which involves linking physical objects to the Internet; Artificial Intelligence (AI), which is the ability of machines to learn and take decisions; and blockchain, which is a secure and transparent online record. These technologies are effective in enhancing efficiency, mining safety and environmental performance of the mining sector. The latter potential has recently been well-documented in analysis industry reports and literature (ICMM, 2024; WEF, 2023; Gao and Shao, 2023; Schwab, 2016).

However, the implementation of 4IR technologies is still asymmetrical, especially in the countries of the developing world, where regulatory frameworks in many cases do not keep abreast (Kinyondo & Tomassi, 2024; UNCTAD, 2022). The Namibia case study of this disparity is interesting because it has significant disconnects in its technological ambitions and the current regulatory landscape.

The study is based on the growing literature on the socio-technical systems, which states that the adoption of technology is, in fact, not just a technical project but it is socially, organizationally, and even legislatively deeply embedded (Smith and Stirling, 2021; Geels, 2004). The theoretical tension to be pitted is the often-technological deterministic discourses around the 4IR and other complex realities of socioeconomic frameworks, institutional limits, and human actors that abound in developing nations. The fact that technological solutions are often put forward as universal panaceas does not mean that they are effective but depends on the adaptive capacity of the regulatory environment and readiness to the human capital (Rogers, 2003; Davis, 1989). The practical relevance of the study is emphasised by the fact that Namibia has a critical necessity to modernise its mining industry, so that technological progress would indeed add to, but not harm, its sustainable development goals and the livelihood of its communities (Chamber of Mines of Namibia, 2023).

This paper examines the possible obstacles related to the 4IR technologies in the Namibian mining industry. By so doing, it will fill knowledge gaps therein in the governance of resources. This paper is, ultimately, intended to be used in the development of a sound sociotechnical framework and practical policy suggestions to build an inclusive and sustainable mining future.

Problem Statement

The 4IR technologies have a high potential of promoting the mining sector in Namibia. The fact that Namibians have tried to adopt technology at a slow rate is not because the technology is not up to date, but rather a confluence of old rules, lack of institutional structures and systemic lack of trust. This has led to undermonitoring and enforcement of proper standards, which resulted in a number of the mining activities not satisfying the required Environmental, Social, and Governance (ESG) standards (ICMM, 2024; Kinyondo and Tomassi, 2024).

The causes of inefficient monitoring and implementation of the operations in Namibia are manifested in the low usage of 4IR technologies within the industry. In the case of the mining companies, this disparity is caused by lack of instruments to comply with international regulations and escalating sociopolitical demands. Therefore, they expose themselves to technological as well as regulatory market risks. Other stressors are based on the sociopolitical environment of social conditions of the workers (Chamber of Mines of Namibia 2023). As enforcement of mining standards becomes weak, investor confidence declines, thus making the mining sector in Namibia less competitive and the overall economic performance in Namibia.

Since mining industry is a significant part of Namibian economy, the challenges are important to be addressed in terms of economic viability in the long-term. The Namibian economy is still based on mining. This means that sustainable mining cannot be achieved without regard to the development objectives of Namibia. According to Baxter and Sommerville (2024), the SDGs in Namibia need to integrate environmental and social sustainability

issues in the process of implementing the mining technologies.

Hence, mining operations should be changing to meet worldwide standards and expectations. Green and open supply chains are also another major trend in the world that mining companies should adopt. Moreover, 4IR technology implementation should be conducted in pace with responsible mining and striving towards sustainable development objectives of Namibia.

METHODOLOGY

The interview guide has been created in response to the preliminary survey data, and the questions were created to address the discrepancy between how 4IR technologies should be perceived and how they should be adopted in reality. The guide centered on implementation barriers and employment and inequality concerns by the stakeholders. The interviews were carried out on 14 participants with a duration of between 45 and 75 minutes. The transcripts were later coded on NVivo software and the initial open coding process was applied, followed by the use of axial coding to gain the main themes and then selective coding to come up with theoretical categories.

In this study, a sequential explanatory mixed-methods model was used and finished refinement of the analysis was achieved (Creswell & Plano Clark, 2022). A survey of this nature and in particular scale was used to inform purposive sampling and semi-structured interviews that provided an empirically informed theory about the mining industry in Namibia (Charmaz, 2023; Morgan, 2022). An assortment of stakeholders was reached on a purposive basis with the help of a snowball to eliminate any biasness (Patton, 2015; Bryman, 2021). Quantitative data (n=179) was used to define the patterns exhibited in the industry and 14 qualitative participants were required to be certain that the theoretical saturation was achieved (Thornberg and Charmaz, 2024). Questionnaires (Dillman et al., 2023) and interviews (Brinkmann and Kvale, 2023) were the methods of data collection. The review discovered that technology is a Double-Edged Sword (Charmaz, 2023; Strauss and Corbin, 1998). It was done by means of securing ethical consent and establishing trust using Guba and Lincoln (1985) framework and triangulation (Creamer and Reeping, 2024).

RESULTS AND DISCUSSION

The next part of the report presents the results in relation to Objective B, the hindrances to integrating Fourth Industrial Revolution (4IR) technologies into the Namibian mining industry, and the opportunities to reduce gaps in sustainability compliance. The quantitative survey data were merged with the qualitative interview data to attain a holistic socio-technical analysis. This article is based on Objective B of my DPhil dissertation, which investigates the socio-technical factors influencing the adoption of 4IR technologies for sustainability compliance in the Namibian mining industry.

Namibia roadmap policy scenario of technology-enabled compliance.

1. **Phase 1 (0-12 months):** The Ministry of Mines and energy together with the Chamber of Mines should facilitate the digital preparedness checks. Authenticate the digital preparedness. Build comprehensive guidelines on the compliance of the digital. Fund the digital pilots available with a priority on the high-risk areas (water, tailings, occupational health and safety).
2. **Phase 2 (1-3 years):** Namibia University of Science and technology and vocational training centers are to establish 4IR skills programs together with mining companies. Broadband infrastructure (power and broadband) alliances. Upskill regulators. Current industry re-skilling in the mining industry.
3. **Phase 3 (3-5 years):** Broadband infrastructure development is to be synchronized with the needs of the mining sector by the Ministry of Information and Communication Technology. Develop a systemic compliance platform. Assist SMEs on a small scale. Implement a priority indicator to mandatory digital reporting.

The Potential Positive Impact of 4IR Technologies.

By changing the question to specify responses on which technology has been most useful in improving regulatory compliance, the responses were provided creatively. Artificial Intelligence has been regarded as the most

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powerful facet, and some 31% of respondents noted that it was the most convenient technology in one of the fields. Right after it, there is blockchain with 26% and the Internet of Things with 25%. Interestingly, 16% of respondents said that none of these technologies had positive effects on compliance, indicating that the perceived potential is not realised in practice across all areas of operation (Smith and Davies, 2024).

This suggests that, despite the overall benefits of the Internet of Things being widely accepted, Artificial Intelligence and blockchain are perceived to have a more immediate and substantive impact on regulatory compliance. The information points to a promising area of inquiry into emerging technology, while also expressing scepticism about the unique advantages each technology might offer across various operations and regulatory procedures.

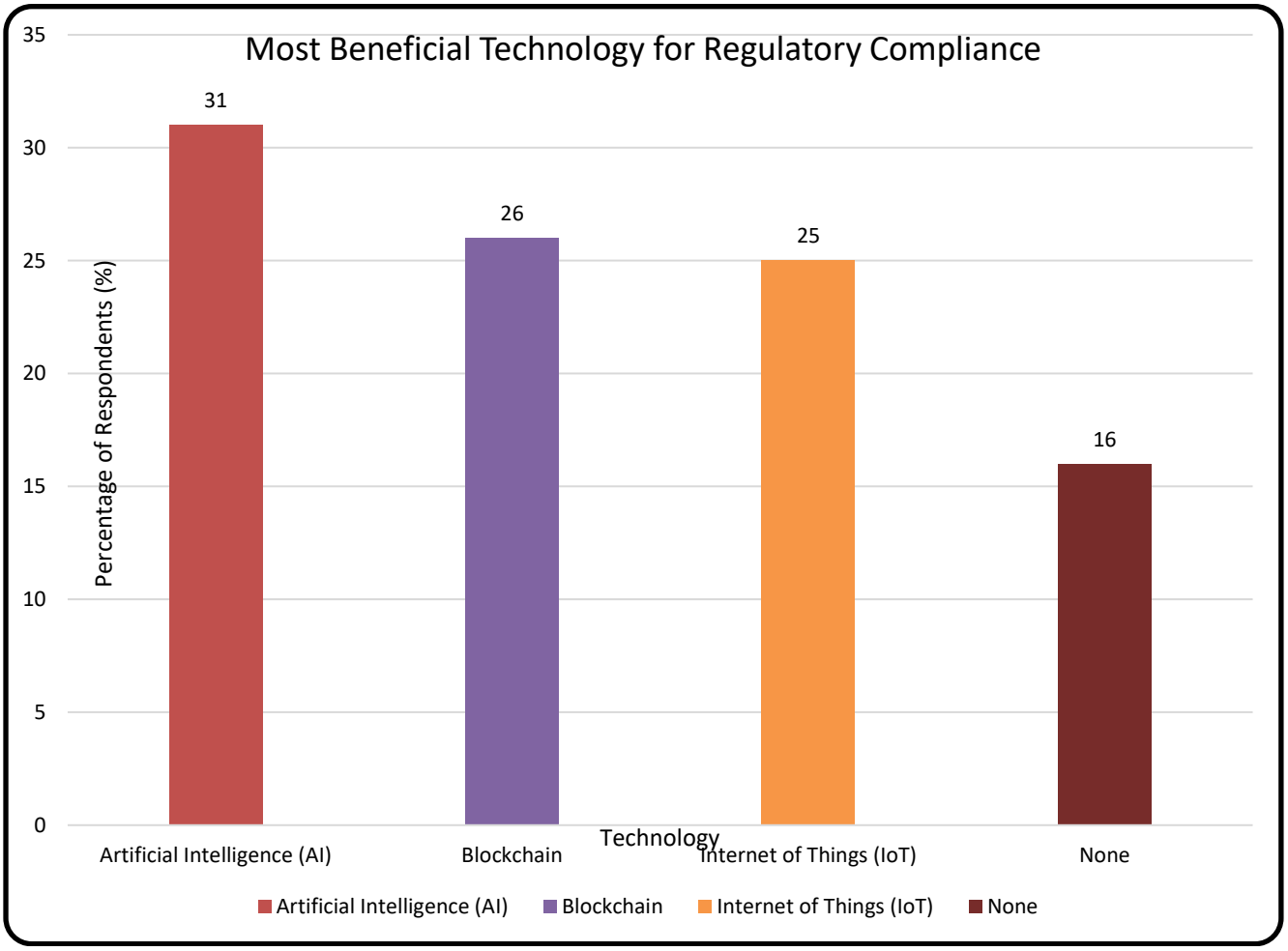

Figure 1: Stakeholder perceptions of which 4IR technology offers the greatest potential for improving regulatory compliance in Namibia's mining sector (n=179).

The survey findings where particular technologies are considered as a source of regulatory compliance are both aligned with trends in the rest of the world and with conventional use cases. Artificial Intelligence (31) has a high ranking because there is increasingly more concentration around the world on Martin learning to make predictive analytics of both risk and compliance monitoring (WEF, 2023). It is also high when it comes to blockchain since that percentage of respondents is the highest among those who selected a technology as it has attracted much of the attention due to its ability to ensure transparency and immutable record keeping in the supply chain (Jones et al. 2021).

The most known concept is the Internet of Things (25%), and as a compliance issue, it is generally identified in direct connection to real-time data collection to be fed into AI-related systems (Gao and Shao, 2023; ICMM, 2023). Tailing Dams in Chile have seen the implementation of IoT Sensors enhance risk management (Schneider Electric, 2021), and AI-controlled safety systems in South Africa mines have improved safety which is one of the regulatory compliance requirements (Mining Weekly, 2023). These nations in the mining sector sink the mere potentials of 4IR technologies in addressing the identical regulatory challenges in Namibia.

Key Factors Influencing 4IR Technology Adoption

Barriers and Strategies to Overcome Them

Qualitative data reveal the nuanced nature of barriers to adoption and contextually appropriate strategies to overcome them.

a) **Regulatory and Policy Interventions**: Participants indicated the need for a more supportive regulatory framework that encourages technology adoption. Such support includes developing a national digital mining roadmap, establishing targeted funding for pilot projects, and integrating technology-specific provisions into environmental and safety regulations. As one government official stated, *"We cannot simply wait for industry to act; we must create conditions for innovation*". This approach aligns with experiences in Chile and Australia, where government support has facilitated digital transformation of the mining sector (Ernst & Young, 2022)

b) **Infrastructure Development**: Infrastructure provision requires a multi-stakeholder approach, including public–private–community partnerships to deliver broadband connectivity to remote mining sites. This approach has proven effective in other African countries, particularly through universal service funds supporting broadband provision in rural areas (ITU, 2023). Additionally, off-grid renewable energy is essential for powering digital technologies in areas with unreliable electrical supply.

c) **Human Capital Development:** Bridge the skills gap requires a two-pronged approach. In the short term, this involves upskilling the current workforce through training programmes and workshops developed collaboratively with industry and academic institutions. Long-term solutions require fundamental revision of national education curricula to include digital literacy and data science, ensuring a sustained pipeline of skilled talent for the mining sector. This aligns with best practices in 4IR workforce development, which emphasise flexible curricula and lifelong learning (WEF, 2023). For example, UNDP (2022) highlights Botswana's 'Mponela' digital skills programme as a successful model for workforce upskilling in the diamond industry, offering potential lessons for Namibia.

According to the survey results, lack of technical expertise represents the most critical barrier, cited by 28% of respondents. High implementation costs required to operate and maintain advanced systems constitute the second major challenge, identified by 26% of respondents. Resistance from management presents another substantial impediment, noted by 24% of respondents, whilst unclear regulatory guidelines pose an additional constraint cited by 19% of respondents. These findings demonstrate the multifaceted nature of the barriers to adopting IoT, AI, and blockchain technologies in Namibia's mining sector, with technical capability gaps and financial requirements representing the most pressing concerns for industry stakeholders.

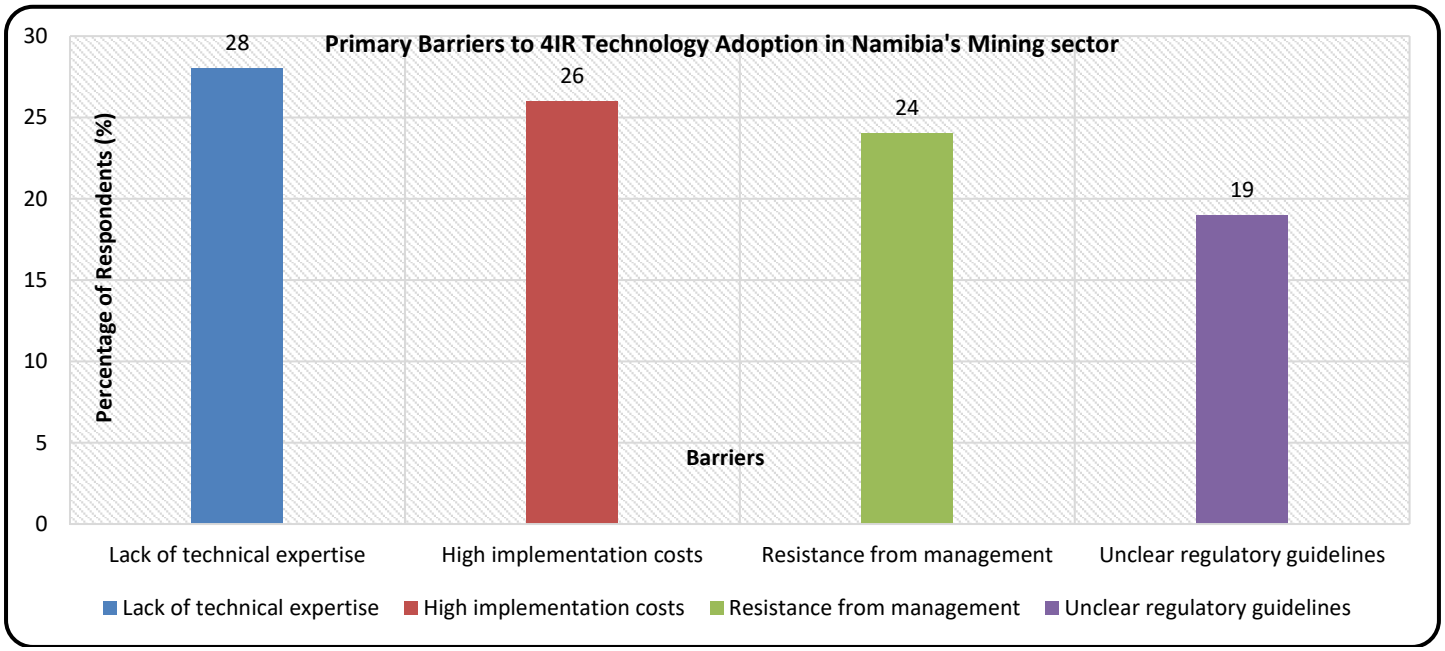

Figure 2: Primary Barriers to 4IR Technology Adoption as identified by Mining industry stakeholders (multiple responses possible).

The qualitative data prove and complement the quantitative results, which can be correlated with theme 2, "Tech as a Double-Edged Sword: Explaining the Gap." This theme throws light into the paradox when the stakeholders bear in their heart a true interest towards the technological advances, but hits the brick wall of concrete concern and barriers. Interviewees have described the complexities of the issues placed between the potential advantages of 4IR technologies on the one hand and the large-scale challenges that these innovations pose on the developing economies on the other hand. The qualitative descriptions support the findings established in the quantitative barriers as being technical capability gaps, financial constraint, organisational resistance to change and regulatory unacknowledgeable. Although it is acknowledged that 4IR technologies promise a lot, the path to the sustainable adoption of such technologies is still disturbed by the complex of related practical, organisational, and systemic obstacles.

Nevertheless, opportunities that can be created with the aid of 4IR technologies should also be mentioned. An example of such technologies is the possibility to work remotely, the opportunity to access training with the help of online platforms, and the emergence of new skilled jobs. The recognition of these possible advantages gives a more in-depth analysis that does not decrease the valid apprehensions regarding the digital divide. These barriers need to be solved with comprehensive strategic intervention in order to promote effective technology adoption in the Namibian mining industry.

The convergent qualitative data support and helps to interpret the quantitative results in greater detail and provide a more in-depth picture of the barriers to 4IR adoption. The quantitative survey recognizes the absence of technical expertise as the most dangerous barrier, mentioned by 28 percent of the participants, which indicates a serious HHCM deficit of Human Capital (Tomassi & Kinyondo, 2024). Workforce available is usually not trained adequately to utilize the 4IR technologies, thus creating the fear of job displacement and consequently, a reaction to technological change.

The second biggest barrier coming up as a significant financial challenge is high implementation costs (identified by 26% of respondents). The qualitative data reveals that these costs mean not only acquisition but also licensing and maintenance costs, which leave firms (especially, Small and Medium Enterprises (SMEs)) next, which must use technology to comply with the requirements but do not have the necessary financial resources (Kinyondo and Tomassi, 2024).

Another significant barrier to the adoption of technology is resistance by the management as was reported by 24% of respondents. This organisational obstacle, which is complemented by the lack of digital infrastructure, is not only related to connectivity but also to unreliable power sources and inaccessible remote mines, putting a new digital divide at risk that may further marginalise smaller players (UNCTAD, 2022; Ndjamba, 2022).

Regulation is another limitation that makes the adoption landscape complicated as 19% of the respondents mentioned unclear regulatory guidelines. The results of this research lead to a holistic conclusion of the paper Aspiration Tempered by Anxiety, which provides a paradox of the motivation of 4IR towards frustration and thrill. This duality of facet shows the paradox where on one hand technologies have very high potential, but on the other hand, they can also contribute to the further polarization of socioeconomic processes (Smith and Stirling, 2021). As a result, the main obstacle is the integration of the ecosystem that will be supported by favourable policies, special training programs, comprehensive infrastructure, and clear regulatory frameworks that should overcome this complicated transition (World Bank, 2020).

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The outcomes embrace a paradox because frustration and anxiety constitute essential components of the 4IR drive. The two-sided nature of the so-called double-edged sword perfectly captures the paradox: as much as technologies can offer the world, they can also develop it (Smith and Stirling, 2021). The key task is to continue to create an integrated ecosystem of technologies to progress and supportive policies and dedicated training and more comprehensive infrastructure (World Bank, 2020).

Main Findings

The latest study on Objective B illustrated a given socio-technical gap in the mining industry in Namibia. The disconnect here refers to the mismatch between the perceived positive impacts of Fourth Industrial Revolution (4IR) technologies and the massive impediment to their application. The combination of qualitative and quantitative data provides valuable insights that can inform the situation, including observations on the Implementation Gap and the Technology as a Double-edged Sword.

a) The former insight offers a cohesive viewpoint on the potential opportunities of 4IR. The stakeholders concur with the general positivist perspective to overcome the current compliance loop loopholes within the spheres of monitoring, safety, and transparency. This indicates a desire for more advanced technologies (ICMM 2024).
b) In existence, there is a heavy exorbitant aspiration that is obstructed in terms of overwhelm of the three critical variables that include high implementation costs, inaccessibility of requisite technological aptitudes, and imperfect digital/telecommunication infrastructure. This cycle of a stagnated and/or non-adoption of a new technology is not an indicator of the indifference of the concerned stakeholders (Kinyondo and Tomassi, 2024) as much as the lack of a favorable environment.
c) The qualitative data also indicate the discomfort happened with the incorporation of technology and resultant attitudes of the socio-economic effects of that specific technology. The anxiety about the role of new technologies on employment and inequality are not unreasonable. There is concern that the potential detrimental effects that emerging technologies might have on employment and expand inequality would result in a new digital divide. Such strains indicate the desire to have structures that take into account the manner in which to develop and harness new technologies to facilitate the achievement of fair social results and inclusive economic development (Tomassi & Kinyondo, 2024; Ndjamba, 2022). Without conscious investment in training people with new skills and high-quality local content and enhancing the availability of digital access at lower prices, the potential of 4IR technologies to reduce inequality will go to waste.
d) The final one is that nearly all the new theory implies that successful implementation of the 4IR technologies requires the inclusion of the new technologies and frameworks so that it is inclusive of wide social systems and structures. It is mainly a socio-technical challenge, and requires regulatory frameworks that prefer motivation, not with technology, to invest in systems that empower people, enhance infrastructures and solicit partnership by various social actors to diminish social tensions (Smith and Stirling, 2021; Chamber of Mines of Namibia, 2023). The outcome of Objective B comes in handy in bridging between finding gaps in the compliance (Objective A) and the future position of a regulatory framework (Objective C), and also a reminder that proper technologies should be developed within an appropriate, inclusive and supportive governance framework.

LIMITATIONS OF THE STUDY

Although the current research has provided valuable information about the issues encountered by 4IR technologies in the Namibian mining industry, its shortcomings cannot be ignored. The use of self-reporting in surveys, while covering a broad spectrum of stakeholder perceptions, may be subject to social desirability bias, where respondents over-represent the positive and under-represent the negative (Podsakoff et al., 2024). Although the qualitative element was intended to triangulate and extend information regarding the findings, the 14 participants selected for the in-depth interviews, even though the sample was purposefully selected to encompass as much variety as possible, might not mirror the full range of complexities and experiences across all subsectors and marginalised groups (Guest et al., 2023).

Contextually, research has long been concerned with the mining industry in Namibia. Although the findings may be applicable to other developing nations with a similar socioeconomic environment and legal framework, generalising them requires considerable caution (Lincoln and Guba, 2024). The specific historical, political, and economic processes that define the mining industry in Namibia imply that these will present significantly different challenges and opportunities elsewhere.

The technological transition is rapid, and that is why the perceived potential and obstacles of 4IR technologies

are likely to be dynamic at all times. Innovative solutions or significant obstacles are likely to evolve quickly (Dearing and Cox, 2024). These changes need to be incorporated into future research.

This paper examined how stakeholders perceived possible barriers to 4IR technologies. Although this is a useful approach that assists in the examination of current barriers in the socio-technical environment, it lacks estimates of socio-technical viability or evaluations of the technologies in practice within pilot frameworks. Therefore, the results are not an empirical evaluation of the impediments to 4IR technologies in the Namibian context but rather the perceptions of those impediments by the stakeholders. This is important to make clear in order to appropriately frame the results and to steer the interest of further research and related policies.

FUTURE RESEARCH IMPLICATIONS.

The conclusion on the based of Objective B offers several strong perspectives of the future research, including both theoretical and practical aspects.

Theoretical Implications: The motifs of the Double-Edged Sword and the Digital Divide are emerging concepts that warrant deeper investigation within current socio-technical perspectives. The next generation of research must examine the complex elements that underpin this ingrained duality, particularly in weak institutional settings, using longitudinal studies and comparative analysis designs (Smith and Stirling, 2021; Geels, 2004).

Methodological Implications: The mixed-methods approach applied in this study was highly effective in providing comprehensive knowledge of the topic. Further studies could adopt even more integrative mixed-methods research approaches, including convergent parallel designs that would allow data collection and analysis to be conducted simultaneously, thereby providing a more comprehensive and immediate synthesis of quantitative and qualitative information (Creswell and Plano Clark, 2024). Moreover, the use of action research methodology with pilot projects on the implementation of 4IR technology may produce valuable empirical information on actual performance, costs, and socioeconomic outcomes, which would remain beyond stakeholders' perceptions and reflect the reality of performance (Bradbury et al., 2023).

Policy and Practice Implications: The barriers identified in terms of costs, skills and infrastructure require policy intervention to be developed. Further studies would benefit assessing the effectiveness of particular policy tools, e.g., tax incentives to promote the use of technologies, vocational training to match 4IR skills, or private-public interactions to develop digital infrastructure (Chamber of Mines of Namibia, 2023). A study focusing on the design and execution of the programs focused on the so-called just transition in the mining industry, whose main aim is reducing the risk of displacement and the issue of inclusive growth, would be valuable. In addition, researches that investigate ideal measures to apply when engaging stakeholders in terms of technology-based regulatory restructuring may be used to create effective and more fair governance frameworks (Responsible Mining Foundation, 2024).

CONCLUSIONS

The study has critically examined the possible obstacles to the adoption of Fourth Industrial Revolution (4IR) technologies in Namibia’s mining industry. It has been indicated that stakeholders have a strong awareness of 4IR’s potential to improve monitoring, safety and transparency. Nonetheless, this optimism is significantly constrained by factors such as cost, skills and a lack of proper infrastructure.

In this study, the phenomenon of the Double-Edged Sword of digital transformation can be used, which suggests that 4IR opens the possibility of improved sustainability and, at the same time, endangers the increase in the existing inequalities (Tomassi and Kinyondo, 2024). The successful integration of these technologies is, thus, a profound sociotechnical endeavor that involves a comprehensive approach to such issues as economic, human, and infrastructural in a balanced way.

Finally, the results of Objective B provide invaluable empirical evidence for the development of a holistic, technology-based regulatory system, which Objective C discusses. These revelations highlight why such an architecture needs to be carefully crafted to not only incentivise the uptake of technology but also to ensure that

its negative social consequences are avoided in advance. This involves a fair transition of the workforce and ensuring that benefits are shared fairly among all stakeholders. The path of sustainable mining, led by the use of 4IR technologies, will depend on Namibia's ability to provide solutions that effectively close this socio-technical divide and hence convert the visions into viable, actual, and sustainable lives.

New or Emergent Theory

Objective B aims to develop the Theory of Socio-Technical Regulatory Alignment in Digitalising Extractives. It builds on the foundations of a pragmatic grounded theory approach. According to this emergent theory, the successful implementation and adoption of Fourth Industrial Revolution (4IR) technologies to support sustainability compliance in resource-abundant developing countries depend on the flexibility and synergy of adjustments across three dimensions. Figure 3 provides a visual representation of the associations within the socio-technical model, showing the interrelationships among the technology, regulatory, institutional, and socioeconomic layers, and the major obstacles to implementation

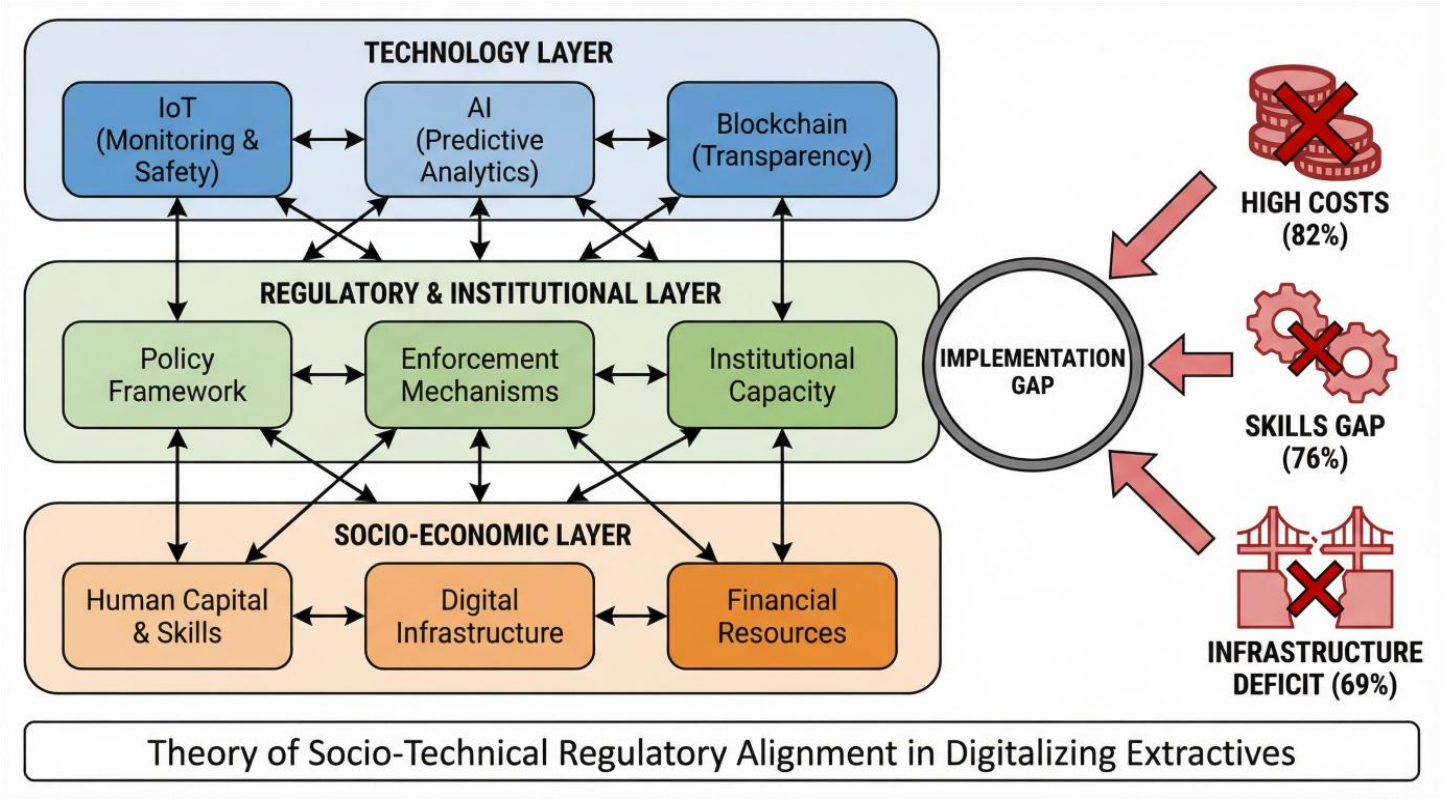

Figure 3: Socio-Technical Model of 4IR Technology Adoption in Namibia's Mining Sector

The framework shows how the Technological Readiness, Socio-Economic Preparedness, and Institutional and Infrastructure Facilitation interact. The identified barriers of this study can be placed on these dimensions, which illustrates the complexity of the 4IR adoption problem.

The model focuses on the following, as illustrated in Figure 3:

a) **Technological Readiness**: This dimension encompasses the availability, accessibility, and perceived usefulness of relevant 4IR technologies, including the Internet of Things (IoT), Artificial Intelligence (AI), and blockchain, in addressing specific, identified compliance gaps.

b) **Socio-Economic Preparedness**: This relates to the ability of human capital (skills, training, and labour market adaptability) and the wider societal fabric (equity, inclusion, and digital literacy) to respond to and manage the change associated with technology without worsening existing inequalities.

c) **Institutional and infrastructure facilitation**: This dimension entails enabling and supportive regulatory frameworks, healthy and viable digital infrastructure, and a financial engine that enables investment and innovation, as well as equitable access to technology for stakeholders.

Core Propositions:

a) **Hypothesis 1 (Paradox of Potential**): Having a high perceived technological potential of improving sustainability compliance (e.g. the adoption of the Internet of Things to track real-time sustainability performance) does not ensure adoption. The turning point to successful integration depends on the simultaneous availability of socioeconomic preparedness and institutional enablement.
b) **Propositions 2 (Triad of Impediments):** Implementation expenses, skills shortages and lack of infrastructure are a triad of barriers which are reinforcing. Taken together, these barriers cause a great socio-technical gap which stands as the most indicative hindrance towards the uptake of 4IR technologies compared to any one of these barriers.
c) **Proposition 3 (Digital Divides Amplification):** Uncontrolled implementation of 4IR technologies in environments with pre-established socioeconomic inequalities is a significant threat to increasing the digital divide. It may result in an increased job displacement fear and the marginalisation of smaller businesses and local communities even more.
d) **Proposition 4 (Socio-Technical Alignment Imperative):** 4IR technologies must not be integrated into the mining industry blindly and in an inclusive manner; instead, the adoption needs to be a multi-stakeholder strategy. This solution should also take the initiative in synchronizing technology with sound human capital growth, equal availability of infrastructure and enabling regulatory systems. This way, it will be able to create a so-called just transition, overcoming the so-called double-edged sword effect.

This new theory visualised in Figure 3 is beyond the technical or purely economic conceptualisation of technology adoption. Rather, it highlights the importance of socio-technical alignment, as a fundamental requirement in the quest of sustainable and equitable results in the entire process of digital transformation of extractive industries. The model shows that the divide between implementation and application of the technologies is not only a product of the technical constraints but a lie in the mismatch of the three essential dimensions. Such gap needs to be taken care of with a multi-stakeholder response that will not only enhance the technological preparedness but also increase the socioeconomic preparedness, but also institution and infrastructural enablements.

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Competing Interests

Its author states that there are no competing interests.

Author Contributions

The current journal article is the original work of Mr Felix Mutau, and he will be responsible for conceptualisation, research design, data collection, data analysis, findings interpretation, and manuscript writing. The article is premised on Objective B of his DPhil Dissertation entitled: ***Developing a Technology-Driven Regulatory Framework to improve Sustainable Mining Practices in Namibia: A Grounded Theory Pragmatic Approach.***

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Data Availability

The datasets obtained and the analysed data within the framework of the current study will be provided by the respective author upon reasonable request.

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