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Leveraging Digital Infrastructure for Mining Community Resilience

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Leveraging Digital Infrastructure for Mining Community Resilience

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Executive Summary

The mining industry has made significant strides in adopting cutting-edge innovations and digital infrastructure to enhance operational efficiency and worker safety. New mining projects are increasingly technologically intensive, with investments in high-speed connectivity and data processing technologies playing a critical role. These advancements enable real-time decision making, continuous and agile operations, and improved precision in mining activities. However, to function effectively, these digital technologies require robust, secure digital infrastructure and reliable internet connectivity. For governments, these investments are particularly important as they not only improve mining operations but also provide opportunities to enhance local socio-economic development.

Since the beginning of modern mining, resource-rich countries have attempted, with mixed results, to translate mining investment into greater benefits to host states and communities. As global demand for minerals and metals rises to meet digital and energy transition needs, the number of mining operations, particularly in developing countries, is set to increase dramatically. This surge presents a renewed opportunity for resource-rich nations to not only boost fiscal and export revenues but also to catalyze local economic development and improve livelihoods in mining communities. The integration of digital infrastructure within the mining sector offers a transformative potential, unlocking significant socio-economic benefits such as job creation, enhanced educational access, improved supply chain efficiencies, and greater financial inclusion.

This report raises important questions about the potential to harness the needs and capacity of the mining industry to deploy digital technologies and how these may have wider socio-economic impacts. It also raises questions for policy-makers about what needs to be considered in terms of the social and security risks that accompany increased connectivity and what that means for governments, mining companies, and communities. There are numerous regional, national, and community-level benefits that governments could tap into through appropriate policy interventions that support and incentivize wider connectivity through leveraging the mining sector's capabilities.

However, despite these clear benefits, challenges remain, particularly in ensuring that sophisticated digital networks reach all community members. For example, in Lesotho, while advanced networks have been deployed by mining companies, these networks often fail to reach local communities due to low literacy rates and inadequate access to modern devices. This digital exclusion highlights the need for coordinated efforts between the public and private sectors to ensure that digital connectivity is inclusive and responsive to the needs of marginalized populations, particularly women and other vulnerable groups. Educational campaigns to boost digital literacy and close the gender and rural digital divide are crucial in this regard.

The report also highlights successful case studies from other countries. In South Africa, the Maru a Mokopane project by Ivanhoe Mines has provided free wi-fi and digital literacy training to host communities, significantly improving local connectivity. In the Democratic Republic of Congo, the Umoja project has extended digital infrastructure to local communities, facilitating education and financial transactions. In Senegal, the government's National Digital Strategy has improved digital infrastructure across sectors, including mining, ensuring that remote areas benefit from reliable communication networks. These examples demonstrate

how targeted investments and policies can enhance the socio-economic benefits of digital connectivity.

In this context, this report emphasizes the crucial role of governments in creating a regulatory environment that fosters the sharing of digital infrastructure with local communities. By aligning digital initiatives with broader socio-economic goals, governments can reduce dependency on the mining sector and promote diversification into education, health care, and local enterprise development. Lessons from countries like Ecuador, where mining royalties are used to enhance digital infrastructure, illustrate the effectiveness of aligning infrastructure investments with community needs.

Building on extensive consultations with governments, mining companies, civil society actors, and local community representatives, this report emphasizes the need for inclusive, community-focused policy frameworks that ensure digital infrastructure investments in the mining sector align with broader socio-economic goals and puts forward the following key policy recommendations:

- strengthening local content policies to integrate digital infrastructure into local content strategies, ensuring that mining operations prioritize the benefits of these investments extend to local communities;
- promoting digital literacy and skills development to equip local communities, particularly women and marginalized groups, with the digital skills necessary to participate fully in the evolving digital economy;
- enhancing policy coherence and coordination between ministries responsible for mining, information and communication technology, education, and energy to avoid the pitfalls of overlapping mandates and misaligned priorities;
- fostering public–private partnerships that leverage the mining sector's capabilities to enhance digital connectivity for entire communities through incentives for mining companies to share digital infrastructure, such as tax deductions or subsidies for last-mile connectivity projects;
- ensuring sustainability and long-term impact by planning for the maintenance and upgrading of infrastructure over time, even in the face of economic downturns, changes in the commodity cycle or the closure of mines;
- addressing the gender digital divide by ensuring that digital literacy programs are accessible to women and that digital technologies are designed to meet the needs of women and other historically underserved groups.

Overall, this report complements the Intergovernmental Forum for Mining, Minerals, Metals and Sustainable Development's 2018 *Guidance on Local Content Policies* and highlights the transformative opportunities that digital technologies present for local economic development and community resilience.

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Acronyms

AfDB	African Development Bank
apps	applications (software)
CSR	corporate social responsibility
ICT	information and communication technology
IGF	Intergovernmental Forum for Mining, Minerals, Metals and Sustainable Development
IoT	Internet of Things
ITU	International Telecommunication Union (United Nations Specialised Agency)
LEO	low-Earth orbit (satellite constellations)
MSPs	multi-stakeholder partnerships
USSD	Unstructured Supplementary Service Data
WEF	World Economic Forum

1.0 Introduction

This paper provides new insights for the Intergovernmental Forum for Mining, Minerals, Metals and Sustainable Development (IGF) guidance on local content policies, with a focus on digital and data infrastructures and connectivity.[1] It sheds light on key issues that policy-makers may consider when designing, reforming, and implementing policies to harness the benefits of digital technologies being adopted by mining companies to strengthen horizontal linkages with the local economy.

Digital infrastructure and access to real-time data have become indispensable to the functioning of our society. They are made possible due to the widespread use of vast communication networks (terrestrial, satellite, and maritime), coupled with the increasing adoption of artificial intelligence (AI), the Internet of Things (IoT), and various software applications, among others, that are disrupting the way businesses perform (IGF, 2019). They power the knowledge-driven economy, enabling global trade, financial transactions, public services, transportation, navigation, aerospace, and the connection of people around the world. Sharing of and access to digital technologies can significantly improve the quality of life of citizens.

Although the pace of technological adoption varies across and within countries, due to geological circumstances, the mining industry, like other economic sectors, has made significant strides in investing in cutting-edge innovation and in digital infrastructure and connectivity to improve operations and to ensure the health and safety of mine workers (IGF, 2019, 2021; World Economic Forum [WEF], 2021). When combined with physical infrastructure, these technologies augment the capacity of workers and of mining operations, making them more precise and efficient. They ensure continuous operation of mining activities and enable real-time decision making that helps anticipate potential dangers and address failures (IGF,

[1] "Digital infrastructure includes macro cell towers, small cell networks, data centres, fibre infrastructure, server hardware, personnel, IT virtualization and infrastructure software, and operating systems. However, it may also include spectrum, Citizens Broadband Radio Services infrastructure, satellites, subsea cables and any operating companies that specialize in or have a material focus on providing services (including online and software applications) for digital infrastructure. Digital infrastructure also means joint fibre-optic and wireless-based advanced information and communication technology platforms with embedded multi-functional application services that facilitate 24/7 online real-time connectivity between nodes in the operational network to allow remote management of production assets" (The Law Insider Dictionary, n.d.).

2021). However, to function effectively, digital technologies require robust, reliant, and secure digital infrastructure, as well as reliable and fast internet connectivity.

The adoption and deployment of digital and data infrastructure, as well as myriad information technologies, is a relatively new area for policy-makers to contend with. However, despite the wide acknowledgement of the importance of digital technologies, in particular the spillover effects for local economies, research and consultations conducted for this study paradoxically showed that generally there appears to be little knowledge about policies to encourage or to require mining companies to share their infrastructure or non-sensitive data with local communities.

In that respect, in a rapidly changing world, there is an opportunity for policy-makers to review and improve their national policies, such as their mining regulations, their information and communication technology (ICT) strategies, and their local content policies to leverage such technologies to better support socio-economic ambitions and better enable community resilience. With regards to specific technologies being deployed by the mining sector, as well as some data obtained, it is also an opportunity to align strategies to mutualize the benefits of technology for local economic development (Ediriweera & Wiewiora, 2021).

Digital infrastructure and access to information (the Internet) are interconnected, interdependent, and complex fields. This paper highlights the challenges, risks, and opportunities that countries should consider when formulating policies aligned with their mining sector. It also discusses the linkages between infrastructure, access to information, cybersecurity, and associated risks, which are of increasing concern to all stakeholders. Finally, the paper makes a case for governments and mining companies to consider the extension of digital infrastructures for the benefit of surrounding mine-host communities.

2.0 Digitalization: Key trends driving change

2.1 Digital and Data Infrastructure: Definition and scope

"Digital infrastructure refers to both physical hardware and software-based components working together to relay information and digital products and services from one point to another" (Trava Security). Its main objective is to ensure information transmission through the infrastructure is seamless for sharing and consumption across various stakeholders (Trava Security, n.d.). This forms the backbone of a country's ICT capacity and capability.

The ecosystem around the data infrastructure includes features such as data integration, computer networks, cloud computing, software as a service and platform as a service applications, databases, data centres/server warehouses, security, etc.

FIGURE 1. Core functions provided by digital and data infrastructure

Enabling seamless communication

- Facilitating internal and external communication
- Collaboration tools and platforms

Streamlining management processes

- Automating workflows and optimizing operations
- Leveraging information for increased productivity

Enhancing user experience

- Providing seamless online experiences and personalized services
- Leveraging data insights to improve decision making
- Internet search engine capabilities

Source: Adapted from Trava Security, n.d.

Some of the core functions provided by these technologies (Trava Security, n.d.) are shown in Figure 1.

Examples of digital infrastructure technologies used in the mining sector include the following (see Anglo American, 2019; Dziengel, 2023; IGF, 2019):

- data server centres and data infrastructure (remote and on-site operating control rooms for robotics and high-precision automated machinery, electronic shift-based risk cards of workers)
- networks, IoT, and digital communication suites (high-spec connectivity for real-time monitoring via sensors and devices)
- mobile telecom and broadband connectivity (including communications and low-Earth orbit (LEO) satellites)
- storage equipment and portable devices (monitoring, warning systems, wearable sensors, etc.)
- high-spec processing hardware and software (3D field models in design and management, predictive methods for analyzing geological and production data)
- business software and applications (apps), software as a service, and platform as a service (financial, HR, payroll, management, marketing, etc.)
- geographic information systems, the Global Positioning System, and drones
- visualization of technological processes in inaccessible areas
- virtual simulation software (equipment operation safety training/emergency response simulations)

2.2 The Digital Landscape: Global trends

The last decade has seen an exponential rate in advances of digital technologies, driven and fast-tracked by high-tech devices, powered by AI, big data, IoT and automated operations, amongst others. More recently, following the COVID-19 pandemic, there have been significant changes in workplaces with the rise of remote and hybrid workplaces and digital nomads. The need to adapt to remote work and online operations through various pandemic lockdowns has led to a greater adoption of digital technologies both at home and by companies (Jaumotte et al., 2023).

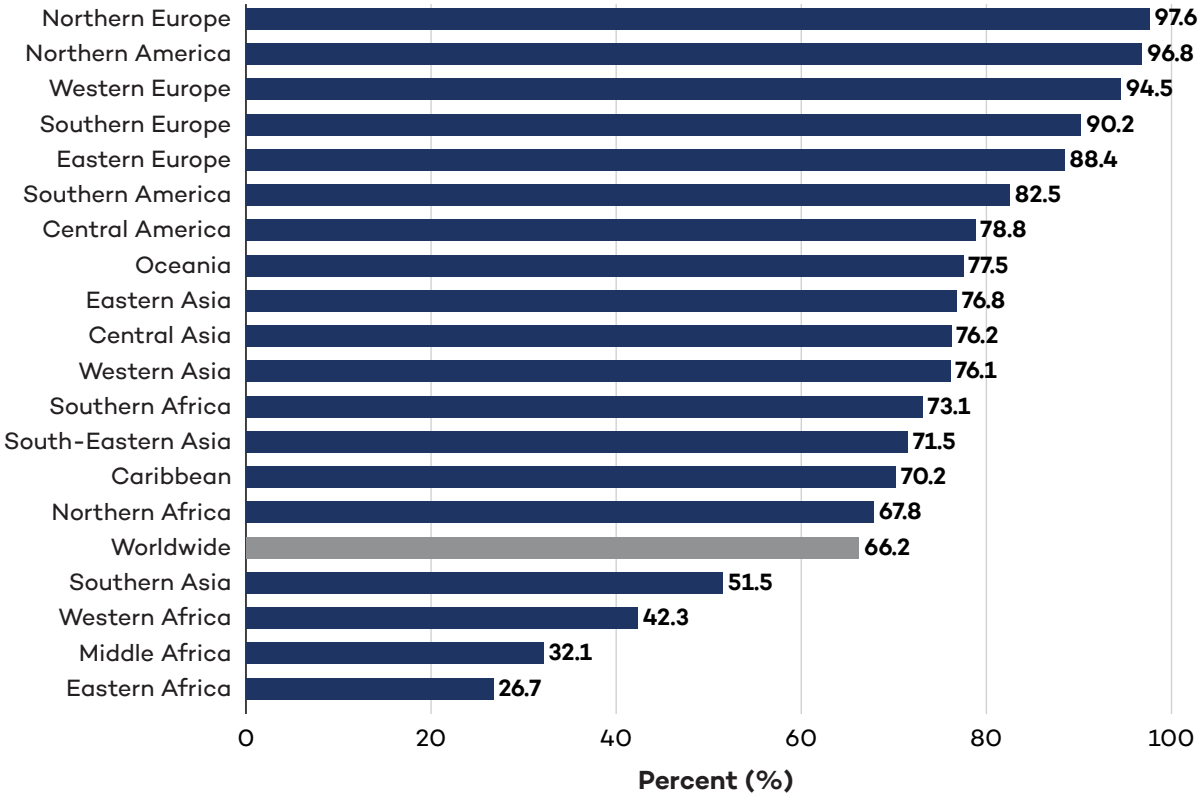
These changes in the work culture—coupled with the advancement of mobile technology and the continuing development of digital infrastructure and communication networks—have directly impacted internet penetration on a global scale (IGF, 2019). Data show that in 2023, the number of internet users was estimated at 5.3 billion, equivalent to a global penetration rate of 64% (Statista, 2024). As indicated in Figure 2, the regions with the highest internet user rates were Northern Europe, with over 97% of its population using the Internet followed by North America, with an internet penetration rate of 96.8%. Regions with the lowest access were all in Africa, with Eastern Africa closing the march with an internet penetration rate of only 26.7% (Statista, 2024).

Indicative of this, broadband services are still prohibitively expensive for most Africans, which explains the ongoing gap in digital services and connectivity across the continent. As of 2024, only 40% of Africans had access to the Internet (Africa Finance Corporation, 2024).

Addressing this affordability gap is crucial to driving economic growth and productivity on the continent, as the digital gap is leaving hundreds of millions of people priced out of the digital economy. Investment is much needed across all segments of digital infrastructure—from initial network connections to middle-mile fibre and last-mile delivery—each of which presents unique challenges and opportunities (Africa Finance Corporation, 2024).

Looking ahead, the trend of expanding internet access is likely, in particular as less-developed regions become more connected and as budget smartphones become more widely available (Statista, 2024). As industries transform business processes from analog to digital systems and citizens embrace online services, worldwide digital transformation spending is projected to reach USD 3.9 trillion by 2027 (Sherif, 2024).

FIGURE 2. Global Internet penetration by region, Jan. 2024



Source: Petrosyan, 2024; Statista, 2024.

In terms of the number of individuals not using the Internet by region, as of January 2024, close to 1 billion individuals in Southern Asia did not use the Internet. Eastern Asia ranked second, with nearly 390 million people, and Eastern Africa ranked third, with 360 million people being unconnected to the Internet (Petrosyan, 2024).

While regional infrastructure remains an important factor in broadband versus mobile coverage, the rollout of 5G across the globe, spearheaded by tech leaders China and the United States, is forecasted to reach more than 4 billion subscriptions by 2026. It is also important to note that a very high percentage of mobile internet users (more than 92%) are also active social media consumers. Globally, the highest penetration is in developed

countries in Europe and North America, while in Africa and southern Asia, there is still room for growth (Bianchi, 2024).

According to the International Telecommunications Union's (ITU's) *Global Connectivity Report 2022*, there are still significant differences between and within countries in terms of network quality and availability. Bridging the coverage gap requires a considerable increase in investment in digital infrastructure and reliable connectivity. At the same time, it is important to ensure that greater digitalization does not widen inequalities in terms of access to digital services and the job market due to digital illiteracy. Occupations may require higher skill levels and displace low- and medium-skilled workers without appropriate training and skill building.

Changes take time to be seen at a large scale. In advanced economies, there is little evidence of a structural shift in labour composition toward digital occupations. The more persistent change, with likely implications for the labour market, is the post-pandemic work-from-home revolution. Prior to the pandemic, it was estimated that only 5% of workers in Europe worked from home, but by 2021, that number had increased to 16% (Jaumotte et al., 2023).

Finally, it is important to underscore that as the use of the Internet increases, so do the risks and exposure to the downsides of connectivity, such as privacy infringements, cybercrime, harmful content, and the outsized power of large corporations. Addressing these issues is part of the journey toward universal and meaningful connectivity, which requires analog complements, including governance, security, health, education, transport infrastructure, and entrepreneurship (ITU, 2022).

3.0 Digital Adoption in the Mining Industry

Mining operations require significant capital investments. While technological innovations are not new to mining, their benefits at mine sites are now proven to improve the efficiency and safety of operations and workers (Ramdoo, 2019). The digital revolution is expected to make mines “smarter” and more “agile,” although, as seen in Figure 3, mines have different characteristics and, therefore, require specific and tailor-made solutions designed and adopted in a flexible and pragmatic way.

In recent years, mining companies have invested a higher share of capital investment in digital technologies, not only to improve the productivity of operations but also to automate tasks and embed advanced analytics and real-time data and integrate platforms in the workplace and at mine sites to optimize mining operations and streamline processes, to reduce costs and improve decision making (Onifade et al., 2023).

In 2023, the global market value of technological investments in mining was estimated to be USD 34 billion (Statista, 2023). It is estimated that by 2025, 50% of companies are expected to adopt technologies to connect workers, while 30% are expected to invest in remote operation centres. Investments in advanced analytics, autonomous operations, and 3D printing are projected to be adopted by a quarter of mining companies on average (Garside, 2024).

As in other sectors, increasing reliance on digital and connected technologies has its own challenges. Companies are exposed to threats, such as hacking, that have led to a need for both country- and company-level policies that protect digital and data infrastructure as well as personal information privacy for end users. By 2025, it is projected that 75% of the global mining industry will have adopted asset cyber security technology (Garside, 2024).

FIGURE 3. Applying a digital approach to a mining operation

Deeper orebodies, complex infrastructure

Rising stripping ratios, complexity of infrastructure and capital costs

- Unit operation simulation
- Augmented exploration target generation
- Real-time orebody monitoring
- Engineering design on cloud

Remoteness of deposits

Increase in costs of fly-ins/fly-outs, establishing infrastructure, constrained supply chains

- Asset visibility
- Collaborative decision environment
- Condition-based monitoring
- Asset productivity analytics
- Asset intelligence network

Generation X, Y, Z

Innovative workplace to the entire range of roles—geologists, operators, supervisors, managers

- Mobility-enabled mining
- Drone-enabled mining operations
- Worker collaboration
- Mining bots

Health & safety

Proactive approach to safety, replace hazardous manual operations by automation

- Worker safety through wearables
- Predictive safety analytics
- Video analytics for safety & security

Decline in productivity & price volatility

Rising input costs with increased volatility of commodity prices

- Digital short interval control
- Optimized delivery planning
- Energy analysis and optimization
- Mine value chain analytics
- Predictive maintenance

Community

Engage with the community to move the needle of perception and gain the social licence to operate

- Social sentiment analytics
- Predicting environmental events

Source: Wipro, 2024.

3.1 The Importance of Skills

One key issue in the adoption of technologies is the availability of skilled workers to operate the technologies. Some mining companies face challenges in recruiting sufficiently skilled workers and are concerned about retaining their talent pipelines. As observed in several

studies (see IGF, 2023; WEF, 2023), technology adoption will remain the key driver of business transformation over the next 5 years, with significant implications for occupations in the mining industry as well as skills required to perform these jobs. As shown in Figure 4, it is estimated that the fastest-growing and declining jobs are all related to digitalization (WEF, 2023). The former relate to new occupations that will be required to operate new technologies, while the latter are likely to be replaced or restructured because of the adoption of digital technologies. Most of these jobs are relevant to the mining sector, where jobs will change to reflect the digitalization of operations.

The trends in Figure 4 were confirmed in the findings of the 2023 IGF flagship report, *Women and the Mine of the Future* (IGF, 2023). The report was based on an in-depth analysis of 12 countries from different geographies and with different levels of development. It found that sophisticated technologies, such as digital technologies, often require highly specialized skills, many of which are not yet present in developing countries.

FIGURE 4. Fastest growing vs. fastest declining jobs (anticipated between 2023 and 2027)

**Note: The jobs that survey respondents expect to grow most quickly from 2023 to 2027 as a fraction of present employment figures.*

Source: Adapted from WEF, 2023.

For women, who already face a significant skills deficit in science, technology, engineering, and mathematics (the STEM fields), this challenge is even more pronounced. Data from Ghana illustrates this issue well: in 2017, only 16% of women working in the mining and quarrying

sector had basic, intermediate, or advanced education compared to 84% of men. Additionally, in 2020, about 92% of the labour force in large-scale mines within the Ghana Chamber of Mines membership was skilled, but women accounted for only 10%, with the majority of skilled female workers being non-Ghanaians (Weldegiorgis, 2022).

While technologies themselves are gender neutral, mining operations and the social contexts in which new technologies are introduced are not. It is important to recognize that the pace and breadth of technological adoption in large-scale mining will vary within and across countries, with significant ripple effects on mining occupations. Often, the necessary skills and talent cannot be found at the national level and, therefore, need to be sought abroad. Even when sourced nationally, local communities may not have the requisite skills, further complicating recruitment and retention efforts. Therefore, addressing these challenges requires a focus on gender equity, social inclusion and local talent development (IGF, 2023).

3.2 The Importance of Data Protection and Cyber Security

Mining digital infrastructure and connectivity can be a key enabler of economic transformation, particularly in remote regions that are less connected. However, without providing assurance to mining companies and local communities about data protection and privacy, there is most likely to be a reluctance for the former to share connectivity and for the latter to use the digital and network facilities that can be provided.

Strong data protection regulatory frameworks and safeguards are crucial to protect companies' data as well as personal data. They are necessary to protect sensitive and confidential information from unauthorized access, use, disclosure, change, and destruction (Kolbach, 2023).

At the global level, countries are not at the same level of protection and regulation, although 71% of countries have legislation in place. According to UN Trade and Development, about 20% of countries still do not have legislation in place to protect data (or have not disclosed it) (UN Trade and Development, 2024).

Among those that have legal frameworks in place, many have quite general legislation that does not provide sufficient levels of protection to industries (including mining companies) and to local users. Weak regulatory systems cannot properly address data breaches and privacy, which can have far-reaching implications for companies and users alike. For companies, data breaches can have financial implications and can compromise business activities. They can lead to legal actions, impacting companies' reputations. For users, a breach of data can erode trust and damage the reputation of mining companies and can have significant impacts if personal data is stolen or hacked (Kolbach, 2023).

Together with data protection, ensuring cybersecurity is a critical complementary issue that must be regulated and monitored. Cybersecurity involves implementing measures to safeguard networks, systems, and programs from digital attacks, which can range from identity theft to sabotaging critical infrastructure like port operations. It is aimed at preserving the confidentiality and integrity of personal data, securing communication, and protecting digital infrastructure from hackers, data breaches, and other malicious activities. By working together, cybersecurity measures and data protection protocols help maintain the integrity and security of vital systems (Trava Security, n.d.; Tuffley, 2023).

Besides cybersecurity and data protection, digital infrastructure is vulnerable to risks of unforeseen digital disruptions, particularly when these are due to external circumstances. For instance, in March 2024, an internet outage hit a dozen African countries following the breakages of four undersea telecommunications cables. Although some countries were able to reroute traffic as there were agreements in place with service providers, others had only one fibre-optic cable coming to the country. Internet traffic to and from these countries basically stopped when the cable was broken (Auerbach Jahajeeah, 2024).

3.3 Expanding Socio-economic Benefits Beyond the Mining Sector

Digital infrastructure and connectivity can provide opportunities for horizontal linkages[2] beyond the mine gate. These can create wider socio-economic benefits using the skills, capabilities, and infrastructure investment initially intended for the mining sector but with spillovers to other sectors, such as energy, agriculture, ICT, manufacturing, etc. To trigger these linkages, governments must have specific policy mechanisms in place, supported by a conducive regulatory framework, and agreements need to be made with the mining sector to synchronize and coordinate efforts.

BOX 1. SENEGAL: DIGITAL STRATEGY IN SUPPORT OF ECONOMIC ACTIVITIES

A national approach to ICT policy has been adopted through the government's development of a Digital Strategy for 2025 (ITU, n.d.)[3]. The Ministry of Communication, Telecommunications and Digital Economy has developed capacity and administrates a centralized data centre for all sectors of the economy, which includes the Mining Ministry as a stakeholder. This centre provides affordable digital services and ensures national coverage with optical fibre and high-end data connectivity to promote services. Increasing numbers of service providers and end users are taking up the opportunity to have unlimited access at very affordable costs, which also extends to mining areas. This connectivity benefits people in remote areas as they now have access to current information and links to the outside world (Deutsche Gesellschaft für Internationale Zusammenarbeit, 2021). For example, the ability to view currency exchange rates, interest rates and prices in various markets has had an economic benefit in helping people grow their access to markets, increase revenue and diversify income streams.

[2] There are two types of horizontal linkages: capabilities-led and infrastructure-led. The latter happen when infrastructure that would have been developed for the mining sector (e.g., roads, rail, ports, water services, electricity, and Internet) benefits other sectors as well. The former happens when the technology or skills developed in the mining sector become the basis for economic activity in non-mining sectors (IGF, 2018).

[3] The Digital Senegal 2025 strategy is linked to the Emergent Senegal Plan (PSE): "Senegal in 2025: digital for all and for use in everything, with a dynamic and innovative private sector within an efficient ecosystem. The aim of the strategy is to breathe new life into the economy by providing stakeholders with new growth drivers and sources, by raising the contribution of digital technologies to GDP by 10%, and by creating 35,000 direct jobs by 2025" (ITU, n.d.).

4.0 Integrating Digital Infrastructure and Connectivity in Policy-making

This section looks at key considerations regarding leveraging the mining sector's digital and data infrastructure and connectivity for wider socio-economic benefits. It focuses on the importance of understanding the local context to meet the needs of local communities and on the gaps that must be filled to ensure the efficient use of technologies.

4.1 Considering the Geographic Context

A country's specific geographic advantages or constraints—mountainous regions, coastal zones, open deserts, wetlands, deltas, or rivers—determine what types of digital infrastructures are economically viable to install and deploy. Climate conditions also matter. Many resource-rich developing countries are in geographical areas that experience much higher average daytime temperatures than countries in the northern hemisphere. This has practical implications for infrastructure, such as data server centres, whose hardware requires constant cooling: it is thus highly energy intensive and, therefore, requires a reliable and affordable energy supply. In these instances, it is important to consider digital infrastructure together with energy sources and storage systems[4] when existing national power infrastructure may be insufficient or unreliable.

Similarly, mountainous regions may experience problems where signal may be obstructed or unable to reach into valleys. Lowland deltas or seasonal flooding areas can present equally challenging and expensive problems for installing stable network communication towers for mobile connectivity.

[4] Many mining companies are investing in renewable energy to green mining operations. They need to have battery energy storage systems to ensure constant supply. There is, therefore, an opportunity to provide access to energy to remote communities. Some battery energy storage systems can be containerized, are transportable, and relatively easy to install (van Diemen, 2023). A forthcoming IGF publication will discuss these possibilities in more detail.

BOX 2. BRAZIL AND AFRICA

In the Amazonia region in **Brazil**, nine states are largely covered by dense rainforests that have many rivers and deltas, which are subject to annual flooding. Internet access is not easily available, so the main form of communication relies on a land-based array of four large radios (Radial Amador), which is widespread and well used. Indigenous populations living near mining projects encounter many communications challenges. Some populations living in the deltas and along rivers are seasonal migrants, and it is difficult to implement policies or regulations that support them. Interviews conducted for this paper recorded that a program of work was underway through the Ministry of Communications to improve engagement between the mining industry and Indigenous communities to provide access to more reliable communications through the companies' networks.

Africa's dependence on subsea cables for internet access has exposed vulnerabilities in its digital infrastructure. Recent damage to these cables in 2023 and 2024 has highlighted the urgent need for investment in backup solutions, such as terrestrial fibre and regionally integrated networks, to enhance the continent's connectivity resilience (Africa Finance Corporation, 2024).

4.2 Assessing the State of Digital Infrastructure

It is necessary to assess the state and condition of existing digital infrastructures and connectivity networks (or lack thereof) to identify the gaps and related investment needs. While the responsibility for providing digital infrastructure and network services lies with the government, these are often absent for logistical and cost reasons in many remote locations where large-scale mining projects operate.

There is a lack of public investment in digital and data infrastructures in some countries because other public services, such as basic infrastructure, energy, or transportation, are prioritized. In those cases, private sector communications networks, including those installed by mining companies to meet their operational requirements, have often filled the market gap and are more commonly relied upon.

One way to address these challenges is to consider existing digital infrastructure solutions that allow access to LEO satellite constellations,[5] which can provide broadband connectivity to underserved, remote, and/or geographically challenging areas (Gur & Kulesza, 2024). Many companies in the mining industry have used satellite technologies for geographic information systems and communications purposes for several decades. Similarly, other types of technologies, such as Unstructured Supplementary Service Data (USSD) messaging[6] systems have been used by many mining operations for over a decade, including beyond mine sites.

[5] This technology has made modern GPS navigation possible and helped increase the global movement of goods. It is only in the last decade that exponential advances in the delivery capabilities and the scale of coverage of LEOs that this form of digital infrastructure has become a potentially affordable option for individuals and/or remote communities.

[6] USSD is a mobile communications protocol used to send text messages. USSD, like the Short Message Service, use codes made up of the characters that are available on a mobile phone, so a smartphone device is not a requirement to receive communications. Push notifications are messages that can be sent directly to a user's mobile device at any time and can appear on a lock screen or in the top section of a mobile device.

They enable management to communicate with workers regarding shift schedules, to send safety messages, to share production quotas, conduct polls and surveys, etc.

In Africa, for instance, the rollout of broadband infrastructure has faced numerous challenges, primarily due to the high costs of implementation. This has particularly affected last-mile connectivity, which is often missing in smaller towns and rural areas. As a result, there is a growing disparity between urban centres, where digital access is better, and more remote areas that are being left behind (Africa Finance Corporation, 2024). To bridge this gap, alternative solutions, such as satellite services, could provide crucial connectivity to geographically challenging areas, ensuring broader access (Africa Finance Corporation, 2024).

BOX 3. ECUADOR AND LESOTHO

Ecuador: The Ministry of Energy and Mines is trying to address the provision of digital infrastructure by implementing policies such as the use of royalties from mining operations to provide basic infrastructure that would allow access to connectivity. While these initiatives are reported to be quite recent, the ministry is being proactive in collaborating with the private sector to try and reduce the access gap for communities near mining operations in remote areas where connectivity is very limited.

Lesotho: Mining companies operating in this mountainous kingdom require robust digital and ICT infrastructures due to their extremely remote locations. In fact, Lesotho was one of the first countries in Africa to deploy 5G technology (Reuters, 2018). Communities living near mines, however, do not have access to the more sophisticated networks deployed by the mines, but only to local 3G and 4G connectivity. However, even if high-speed networks were shared and data made available, the very low literacy rates and insufficient access to the latest devices would prevent a large part of mining communities from benefiting from the spillovers.

Source: Interviews conducted for this study.

4.3 Bridging the Missing Links

Globally, it is now widely recognized that digital infrastructures and connectivity have a profound and far-reaching impact as a catalyst and enabler for sustainable development and for countries to reach their targets under the United Nations Sustainable Development Goals (see, for example, Mondejar et al., 2021; Vinuesa et al., 2020). Depriving citizens of the possibilities offered by the Internet is ultimately costly, as it stunts economic development and deepens inequalities.

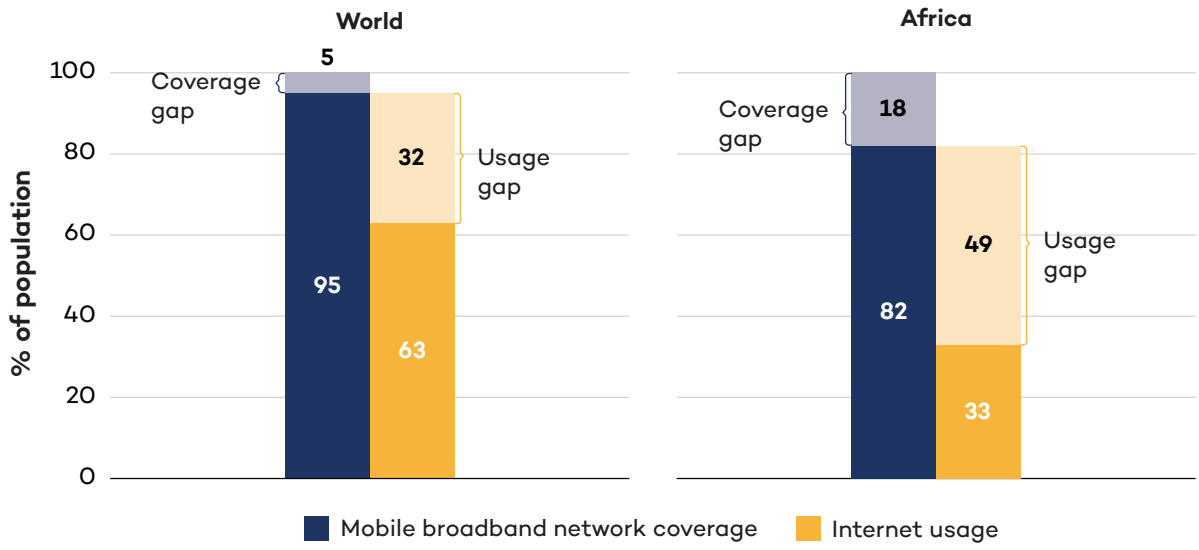
Although the COVID-19 pandemic accelerated the adoption of digital technologies, persistent gaps remain across countries and sectors. There is a digitalization gap across and within countries, which indicates that there are clear missing links in the policy space that need to be filled to ensure that gains from the technological revolution are broadly and equitably shared. Two issues need to be addressed. First, it is important to have a good understanding of the root causes of the digital divide. Secondly, it is necessary to be aware of in-country challenges, such as disparities between rural and urban areas. Finally, some perceptions about the use of digital technologies by communities create barriers to deployment.

4.3.1 Understanding the Digital Divide

At present, these missing links have ripple effects and create multiple digital divides, affecting settlements, countries, genders, and generations differently (ITU, 2022). Four priorities emerged in the last decade to address these challenges.

First, there is a need to bridge the **coverage gap**. Figure 5 reveals that, although 95% of the world population is said to be within range of a mobile broadband network, at least 390 million people still have no access to the Internet (ITU, 2022). When taken at the regional level, the coverage gap in Africa is 18%.

FIGURE 5. Bridging the coverage and usage gaps, 2021



Source: International Telecommunications Union, 2022.

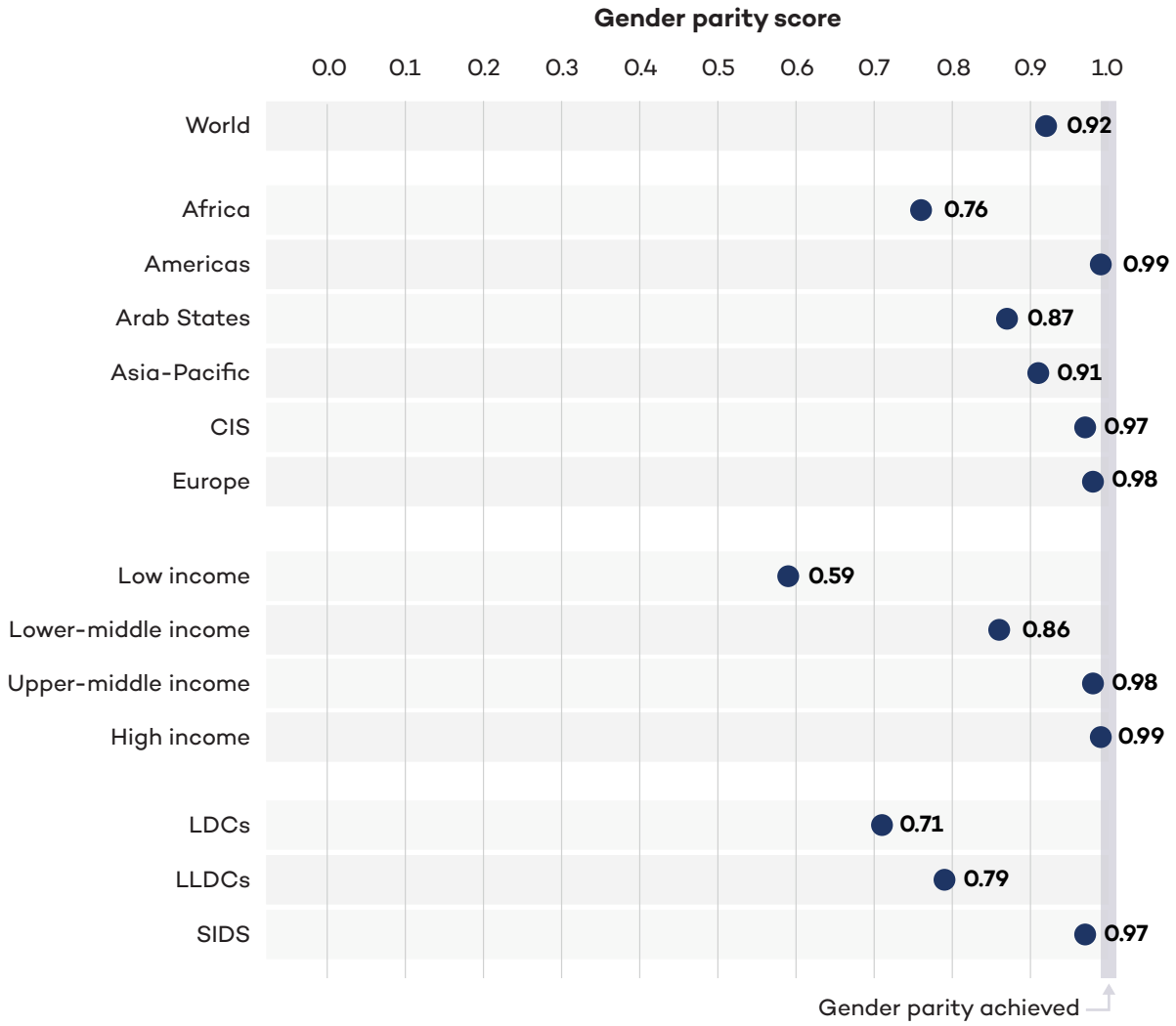
Second, it is crucial to close the **usage gap**: According to the ITU, a third of the world's people do not use the Internet (although they could do so). Possible reasons include affordability, i.e., prohibitive costs, lack of access to a device, and/or lack of awareness, or skills to use the Internet. Disparities across countries are also significant with regard to ownership of mobile devices. By income level, the share of mobile owners was 95% in developed countries as opposed to only 57% in least developed countries (ITU, 2022).

Indicative of this, in many parts of Africa, broadband affordability remains a significant barrier to widespread digital connectivity. Fixed broadband services are often priced far above global affordability benchmarks, accounting for approximately 14.8% of gross national income per capita, while the global target set by the Broadband Commission is just 2% (Africa Finance Corporation, 2024). This cost disparity limits digital access, especially in rural and remote regions, where infrastructure is either underdeveloped or completely absent.

Third, it is critical to tackle the **gender digital divide**. It is estimated that 200 million fewer women than men own a mobile phone, and only 6% of women develop apps (GSMA, 2015). Women also generally have a lower chance of making use of digital infrastructures and connectivity because the opportunity is skewed toward male participation. In 2023, it was estimated that 244 million more men than women were using the Internet (ITU, 2023).

Figure 6 reflects the gender digital divide and shows that the Africa region continues to lag other regions by a sizable margin, where roughly 4 in 10 men and 3 in 10 women use the Internet.

FIGURE 6. Internet use gender parity score (2023)



Note: "The gender parity score is calculated as the proportion of women who use the Internet divided by the proportion of men. A score of less than one indicates that men are more likely to use the Internet than women, while a score greater than one indicates the opposite. Gender parity is considered to be achieved when the score lies between 0.98 and 1.02" (ITU, 2023).

Source: ITU, 2023.

The gender digital divide widens in developing and less-developed countries. Research by the World Wide Web Foundation (2015) found that across urban poor areas in 10 cities, including Lagos, Nairobi, Jakarta, and Bogotá, women are 50% less likely than men to be online and 30%–50% less likely than men in the same communities to use the Internet for economic and political empowerment.

Fourth, it is imperative to achieve **universal and meaningful connectivity** by upgrading the quality of connectivity services to allow everyone to have affordable, secure, and sustainable access.

Addressing these issues requires, at a minimum, a dedicated focus on training regarding the use of basic digital tools and the Internet. Basic digital illiteracy can severely impact local employability by putting a local workforce out of the job market or limiting their ability to even apply for jobs, including those offered by the mining sector.

One of the key challenges, particularly in developing countries, is that digital skills are not well taught in schools (if they are taught at all). When they are, curricula are not always well adapted to meet the demands of the digital economy (International Labour Organization, 2021). More concerning is that secondary and tertiary enrolment rates in the STEM fields that are foundational to the digital economy are too low in developing countries. It is estimated that fewer than 25% of students in higher education in Africa take STEM subjects. This contrasts sharply with the United States, where STEM degrees represent more than 30% at the bachelor's and master's levels, over 50% of research doctorates, and close to 65% of post-doctorate degrees (Office of the Special Advisor on Africa, 2022).

In the mining sector (but not exclusively), these skills are crucial as they are needed throughout an entire career and are decisive for the future upskilling and reskilling of the workforce. In countries like Australia, the task of upskilling is facilitated by the relatively high levels of digital skills among the active population—65.5%. Similarly, Canada records high scores, providing more opportunities for women to transition to digitalized occupations (IGF, 2023).

In lower-income countries, the **digital gender divide** is more pronounced, and access to digital infrastructure is more challenging. Women in local communities may face greater obstacles in being trained and upskilled to perform emerging tasks. Digital skills are essential in this process, yet many women lack access to the necessary training and resources (IGF, 2023).

Addressing this challenge is, therefore, crucial for local workers, and in particular for women, as this is a major challenge in countries with low levels of education and with particularly stark differences between rural and urban areas. Concurrently, it is vital to promote policies that maintain healthy competition in digital markets, adapt labour laws and regulations to facilitate remote work, ensure inclusive access to digital education and infrastructure, and build a more resilient and adaptable economy that is better prepared to navigate future crises (Jaumotte et al., 2023).

4.3.2 Understanding the Challenge of Remoteness

Globally, the number of users that can connect to mobile networks continues to grow, with internet penetration in the most advanced countries already near 100% (ITU, 2022). Access to the Internet through mobile phones has fundamentally transformed how people go online and what the Internet can be used for. However, as mentioned in the previous section, access is neither equitable nor universal, and wide disparities exist across countries due to geography, capacity to use the Internet, or cost factors.

Connectivity, sometimes via simple apps, is a powerful enabler of socio-economic development in remote locations and for isolated communities. It can facilitate and accelerate access to many facilities such as health care and education/skills development;

trade, business development, and access to markets; banking and access to finance; and diaspora remittances. It can also be instrumental in saving lives in the event of severe weather conditions, allowing the sending of climate disaster warnings in real time (World Meteorological Organization, 2022) and provide security and other safety alerts (FasterCapital, 2024) for communities and vulnerable people. These can be profoundly transformative for the lives of rural families. This has proved to be the case since simple money apps have enabled workers to send remittances to rural villages in developing countries (Aranda-Jan and Qasim, 2023; International Fund for Agricultural Development, 2024), particularly during the COVID-19 pandemic.

Despite recent advances, the high cost of broadband services continues to exclude millions of Africans from the digital economy. With only 40% of the population having internet access, there is a clear digital divide that must be addressed through targeted investments in infrastructure, especially in underserved and remote regions. Expanding last-mile connectivity while improving affordability remains a critical challenge (Africa Finance Corporation, 2024).

4.3.3 Breaking Down Perceptions

While the benefits of digital technologies are widely acknowledged, paradoxically, there is also a perception that if internet access was provided free to communities, it would be used to surf social media and for entertainment, streaming sites, and online activities, therefore increasing social ills rather than providing socio-economic benefits.[7] To counter this risk, there is a need to accompany the digital transition with proper educational campaigns about the risks associated with misinformation and social media, such as "deep fakes" (WEF, 2024).

However, several mining companies that rolled out programs to provide free wi-fi and data bundles to communities confirmed the benefits communities derive from connectivity. During interviews conducted for this report, one mining company followed trends on dashboards on how free wi-fi access and the data bundles supplied to a host community were being used. The results revealed that community members were searching for opportunities such as employment and free online education and training courses. The time spent looking for work or training opportunities, as a result, was higher than was spent for entertainment purposes, pointing to the fact that access to the Internet and to data bundles can open opportunities and improve social and economic conditions.

Another mining company in South Africa's coal region of Mpumalanga had a similar experience: free wi-fi hotspots were installed in places where communities normally gather, such as town halls, taxi ranks, and spaza shops. While users had to log in via the company's platform to access the free service, their details were anonymized, and the mining company could not receive or view any personal information. However, they could track what people searched for using Google Analytics (IGF, 2024). The top three ranking searches were for online education, job vacancies, and bursaries, which again revealed that there were enormous benefits to local communities having access to digital infrastructures and data connectivity.

In the Democratic Republic of the Congo (DRC), a Pan-African network provider partnered with a bank and mining company to extend digital infrastructure and internet connectivity to host communities around a copper mine. This initiative has been successful, with local communities using the improved access to education, financial transactions, and more.

[7] This was gathered from interviews conducted for the report.

Access to innovative financial transaction apps, such as MPESA and Mukuru, has enabled mine workers to send remittances to their families, especially migrant workers employed in other countries. These have had tremendously transformative impacts on the livelihoods of their families and on the local economy (IGF, 2024).

Access to digital technologies and connectivity creates more benefits than risks, and it is important to avoid unfounded assumptions about what mining communities would do or not when provided with free access to connectivity and data bundles.

5.0 Critical Success Factors and Challenges to Be Addressed

5.1 Unlocking Business Opportunities

Fast communication and real-time access to suppliers have helped companies reorganize their supply chains and inventories. While technologies have been beneficial for the productivity of mining companies, including through easier access to international procurement markets, this has often been done at the expense of local suppliers, who must compete directly with global producers on costs and delivery time.

BOX 4. SENEGAL

In **Senegal**, the local content policy requires mining companies to share their procurement plans on publicly accessible online platforms, which is facilitated by the national connectivity strategy. These platforms have enabled suppliers from local communities to access information on market opportunities, what services or suppliers are needed by mining companies, and information regarding a mine company's social plans.

This access to information has opened avenues for local businesses. It also enabled them to build supply chain relationships with mining companies, which are important for growing their business over time. An additional benefit of sub-contracting platforms is access to information from multiple companies, which helps communities select and/or negotiate better deals with companies.

As in the case of Senegal, most resource-rich developing countries have local content policies that favour local suppliers (IGF, 2021). Internet access and the ability to use digital platforms are, therefore, indispensable enablers in connecting local businesses to procurement markets to avoid marginalization.

5.2 Providing Access to Devices and Digital Equipment

While access to digital infrastructures and connectivity can be leveraged together to strengthen community resilience, there is little utility in mining companies sharing infrastructure or providing access to technologies or the Internet if communities do not have the equipment or devices to make use of it.

BOX 5. SOUTH AFRICA

The importance of digital accessibility for communities was highlighted in a project conducted by the Wits Mining Institute for the Mandela Mining Precinct on digital literacy (Mandela Mining Precinct et al., 2021). The research revealed that access to devices was also a key issue, not only data connectivity. Many people and households use a smartphone that is often shared within a family. However, there are limits as to what can practically be done on a smartphone, so one of the research recommendations was that in addition to data connectivity, access should be provided to devices with more capability and larger screens, such as tablets and laptops.

Low-cost devices, such as laptops and tablets, are widely available. Governments should make it a priority to enable access to equipment to help bridge the digital divide. For example, schools could be equipped with computer labs, and students and parents could benefit from digital equipment for working at home. Similarly, loans on very favourable terms could be provided to small businesses to enable them to improve their productivity through digital technologies.

Partnerships between mining companies and public authorities could accelerate mining communities' access to digital technologies and connectivity. Where the companies can share their digital infrastructures and/or connectivity, governments can provide related services, such as cheap data bundles, telecommunication services, and training to enable communities to use what mining companies are able to provide.

5.3 Ensuring Sustainability Over Time

As mentioned, many mining companies are investing heavily in digital technologies. These can only function efficiently if high-speed and uninterrupted wi-fi networks are available. Only a few companies share their infrastructure and networks with local communities, in part because it is difficult to sustain programs over time when there are downturns in the commodity price cycle or if there are budgetary constraints, as was the case during the COVID-19 lockdown periods when communities needed connectivity the most. In South Africa, a mining company in the platinum belt that was piloting a local data connectivity program stopped making digital access available during the lockdowns because it became too expensive and unsustainable to provide internet access to roughly 180,000 people in their surrounding communities.

An important factor of sustainability over time is scale. In the DRC, a critical success factor of the Umoja project was the healthy allocation of data given to each smartphone (approximately 8.5 gigabytes per employee per month), which then became central in the

homes of the mineworkers in town. This enabled the network provider to address the issue of sustainability because, with 10,000 individual "lines" in the town, the network was able to justify investing significantly in infrastructure enhancements in the community, not only on the mine site. Consideration is now being given to establishing hotspots in the mine's surrounding towns.

5.4 Empowering Communities Through Early (Digital) Consultation

Building community resilience must be grounded in participatory actions that start in the early stages of mining project development. Communities must be consulted throughout the permitting process, including while conducting environmental and social impact assessments. This is essential for the success of any project; otherwise, there are risks of conflicts during project execution.

While governments have a role to play in setting goals for local socio-economic development, more recognition needs to be given to the role of communities in determining their needs from the outset. This is valid for plans around access to digital infrastructures and data connectivity.

Effective community consultation processes are challenging in remote areas. They are often limited to small groups of people that are not always truly representative of all communities living around mining projects. This can be a cause of contention or conflict during the life cycle of the mine.

In most instances, people cannot afford to participate in consultations without some form of financial support, such as daily allowances, travel sponsorships, and rental of meeting rooms. Their participation in consultations often takes them away from their daily work, for which they may not be paid when they are asked to take time off to participate in consultations.

BOX 6. EXAMPLE OF A DIGITAL ENGAGEMENT PLATFORM IN PERU

In partnership with SENACE, the Canadian International Resources and Development Institute, Simon Fraser University's Co-Lab Peru project, and the Centre for Analysis and Conflict Resolution at Pontificia Universidad Catolica of Peru, Ulula deployed its digital engagement platform in the copper mining region of Junin, Peru. This initiative was co-designed with input from both leading and community stakeholders, utilizing interactive voice response and Short Message Service technology to cater to a low-literacy and low-connectivity area.

The program included tools such as messages in local languages to raise awareness about human rights among community members in mining areas, a two-way support line for grievance recourse, and a news broadcast related to mining developments. Impressively, over 40% of participants in the pilot were women, who received messages about their rights as mining stakeholders and had access to a two-way communication channel to voice their concerns.

Source: IGF, 2024.

With the advent of digital technologies, representativity in consultation processes can be improved. For instance, the availability of inexpensive smartphones can make consultations faster, more cost-effective, and more inclusive, as they can reach a wider audience without additional costs. Communities would feel more actively engaged and could share their wealth of wisdom and local knowledge, including jointly developing plans around the deployment of digital infrastructures and connectivity.

5.5 Digital Technologies in Support of Gender Equality

The deployment of digital infrastructures and data connectivity should be viewed as a vector to improve gender equality and with regard to the roles that women play (both domestically and economically) to foster inclusive economic growth. As the mining sector transforms and increasingly adopts digital processes, many occupations become more accessible to women in mining operations (see IGF, 2023). Online access to information about goods and services needed by mining companies can open up new business opportunities for local suppliers, including for women.

BOX 7. SOUTH AFRICA: LEVERAGING TECHNOLOGY FOR GENDER EQUALITY AND COMMUNITY RESILIENCE

Ivanhoe Mines, through its subsidiary Ivanplats, is developing the Platreef platinum group metals mine in Mokopane, South Africa. The company has implemented several initiatives to leverage digital technologies and promote community resilience. Launched in 2017, the Maru a Mokopane project provides the host communities with free access to wi-fi at 20 hotspots around the mine. Wi-fi use is capped at a cutoff point for each user. Maru a Mokopane has 30,400 registered users, of whom approximately 42% are female. During the rollout of the project, the mine employed 40 young people from host communities on a contract basis to provide digital literacy training to potential users. Community members use the platform to communicate with the mine, view job and procurement opportunities, and raise concerns (IGF, 2024).

6.0 Policy Recommendations to Enhance the Sharing of Digital Technologies

Unlike other types of infrastructure, digital infrastructures and connectivity have a more complex ecosystem that goes beyond the mine gate and sometimes even beyond national borders. They require

- physical infrastructure to connect technologies to digital services and process information, transmit data and information to and from service providers, and store large amounts of data on servers;
- information infrastructures, such as cloud resources and services, virtual platforms, business applications, and data repositories;
- analytical infrastructures, tools and applications, such as big data, AI, and machine learning;
- appropriate regulatory frameworks that protect data, users, and intellectual property, and prevent cybercrimes and piracy. This is the precondition for any investments in data and digital infrastructure.

It thus requires a whole-of-government approach, a coordinated approach with multiple sectors, and solid partnerships across a range of stakeholders beyond the mining sector and beyond national borders.

This section focuses on what governments can do and how they can work with the mining industry to leverage the latter's investments in digital infrastructures and connectivity to support community resilience.

6.1 Scaling Up Local Initiatives: The importance of policy coherence with national policies

6.1.1 National and Regional Development Plans

Mining companies are deploying digital infrastructure to bolster the safety and efficiency of their operations and are enhancing connectivity to enable mining operations to utilize

integrated technologies. Although it is not yet common practice, some companies have begun to share digital infrastructure and connectivity with their local communities to bridge a gap left by the absence (or poor condition) of existing public infrastructure. Those initiatives can be transformational.

If mining companies decide to support community resilience through the sharing of their infrastructure and networks, it is important to **align investment and sharing plans with national and regional development planning**, when they exist. This can allow for the co-design, co-financing, and co-management, and long-term sustainability of costly infrastructure. In the absence of existing national and regional plans, engagement with local and national authorities in the early stages of community development projects can be instrumental in getting the government involved in digital infrastructures in remote regions.

Investments in digital technologies are expensive. Coordination with national planning agencies and finance ministries can help both governments and mining companies **sequence and mutualize efforts and reduce costs**.

As mentioned, the use of digital infrastructure requires addressing digital illiteracy and providing training to the local population.

A coordinated approach is necessary to address the skills gaps and can inform the government's educational policies and skills anticipation plans accordingly.

Furthermore, planning is important to build synergies across different types of infrastructures. For example, where possible, policy-makers should consider **opportunities to simultaneously leverage the deployment of renewable energy and digital infrastructures to address the dual challenges of energy and connectivity needs**. This can leapfrog traditional infrastructure installation, reduce implementation costs considerably, and accelerate delivery timeframes. This combined approach may be an attractive investment proposition for international partners as well as for public and private partnerships.

BOX 8. AN EXAMPLE FROM COLOMBIA

During interviews conducted in 2023 for this report, it was mentioned that a National Development Plan was being developed by the new administration in Colombia. When approved, the Ministry of Mines and Energy is expected to implement the sections of the plan related to the energy transition that will allow both the state and companies to implement mechanisms to improve their digital infrastructure. It is interesting to note that Colombia's energy transition plan includes the implementation of regulations to promote and strengthen digital infrastructure. This will enable the transformation of the energy grid through the introduction of renewable energy, such as hydrogen or geothermal generation. To promote cleaner energies, the government is gearing up to strengthen digital infrastructure throughout the country.

6.1.2 Improving Inter-Ministerial Coordination

There may be overlapping mandates across various government departments, such as ministries responsible for ICT, energy, and mining. However, in many cases, policies are developed and administered separately by different ministries, and they might not always happen in concert. This results in siloed approaches and misalignment in policies and regulatory frameworks, lack of coordination, and inefficiencies that limit intended and potential impacts. There must also be due consideration for the roles and responsibilities of relevant decentralized administrations.

It is crucial to improve coordination across government agencies and ministries at different levels of implementation. Policies such as ICT can sometimes be discussed only at a national level when, in practice, provincial or federal states/governments are at the front line when it comes to access to (and functioning of) networks. In other cases, subnational policies and initiatives may already exist and may be more effective than national policies because they better understand the realities of local communities.

Particular attention must be given to the link between policy design and budgetary considerations because a lack of coordination will render effective policy implementation difficult and investments in digital infrastructures costlier. The lack of coordination can result in insufficient budgetary allocation for the deployment, upgrading, and maintenance of digital infrastructures and networks. This is particularly relevant for countries with reduced fiscal space.

BOX 9. SOUTH AFRICA

In **South Africa**, waste-to-energy initiatives within the mining sector are gaining momentum. The Gauteng provincial government's Economic Development Department is implementing a plan that connects mine waste and rehabilitation with smart reporting technologies, focusing on energy security and data management through smart metering and financial systems. These efforts have rapidly advanced at the local government level, sparking interest and collaboration with national departments like the Department of Forestry, Fisheries, and the Environment, which is now considering environmental, social, and governance impacts and community inclusion in mine waste value chains using digital technologies.

6.2 Strengthening Regulatory Frameworks

6.2.1 Coherence and Consistency Across Regulatory Frameworks

Policy coherence and consistency are particularly key when regulations are complex. Sometimes, regulatory measures are designed to support and protect one sector (such as ICT). However, they may have unintended (negative) consequences on other sectors, potentially preventing the deployment of digital infrastructure services, notably in rural areas. Strict regulations may also create perverse incentives for the development of the informal and black market for services to bypass regulations, such as attracting “grey” suppliers to set up shop on neighbouring country borders.

BOX 10. A TALE OF CAUTION—THE OPPORTUNITY COST OF PROHIBITIVE POLICIES

An example of policy not keeping pace with technology and, in fact, constricting socio-economic development opportunities can be seen in various countries' approaches to broadband connectivity offered by private sector providers, such as SpaceX's Starlink LEO satellite network.

In South Africa,[8] overly complex licensing conditions and compliance with policies such as Black Economic Empowerment conditions have deterred international services from applying to set up network access. The inability to leverage the affordable price that global services offer at scale limits network access in rural areas, which in turn limits opportunities for remote communities to become more resilient. It also prevents private sector actors, such as large-scale mining companies, from using their corporate social responsibility (CSR) budgets to provide LEO equipment to communities, which could facilitate access to services such as education and health care as well as stimulate entrepreneurship and diversification from mine dependence.

While broadband private sector connectivity is not welcome in South Africa without a licence (Gilbert, 2023), several African countries, including Benin, Nigeria, Rwanda, Malawi, Kenya, Mozambique, and Zambia, have already launched satellite internet services with positive spillovers for local development.

6.2.2 Strengthening Data Protection and Cybersecurity

The pace at which mining companies are embracing digital technologies requires regulatory frameworks regarding data protection and cybersecurity that are fit for purpose. The sheer volume of data generated—some of which are sensitive and critical—and stored on external support systems like clouds presents significant risks for mining companies if there are no appropriate regulatory frameworks and mechanisms in place.

Similarly, if companies want to share digital infrastructure and networks with local communities, they need to be sure that the legal framework will provide the necessary guarantees to avoid legal and trust backlash. Furthermore, without policy and regulatory oversight, there is a high risk of information being collected and used inappropriately, with related but different implications for providers and users.

Governments thus need to provide a safe regulatory environment and institutions that can take action in case of breach of the law related to data protection and cybersecurity. These include

- designing and implementing policies that remove regulatory barriers to enable access to existing technologies and to facilitate the adoption of newer technologies;
- adopting strategies to support cost-effective access devices and connectivity;
- enacting reforms to promote wider access to the Internet while also protecting data privacy and cyber security.

[8] Under the Department of Communications and Digital Technologies, South Africa's Electronic Communications Act prescribes in its licensing conditions that it "may only accept and consider applications for Individual Electronic Communications Network Services [I-ECNS] licences in terms of a policy direction issued by the Minister." A further hurdle is that in order to apply for a licence, the company must adhere to rules around Black Economic Empowerment equity ownership by South African citizens and historically disadvantaged people.

Threats to cybersecurity are of increasing concern to governments, companies, and citizens. Therefore, well-regulated policies are needed and should be enforced. At the global level, attention is being paid to mitigating the security risks presented by cybercrime. For instance, many countries are signatories to the Budapest Convention, which provides a legal framework that can be applied nationally and covers all sectors, including the mining sector. However, there are important gaps in national legislation, and there is an ongoing need to support policy-makers in keeping pace with the rapidly evolving digital landscape.

BOX 11. INTERNATIONAL LEGAL FRAMEWORK AND TOOLS

"The Convention on Cybercrime ("Budapest Convention") is regarded as the most comprehensive and coherent international agreement on cybercrime and electronic evidence to date. It serves as a guideline for any country developing domestic legislation on cybercrime and as a framework for international cooperation between State Parties to this treaty" (Council of Europe, 2022).

"The Budapest Convention provides for (i) the criminalization of conduct – ranging from illegal access, data and systems interference to computer-related fraud and child pornography; (ii) procedural powers to investigate cybercrime and secure electronic evidence in relation to any crime, and (iii) for efficient international cooperation. The treaty is open for accession by any country. In addition, capacity building programmes are offered to help countries build the necessary capacities to implement the Budapest Convention, its protocols or to follow up recommendations of the Cybercrime Convention Committee" (Council of Europe, 2022).

6.2.3 Enhance Transparency Through Digital Technologies

Digital technologies, such as blockchain, could also be deployed by governments to instill transparency regarding payments received from mining companies, thereby verifying the mining sector's contribution to the country's economy. This kind of technology-assisted transparency could also potentially mitigate trust issues and conflicts between mines and communities while supporting local development by empowering small-scale producers and promoting environmentally responsible practices.

BOX 12. PERU

In **Peru**, Sissai, a jewelry company, utilizes blockchain technology to communicate the origins and production route of the gold used in its products. The company sources its gold from an association of women mineral selectors in Peru. These women use a blockchain traceability program to generate an immutable record of the ecological gold process.

This innovative system engages and motivates women artisanal and small-scale mining producers to adopt more environmentally responsible practices. By ensuring higher prices for their gold, the program supports the economic empowerment of these women. Additionally, it educates gold jewelry consumers about the gold value chain, fostering greater transparency and awareness.

6.3 Leveraging Local Content Policies to Foster Investment in and Sharing of Digital Technologies and Connectivity

Local content policies are important policy tools that governments can leverage to foster local economic development through mining procurement linkages and through diversification outside the mining sector. In 2018, the IGF developed a guidance document intended for governments that aim at strengthening linkages with the mining sector. The guidance document covers five types of local content policies:

1. local procurement of goods and services
2. direct employment
3. downstream value addition
4. horizontal linkages using mining infrastructure
5. local ownership.

Digital technologies and connectivity are considered to be infrastructure and, therefore, fall within the scope of horizontal linkages. This means that they can be leveraged to advance the development of other (or new) sectors to reduce the economic dependency of mining regions on the mining sector and, hence, create more resilient local economies.

To enable local economic diversification, governments may require mining companies to indicate whether it is feasible to share their infrastructure with local communities by **submitting their digital infrastructure development projects**, either at the time of the project development or when these installations are planned. This can provide an avenue for governments and mining companies to discuss modalities of shared infrastructure deployment, such as how companies intend to deploy the infrastructure and to which types of stakeholders. It can also allow governments to align priorities, such as helping bridge the digital divide for basic services (such as education and health facilities) or extending wireless hotspots in public areas for wider connectivity.

In cases where there are no such plans, governments could require mining companies to indicate how much it would cost to extend the last mile of physical and/or network infrastructure to mining communities. Last-mile infrastructure extension is generally less costly than greenfield infrastructure investments. In that regard, based on cost extension estimates, governments could include these in budgetary provisions (if possible) or seek private–public partnerships with mining companies or with other stakeholders that may be willing to invest in local development.

There may be cases where it may not be possible to extend mining digital infrastructure to reach mining communities. In that case, governments **may require mining companies to contribute financially** to such infrastructure, which would then be built by government.

If governments want to take a stronger regulatory stance, they may require mining companies to build/share infrastructure as part of a bidding process.

A conducive business and investment climate are particularly important to facilitate investment, encourage and reward risk taking, foster innovation, enable infrastructure, and stimulate enterprise development across all economic sectors. They are key enablers of

economic activities in support of livelihoods and community resilience. However, building and sharing digital infrastructure and connectivity with local communities and neighbouring sectors costs money, and over time, they need to be upgraded and maintained. Moreover, access to the Internet requires data plans that must be purchased regularly, and therefore have an additional cost that generally must be borne by the consumers.

The high cost of data in many developing countries is a barrier in low-income communities because they may not be able to afford data packages. On their side, if mining companies are willing to share the infrastructure and the networks, they are not likely to pay for data packages for wider communities, except perhaps for their workers. Without incentives to maintain the infrastructure and the networks or without partnerships with local authorities that can do so, mining companies are unlikely to invest in the extension of digital infrastructure to communities and, importantly, ensure continuity in service provision during downturns.

Another way to stimulate investment in data and digital infrastructures is to provide incentives to mining companies that can invest in last-mile digital and connectivity infrastructures. These should be conditional on the extension of access to host communities and to priority sectors jointly identified by governments and companies. Types of incentives could include

- **fiscal incentives and tax deductions** as part of a trade-off for the investment in infrastructure;
- **import duties** exemptions applicable to infrastructure equipment for last-mile extension;
- **subsidized rates** for telecommunication network access if mining companies agree to provide free access to the Internet for communities or for priority sectors;
- provision of **public subsidies** to cover a portion of expenses under the digital infrastructure investment plans. These would be reserved for last-mile infrastructure and network extensions;
- in cases where mining companies have leasing agreements on infrastructure (with original equipment manufacturers, for example), **provision of leasing subsidies**, where the government agrees to cover part of the instalments as per the leasing agreement in exchange for the extension of digital and connectivity infrastructure to communities and priority sectors;
- **risk financing**, where government partially covers interest payments on loans for last-mile connectivity projects, reducing financial strain on companies. If extending infrastructure to communities increases financial risk, the government may offer state-backed guarantees or subsidize insurance costs.

However, careful consideration needs to be given to the effectiveness of incentives against benefits to be obtained, as incentives could have potential implications for government revenue if the economic activities created do not bring in sufficient additional revenues.

6.4 Digital Literacy, Skills Development, and Training

The digitalization of economic activities is changing the job landscape in all industries and, by extension, the skills requirements for the global workforce. The mining sector is no exception. If made available to the mining community, the effective use of digital technologies will only take place if users have the requisite digital skills.

TABLE 1. Types of skills and expected requirements

Types of skills	Examples of technologies and applications requiring types of skills
Basic digital skills	• Basic use of digital devices (such as phones, tablets, and laptops) • Internet navigation (e.g., web browsing, emails) • Mobile communication
Intermediate digital skills	• Ability to use multiple devices • Ability to perform transactions (e.g., mobile banking, e-commerce) • Ability to use social media • Ability to use software (such as office packages)
Advanced digital skills	• Programming • Web design • AI development • Data science

Source: Adapted from African Union Commission & Organisation for Economic Co-operation and Development, 2024.

Table 1 provides a broad categorization of the types of skills that are needed to adapt to the digital landscape. The demand for basic skills is expected to increase significantly. The World Bank estimates that in Africa, by 2030, 70% of the demand for digital skills will be for basic skills, and 23% of the demand will be for intermediate skills (World Bank, 2021).

As highlighted earlier, it is observed that while the level of digital skills is relatively low in low-income, resource-rich countries, there is a wide disparity between urban areas and rural communities. It is, therefore, key for governments and mining companies to work together to address the skills gaps, both within the mining workforce and in communities.

Governments must play a key role in ensuring that curricula are adapted from early childhood education. Schools must be equipped with digital devices and good internet connection, and digital skills must be included in all educational programs.

Any initiatives by mining companies to share digital infrastructure and connectivity outside the mine gate, therefore, need to be consistent with government plans to expand digital skills in the educational system. If such plans are not yet a priority, governments/ mining regions could develop a roadmap to enable mining regions to make the leap.

Specifically for mining communities (not in school), initiatives for shared infrastructure and connectivity must be accompanied by skills building and training. As part of local content

requirements, companies are often expected to provide skills development plans for their workers. Governments may want to consider extending the requirement to provide basic and intermediate digital skills training programs to mining communities. If such mining companies do not have such training facilities, Governments may require mining companies to contribute to a training fund that will be dedicated to digital skills building for mining communities and delivered through existing training facilities. Schools and other training centres could provide specific courses (in the evening) adapted to the literacy and numeracy levels of local communities.

In addition, governments can provide incentives for mining companies to support digital skills development training centres by allowing for tax deductions for contributions to training funds or to other existing facilities that companies may want to support and upgrade through shared infrastructure and connectivity.

6.5 Digital Inclusion in Support of Gender Equality

Digital inclusion can significantly enhance gender equality by addressing the barriers women face in accessing and utilizing digital technologies. Mining companies, (local) governments and local NGOs need to work in concert to address the multiple challenges faced by women, in particular in rural areas. Key strategies include the following:

- **working with community facilitators to improve women's digital literacy**: Empowering women with digital skills is crucial for their participation in the digital economy. Through their CSR initiatives, mining companies can support community facilitators to provide training and support to help women navigate digital tools and platforms effectively.
- **offering connectivity hotspots at places commonly used by women and other groups with limited digital literacy**: Providing internet access at locations such as schools, health clinics, and community centres ensures that women have convenient access to digital resources.
- **providing interfaces in local languages and supporting voice recognition**: When technologies are made available, they need to be accessible to local communities. Offering interfaces in local languages and voice recognition capabilities is critical to help overcome language barriers and enhances usability for women and others who would otherwise be excluded.
- **offering courses and ongoing support**: In line with the previous recommendation, providing educational courses and continuous support helps women and others with limited digital literacy stay updated with technological advancements and improves their digital proficiency.
- **prioritizing connectivity for women and marginalized groups**: Ensuring that women and the most marginalized groups have priority access to digital connectivity can help bridge the digital divide and promote inclusivity. This needs to be integrated into governments' gender strategies and companies' corporate strategies.

6.6 Planning for Mine Closure and Post-Mining Transition

To better leverage and foster the positive impacts and spillovers that digital infrastructure and connectivity deployment offer, governments may consider policies that integrate digital infrastructure planning into the entire mine life cycle, including closure and post-mining transition. This can include the following:

- **plan from the early stages**: integrate digital infrastructure planning into community development agreements from the outset with a clear plan for financial sustainability;
- **set aside funds**: allocate resources and funds for the successful transfer of digital infrastructure assets to the community;
- **establish agreements**: create memoranda of understanding with public or private entities for the maintenance and sustainability of digital infrastructure and connectivity;
- **include in mine closure plans**: make the transfer and maintenance of digital infrastructure and connectivity a key component of mine closure and post-mining transition plans.

6.7 Strengthening Partnerships

The landscape of stakeholders engaged in the design, implementation, management, and maintenance of digital infrastructure projects can be quite large. It includes owners or leasers of digital infrastructures (such as mining companies), telecommunication operators and internet providers, regulators (national and regional), and other service providers.

Managing large infrastructure contracts is generally challenging. Digital infrastructure projects have additional layers of complexity because they are embedded with software and applications that are constantly evolving (Whyte & Eshraghi, 2024). In developing countries, where gaps and financial risks are higher, the mining industry has legitimate concerns about the practicalities of such partnerships regarding

- the roles and responsibilities of each stakeholder in the sharing arrangements;
- the management and control of infrastructure once the mine shares its digital infrastructures and data connectivity outside its operations;
- the cost of implementation: providing digital infrastructure and connectivity is not a one-off investment. There are recurrent operational costs, which raises questions such as who would bear the cost of investment? If infrastructure is shared, who would pay the monthly connectivity costs? Are local communities expected to pay for internet access/data connectivity and if so, do they would pay the full cost? If not, who would pay for the subsidized amount?
- the risk of data protection and cybersecurity and the extent to which sharing the networks is safe and will not impact their internal systems;
- potential unintended (negative) impacts on communities that may be at risk of abuse or be exposed to criminal activities, such as personal or financial information theft, due to their low levels of digital literacy.

Establishing strong partnerships among relevant stakeholders is crucial to sustaining infrastructure installations and maintenance over time to maintain spillover benefits, such as opportunities for diversification with other economic sectors. Such partnerships must be co-defined at the early stages of infrastructure development so that the terms of the partnerships—as well as the roles and responsibilities with respect to construction, operation, management, maintenance of digital infrastructures, and connectivity—are clearly identified and budgeted for (Limpitlaw & Johnson, 2021).

At times, new partnership initiatives use existing infrastructures and are scaled up to reach other communities.

BOX 13. WESTERN CAPE PROVINCE OF SOUTH AFRICA

One example is an initiative taken by **Western Cape province of South Africa**. The provincial government has connected all schools (1,449 public schools) to the Internet through its broadband project in partnership with a private sector digital infrastructure provider. Building on this, a partnership between private sector actors has initiated a project to bring "pay-as-you-go" fibre internet to township communities that costs roughly USD 0.27 per day (Mzekandaba, 2023). This service offers fast, uncapped, and time-based open-access fibre Internet to townships while also providing a gateway to initiate micro-payments for accessing the Internet.

The municipalities also invested in bringing power to the dwellings. To date, the project has connected 6,500 households with fast, affordable, and uncapped internet access in one community and has plans to extend to more townships across the country, including Rustenburg in the North West province, where numerous platinum group metals mines and host communities are located. This innovative approach could potentially resolve partnership challenges with regard to the responsibility for installation and maintenance as well as ongoing affordability not being dependent on the state or mining companies.

Such initiatives require well-structured engagement and coordination with stakeholders, along with knowledge of existing projects that can be leveraged, scaled up, financed, and maintained, which remains a challenge in most countries.

6.7.1 Establishing Dedicated Agencies

Governments can consider establishing dedicated infrastructure agencies to ensure that all the appropriate steps are taken in developing infrastructure projects and facilitating multi-stakeholder partnership (MSP) activities. These agencies would support public authorities and regulators in designing projects that can be implemented through MSPs and developing and managing effective partnership frameworks.

These agencies can serve as communication channels and one-stop shops for investors to address their concerns and to help bidders and financiers with information and opportunities. They can also provide contract management after financial close (World Bank, 2023).

Given the costs of projects, where relevant, partnerships need to include international agencies. International development funds and regional banks, such as the African

Development Bank[9] (AfDB) (n.d.) and the Inter-American Development Bank, are important partners for the financing and implementation of digital infrastructure projects. Besides providing finance in the form of grants or concessionary loans and guarantees, these institutions can offer international expertise and advice to support governments in negotiating MSPs or in designing projects based on international best practices.

To enhance community engagement in local development, governments may require mining companies to include plans to consult, involve, and partner with local actors for the management of digital infrastructures. This requirement should include commitments to

- ensure that the needs of communities are integrated into the planning and development of digital infrastructure;
- enter into sharing agreements with communities, in which the latter have a leadership role to play in the implementation of sharing projects;
- support communities in finding ways to take stakes in the partnerships so that, over time, they are able to participate financially to maintain and operate the infrastructure. This is key for long-term sustainability.

6.7.2 From CSR to Impact Delivery

A relatively common and well-known approach for mining companies to assist with local access to digital technology is through their CSR programs. This usually takes the form of building and fitting out computer labs in schools and tertiary training facilities or donating computers to health care centres, local government, or traditional authority offices. While providing important short-term support, these are not sufficient to create long-term improvement in the quality of life of most communities, as they tend to focus quite narrowly on projects that try to address an immediate need.

The digital revolution is an opportunity to move beyond traditional forms of community engagement and to support local economies in leapfrogging to digital solutions to unlock economic opportunities. Being a key lead actor in local economic opportunities would leave a longer-term legacy and help open alternative livelihood opportunities to diversify often enclaved local economies that are overdependent on mining activities.

[9] The AfDB's investment mandate has three objectives: "(i) enhancing access to digital infrastructure in underserved areas with funds from the public sector, leveraging loans, grants, and trust funds; (ii) de-risking investments and creating an enabling environment to optimize investment in the ecosystem; and (iii) creating and deploying ICT infrastructure with scaled public–private partnership models in the design and implementation of operations" (AfDB, n.d., n.p.) Examples of projects funded by the AfDB include (i) the Central African Backbone to connect onward terrestrial fibre from the West Africa undersea cable system (SAT3) to several central African countries; and (ii) the Eastern Africa Submarine Cable System (EASSy), a 10,000km submarine cable system deployed along the east and south coast of Africa with landing points in Mozambique, Madagascar, the Comoros, Tanzania, Kenya, Somalia, and Djibouti (AfDB, n.d.).

BOX 14. DRC

A good example of a "beyond a mine-site" initiative is a partnership between a network provider and a bank that rolled out the Umoja app for a mining company in the DRC. This bespoke solution was originally designed as a digital workplace tool to address communication challenges in the business and with the workforce. Ten thousand employees are provided with a device and airtime, i.e., a smartphone and 8GB data bundle per month, which they take home and is available for others in the household to use. This digital inclusivity has given families access to online education, health information, markets, and the ability to transact financially. This partnership has pioneered the shared use of digital infrastructure and made data connectivity available to the local communities, which is reported to have had a significant positive impact for the mineworkers' families—and not purely for the purpose of mine management interacting with their employees. By making a strategic decision to provide digital solutions and, very importantly, network access, the mine has strengthened its social licence to operate. This partnership has acted as a test bed for the company to implement shared-use programs in other operations with their global workforce, not only in Africa.

Mining companies could consider **revisiting their CSR policies by including shared infrastructure in investment decisions**. That way, there is a lower risk of projects being cancelled when commodity cycles downturn. This would also involve companies sharing other forms of infrastructure where necessary and feasible. For example, the use of digital infrastructure requires households to have seamless access to electricity, which in many remote locations may be unreliable or non-existent. As more mining operations are looking to replace diesel power generation with renewable energy solutions, there may be an opportunity to also share renewable energies with local communities to enable internet connectivity and access.

To encourage mining companies to do so, it is important to ensure that utilities' regulations such as energy and telecommunications facilitate rather than inhibit the ability of companies to share their infrastructure. In many countries, these markets are not open to private investments or are highly regulated. To bridge the digital divide, **governments may, therefore, consider revisiting their utilities regulations** to enable mining companies and other actors involved in digital infrastructure and connectivity services to support local economic development (ITU, 2022).

7.0 Conclusion

The deployment of digital infrastructure in mining regions can optimize socio-economic benefits by creating new job opportunities, improving access to education through online learning platforms, and enhancing supply chain efficiency by connecting local businesses to broader markets. It can also enable better access to financial resources, such as mobile banking and digital payment systems, which are critical for economic participation in remote areas.

Moreover, the integration of digital technologies, such as blockchain, can ensure transparency and security in transactions while also enabling civil society to monitor and support the integrity of these processes, which is particularly beneficial for mining companies operating in remote areas. Furthermore, digital infrastructure can support community resilience through improved access to health care, productive resources, and international markets, and foster local entrepreneurship by providing the tools necessary for innovation and business growth. At the same time, it is important to ensure that greater digitalization does not widen inequalities in terms of access to digital services and the job market, particularly due to digital illiteracy and the gender digital divide.

However, the potential benefits of digitalization must be carefully managed to avoid exacerbating existing inequalities. The risk of digital illiteracy leading to unequal access to digital services and job opportunities is significant, and this risk is even more pronounced for women in many developing regions. Educational campaigns and digital literacy programs are essential to ensuring that the benefits of digital technologies are broadly and equitably shared. As mining companies continue to invest in advanced technologies to enhance operational efficiency and worker safety, it is crucial that the spillover effects on local communities are strategically harnessed. Achieving this will require robust public and private policies, including local content policies, that align mining activities with broader socio-economic goals, ensuring that the benefits extend beyond the mine gate and contribute to local development and community resilience.

Moreover, access to the Internet is increasingly recognized as a human rights issue, as it enables communities to stay informed about events that impact their safety and security. This is especially crucial in the context of climate change, where real-time information can be lifesaving during catastrophic events. Future policy frameworks between states and the mining sector are advised to mandate real access to networks for local communities, possibly during early-stage social and environmental impact assessments of mining projects, as

this is fundamental to ensuring the equitable sharing of benefits. Shared infrastructure and sustainable practices, supported by public–private partnerships, are key to ensuring that digital connectivity benefits entire communities, not just the mining sector.

The growing interest from both public and private sectors in digital infrastructure and connectivity projects highlights their importance as vital economic enablers, particularly in resource-rich developing countries. This is especially pertinent for nations with critical mineral reserves, where mining projects are increasing rapidly to meet global energy transition demands. For these governments, there is a significant opportunity to leverage the growth of the mining sector to align with national socio-economic development priorities for national benefit.

Nonetheless, current partnerships often remain limited to national governments and the private sector. This effectively excludes a wealth of wisdom and expertise that could be tapped into at the local level in terms of what resilience looks like for communities. In fact, it appears that mining companies engage more substantially with communities than governments, and this raises questions about inclusivity in policy formulation, overlooking the valuable insights that local communities can offer in terms of the needs for digital infrastructure, skills, and assets that could improve resilience and local socio-economic development. The lack of inclusive, community-focused policy-making in public and corporate policies on digital infrastructure and skills development leaves communities vulnerable, unable to adapt to economic, social, and environmental challenges, and disconnected from opportunities that could strengthen their resilience.

As mining policy and regulations continue to evolve, particularly in areas such as health and safety, environmental protection, local socio-economic development, and climate change, there is a pressing need for better integration of digital infrastructure and shared-use initiatives to empower local communities and diversify economies away from mine dependence. The success of these efforts depends heavily on aligning digital infrastructure policies with related sectors such as energy, education, and finance while ensuring coordinated and coherent action across ministries. Therefore, sharing access to renewable energy and digital infrastructure becomes not just a policy recommendation but a critical strategy for socio-economic resilience and sustainable development.

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