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Book

Digitalization in the extractive sector : a comparative analysis of the Andean region

Reference: Rentería Palomares, Zaira/Gutiérrez García, Jorge et. al. (2022). Digitalization in the extractive sector : a comparative analysis of the Andean region. [Washington, DC] : Inter-American Development Bank. https://publications.iadb.org/publications/english/document/Digitalization-in-the-Extractive-Sector-A-Comparative-Analysis-of-the-Andean-Region.pdf. doi:10.18235/0004675.

DECEMBER 2022

Digitalization in the extractive sector: A comparative analysis of the Andean region

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IDB

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library

Rentería, Zaira.
Digitalization in the extractive sector: a comparative analysis of the Andean region / Zaira Rentería Palomares, Jorge Gutiérrez García, Daniel Perdomo Rodríguez.

p. cm. — (IDB Monograph ; 1065)
Includes bibliographic references.

1. Mineral industries-Effect of technological innovations on-Andes Region. 2. Regional economics-Andes Region. 3. Mineral industries-Social aspects-Latin America. 4. Mineral industries-Environmental aspects-Latin America. I. Gutiérrez, Jorge. II. Perdomo, Daniel. III. Inter-American Development Bank. Country Department Andean Group. IV. Title. V. Series.

IDB-MG-1065

JEL codes: L71, L72, O33, Q35, Q42, Q48.

Keywords: Science and Technology, Digital Technology, Extractive Industry, Energy Transition, Mining, Automation, ESG, Blockchain, Social Impact.

Acknowledgement

This report is a joint effort of the Country Department Andean Group and the Infrastructure and Energy Sector at the Inter-American Development Bank. It was written under the coordination and supervision of Osmel Manzano (Regional Economic Advisor), Lenin H. Balza (Sector Specialist), and Javier Beverinotti (Country Economist for Peru). The report benefitted from valuable and insightful contributions from Luis Guillermo Alarcón (Lead Telecom Specialist), Lina Diaz, Nicolás Gómez-Parra, Kenji Moreno, Jose Luis Saboin, and Adriana Unzueta. The authors of this report are Zaira Rentería Palomares, Jorge Gutiérrez García, and Daniel Perdomo Rodríguez at Carbon Trust. Daniel McNaughton took care of the editorial supervision, and Nicole Ramirez devised the layout and design. This report would not exist without the generosity of external experts who shared their time and knowledge with us. Their names and affiliations are listed in the Appendix.

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Executive summary

Global efforts to achieve the climate goals specified in the Paris Agreement pose major challenges for the global production system, because demand for clean fuels, metals, and minerals will increase considerably in the coming decades. This trend is the main driver for extractive companies' transformations of their production systems to maintain their profitability and operability in the face of an increasingly stringent context in economic, environmental, and social terms.

Hence, **the adoption of digital technologies appears as a unique opportunity that would enable the industry to meet the challenges posed by the energy transition** that is looming. The successful adoption of disruptive technologies, the availability of which has increased rapidly over the last decade, will undoubtedly translate into not only a competitive advantage for the extractive industries, but their sustained operation.

As the activities of the extractive sector are increasingly subject to scrutiny, proper communication of the sector's economic, environmental, and social performance is an essential part of a corporate strategy that enables it to continue to operate. **In this challenging context, companies in the extractive sector have started to rethink not only their internal operations, but also the ways in which they interact with communities, the environment, and public opinion.** This is especially true in the Andean region, which has a critical role to play in the energy transition as a provider of key minerals, such as lithium and copper, as well as a supplier of the raw materials and fuels necessary for the transition. At this point in time, digital technologies represent a major opportunity to enhance the energy transition in the region.

For instance, blockchain applications have emerged not only internationally but in the Andean region as well as a powerful tool to meet transparency and traceability goals in the context of sustainability and social impact. Blockchain can be a powerful tool for tracking minerals and metals from the extraction sites to the sale of the final good as a means of verifying that the final good complies with sustainability standards. This is particularly relevant because, for instance, producers of electric vehicles are increasingly concerned with including materials in their production that are extracted with a minimal impact on the environment.

A cross-cutting aspect is the importance of digital technologies in promoting sustainable investments within the framework of environmental, social, and corporate governance (ESG) criteria, given that extractive companies are increasingly subject to demands from investors to comply with

sustainable and social standards and practices. There is presently a prime opportunity for the Andean region, by adopting ESG criteria, to advance in terms of providing differentiated sustainable goods from a footprint point of view. This is especially important because upstream markets may want to take advantage of metals and minerals with low environmental impact along the entire supply and production chain.

Andean extractive companies have realized that effectively managing the social and environmental impacts of the sector's activities can make a substantial contribution to local development as well as ensure the continuous renewal of the social license. **The adoption of digital technologies has the potential to leverage the social license in diverse aspects, mainly through enhancing transparency.** Digital tools facilitate not only the control and monitoring of operations but also compliance with environmental and safety regulations by generating information that, when regularly reported to regulatory bodies, can reduce the risk to public health.

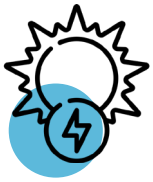
At the same time, **the deployment of digital technologies in the Andean region presents major challenges, particularly for currently operating and small-scale companies.** For new and large-scale companies, the integration of digital technologies is not a decision—rather, their adoption is intrinsic from the initial conception of an extractive project to its final implementation. In addition, these companies as early adopters of digital technologies benefit the sector as a whole, as they lead the way for companies that are not as well positioned and hence perceive higher risks and costs in the uptake of those technologies.

Beyond the extractives sector, **the adoption of digital technologies brings positive externalities that have been overlooked.** Digital technologies present great opportunities to leverage governance in the Andean region, mainly because extractive activities heavily influence socioeconomic conditions in the local communities. For instance, the lowering of the level and frequency of exposure to harmful conditions via digitalization has increased its visibility as a tool that can create safer environments.

The economic benefits of increasing efficiency and productivity through technological innovation will not be reaped by companies alone. Instead, **companies, governments, and communities will achieve shared value:** the high-skilled personnel (who are paid higher salaries) necessary for digitalization boost companies' bottom lines, thus generating higher tax revenues for governments. Some cases of public-private collaboration in the Andean region, particularly in Colombia, have proved that this type of shared value synergy has a great impact for all stakeholders.

Finally, **governments have the great potential to become key drivers of the acceleration of adoption of digital technologies in the extractives sector.** Two of the biggest barriers are risk aversion in relation to the adoption of new disruptive technologies and the availability of specialized technicians in the region. Governments can establish both development hubs, such as those in Peru that serve as pilot centers for new technologies, and specialized educational training centers that can serve as interlocutors between academia and industry. This could trigger public-private synergies in the acceleration not only of digital technologies, but of other technologies as well.

Key messages



Energy transition is a key driver for the extractive sector because it is increasing the demand for mineral, metals, and energy essential for renewable technologies.

Adoption of digital technologies is a unique opportunity that would enable companies to overcome the socioeconomic challenges posed by the energy transition

ESG criteria in the extractive sector are playing an increasingly decisive and role in terms of where investments in the extractive sector are allocated. Digital technologies can assist with compliance with these criteria.

For instance, blockchain applications have emerged as a powerful tool to meet transparency and traceability standards with regard to sustainability.

Data systems and automation would bring significant economic savings to the sector, for instance in terms of indirect and induced jobs and social license renewal.

If well-managed, digitalization could foster positive social impacts due to job creation. The increasing mineral demand in the coming decades could boost this effect.

The adoption of digital technologies has the potential to leverage the social license in diverse aspects, mainly by enhancing transparency.

Public policies and institutions are required to unlock and push forward the innovation process through their coordination and stimulation of digital ecosystems.

Governments can play a key role in the fostering of digitalization through the establishment of innovation hubs where synergies between industry, academia, and public sector can accelerate digital adoption.

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List of Acronyms and Initialisms

Acronym	Name
AI	Artificial Intelligence
ACM	Colombian Mining Association
ANM	Colombian National Mining Agency
CAF	Development Bank of Latin America
CMSP	Southern Mining Cluster
ESG	Environmental, Social, and Corporate Governance
GDP	Gross Domestic Product
GHG	Greenhouse gases
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
ILO	International Labor Organization
IoT	Internet of Things
IT	Information and Communication Technologies
KPI	Key Performance Indicators
MINEM	Peruvian Ministry of Mines and Energy
PoC	Proof of Concept
RE	Renewable energies
SAMMI	Andean Mining Cluster
SDG	Sustainable Development Goals
SDS	IEA's Sustainable Development Scenario
STEM	Science, technology, engineering, and mathematics
STEPS	IEA's Stated Policies Scenario
WEF	World Economic Forum

01 Introduction

The aim of this report is to present a high-level understanding of the adoption level of technological innovation within the value chains of key extractive industries in the Andean region with a particular focus on digitalization. To this end, the report focuses on key technologies that are available worldwide as well as on how companies in the region are undertaking their implementation and how their initiatives compare with international best practices.

The report does not comprehensively analyze the process of the adoption of digital technologies in the region, but rather aims to give a**n overview of why (a) digitalization is important in the Andean region, (b) where the digital opportunities lie along the value chain, (c) the key digital trends in the sector, (d) the main actors, (e) the core challenges, and (f) the spillovers of digitalization in the region.** The idea is to provide an overview that will promote understanding of this process and serve as a seedbed for new ideas for future analysis.

Figure 1. Countries in the Andean region

Source: Own elaboration

The report is structured as follows: Chapter 2 presents the methodology description followed while preparing this document, specially explains how the information was gathered. **Chapter 3 describes the importance of the extractive sector as a supplier of energy, minerals, and metals needed for the energy transition underway and in the coming decades.** It discusses the challenges posed by the growing demand for these goods and the reorienting of their production systems in a context of increasingly stringent economic, environmental, and social benchmarks for the sector. In this context, the role of digitalization is described as an opportunity to improve the sector's performance in these areas.

Chapter 4 considers the three main drivers of digital technology adoption in the extractive sector in greater depth[1]. The first is the economic driver, where efficiency gains appear to be the most important. Second, on the environmental side, the use of digital technologies for reducing the impact on environmental resources and preventing accidents such as spills appears to be one of the main drivers. Third, regarding the social aspect, renewing the social license by providing transparency concerning the impact of companies' operations through the use of digital tools appears to be the main motivation.

Chapter 5 describes in general terms some of the main spillovers of digital adoption. On the social side, the adoption of technologies by large companies and in particular their acceptance of the higher risks that come with testing technologies serve as an example for smaller companies to follow, generating indirect impacts in terms of the increased connectivity of surrounding communities, the increased participation of women in extractive activities, and the triggering of local digital solutions.

On the environmental side, the chapter describes how digital technologies enable greater traceability, confidence, and transparency in relation to environmental impacts, as well as strengthen corporate social responsibility. On the economic side, greater impacts are generated in terms of increased opportunities for job creation and training of local specialists; in addition, the application of digital technologies promotes transparency in extractive companies' performance, which in turn will attract investors that are more and more taking into account ESG indicators.

Finally, Chapter 6 discusses the roles of innovation initiatives, public policy, and regulation in the deployment of digital technologies. The focus of the discussion is on the cooperation of businesses, governments, and academia on the establishment of innovation centers where pilots can be tested, local solutions can be generated, and local capabilities can be created through the training of specialized professionals. Here governments should play the leading role in the creation of technological innovation centers and the design of public policies and economic instruments that will serve as catalysts for the acceleration of the adoption of digital solutions.

[1]Chapters 4 and 5 are heavily based on the information provided during the interviews, so many of the statements and ideas included in those chapters arise from the summarizing of the results of the interviews.

02 Methodology

The methodological framework used for preparing this report consisted of desktop research on the state of digital adoption in the extractive industries in the Andean region. The research had the aim of identifying successful examples of digital adoption in the extractive industries both in the Andean region and across the world, as well as potential spillovers and externalities of adopting digital technologies. In addition, as part of the desktop research key stakeholders from the industry and other relevant actors were identified for interviews.

The desktop review served as basis for the design and development of a questionnaire for interviews. The interviews, intended to deepen understanding of the topic at hand and complement the desktop research, had the specific goals of

- gaining further details on the examples identified for additional analysis,
- supporting the analysis of the socioeconomic drivers and spillovers of identified examples and identifying some enablers of digital adoption in the region, and
- identifying and confirming spillovers/externalities.

A variety of interviews were conducted to learn from the first-hand experience of the actors directly involved in the adoption of digital solutions in the extractive sector[2], focusing mainly on the Andean region, though relevant success stories in other regions were considered as well.

As a result, the analysis was largely based on primary sources such as interviews with a variety of actors, including company managers, members of public and private associations, digital solution providers, staff members of development banks, consultants, and academics. The interviews were structured to identify (see Table 4. Interview questions in the Annexes)

- the importance of digitalization for companies or any other relevant organization,
- the segments of the value chain where innovative digital opportunities exist,
- the major challenges to be overcome to ensure a digital transformation,
- the impact of digital adoption in the extractive sector on communities, and
- key lessons learned by current adopters.

The companies and institutions contacted included the following mining and technology companies, governmental institutions, local associations, and academic organizations: Anglo American, Ecopetrol, Nokia Digital Industries Latin America North, Development Bank of Latin America (CAF), the Colombian National Mining Agency (Agencia Nacional de Minería), the Colombian Mining Association (Asociación Colombiana de Minería), Southern Mining Cluster (Cluster Minero del Sur, CMSP), Andean Mining Cluster (Cluster Minero Andino, SAMMI), Peruvian Mining Innovation (Innovación Minera del Perú), Linkminers, Cumbre del Sajama Consultants, LQG Energy and Mining Consulting, and the Pontifical Catholic University of Chile (UC).

[2]Identifying case studies for the Andean region proved challenging due to the lack of publicly reported cases. This could have a variety of causes, such as the small size of initiatives, efforts being in the testing or evaluation stages, or even that companies were seeking a competitive advantage in the sector and did not wish to reveal trade secrets. However, digitalization has been mentioned by international experts as a short-term and high-level impact opportunity for mining operations in Latin American countries (IDB, 2022).

03

Future of the extractive sector in the context of energy transition

This section explains the key role of the extractive sector, as a supplier of metals, minerals, and energy, in the efforts to decarbonize the world economy. This new transformational reality poses challenges for the sector in the coming decades in different areas, with the main challenge being the reorganization of the sector's productive system to meet more-stringent standards. In this context, digitalization has the potential to play a critical role in improving the economic, environmental, and social performance of the extractive sector.

For this reason, in this chapter global trends in the adoption of digital technologies in the extractive sector are described at a high level, with the aim of identifying opportunities for their adoption in the Andean region. This context will serve as the background for chapter 5, in which the potential consequences of their adoption are analyzed, particularly regarding employment, health, safety, and environmental issues. This will provide a broader perspective on the sector's digital transition and its spillovers in the Andean region.

3.1. The extractive sector and the energy transition

The extractive sector has played an important role in the global economy for centuries. Its importance comes from the fact that it provides a large part of the raw materials and fuels supporting the physical capital and meeting the energy demands of the global economy. **The mining sector supplies metals and minerals and the oil and gas sector supplies energy and raw materials to the economy.** Both sectors are at the center of the analysis in this report in the context of the energy transition.

The extractive sector is facing a distinct demand for modern goods that differ from those used in the past decades and even centuries, when lower amounts and fewer types of minerals were consumed, compared to what today's complex technology requires. **The mining sector will have to adapt to the demand for increasingly specific and scarce minerals and metals such as lithium, gallium, indium, and selenium.** The oil and gas sector is also facing challenges to include in its energy portfolio the production of alternative fuels, for instance hydrogen and biofuels.

The rationale behind this trend is that minerals and metals such as iron, aluminum, and copper that serve as the basis of the physical structure of production are fundamental to the generation, storage, transfer, and processing of energy and information. Furthermore, **mining plays a vital role in the provision of minerals that are fundamental for the development of renewable technologies,** which are a key element of the energy transition to a low-carbon economy. For instance, lithium and cadmium are essential to the production of

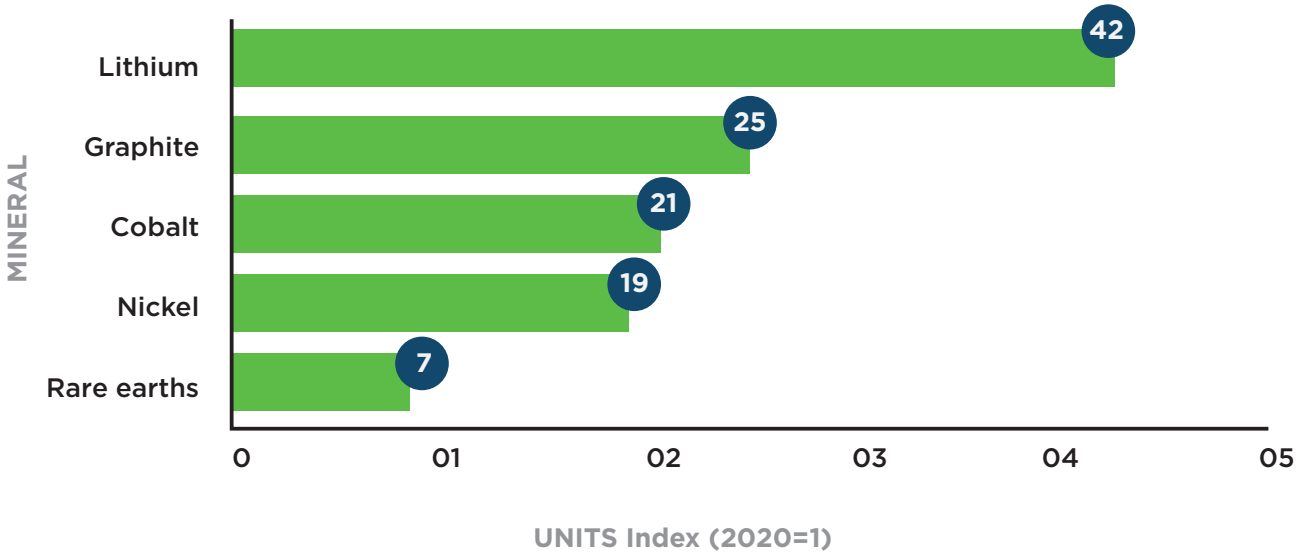
some widely used renewable technologies. In fact, the sector has in a sense already had to adapt to technological changes, in order to meet the increased demand for materials and energy that are key in the context of the energy transition.

Demand for the metals and minerals needed to produce renewable energy technologies is expected to grow in the coming decades. The International Energy Agency (IEA) has developed several scenarios that project varying levels of this demand.

In the scenario in which the Paris Agreement is implemented, IEA (2021) estimated that the share of total demand for minerals associated with clean technologies will reach 40 percent for copper and rare earth elements, 60–70 percent for nickel and cobalt, and close to 90 percent for lithium. In this scenario, it is estimated that demand for minerals for electric cars and batteries will overtake demand for minerals for consumer electronics.

Figure 2 shows the increase in demand for metals and minerals by sector by 2040. It presents the demand for the Sustainable Development Scenario (SDS) scenario, in which the terms of the Paris Agreement are assumed to be met, and the Stated Policies Scenario (STEPS) scenario, in which it is assumed that energy systems reach the announced targets by sector consistent with currently announced policies. For instance, Figure 2 shows that lithium demand is expected to be 42 times higher in 2040 with respect to 2020 demand.

Figure 2. Mineral demand for clean technologies in the Sustainable Development Scenario by 2040



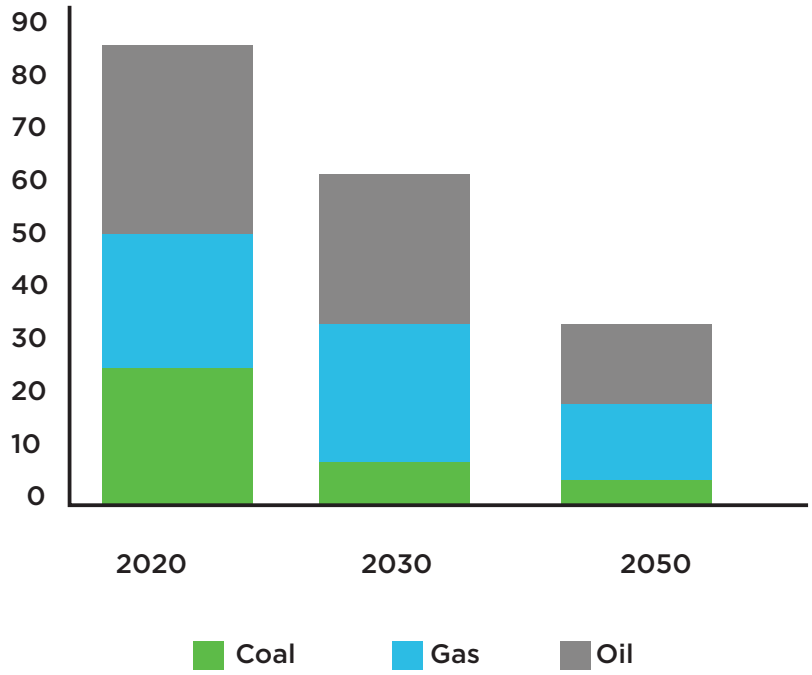
Source: Based on IEA (2021)[3]
Note: Rare earths are neodymium and dysprosium.

[3] Rare earths are needed for the development of renewable energy and other modern technologies because of their strong magnetic proprieties. Some examples of these elements are neodymium, terbium, indium, dysprosium, and praseodymium.

Even the intermediate SDS scenario shows that demand for metals and minerals will grow significantly over the coming decades and thus the performance of the sector will be crucial if this demand is to be met.

Furthermore, the production of metals and minerals in the remainder of the current decade will be relevant to the achievement of the 2030 Sustainable Development Goals (SDGs) set by the United Nations, which will have an economic impact on the entire production value chain. At the same time, the production of metals and minerals involves major challenges in terms of social and environmental impacts so that this production does not negatively impact the achievement of other SDGs related to clean water, health, and climate issues. The oil and gas sector has experienced similar trends, despite the possibility that its production might substantially decrease in the coming years. Nevertheless, oil and gas companies will continue figure prominently in the world's energy mix in the coming decades. Figure 3 shows the worldwide participation share in primary energy for fossil fuels, i.e., coal, gas, and oil under the 1.5°C-low-OS[4] pathway of the IPCC scenarios. Despite the unambiguous decreasing tendency in the next decades, fossil fuels will still have a significant share in 2050 of around one third of the total of primary energy use (Rogelj, J.D. et al., 2018).

Figure 3. Share (as %) of worldwide primary energy use of fossil fuels (IPCC Scenario: Below-1.5°C and 1.5°C-low-OS pathways)



Source: Own elaboration with information from Rogelj, J.D. et al. (2018).

[4]Pathway limiting median warming to below 1.5°C in 2100 and with a 50–67% probability of temporarily overshooting that level earlier, generally implying less than 0.1°C higher peak warming than Below-1.5°C pathways (Rogelj, J.D. et al., 2018).

Against this landscape of declining fossil fuels demand, the oil and gas sector has developed strategies to keep the industry relevant during the energy transition. **The strategies include taking the necessary actions to lower emissions in the sector's operations and thus reduce its carbon footprint,** as well as gain access to capital markets for sustainable investment by improving disclosure and aligning the sector's strategies with a sustainable path (IEA, 2020). In this regard, oil and gas companies have identified some opportunities in terms of committing to sustainability in the coming decades that could secure their access to the financial markets. Atlantic Council (2020) and McKinsey (2021) lay out some specific actions the sector should consider:

- Increase resilience through the development of transparent and objective ESG metrics that are accessible to investors.
- Invest in net zero emission strategies (e.g., clean hydrogen) and the circular economy and encourage the growth of international carbon markets.
- Develop a workforce strategy that leverages the above into restoring oil and gas as an attractive destination for younger talent concerned about the ESG footprint.

However, the most pragmatic strategy has been geared toward offering products that reflect the reality of the energy transition. Because oil and gas cannot just cease to exist, when a reliable and affordable fuel source is needed for driving clean energy maturity to reach the net zero emissions targets as specified in several scenarios by 2050 (IEA, 2020), **a key strategy is to move from being a fuel supply industry to an energy industry.**

The oil and gas sector has the potential to play a major role by increasing its provision of alternative energy sources. According to IEA (2020), the use of biofuels will contribute significantly to the reduction of energy emissions intensity, while both hydrogen and biomethane will play a growing role in this regard as they start to come into the energy system at larger scale. Furthermore, growth in the noncombustion uses of oil, such as the use of oil products as a petrochemical feedstock, will also help to reduce energy emissions intensity.

Likewise, taking advantage of the current assets in the oil and gas sector to integrate other energy sources and carbon capture technologies could preserve the infrastructure value and save between 20 and 30 percent of capital (Achilles, 2021a). Furthermore, according to McKinsey (2021) retiring the least productive and most carbon-intensive wells and associated assets could improve both emissions performance and profitability of existing oil and gas portfolios. In the upstream segment, there are mature digital solutions, ranging from geological prospectivity and exploratory drilling to production operations and well intervention (Deloitte, 2017a).

In this challenging context, the adoption of digital technologies appears as a strategy that would enable the industry to meet the challenges posed by the energy transition in the coming decades. According to Deloitte (2018), in the midstream segment, a more efficient operation could reduce annual downtime by 70 percent, and unplanned costs to 22 percent in unplanned costs which currently make up 50 percent. However, these advantages have not translated into increased technology adoption in the sector. For example, in the United

States over the past decade, 90 percent of midstream jobs were in the construction, maintenance, and materials fields, compared to a couple of hundred jobs in digital operations.

These are the challenges facing the extractive sector, particularly in the next three decades. Its successful adaptation to the new demands for materials and energy will depend on the designing and execution of strategies in its production systems that meet economic, environmental, and social requirements. It will also depend on the adoption of disruptive technologies, the rapid growth in the availability of which over the past decade will undoubtedly provide not only a competitive advantage, but define the sector's continued operations. The following sections describe the technologies currently available and how companies around the world are using them in their operations and then focus on the case of the Andean region.

3.2. Global trends in digital technologies

Since the Industrial Revolution, technology has been a fundamental part of human daily life. Thanks to the progress of technology, all human activities have significantly advanced to the point that they have become easier, faster, and more efficient. From sending an email that arrives in a couple of seconds to controlling remote equipment in a big manufacturing facility from a safe room, technology has profoundly influenced the development of society as we know it today.

The current technological transformation taking place in all industries is commonly referred as Industry 4.0, which can be conceptualized as the transformation through digitalization and integration of all industrial processes in the value chain. This digital revolution is the result of the combination of advanced production and operations techniques using smart and disruptive technologies such as robotics, analytics, AI, and IoT, which are integrated into organizations, people, and assets.

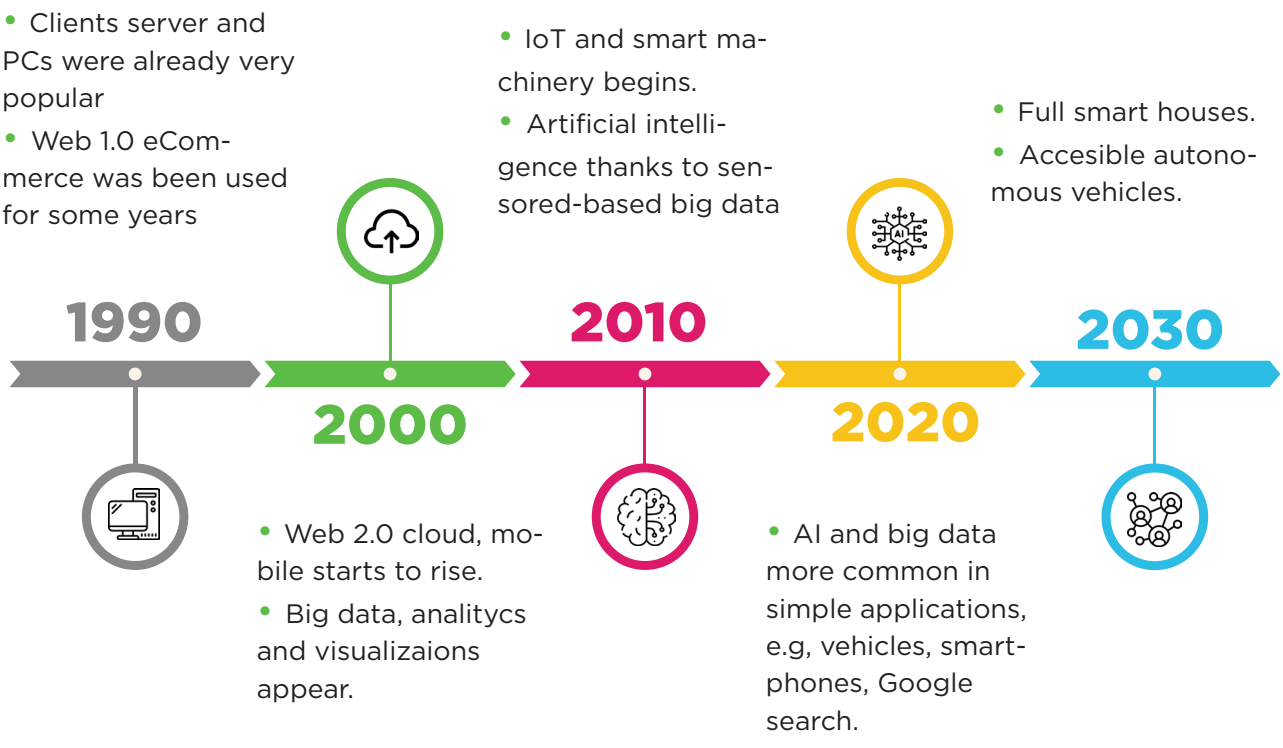
According to Salkin et al. (2018), Industry 4.0 relies on the integration of dynamic value-creation networks with regard to the integration of the physical basic system and the software system with other branches and economic sectors, and with other industries and industry types. According to the concept of Industry 4.0, research and innovation, reference architecture, and the standardization and security of networked systems are the fundamentals for implementing Industry 4.0 infrastructure. This transformation can be achieved by providing adequate substructures supported by sensors, machines, workplaces, and information technology systems that are communicating with each other initially within a single enterprise and later with other communicative systems.

In other words, Industry 4.0 refers to smart industries that integrate the physical field with virtual technologies, where manufacturers and machines share information with the supply chain, processes can be automatically optimized, and AI is used to complete tasks based on complex workflows.

Over the last few decades, the digital movement has advanced at an increasing pace. Two factors have mainly driven its deployment. The first is the **progress in technology and discovery** of new materials that have enabled data to be transferred faster and stored using less space.

Second, the **reduction in technology investment and operating costs** has accelerated over the last few decades. Some examples are the price of electricity generation with photovoltaic panels, which has fallen from USD 30 per KWh in 1984 to USD 0.14 in 2014, and the average cost of an industrial robot, which has fallen from USD 500,000 in 2007 to USD 20,000 in 2014 (WEF, 2017a). Figure 4 presents the technologies that have become available in the past three decades, which have seen an evolution from the scattered basic data system to the full integrated system of information, so that AI and data-driven decision making are now part of daily operations.

Figure 4. Timeline of the development of digitalization technologies, 1990–2030



Source: Based on WEF (2017a).

At the global level, at least four relevant aspects have been identified in the adoption of technologies for the coming years, according to McKinsey (2015) and WEF (2017a):

1. Information, data processing, and connectivity
2. Analytics and artificial intelligence embedded in digital platforms and ecosystems
3. Human–machine interaction
4. Conversion from digital to physical

These elements refer to the growing capacity for data collection through sensors throughout the whole production chain, which today is more affordable and achievable. These data alone are not useful; they must be converted into information, i.e., using computer systems and software, that can be organized for statistical analysis and as input for machine learning. The integration of operations and devices in unified systems will provide decision-oriented information for optimizing operations.

This will enable both the management of uncertainty and the anticipation of operations. In the extractive sector, this is particularly relevant for geological modeling, daily task scheduling, and predictive maintenance (McKinsey, 2015). The use of devices, powered by algorithms, for the execution of tasks such as equipment assembly and repair could increase efficiency. Another important application has to do with physical operations that can be done with remote human support, particularly in environments that are dangerous for humans, such as mines and oil rigs.

While the ever-increasing individual connectivity in recent years has not only reduced the direct environmental footprint of technology (in the form of devices and digital infrastructure), it has led to positive externalities that have been overlooked. For example, the European Commission reports that truck loading efficiency has increased by 14 percent in the last 15 years due to the integration of information systems in the logistics value chain. The home-office context is another such example, as it has reduced energy-intensive transport. Synchronizing needs with supply and flows with infrastructure through digitalization at all levels of the production chain is one of the most effective ways to reduce the sector's value chain environmental footprint. Therefore, information technologies may not aim to produce more, but to produce better (Babinet, 2021).

3.3. Opportunities for digital technologies in the extractive sector

In the last few years, the extractive industry has faced increasing difficulties in identifying new mineral and fuel reservoirs that are economically feasible to explore. Likewise, variability and uncertainty in the exploitation of reservoirs intrinsically prevails in the industry, which has a direct impact on the efficiency of its processes. In this context, the search for new practices and technologies to increase the economic viability of the sector has been stimulated. For more than a decade, at least five major

drivers—social, technological, economic, environmental, and geopolitical (WEF, 2010)—for digital technologies adoption have been identified that will have the greatest impact on the extractive industry by 2030. Among them, in the technological component, the automation of operations was identified as a relevant component in the sector's performance. However, just a decade ago it was difficult to anticipate the technological changes in the generation, capture, storage, and processing of data that are now part of everyday life in various areas, mainly in the technology industries. These advances have opened up important opportunities in the extractive sector for automation, not only in regular operations, but also in resource prospecting and along the entire value chain of the sector. Notably, technology adoption trends are not oriented to a specific mineral or energy source, but rather to productivity enhancement through automation and autonomation of processes[5], such as remote control of critical/hazardous activities.

One of the most important advances on the road to digitalization in the sector is the processing of data for real-time decision making, which makes it possible to anticipate problems and reduce the variability inherent in the sector's operations. The following is a generic description of some of these opportunities and the available technologies and their field of application in the extractive sector.

According to McKinsey (2015) and WEF (2017a), the mining sector has multiple challenges that could determine its performance in the coming decades, some of which are:

- an excess of production capacity[6],
- a high-skilled-people gap,
- a deficit in access and quality resources,
- supply value chain disruption[7], and
- growing regulation of the extraction of minerals and materials.

Moreover, the sector has been forced to respond to the challenge of reducing its environmental footprint. Recently, the members of the International Council on Mining and Metals (ICMM)[8] committed to achieving the goal of zero net emissions by 2050, in line with the Paris Agreement (ICMM, 2021). To become more sustainable, the mining sector's strategies for reducing emissions can be grouped into four different approaches:

[5]Automation is when a process or procedure is programmed to be carried out independently; there is no assumption that mistakes will be avoided. Autonomation, on the other hand, while also involving programming so that a task is completed independently, detects errors and adjust actions within the process/procedure, thus mimicking a human reaction. An automatic car that changes gears itself is an example of automation; a self-driving Tesla car is an example of autonomation.

[6]The boom in the mineral markets from 2004 encouraged massive capital investment to expand capacity. The expansion had not even finished before prices collapsed, forcing companies to open the added capacity to recoup some of the financial investment and to keep royalty and social payments flowing. The resulting global excess capacity for production of most minerals and metals put even more downward pressure on prices.

[7]The end of the commodities boom generated global financial crises and led to increase in exports from the countries with excess capacity, leading to plant idling and workforce reduction across countries. This trend has been intensified due to political sensitivity that has led countries to impose trade restrictions (USA, Brazil, the EU) and t the current COVID-19 pandemic, which paused economic activities in many countries.

1. Incorporation of renewable energies, mainly electricity
2. Reduction of the demand for materials under circular economy principles (WEF, 2017a)
3. Increases in energy efficiency by optimizing processes using, for example, digitalization in production processes
4. Incorporating decarbonization actions by supporting emissions reduction in the transportation of products and engaging with downstream industries to support emissions reduction in mineral processing (ICMM, 2021)

For the oil and gas sector, supply and demand have been impacted significantly. On the supply side, the rise of new hydrocarbon sources (especially those related to tight oil and shale gas), greater penetration of renewables and efficiency increases, and geopolitical changes have disrupted the industry value change. On the demand side, the shift of global demand patterns, the increase of the number of electric vehicles, new utility models (smart grids), and climate regulation have been significant triggering factors in the sector. For this sector, the focus has been on understanding production potential, improving health and safety, and boosting marginal operational efficiencies (WEF, 2017b).

Among sustainable strategies, digitalization has made great strides in recent years due to the advance of technologies for data generation, capture, storage, and processing. Thus, it has generated new opportunities for increasing operational efficiency in the extractive sector. For example, prospecting for fuel or mineral extraction involves the processing of large amounts of geological and seismic data, which in turn interacts with more data from complex supply chains (Achilles, 2021b).

The supply chain itself is a great challenge, mainly because the existing data were never created to be shared. In addition, there is a lack of standardization and data interconnections within the sector's ecosystem, which is furthered hindered by the preference for speed of processing over efficiency, which generates high costs (Achilles, 2021b).

This is precisely how digital technologies can transform the operation of companies: they can catalyze new opportunities for greater control of operations, reduction of variability, greater efficiency in the execution of daily activities, and for the anticipation of problems that could delay or stop production. Similarly, the automation of processes becomes attractive, not only in companies' regular operations, but also in resource prospecting and in the monitoring of the entire value chain.

The following is a generic description of some of these opportunities, the available technologies, and their field of application in the extractive sector, as identified by McKinsey (2015):

a. **Deeper understanding of existing resources:** Prospecting and exploration

[8]Among the members of the ICMM are Anglo American, Antofogasta Minerals, BHP, CODELCO, Glencore, Minera San Cristobal, Minsur, and Rio Tinto, all of which are major players in mining in Latin America. Hence, the commitment to achieving net zero emissions may have a relevant impact on the mining sector in the Andean region, in turn enabling these companies to become leaders in sustainability issues.

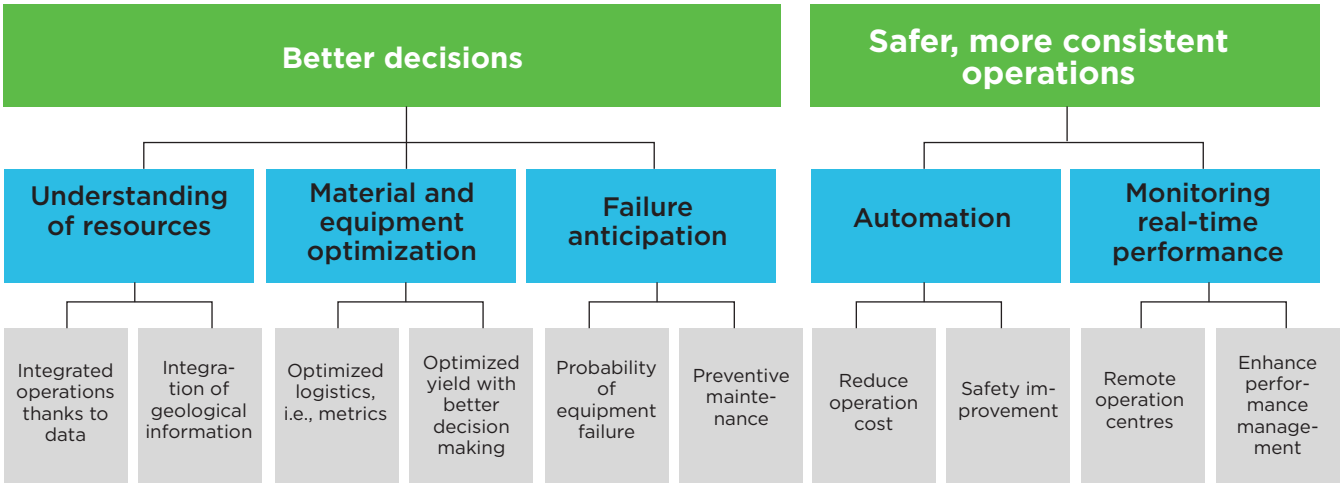
tasks for new resources can take advantage of digital technologies by combining information on deposits modeling and drilling activities, which would maximize the probability of finding richer veins. The resultant reduction of costs and energy in these phases would make operations more efficient.

b. Optimization of material and equipment flow: Real-time data generation and processing could increase efficiency regarding scheduling and optimal utilization of equipment. The benefits of carrying out optimization tasks would be reflected in time savings in material resources management, as well as the optimization of routes and cargo load movement within the mines. In the case of gold, nickel, and phosphate sites, efficiency can be increased between 3 and 10 percent.

c. Improved operational risk management: Better management of the variability associated with the operation of a site would enable the narrowing of the uncertainty ranges of possible failures. This would translate into better planning and preventive maintenance procedures, saving time and energy and extending assets' usefulness. In addition, the data regarding risk management serves as input for machine learning algorithms for autonomous equipment so that they can perform activities with greater accuracy.

Figure 5 presents some extended benefits that digital technologies have brought to the sector globally. The opportunities are of two broad types: they can (1) enhance the decision-making process and (2) provide more-efficient operations while decreasing accidents.

Figure 5. Digitalization opportunities in the extractive sector

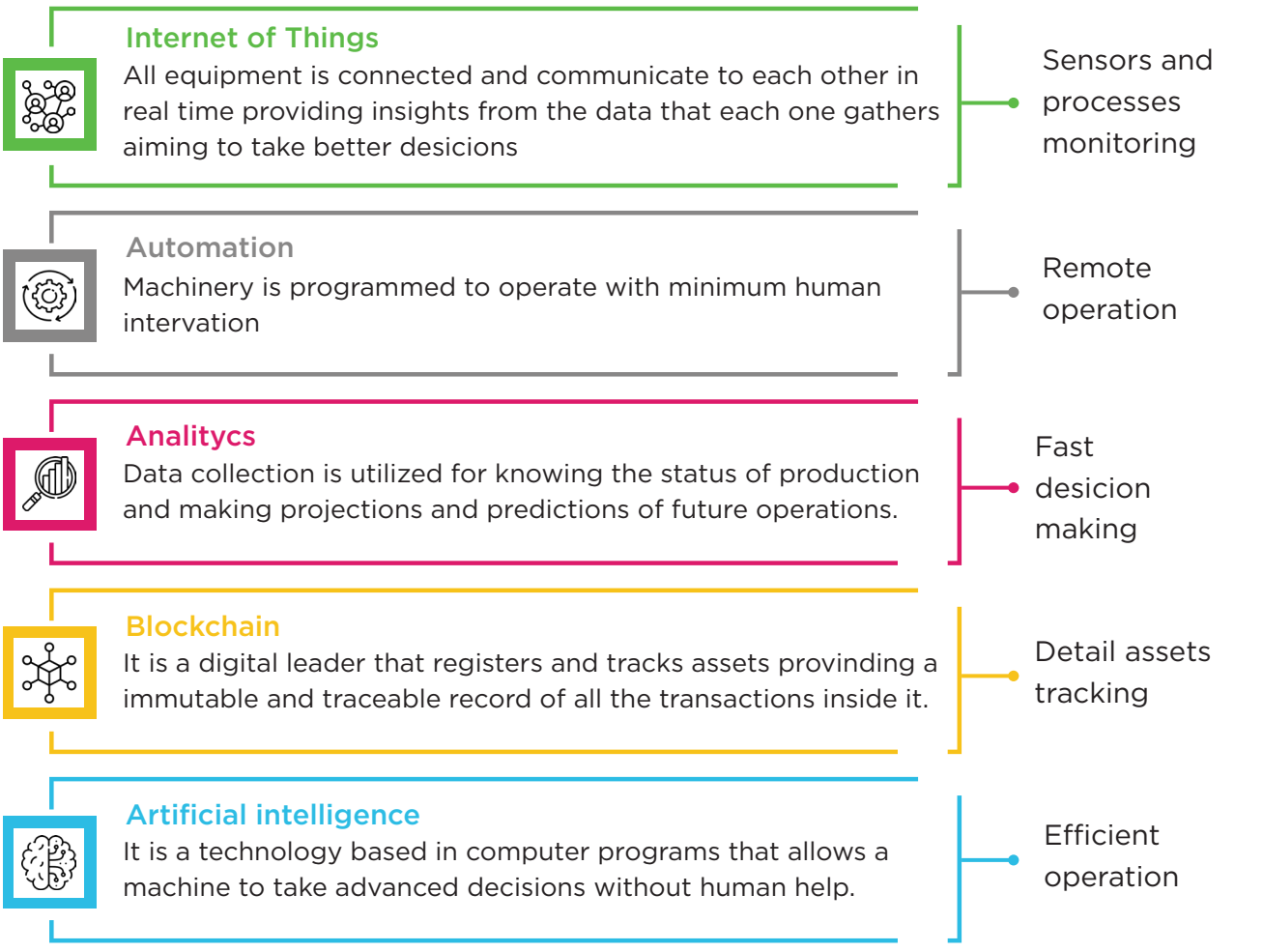


Source: Based on McKinsey (2015).

The sector is currently not only adopting digital solutions to control its production systems within companies, but is also using these technologies to modify its interaction with external stakeholders. For example, blockchain applications in energy trading have emerged as a powerful tool to meet transparency and information dissemination requirements. These applications ensure that the information (amount of energy generated and traded) is validated by all the users, is traceable (each transaction is recorded and kept visible), and cannot be manipulated, because the blockchain is designed to prevent information manipulation once it gets in the chain. The use of this technology will save time by eliminating inefficient, routine, and bureaucratic processes, which, due to their volume, require many man hours of attention (Deloitte, 2016).

Figure 6 summarizes the key generic technologies in the extractive sector that will define the performance of companies in the coming decades. It is important to emphasize that the adoption of these technologies should not be seen as a matter of deciding which to select, because together they form a digital ecosystem that feeds off of the results of all of them. The application of each technology in each stage of the production system in the extractive sector obviously depends on the technical characteristics of each segment. However, their interaction in an integrated system is where their maximum value can be obtained.

Figure 6. Digitalization technologies



In light of these global trends in available digital technologies, there are multiple opportunities and challenges for the extractive sector. The following sections first describe the context of the Andean region, in particular its importance in the global context of metals, minerals, and energy production, as well as the importance of the sector within the economies of the individual countries. Then the discussion turns to the opportunities and challenges that the region will face in adopting digital technologies in the coming decades.

3.4. The Andean region context

For centuries, Latin America has benefited from mineral exploitation as a supplier of raw materials to the worldwide market. Latin America has 59 percent of the world's lithium reserves, Chile is the main copper producer, Brazil is the third-largest producer of iron, Mexico is the largest producer of silver, and Peru is among the top producers of silver, copper, gold, and lead (USGS, 2022).

Due to its morphological characteristics, the Andean region is especially rich in very important minerals. The largest deposits in this area are of gold, copper, silver, tin, iron, zinc, and lead and there are deposits of oil, natural gas, and coal as well. Thus, it is not surprising that for the countries in this region, their main exports consist of these commodities. For instance, Colombia's top exports are crude oil, coal, and refined oil; Ecuador's are crude and refined oil; Peru's are copper, gold, refined oil, and zinc; and Bolivia's are gas, gold, and zinc (OEC, 2019).

The extractive sector in the Andean region has a significant impact. In Bolivia, the extractive sector contributes 29 percent of government revenues, constitutes 82 percent of exports, and 18 percent of GDP. In Ecuador, the oil sector constitutes 20 percent of GDP and 58 percent of exports and in Peru, the extractive sector generates 11 percent of GDP and 64 percent of exports (NRGI, 2017). Table 1 summarizes the metallic mineral and metal contribution to exports, production value, and rent as percentage of GDP for countries in the region.

Table 1. Metallic mineral and metal contribution to GDP and rent

Country	Metallic mineral, metals, and coal export contribution,[9] 2018 (%)	Metallic mineral and coal production value, 2018 (as % of GDP)	Mineral rent,[10] 2018 (as % of GDP)
Bolivia	43.3	6.66	4.11
Colombia	22.8	3.13	0.52
Ecuador	2.1	0.50	0.17
Peru	60.5	13.04	8.21

Source: ICMM (2020).

One of the most important minerals for the region is copper, as it is associated with 86 percent of the economic benefits from the demand for minerals needed to achieve the world target of nationally determined contributions (NDCs). For instance, between 2020 and 2050, the economic opportunities associated with lithium (mainly in Argentina, Bolivia, Brazil, Chile, Mexico, and Peru) could grow more than tenfold, reaching almost USD 1 billion, given that lithium production has a higher growth rate and profit margin than other minerals. However, lithium accounts for only 2 percent of total mineral revenues, so the market for this mineral is still much smaller than that for copper (IDB, 2022).

Regarding the oil and gas sector, even with the energy transition, certain Andean countries will continue to depend heavily on their hydrocarbon reserves. In 2018, oil rents in Ecuador, Colombia, and Bolivia were 6.7, 3.7, and 1.3 percent of GDP, respectively.[11] Furthermore, the COVID-19 pandemic has had a great impact on the demand for and prices of hydrocarbons, which has led to social and energy crises not only in Latin America, but in many other countries as well. The major problem is that even if the use of fossil fuels to be lowered to avoid global warming above 1.5°C, the transition cannot be made abruptly, because a large number of jobs and significant public revenues are tied to oil (Monge, 2021).

Because more mineral extraction and oil will be needed to support the maturity of renewables and hard-to-decarbonize sectors (IEA, 2020), it is vital that the extractive industries adjust their processes to ensure their role in the future economy. Starting in the past decade, the digital transition could be observed at the global level and its drivers have remained the same: social, environmental, and economic, the last being the main incentive for digitalization. This is particularly relevant for the Andean region, where the extractive sector has direct economic, social, and environmental impacts.

[9]The contribution is estimated from exports of metallic minerals, metals, and coal as share of total merchandise exports (ICMM, 2020).
[10]This is production values minus "normal costs," which provides an indication of tax and profit above 'normal' profits from mining (ICMM, 2020).
[11]Estimated with information from the World Bank: data.worldbank.org/indicator/NY.GDP.PETR.RT.ZS.

A report on mining innovation in Latin America (Deloitte, 2017b) identified five aspects on which mining companies have focused: (1) reducing operating costs, (2) reducing risks, (3) increasing safety, (4) improving asset productivity, and (5) reducing their environmental footprint. Complementing this report, IDB (2022) focused on the environmental, social, and economic impacts related to mining in the coming years for Latin American countries. This publication emphasized that with regard to environmental impacts, not only will the environmental footprint broadly be relevant for mining operations, but that specifically water management, climate change, biodiversity, and hazardous materials and waste management will be key subcategories where digitalization can be crucial to the accurate measurement and prevention of negative impacts.

In Latin American countries, the environmental and social aspects have been shown to be closely linked, based on previous conflicts between companies carrying out extractive activities and the communities where those activities are taking place. **Experience has also shown that the social aspects are not only relevant to the perception of the operation on the part of external audiences, but that the issues within the companies can also change the community's opinion or lead to reputational risks.** Internal and external relevant issues could be (a) employees' health and safety, (b) labor relations, and (c) community relationships, including with indigenous communities (IDB, 2022). Thus, improving disclosure and information channels through digitalization can produce several benefits, such as the renewal of the social license, which will be discussed further in chapter 3.

Figure 7 shows the information and communication technologies that are currently being used in many sectors. Highlighted are those observed, generally in the first phases of adoption, in the extractive sector in the Andean region. The most popular technologies are data analytics and blockchain, which have been implemented across public and private Andean organizations.

Figure 7. IT technologies and those present in the Andean region

01 Digital infrastructure

- Connectivity (Wi-Fi, 5G)
- Sensing and systems (IoT, RFID)
- Cloud
- IT Architecture

02 Cybersecurity

- IoT security
- Supply chain security*
- Ecosystem's security

03 Ecosystems integration

- Interoperability
- Legacy Systems
- Convergence IT/OT

04 Information management

- Business Intelligence
- Data Analytics*
- Machine learning
- Blockchain*

05 Autonomous and autonomy

- Autonomous devices*
- IoT/OT
- Robotics
- Change management

06 Immersive experience

- Virtual reality
- Digital Twins
- Gamification

* Observed in the Andean region

Source: Based on GIZ (2021).

With the advancement of technology and trends in the economy, mining in the Andean region is being impacted by these changes. Chile, Peru, Ecuador, and Colombia have begun to adopt technologies to meet the new production and environmental challenges in order to remain competitive (GIZ, 2021). The trends of the Industrial Revolution 4.0 are not always related to the carbon footprint; they are also focused on optimization and improvement of productivity and process safety (WEF, 2017a; GIZ, 2021). Box 1 describes an example from Australia of the digital technologies used in the Andean region.

While both sectors generally use most of the available digital technologies, there were differences in their use (Please see Figure 8). For example, in the mining sector the issues of social licensing, safety, and industrial hygiene were mentioned most frequently in the interviews. In contrast, in the oil and gas sector, blockchain and accident prevention were the main issues identified. We will return to these themes in the following chapters as we discuss both the main drivers of the ongoing digital transformation and the main impacts observed in this process.

Box 1 Automation in Rio Tinto mines

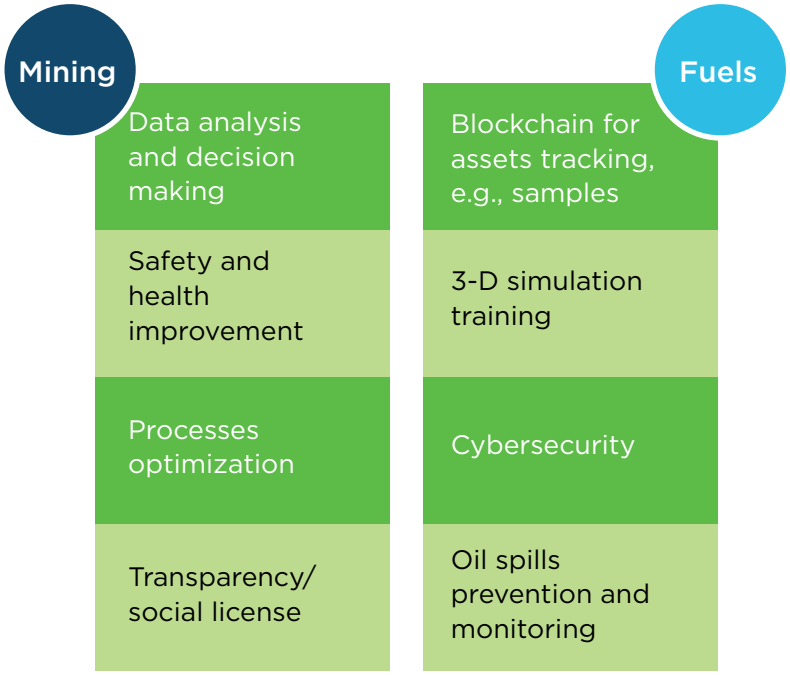
In 2018, Rio Tinto approved USD 146 million for funding the Koodaideri iron ore mine in the Pilbara region of Western Australia, which became the first of its intelligent mining sites. The company planned to use the latest high tech for increasing its automation and robotics, estimating that it would provide 2000 construction jobs and 600 operations staff.

The Pilbara region is an integrated network of 16 mines with a 1700 km rail network and infrastructure, which is the world's first automated heavy-haul rail, called AutoHaul™. This network is operated by a state-of-the-art facility that monitors and controls all autonomous trucks,

trains, drills, ports, and rail systems from a centralized location. All this is possible, thanks to the incorporation of visual and collaborative tools that deliver real-time information across the demand value chain, providing optimization, maintenance, and logistics throughout the network in a more efficient and integrated manner.

The AutoHaul system has improved safety by sending automated responses to speed restrictions and alarms that eliminated the need for transporting mid-journey train drivers, saving 1.5 million km of road travel per year. Similarly, 33 percent of the haul trucks fleet is autonomous, based on a GPS course that automatically navigates roads and intersections while tracking speed, direction, and current position, enabling more material to move efficiently and safely (Rio Tinto, 2022).

Figure 8. Examples of digitalization applications in the Andean extractive industry



Source: Own elaboration.

04 Digitalization drivers, opportunities, and challenges

The best documented drivers in technology adoption case studies have been productive and economic efficiency. However, it is inaccurate to attribute the current transformation to these aspects alone. It is increasingly clear that the adoption of new technologies is not a decision, but rather a necessity in the face of the environmental, social, and economic demands that are being made of industry.

Multiple drivers are changing the way extractive companies operate. The adoption of digital technologies is closely related to all of them, not as an end in itself, but as a means to overcome the new economic, social, and environmental challenges or mitigate their effects. Table 2 presents the main drivers of change for the mining sector; however, they could easily be extended to the extractive sector in general. In the following sections, some of these drivers will be discussed in detail with a focus on the adoption of digital technologies.

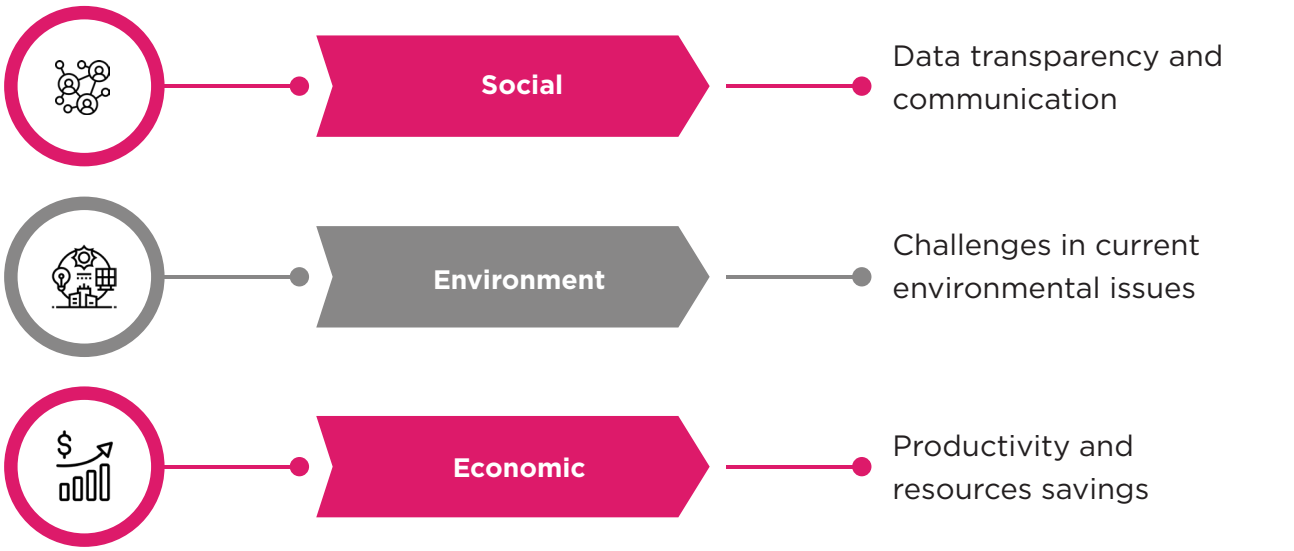
Table 2. Global trends and their impact on the mining sector

Trends	Drivers	Impact/Challenge
Global demand	• Declining global economic growth • Growth in urbanization and developing countries • Geopolitical instability • Focus on circular economy • Increment in the demand for alternative materials	Lower and volatile growth in the long term
Industry	• Resource scarcity in remote areas • Competition	Increment in cost, fewer projects and lower viability
Workforce	• Aging workforce • Millennials • Skills gap in developing countries	Rising costs and transparency assurances
Society and governance	• Resource nationalism[12] in minerals' extraction • Increase in environmental regulation • Strengthening of collaboration with local communities • Increment in sanitary assistance	Rising costs and transparency assurances

Source: Adapted from WEF (2017a).

As a starting point, the drivers of digital adoption by the extractive sector in the Andean region can be grouped into three broad dimensions—social, environmental, and economic—to present in a structured way the motivations and implications for the adoption of digital solutions (see Figure 9). The extractive sector has social impacts on the communities near the extraction sites by providing employment; in addition, these communities are the first to experience any adverse environmental conditions. The second point ties in with the significant environmental impacts of the extractive sector, which are associated with its activities of resource exploration and extraction. Finally, the economic impacts of the sector, besides job creation as noted above, are the generation of economic value broadly speaking and of tax revenues for governments. Moreover, all these aspects are important because they have the potential to improve the social, environmental, and economic performance of the industry, the benefits from which can also be captured by both society and government.

Figure 9. Summary of digitalization drivers in the Andean region



Source: Own elaboration based on conversations with experts (see Table 1).

All these drivers present challenges for digitalization implementation. According to EY (2022), as of 2022 the mining sector faces ten major challenges. The environmental and social risk is the biggest challenge to the industry, with issues such as the local community impact, water management, green production, diversity, and biodiversity being at the center of the discussion. In second place is decarbonization of the sector, which implies the development and implementation of a strategy that can help to achieve net zero emissions and market differentiation. License to operate as provided by the communities surrounding the mining operations is in third place, demonstrating the importance of the mining sector's engagement with peo-

[12]Resource nationalism refers to policies and regulations that seek to deliver the maximum benefit from the extraction and processing of ores and minerals to the host country(WEF, 2017a).

ple in those communities, contributions to the local economy, and protection of heritage sites. Among the other risks,[13] the digital and innovation challenge is ranked seventh. However, digital innovation is not an isolated aspect of the challenges the sector faces. Rather, it is a cross-cutting issue with a relevant role in mitigating many of the highlighted risks: for instance, it comprises concerns about how digital technologies can address problems related to productivity, safety, and ESG priorities.

In the case of the oil and gas sector, the main drivers disrupting the energy value chain are the shift in global demand patterns, greater penetration of renewables, and climate regulation and the push for emission reductions (WEF, 2017b). Unlike the mining sector, the oil and gas sector is facing a decline in demand in the coming decades. However, while companies have realized this, they have also observed that this is not the case for the energy market, which is moving from a market dominated by fossil fuels to a market with a higher proportion of cleaner fuels. Thus, the sector's strategy is to move from being a fossil fuel industry to an energy industry (IEA, 2020) and correspondingly it is focusing its efforts on fuels such as hydrogen and biofuels. This is where digital technologies have an important role to play, both in making production more efficient and as a means to achieve transparency, for example using blockchain (Box 2).

In the face of these challenges, digitalization has received increasing interest from those involved in extractive sector operations along the entire value chain. Technology adoption has become a tool through which these risks can be mitigated. The following sections describe in detail the drivers identified in the region to better understand the status of digitalization.

Box 2. Blockchain in mining

Blockchain appears as an opportunity for the extractive industry from different angles. In very simple terms, blockchain is a technology for storing information and exchanging it between two parties in a secure and transparent way. Because this exchange is handled by a cluster of computers, it is impossible to change the data without the consensus of the network.

The blockchain in the industry has multiple applications along the entire value chain (Weiland, 2018). In particular, this technology facilitates some processes both operationally and commercially through its enabling of the secure exchange of documents and sensitive information.

Blockchain makes possible the less bureaucratic exchange of documents, because there is no need for physical presentation, e.g., documents proving ownership in the shipment of goods.

One benefit of greater agility in commercial transactions is that the fulfilment of requirements in each phase of the process is known through the verification procedures of each of the parties involved.

Finally, one of the most relevant aspects concerns sustainability. Blockchain emerges as a powerful tool for tracking from deposits to final sale; thus it is a means of verifying that the final good complies with sustainability standards and was produced without labor exploitation and so forth. For example, producers of electric vehicles are more concerned with including materials in their production that have a minimal impact on the environment.

[13]Geopolitics, capital, and uncertain demand are in fourth, fifth, and sixth place, respectively.

4.1. Key drivers

4.1.1. Social drivers

In the Andean region, extractive areas are typically in remote zones with few economic activities and low access to services and infrastructure compared to elsewhere in the specific country. As a result, the local communities are very dependent on the services and activities associated with the extractive sector in the region. It is commonly observed that extractive zones do not prosper as much as expected from the extractive richness that the regions possess. Effectively managing the social impacts of the sector can make a substantial contribution to local development (IHRB, 2014a).

Due to the activities of the extractive sector, negative impacts are likely to be generated. There is the risk of poor environmental controls, which can lead to pollution and in turn biodiversity and ecosystem loss, hindering the development of other activities such as agriculture and fishing. Additionally, indigenous communities could be at risk of losing their only sources of food, which would force them to emigrate and lead to land disputes among communities (IHRB, 2014a; 2014b).

In this context, it is crucial for extractive companies to effectively manage the impact of their activities. The concept that ties together all of these social issues is social licensing. According to BDO (2020), the social license **refers to the acceptance of a company by its employees, by its community stakeholders and by the public.** More recently, the understanding of the 'society' that grants the license has widened to include ethical investment funds, international human rights activists, international financial institutions, and local and national governments.

Box 3. Social innovation

In Ecuador, Lundin Gold is aligning its community investment programs with Objective 8 of the SDGs (Decent Work and Economic Growth) through the Fruta del Norte gold project: local agricultural producers have been integrated into the mine's catering supply chain, boosting local employment and economic activity.

One of the most critical aspects of the social license, which is under continuous public scrutiny, is transparency.[14] T**he adoption of digital technologies has the potential to leverage the social license in diverse aspects, mainly through the enhancement of transparency.** There is an increasing movement across digital media toward promoting government and corporate transparency, accountability, and public participation in sustainability and the social performance of projects. The main objective is to facilitate relationships between companies, communities, and governments. Disclosing sustainability and social data is crucial for providing a bet-

[14]According to IDB (2018, pag. 11), transparency "involves the open publication of information about the operations of public sector agencies to outside actors, including citizens, civil society groups, government auditing institutions, and other public entities charged with monitoring and oversight. . . . Transparency requires that information be published so that it enhances these actors' understanding of government activities." While it is true that this definition places the emphasis on governments, it can be assumed that the same applies to corporations in the extractive sector, as their performance is increasingly monitored by a variety of stakeholders.

ter overview of the efforts that are being made toward improving sustainability performance (see Box 4).

Box 4. Antofagasta Minerals and transparency strategy

Antofagasta Minerals is a Chilean copper mining company that in 2015 began using social networks such as LinkedIn, Facebook, Twitter, YouTube, Flickr, and Instagram with the aim of strengthening the link between the company and various stakeholders using these forums. Antofagasta Minerals in Chile broadcasts videos of its meetings with Transparency International on its website and through social media platforms to ensure that affected stakeholders, including local communities, are well informed as to their work (IGF, 2018).

In addition, this seeks to build community trust through transparency, as well as seeking opportunities to improve its link with stakeholders through digital media. For example, in a long negotiation to resolve differences with the Caimanes community, its subsidiary Los Pelambres incorporated the Chilean chapter of Transparency International to monitor and share information, making these meetings public through access to videos of these sessions on its website (WEF, 2017).

In this context, digitalization of the extractive sector has emerged as an opportunity to process data and present it as information. For instance, in the form of performance indicators, that provides stakeholders with the tools to improve their understanding of the industry's actions in regard to social or environmental aspects and how stakeholders may affect those aspects.

Therefore, **digital technologies can leverage transparency, which can lead to accountability where companies assume responsibility for their actions and spillovers, whether they have positive or negative impacts on society.** In other words, digital technologies can support companies in gaining the social license by providing the tools for registering and monitoring it (BDO, 2020).

Transparency initiatives are generally well accepted, particularly if they are accompanied by reliable and traceable information. In this sense, proper communication of information about social and environmental impacts, shared through formal channels, with the participation of governments, investors, and social organizations, could be a strategy to reduce social resistance to projects that generate benefits across different dimensions, thus ensuring social licensing.

For instance, environmental data systems that monitor the stability of a tailings dam and outlet water quality could give communities to access to these data streams in real time. This information would be of great value to the people affected and could support the establishment of a strong social license to operate (IGF, 2021a).

Another relevant example in the case of the extractive sector is the Responsible Mining Index Report, which summarizes the assessment of 40 large mining companies. The report includes results on the following issues: economic development, business conduct, lifecycle management, community well-being, working conditions, environmental responsibility, human rights, harm prevention, gender, and climate change. This effort is relevant not only

from an information perspective, but also from a digital tools' perspective, because the information can be accessed in an interactive way in an online platform (RMF, 2022).

Another aspect identified during the interviews as relevant to the Andean region is that countries are still working toward improving collaboration among all stakeholders. It has been found that digitalization, mainly the adoption of data systems and digital communication, has brought tangible improvements. At the company level, the usage of data systems provides real data to communicate a community's concerns (social revenues and investment reports). This interaction is also supported by the utilization of digital communication tools, such as WhatsApp® or email, that provide an accessible and easy way for the community to engage with the company's activities. The result is a strengthened relationship: the community can guide the company to where social investments can be more efficiently directed in order to meet pressing needs.

Another way to improve collaboration is working within the extractive companies, where the workforce has an interest in continuous training programs to increase technology access for workers who are older or who are less skilled. Recommendations along these lines have been put forth in previous reports[15] that explore the social and environmental impacts of mining operations.

In this respect, it is worth mentioning that the adoption of ESG standards contributes to overcoming three issues mentioned in this report within the scenario of digitalization: (a) the obtaining of the environmental and social licenses required to operate; (b) the minimizing of potential disagreements with employees and local protests, leading to negative impacts or reputational risks, and I the fit with the exigencies of buyers and investors related to companies in the extractive sector (BID, 2022).

In the public realm, **governments have benefitted from digital tools in launching training for small companies and using platforms that expedite licensing requests and communication between them and stakeholders,** especially extractive companies and local groups/associations. Moreover, the information gathered can be applied to governments' own strategic planning as well as the social insights they deliver to the community, such as environmental indicators and mitigation actions. Digital tools, by providing the flexibility and openness necessary for every'ne's needs to be discussed, can thus help to bring about consensus. Additionally, such tools offer transparency, which serves as an anticorruption measure and prevents the misuse of information.

In this sense, **one of the main drivers in the social dimension of the adoption of digital technologies is the need for transparency.** Effective communication channels enable companies to clearly transmit information about their social and environmental performance and their impact on, for example, the surrounding communities. This facilitates the renewal of the social license, which has become a requirement for the operation of companies in the extractive sector. See Box 4 for the example

[15]See Responsible Mining Index reports from previous years, for instance 2020 and 2021, at www.responsibleminingindex.org.

of Antofagasta Minerals, which formulated a digital strategy to improve communication and transparency.

4.1.2. Environmental drivers

As climate change events become more evident and global efforts are being oriented to a more sustainable and low-carbon economy, sustainability concerns have appeared in the radar of many industrial sectors. For the extractive industry, the current energy technology trends involving renewables deployment and energy efficiency interventions have driven companies to enhance all of their business with the help of information and communication technologies. The use of IT has revealed the importance of sensing, controlling, and monitoring activities along the extractive value chain to increase process and energy efficiency.

Moreover, **concerns about the sector's impact on the environment have driven the usage of data systems (e.g., data collection and analysis) and sensors at the company level, with the focus being on effective tools for pollution control, emissions reductions, and accident prevention and reduction** (e.g., in relation to oil spills and wastewater leaks). Companies in the Andean region are still making the transition to digital data gathering; nevertheless, they foresee an opportunity, in terms of the mitigation of severe environmental impacts, in the collection and analysis of more information that gives insights into the status of processes. These efforts may grow into the baseline work of adopting ESG standards if they have not done so yet.

For instance, in the interviews conducted, Ecopetrol (Colombia) shared that it is investing in an open data system that will serve as a data platform for extractive companies to anonymously publish their environmental key performance indicators (KPI), such as their water and carbon footprints. The goal is that these data will be drawn on in public planning and academic research, mainly to drive mitigation and circular economy actions.

In addition, **digital tools not only facilitate the control and monitoring of operations, but also compliance with environmental and safety regulations by generating information to prevent health risks and for reporting to the relevant authorities.** Along these lines, digital tools can accelerate the adoption of ESG standards by simplifying the adoption and compliance processes for companies.

In the Andean region, the public sector is starting to implement data systems for information control that will assist with environmental monitoring and compliance with environmental standards by companies. One example is the deployment of platforms where companies can update their environmental information. Governments in turn could use that information for identifying impact zones and implementing mitigation actions.

4.1.3. Economic, financing, and funding drivers

While the sector faces multiple challenges in its operations and its social and environmental impacts, on the demand side significant market opportunities are projected in the coming decades. On the road to decarbonization, economic opportunities of around USD 50 billion per year of fiscal revenues by 2050 have been identified for the Latin America and Caribbean region

(LAC) due to increased demand for minerals for decarbonization (IDB, 2022).

In this economic context, digitalization will play a critical role in leveraging the transition. Companies understand that becoming resilient is essential to weathering energy transition challenges, among them energy supply disruptions and price volatility. Companies' productive systems must achieve higher standards of efficiency in order to maintain satisfactory revenue levels and protect social interests and the environment.

Operational cost reduction and productivity optimization have become the major drivers for digitalization in the global extractive sector (Deloitte, 2017b). Real-time data collection, IoT, automatization, and autonomous devices not only raise companies' revenues, they also save resources. According to McKinsey (2015), digitalization has the potential to be a global market of around USD 370 billion annually by 2025 in areas of application such as operations management (USD 250 billion), equipment maintenance (USD 100 billion), health and safety (USD 10 billion), equipment supply (USD 5 billion) and employee productivity (USD 5 billion). These reflect the opportunities in the coming years for the global extractive sector to improve its environmental, social, and economic performance.

For the Andean region the scenario is similar, with economic concerns driving the digital transitions in the sector, along with environmental and social drivers. In the region data collection and processing at the company level are the most prominent technologies, as they facilitate data transparency, reliability, and open access. These translate into real-time knowledge of operations that supports better decision-making and offers a degree of certainty to current and future company investors. As one example of what is taking place in the oil and gas sector in the Andean region, Box 5 describes the case of Ecopetrol, a leading company in that sector in Colombia.

Box 5. Ecopetrol's digital strategy

Ecopetrol is an oil and gas company organized in the form of a public limited company, linked to the Colombian Ministry of Mines and Energy, that is active in all segments of the hydrocarbon chain: exploration, production, transportation, refining, and marketing. It has operations located in central, southern, eastern, and northern Colombia, as well as abroad. It has two refineries in Barrancabermeja and Cartagena.

Ecopetrol has reported that over the last few years it has designed a strategy for its digital transformation based on three key elements (Ecopetrol, 2022):

a. Value generation, in which USD120 million will be invested in 10 projects, which could generate close to USD 300 million in returns.

b. Innovation, which will be based on the implementation of a digital ecosystem as an engine of development, aligned with national objectives.

c. Transformation, through which new ways of working and capacity building will be devised to underpin the transformation of the organization.

Its strategy is made up of 10 projects focused on efficiency goals to be achieved via the use of digital technologies: blockchain, AI, IoT, and machine learning, among others. The first phase, initially scheduled for the end of 2020, is being implemented with the following projects (Ecopetrol, 2022):

- **Integrated fields and volumetric management.** Integration of digital enablers to provide real-time information on the production of all Ecopetrol fields.

- **Petro-technical database**. Digital solution by means of which more-accurate decisions about potential reservoirs through advanced analytical methods can be made in shorter times. Aims to reduce the time from evaluation to the start of exploration activities by 3.5 percent.

- **Integrated Transport Management – GREAT.** Digital solution that seeks to implement an integrated operating model for the transport segment, which will make possible exhaustive tracking of its products from start to finish.

- **Gross Refining Margin Optimization.** Tool to monitor and visualize refining information in Barrancabermeja and Cartagena in real time.

- **Integrated commercial management.** Integration of a comprehensive platform to visualize data and operate the relevant tools for trading, market intelligence, and logistics; the pursuit of risk management through more sophisticated risk modeling and optimized contract management; and the consolidation of data into a single repository, with the goal of using advanced analytics with real-time data.

- **Digital financial management.** Technological enabler that seeks to improve the monitoring of the flow of the Business Group's investments.

- **Central employee management.** Project that seeks to optimize, integrate, and fully automate the Human Talent Management process by generating a single, reliable, timely and consistent flow of information as the input for monitoring and decision-making.

- **Digital supply management.** Project that will strengthen the organization's contracting process through the integration of systems that support the purchasing process in the oil operation.

• **Document management.** A single repository for the General Secretariat's documentation that will enable management of information and regulatory risk.

• **Legal management.** Digital document bank that supports the company's legal decisions in a more agile, uniform, and secure way, leveraging technologies such as artificial intelligence and intelligent searches.

This process was accelerated during the pandemic agreement, when Ecopetrol was able to get 85 percent of its plants working remotely, which involved an investment of USD 120 million (Semana, 2021).

For extractive-sector companies, it is not just their economic performance, but also their social and environmental performance that more and more needs to meet the increasingly stringent requirements of investors, whether in the private sector or those who are mandated or regulated to finance the projects of these companies (IDB, 2022).

Responsible funding has become a crucial requirement along with the social license. ESG criteria are increasingly playing a decisive role in terms of where investments in the extractive sector are allocated. For instance, the Global Sustainable Investment Alliance (GSIA) estimated in 2020 that sustainable investment had reached USD 35.3 trillion in assets under management[16] which represents an increase of 15 percent in 2 years (GSIA, 2021).

One of the cross-cutting aspects observed in the interviews was the importance of digitalization in promoting sustainable investments within the framework of ESG criteria, in particular for projects under design and just coming into operation. **The concern was expressed that extractive companies are increasingly subject to demands from investors to comply with sustainable and social standards and practices.** At the same time, those in the sector are becoming aware that this represents an opportunity to provide differentiated goods from a minimum sustainable and social footprint point of view to upstream markets. These markets in turn can take advantage of the demands of, for example, the automotive industry, which is looking to manufacture vehicles with a lower environmental impact along the entire supply and production chain.

[16]According to GSIA (2021) the term "sustainable investment" is inclusive of investment approaches that consider ESG factors in portfolio selection and management. The given figure is associated with seven strategies of sustainable or responsible investment currently being pursued in Europe, the United States, Canada, Australia, New Zealand, and Japan.

4.2. Current initiatives and challenges

As expected, not all countries in Latin America have attained the same level of development. Chile, one of the most advanced in terms of innovation within the extractive sectors, is on the same level as Peru, where cybersecurity, information management, and automation have already been implemented. Further progress still needs to be made, but it is projected that in the next 5 to 10 years there will be greater technological maturity (GIZ, 2021). The successful strategy of a Mexican mining company is described in Box 6.

To realize these advances, IoT infrastructure, big data, machine learning, AI, and 5G networks will figure prominently (see Box 1 in section 3.4). The acquisition of these types of infrastructure, systems, and technologies will pave the way for remote operation, the importance of which was demonstrated during the COVID-19 pandemic (Gtd Perú, 2021).

For instance, an interesting case that came up during the interviews is that of Nokia, which has identified Latin America as a prime area for technology deployment, largely because significant mining activity takes place in countries in the region, specifically Chile, Brazil, Peru, and Mexico. One of the requirements when assessing the feasibility of digital solutions is connectivity. The first country in Latin America to have an industrial network[17] was Chile in 2018 and it was used in the mining sector. Now Nokia is working in more than 10 mines in that country.

Box 3. Social innovation

The metal producer Fresnillo PLC, based in Mexico, has been implementing improvements in its systems for several years to increase its competitiveness in terms of safety and production costs. The projects they have rolled out thus far are:

1. TrackPlus, real-time location of personnel and equipment within the mines;
2. ProxAlarm, proximity alarms to avoid collisions between equipment and people;
3. Ventilation Plus, on-demand ventilation systems that use sensors to ventilate when required;
4. MineOps Optimizer, real-time mine operation information that assists in the optimizing of operations;
5. Intelligent Plants, optimization of each mining unit through levels of control;
6. SmartOps, operational intelligence based on the integration of information collected (data analytics) that assists in decision-making and control and management of operations in each shift; and
7. OneView, use of storage systems at a single site to store all the information collected for dynamic reporting.

These technologies have brought operational efficiency to decision-making and optimization of processes and have reduced the company's costs (CIO, 2019).

[17]Industrial networks operate as private radio networks; only IT equipment (usually a Sim card) with the right credentials can access the specific network's frequency. Industrial networks can also be encrypted for more security.

Another country where connectivity was implemented was Brazil, with the experience that was gained then being deployed to other locations where the specific company was operating. Only in Brazil is the 5G frequencies eing tested for industrial use; in Peru, some communication services providers have shown interest. Nokia did help with a digitalization project based on 4G technology in Las Bambas in the latter country, which was successful despite having lower implementation speed compared to Brazil due to the complexity of the region and the involvement of more actors.

The fourth country where Nokia is working is Mexico where, in contrast to the other countries, there is an operator providing the spectrum service for private use that is interested in accelerating industrial digitalization in the country. Finally, although Nokia is not involved, Colombia despite despite not having significant mining activity is seeing some digitalization projects happening in coal mines to make operations more efficient and thus more competitive.

In the case of Colombia and Ecuador, digitalization is at a very early stage, as investment in large-scale copper mining is just beginning to flow in. The oil and gas sectors in these countries, on the other hand, have been forced to adopt communications technology in their value chains. Some new extractive developments in Colombia are making use of digital elements (GIZ, 2021): for instance, in 2020 alone the company Gtd Colombia (2021) deployed fiber optics in six Colombian cities for public usage, which is the beginning of the digital infrastructure that industry needs for advanced solutions such as AI and robotics (Meneses, 2021). Likewise, the Colombian Petroleum Association increased its investment for 2021 in exploration and production of oil and gas by 51 percent compared to the previous year; with the purpose to increase productivity using digitalization while achieving better communication and information flows that will make business operations more efficient and secure (Technocio, 2021).

In the case of Bolivia, digitalization initiatives are not yet underway, though there is significant potential for furthering the country's growth. Although the technologies used are still somewhat unreliable and not much development has taken place in the last decade, the government believes that the advances of "Mining 4.0" are a vital piece in the boosting of the development of the mining sector and the reducing of the sector's environmental impact (Ibáñez, 2021).

Mining 4.0, including digitalization, is particularly important because Bolivia has the largest lithium resources in the world, representing a latent opportunity for growth due to the industrialization of lithium and the addition of the entire battery value chain. Some actions that could further innovation in the sector have already been undertaken. For instance, in October 2019 Yacimientos de Litio Bolivianos (YLB) and the Bolivian company Quantum Motors signed an agreement with a private company to manufacture electric vehicles domestically with lithium batteries made in Bolivia as well. However, more actions must be taken to achieve the level of development required to advantage of the future market (El Pueblo, 2021; REDIMIN, 2020).

Despite the barriers, it was observed by interviewees that the governments of countries like Peru and Colombia do un-

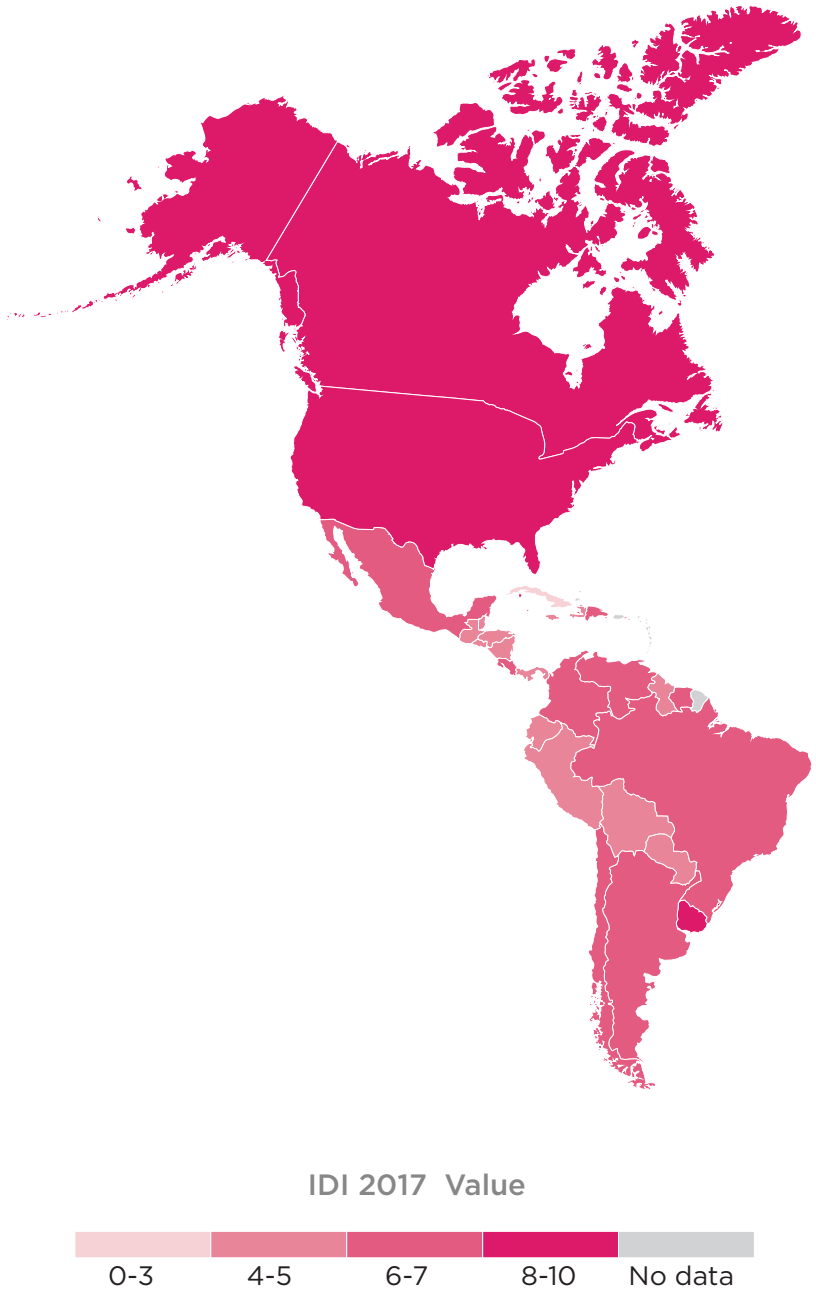
derstand the importance of collaboration among the different subsectors in the extractive industries to solve common challenges. While full transparency might still take some more years to achieve, private companies are starting to share certain types of information, e.g., environmental indicators, that bring benefits not only to them but to communities and governments as well.

Even though digital solutions offer substantial opportunities for the sector's improvement, there is a significant aspect to consider in the Andean region. During the interviews, it was mentioned that, as with many other sectors and geographies in the region, the perception of the availability of financing and the lack of understanding of how digital solutions can benefit the industry at the company level are big obstacles. Likewise, small- and médium-sized companies[18] present a greater lag in the adoption of digital technologies integrated into sustainable practices and energy efficiency. For digitalization, three factors have been recognized as contributing to this: a low level of technological knowledge and awareness, a lack of specialized staff, and inadequate visualization of the long-term benefits that these solutions will bring.

Figure 10 maps the development index values[19] as of 2017 for the Americas, which measure the adoption of information and communication technology. In the Andean region, the values are medium to low, with 4–5 points being the average for the region (ITU, 2017; Matthess & Kunkel, 2020). Moreover, Matthess and Kunkel (2020) show that the use of technology varies between sectors, with primary sectors such as mining and agriculture having low technological adoption, which in turn hinders industrial digitalization across companies of all sizes. The challenge lies precisely in expanding the use of digital technologies in the region and closing these digital gaps, not only in industry, but across all sectors, so that digital ecosystems can be created that work in an integrated, coordinated, and efficient way, thus generating the greatest possible benefit.

[18]According to IGF (2017), artisanal and small-scale mining (ASM) ranges from informal individual miners to small-scale formal commercial mining entities. However, the exact scale of ASM is unknown, given that many operating in the sector do so outside of formal economic and legal structures.
[19]The index is comprised of the following indicators: fixed telephone subscription, international broadband subscription, households with computers, households with internet access, people using the internet, domestic broadband subscription, mobile broadband subscription, average years of schooling, and enrollment in secondary and tertiary education.

Figure 10. Information and Communication Technology Development Index, 2017



Source: Based on ITU (2017).

It is crucial that the development of technology in the Andean region, as in Latin America and the Caribbean as a whole, advances in order to make the benefits of technology in the extractive sector and at the social level more affordable. This issue will be discussed in chapter 6, in which public policies to incentivize the creation of innovation hubs are described; these hubs could facilitate the acceleration of digitalization and the social capture of all the associated economic benefits.

05

Social, environmental, and economic spillovers of digitalization

All economic activities have social and environmental impacts to varying degrees. In the case of the extractive sector, its social and environmental impacts have been more publicly exposed, so social acceptance is a crucial issue. For some time, the sector has made a substantial effort to ensure the that there is a future for its operations, in particular by improving its economic and environmental performance in order to gain social approval.

The social and environmental impacts of the extractive industries have been extensively documented and have recently been incorporated into a more systematic analytical framework to develop indicators to assess industry performance (Mancini & Sala, 2018). However, the documentation and assessment of the impacts of digitalization on the economic and social performance of the sector have been undertaken to only a limited degree.

Among the relevant analyses regarding digital technologies in the Latin-American context is Calzada-Olvera (2022), who provides a panoramic view of the challenges and opportunities along the value chain for local suppliers. This is key, because awareness of how digitalization could positively impact the value chain would speed up the process in región. Molina (2017) narrows the focus to local mining suppliers in Peru in analyzing the factors that foster or hinder innovation. Stubrin (2017) likewise looks at a single country, Chile, in exploring the opportunities for innovation and diversification that open up in association with mining activities in developing countries.

The following sections aim to provide a general overview of the impacts of digital adoption in the extractive sector in the Andean region. The analysis relies heavily on the information gathered through the interviews, so most ideas and statements summarize the information from the interview sessions. Most quantitative reports analyze the impact of digitalization at the global level or in developed countries. In the Andean region, or more broadly in Latin America, the information that has been collected tends to be qualitative, focusing on the nature of the possible impacts without assessing their magnitude. One of the opportunities for future analysis is to explore the impacts over time through a particular diachronic case study. In this regard, the following sections describe some of the findings identified in the interviews and some other reports.

5.1. Social spillovers

Social impact is comprised of different dimensions and consequently this section has been divided into employment and health impacts. However, this section also discusses the effects of technology adoption in the extractive sector focused on communities as entities. The following is a general summary of the impacts observed in each of these categories.

5.1.1. Impact on employment

Any disruptive change has the potential to impact society directly and indirectly in either a positive or negative way (or both). By analyzing the impacts of digitalization on employment in the extractive sector, three groups of labor impacts that digitalization might bring can be identified: (1) the elimination of jobs due to automation and remote operation; (2) the creation of jobs related to the new equipment or that require cognitive skills, e.g. equipment/robot operators and supervisors; and (3) the creation of jobs arising from digitalization, e.g. programmers, robotic system designers, data analysts, and technicians and electricians who repair machinery (WEF, 2015).

The first conventional impact considered is employment loss, mainly as a result of the automation of tasks performed by workers in operational jobs. However, the growing demand for metals and minerals for the energy transition could offset this effect and even overcome it. In other words, new specialized roles will be created and others with routine tasks will be displaced. The opportunity to mitigate this effect lies precisely in the retraining and reeducation programs that will be needed to retain all the expertise associated with the affected jobs.

Repsol's upskilling strategy

This Colombian company is planning to upskill 70 percent of its current employees to support its energy transition goals. Repsol believes that digitalization will free up the working hours needed for upskilling and reskilling and that no jobs will be eliminated.
While it tests and develops digital tools, Repsol is taking steps toward the adoption of a new mindset needed to reach its goals. The company is planning to reskill and upskill its collaborators to create a "Data driven culture"; this will make the energy transition easier for all (Repsol, n.d.).

One potential action that can lessen the loss and/or displacement of jobs (IDB, 2021c) is the creation of tools or mechanisms to enhance the skills of workers and build a new generation of talent for the digital future (WEF, 2015). Companies have also made efforts to capitalize on the skills of people who could be used in other areas; by identifying new opportunities in other, less-mechanized activities, companies can minimize job losses.

This points up the importance of a more in-depth sectoral analysis that provides more-accurate data for estimating the net effect of digitalization on employment at the national or regional level across sec-

tors. For instance, the International Institute for Sustainable Development (IISD) has analyzed different scenarios in the OECD countries that project the impacts of automation on GDP, employment, and government revenues (Cosbey, et al., 2016). The three scenarios considered are reductions of 30, 50, and 70 percent in the workforce. In terms of GDP, between USD 7.2 million and 15.8 million less will be spent in-country in the high-income OECD countries and between USD 4.6 million and 8.9 million less will be spent in the lower-middle-income countries. With regard to direct and indirect job losses due to automation, the figures in the high-income OECD countries range from 1,016 to 2,372 and in the lower middle-income countries from 1,530 to 3,570. In terms of the impact on taxes, the projected reductions in government revenues range from USD 7.6 million to 17.8 million in the lower middle-income countries and from USD 31.7 million to 74.0 million in the high-income OECD countries.

Considering just the global mining sector, WEF (2017a) estimates that the potential loss of jobs around the world due to digitalization could reach 330,000 (about 5 percent of the workforce expected in 2025) by 2025. For instance, the adoption of automation technologies alone could displace up to 60,000 jobs (4 percent of the total) globally by 2025, which would have a significative negative impact on local communities in remote areas where mines are the main source of employment.

In the case of the oil and gas sector, WEF (2017b) estimates that the number of jobs displaced worldwide could reach 30,000 with the transition to remote operations. However, it is expected that this could be partially compensated for by the creation of about 20,000 jobs associated with the remote operation centers, where processes are monitored, and information analyzed in real time.

As discussed in section 4.1.1, a key aspect to be considered is the fact **that extractive activities heavily influence social conditions in the local communities**,[20] especially when it comes to small-scale extraction, where activities mostly occur in informal and unregulated settings and are in conflict with the local social license (GEA, 2019). This is important, because small companies do have not enough resources to make immediate changes; hence, direct employment is left unprotected, with major impacts in the case of redundancies. However, there is also a positive aspect: small companies tend to employ local staff, because they have a better understanding of the local social and business landscape, specifically with regard to culture, customs, and regulations (BDO, 2020).

The impact is not restricted to jobs created within the companies—it is felt along the whole value chain. Digitalization has a direct impact on indirect and induced jobs,[21] an impact that is greater in nearby

[20]An additional socially relevant effect of digitalization would be the increase in technical, industrial, and social innovations, which could strengthen the adaptive capacity of local individuals and institutions but possibly threaten human identity, social stability, and economic security (Morrar, Arman, & Mousa, 2017).

[21]When speaking of the impacts on the number of jobs, three types of jobs are commonly mentioned: direct jobs, generated by the companies or a project development; indirect jobs, related to the economic activities of the providers chain such as software development and telecommunications services; and finally, induced jobs, related to services needed as result of an increase in economic activities, such as retail, dining, and lodging, etc.

communities, which are usually directly dependent on the economic benefits provided by companies in the sector. Displacement of jobs might impact the local employment that exists due to the mining and oil and gas activities to different degrees. It is estimated that the local economies could see a drop in employment of up to 14 percent from direct, indirect, and induced loss of employment due to digital technologies (e. g., autonomous trucks, automatic machinery) (Cosbey, et al., 2016). And of course, the highest impacts would be experienced by communities in the most remote areas where there are few sources of employment.

Communities in which the economic system is totally dependent on mining activities could be drastically impacted in terms of the numbers of direct and indirect jobs (e.g., material haulers, construction personnel, fuel suppliers, waste collectors) lost. To make matters worse, a snowball effect can be generated where all induced jobs in the community are affected as well (IGF, 2021).

In summary, it is vital to discuss job impacts in the context of the early stages of digitalization, so that negative externalities are appropriately addressed prior to those impacts' being felt by individuals and society at large. The anticipated replacement of human functions by technology in particular will result in job layoffs and changing qualification requirements for new jobs, which will become more stringent as new skill and knowledge needs develop.

In this regard, with the aim of ensuring an equitable transition for all stakeholders, the Just Transition framework[22] has been developed to promote understanding of the cross-cutting impacts of the transition to a low-carbon economy (CSIS & CIF, 2020). The important point is to anticipate and manage the transition by strengthening collaboration with stakeholders and maximizing mutual positive impacts (IGF, 2021). Governments have a key role to play within these social arrangements in terms of mitigating the impacts, as will be discussed in a later section.

5.1.2. Health and safety

One of the main concerns in the industry is the reduction of risk to workers. From 2016 to 2020 1,443 fatal injuries associated with the mining sector were reported around the world and according to the International Labor Organization (ILO), mining occupies about 1 percent of the global workforce but is responsible for 3 percent of fatal accidents (ILO, 2022; 2003).

While unregulated extractive companies are known to have more uncontrolled and poor safety practices, unsafe activities and environments are seen across all types of companies within the sector. The continuous exposure to harmful situations and adverse conditions has caused digitalization to be recognized as a tool to reduce accidents.

One of the ways in which digitalization can help with risk mitigation is the use of information to adjust operations and anticipate problems. The uptake of information through sensors and the use of monitors and alarms have become tools for the identification and communication of risky

[22]For more information about the Just Transition Framework, visit the JTI website: usttransitioninitiative.org/a-framework-for-just-transitions/

situations (WEF, 2017a), which translates into better hazard management.

Moreover, data analytics can be paired with simulations to facilitate the optimization of production and protect employees' health and safety. An example of this is automation, where autonomous trucks, trains, and drills are connected to all components of the value chain and projected into a virtual replica of the plant that is accessible in real time by workers outside the mine (Srinivasan, 2021). These reduce the presence of persons in the field and thus the exposure to risky situations.

At a global level, the progressive usage of digital technologies could increase safety by saving close to 1,000 lives and preventing 44,000 injuries, which would be equivalent to a 10 percent reduction in loss of life in the global mining industry (WEF, 2017a). Altogether, safer environments would provide a higher quality of life to employees and their families, incentivizing younger generations to be part of the future workforce of digital extractive companies.

However, although technology develops more or less equally across the globe, the transition to digital tools has not been uniform, with the rate of deployment depending on the country, sector, and region context. In addition to large-scale mines, small-scale mines can exist in a region, sometimes operating in an informal and unregulated manner. In such an arrangement, it is difficult to monitor their performance in terms of health and safety indicators. The main problem is that this can generate an unvirtuous circle of poverty and leave workers without legal and social protection, given that informality puts them beyond the control and monitoring of the state or formalization efforts (GEA, 2019).

According to information collected from interviews, digital technologies could enable the reporting of environmental health and safety indicators to regulatory agencies by remote and technologically underresourced companies. Through simple online forms and quality assurance mechanisms, regulators could collect basic information for the timely detection of health and safety risks in small-scale mines.

In addition, tutorials can socialize a wider audience in the benefits of digital technologies such as remote sensing. In an optimal arrangement, public policies would be implemented that encourage, for example, the placement of air quality monitors in small-scale mines and the remote monitoring of them by public institutions that aim to promote public health and design policies that encourage it.

This could alleviate problems by "decreasing the isolation" of remote mines; by mitigating the impact on health, particularly for the most exposed workers, who are generally those with the lowest incomes; and by identifying the need for qualified personnel for both inspection and process improvement in regions far from population centers.

5.1.3. Community and company shared value

In all economic sectors social and environmental impacts play a role in the supporting and continuity of businesses. In the case of the extractive sector, these impacts have been focal points of public opinion, which has pushed extractive companies to improve their social acceptance

through communication and collaboration with local communities.

Therefore, it cannot be denied that extractive companies and local communities are interconnected—whatever they do will have a joint effect that will impact both sides. In the last few years, the concept of **shared value** has gained traction, as it is oriented to changing the focus of companies so that they seek collective value for all: company and community.

In the last few years, the concept of shared value is becoming more relevant in the extractive sector and in its relations with the communities. This framework assumes that the companies can bring value both to themselves and to the host communities. Shared value relies on rethinking business operations so that the sector's products do as little harm as possible and building supportive industry clusters at the company's locations, with a focus on mutually beneficial improvements in infrastructure, supplier capacity, and human resources (Cosbey, et al., 2016). Digital technologies present great opportunities to leverage mining governance in these regions through the following avenues:

- Education accessibility using electronic tools.
- Access to unlimited sources of information with repercussions for health and agriculture (e.g., online doctors, information on diseases, information on changes in rainfall and temperature rise) (IGF, 2021).
- Empowerment of women and girls by removing the physical and safety barriers that conventional extractive activities create (Ramdoo, 2021).

In the interviews, it was highlighted that in Bolivia, the persisting patriarchal perceptions as in many other places have hindered women from preparing themselves for higher positions in a "man-ruled" sector. This may stem from a lack of confidence on the part of women that the culture continues to reinforce, in part by limiting women to gender-defined roles in society (i.e., the nurturing of children and housekeeping) that reduce the education time women can reserve for themselves. At the same time, it was noted during the interviews that women are participating more and more in extractive sector activities in Bolivia.

In the case of small-scale mines in Bolivia, safety training programs have been targeted at men, but women have shown interest and have participated equally. Cumbre del Sajama, a company promoting social and sustainable development in Bolivia, has identified an increasing number of women who are small-scale mining operators. Interestingly, it has also identified differences between men and women in terms of participation in mining digitalization. For example, it has been observed that women are more careful when using tools, are more interested in gaining new skills, and are more disciplined; for instance, Cumbre del Sajama found that all the women who registered for training courses completed them successfully.

However, in the communities near extractive sites, women continue to have more responsibilities, as they take care of both the house and the children and so are usually overloaded, especially if they have a second job. The limited free time they have available, due to their social obligations, reduces their learning possibilities. Therefore, it has been noted that, from the

point of view of increasing gender equity, differentiated training regimes are needed so that women will be included.

Accordingly, Cumbre del Sajama has tried to provide training for women by using tools that can be accessed in the women's free time: for example, course information is passed along via messaging apps. However, only a small proportion of women who received the information read the material. Hence, because the issue is a complex one, more consideration of how to increase equal opportunities for women in the extractive sector is needed.

On a positive note, Cumbre del Sajama has increased interest in science, technology, engineering, and mathematics (STEM) topics on the part of women. For example, as part of the program "WIN Bolivia: Women Miners," a database of professional women was created who received information about training events. However, there is still a large proportion of women workers who are not participating. It seems that they are not taking advantage of the technology for continuous training due to the existing gender gap in the mining sector, mainly at the national level, and the strong patriarchal influence concerning what is expected socially from women.

Other social programs to leverage mining in creating sustainable local economic development have been created in the Andean region to ensure that communities near mining sites benefit as well as the industries. An example is the program "Beyond Mining: Economic Opportunities in Mining Communities," an initiative implemented by Anglo American, the Inter-American Development Bank (IDB), and the international nonprofit organization TechnoServe. Within this initiative, a regional plan was designed to achieve inclusive and sustainable socioeconomic development in Anglo American's communities of influence in Brazil, Chile, and Peru. The program, with funding of USD 5 million, aimed to have a direct impact on approximately 2,500 beneficiaries, leveraging strategic private investment to create value and future opportunities in order to positively transform mining communities (IDB, 2020).

As noted above, within a country the rate and scale of technology adoption varies, depending on the size and type of company. In the Andean region, small-scale mining operations usually have less adaptative capacity with regard to technology than big private companies. This differentiation at the company level is seen in Bolivia, where small-scale mining operations (cooperativas mineras) are lagging in terms of digitalization and environmental commitments, while regional and private companies are slowly making changes.

ANDEAN REGION

Communication among stakeholders

Andean extractive companies and public institutions have recognized that digitalization provides more control, access, and transparency to information about revenues, environmental key performance indicators (KPIs), employment, land planning, and environmental actions.
It can also be paired with digital communication in social media to strengthen the collaboration among local communities, extractive companies, and governmental institutions.

Cooperative mining operators in Bolivia acknowledge that the process of digitalization of their information is mainly driven by community demands. Communities are demanding better working and health conditions for the miners. For example, the San Cristóbal mining company in Bolivia has a very large community relations department, working on education issues in neighboring communities. While for them technology is very important, use has not increased signficantly.

Among the reported barriers the mining cooperatives face in implementing these technologies are economic concerns and limited knowledge of opportunities to learn about technology. It is necessary to work with technicians to carry out digitalization projects, staff members cooperatives cannot usually afford to have.

A big problem is that reaching people in certain geographic regions comes up against technological limitations. Cumbre del Sajama used digital technologies to do an online workshop on security instead of holding an in-person workshop. It was estimated that 70 people would attend, but in the end 210 did. The success in achieving higher participation was due in part to the use of incentives, such as gifts, certificates, and funds for travel expenses; another reason for the high attendance was that in addition to economic concerns, the amount of time the operators had available was taken into consideration.

This is where digitalization plays an important role in the control of and access to transparent information. In addition, this represents an impetus for governments to develop regulation around the issue. Limitations were reported in all countries by those who participated in the interviews regarding the capacity of governments to support these initiatives. Governments have been reactive for the most part, tending only to respond to problems and lacking a vision of the future of the sector. In other words, the policy component is complicated by multiple problems, and thus far has not been treated proactively, so that long-term planning and direction are absent.

5.2. Environment

Actions toward improving industries' environmental footprint have intensified especially in recent years due to the phenomenon of climate change. While digitalization could promote the efficient use of resources (e.g., water, electricity, fuels), it could also increase the demand for electronic equipment (i.e., sensors, PLCs, processors), which would result in a greater environmental impact on the part of the electronic sector.

The implementation of digital technologies in the extractive sector could reduce global emissions of CO2 by 610 million tons over a period of 10 years, representing an economic value for society and the environment of USD 30 billion (WEF, 2017a). For instance, the utilization of sensors for ventilation-on-demand applications in the Goldcorp mine in Quebec, Canada, has cut the operation's electrical consumption in half just by detecting where and how much air needs to be pumped into the mine (IGF, 2018) .

In the oil and gas sector, digitalization could reduce oil spills through pipelines by the equivalent of 43,000 barrels, potentially saving 66,000 barrels in upstream operations between 2016 and 2025. Therefore, accident prevention in the sector could contribute directly to the mitigation of the emission of around 20 million tons of CO2 globally (WEF, 2017b).

5.3. Economic and finance

As mentioned before, digitalization is primarily seen as an opportunity to increase the competitiveness of companies transitioning to a low-carbon economy. WEF (2017a) makes the case that companies that take the lead in technological adoption will have substantial opportunities to increase their value by 2025 because they will be more responsive and resilient in the face of challenges as well as more-sustainable and transparent organizations.

As in the mining sector, multiple benefits from the implementation of digital systems in the oil and gas sector have been identified. For example, WEF (2017b) estimates that USD 220 billion of potential value could be captured for the industry and USD 10 billion of potential value for society between 2016 and 2025.

ANDEAN REGION

Blockchain in Colombia

In Colombia, ANM and Ecopetrol are utilizing blockchain for data traceability and reliability along the entire extractive value chain. ANM expects that blockchain will open up banking options for small-scale mining operations, which currently do not have access to such services, thereby promoting investment opportunities.

WEF (2017a) estimates that at the global level the digital transformation could generate economic impacts of USD 425 billion for customers, society, and the environment by 2025, which is equivalent to 3 to 4 percent of the extractive sector's revenues. In addition, it would generate about USD 320 billion of value for the industry by 2025, of which USD 190 billion would be associated with the minerals sector and USD 130 billion with the metals sector, representing about 2.7 percent of industry revenues and 9 percent of sector profits.

One of the technology trends in the extractive sector across the globe is cognitive technology to improve exploration and production activities and thus increase productivity. Another is the integration of big data mechanisms with geopolitical and economic global aspects (oil and gas prices, oil availability, among others) to speed up business insights and strategic decision-making (Box 7). Moreover, public, and private extractive actors are using blockchain technology for safer and more consistent information gathering, information that can be shared among shareholders to verify products. For example, Repsol will use blockchain to make quality certification of products more efficient, potentially saving EUR 400,000 through the optimization of Repsol's samples processing, labeling, and data interlinking among energy companies, regulatory bodies, and customers (Repsol, 2019). Data traceability

and credibility also open the door to new forms of investment for small-scale and medium-sized extractive companies such as crowdfunding.

Box 7. Repsol's digital strategy

Repsol has recognized that in order for it to achieve net zero emissions by 2050, digitalization must play a fundamental role. The company believes that technological tools that optimize processes and operations will drive its emissions reduction, add security and reliability to operations, optimize assets, and support an agile posture in regard to external changes. Some of these tools are automatization, value chain and AI integration, customer engagement digital platforms, and smart energy optimization (Repsol, n.d.).

In 2014, Repsol and IBM joined forces to launch the first cognitive technology that will improve exploration and production activities for the oil and gas sector. This project integrates big data collection and interpretation with geopolitical, economic global aspects that will speed business insights and strategic decision-making (Repsol, 2014).

Besides efficiency improvement, such solutions can impact an entire country positively. For instance, Solomon and van Klyton (2020) show that information and communication technologies in African countries have positively impacted those countries' economic growth.

However, the efforts have lost momentum and the economic prosperity expected from digitalization has not materialized due to inequality, skills shortages, infrastructure deficits, and the high cost of infrastructure. Additionally, some local policies have limited the usage of global e-payment and web hosting to African-based businesses (Solomon & van Klyton, 2020). This example is particularly relevant for the Andean region, which has medium-low IT adoption and levels of digital inequality that remain significant (Mendoza-del Villar, et al., 2020). This issue highlights the need for developing countries to orient their workforce development and policies to the new IT demands.

Another concern about digitalization in the sector is that even when the companies' bottom lines benefit greatly due to a rise in productivity and lower payrolls (from the reduction in jobs), the very dependent local economies will feel the negative effects from direct, indirect, and induced employment loss. For instance, from just a 14 percent drop in locally purchased fuel, the GDP reduction can reach up to USD 15.8 million for high-income countries and up to USD 8.9 million in lower-middle-income countries, and furthermore the local procurement and job losses are not the only impacts to the host communities and regions (Cosbey, et al., 2016).

Because digitalization will require high-skilled personnel earning higher salaries and will generate superior revenues (due to higher productivity), it is expected to bring higher tax revenues for governments. Nevertheless, the negative effects on direct government payments will not be mitigated. In other words, government revenues from income taxes associated with direct, indirect, and induced jobs will be reduced up to USD 17.8 million in lower-middle-income countries and up to USD 74 million in high-income countries (Cosbey, et al., 2016).

One of the crucial questions in terms of the mitigation of negative impacts is whether it is possible for both extractive companies and local governments to take actions to minimize negative impacts and to ensure that local populations capture many of the benefits created. Policies that could assist in mitigating impacts are discussedin chapter 6. Box 8 is an example to highlight the negative effects.

Box 8. Intelligent coal mining in China

Between 2011 and 2015, the Chinese government implemented the 12th Five-Year Plan, which included digital technology. During this period, the greatest improvements in intelligent mining were achieved. The main system developed in the mining sector was a hydraulic-powered support system that enables remote operation with a single person working on-site—other words, an intelligent mining model (Wang & Huang, 2017).

A variety of technologies were developed. Among the achievements of the government were intelligent equipment for mechanized mining, information transfer, dynamic decision-making, and performance coordination, as well as the improvement of the reliability of working conditions (Wang & Huang, 2017).

The current Chinese technology in an intelligent mining operation provides control systems that enable automatic production and monitoring by a safe remote-control center at the surface. The system includes a web-based interconnected set of cameras, sensors, lasers, a shearer, hydraulic-powered support, conveyors, a hydraulic station, and a power station. The management of each set of equipment is centralized using control center software (Wang & Huang, 2017).

The main benefit of this intelligent system is that working conditions are much safer. In addition, less manual labor is needed, response time is faster, coal yields are higher, and economic performance is considerably stronger. However, it is estimated that during the 12th Five-Year Plan, the workforce was significantly reduced from 30–50 positions to 5–7. No information is available about whether workers have been retrained (Wang & Huang, 2017).

06

Innovation, policies, and regulation

Governments have great potential to become the key enablers of the accelerated adoption of digital technologies in the extractive sector. One of the biggest barriers to overcome in the Andean region is the risk aversion in relation to the adoption of new disruptive technologies, particularly because of the scarcity of specialized technicians. Governments could establish development hubs that serve as pilot centers for new technologies, that is, as specialized educational training centers, which could function as interlocutors between academia and industry. This could trigger public-private synergies that accelerate the adoption of not only of digital technologies, but of others as well.

The intervention of governments is justified in those areas where there is no incentive to coordinate all stakeholders. Governments have the capacity to generate regulations, laws, and economic incentives with the aim of overcoming the barriers that otherwise will persist. In other words, some barriers to the implementation of digital solutions are due to the lack of incentives such as policies, standards, and other regulatory tools.

The areas in which governments can directly leverage digital adoption strategies can be broadly categorized as follows:

- data management and information systems,
- transparency and traceability,
- digital ecosystems, and
- innovation barriers.

In the following sections, this report describes the role of governments in implementing institutional and regulatory arrangements dealing with the areas just mentioned with the aim of fostering the deployment of digital technologies nationwide. The opportunities and barriers are presented so as to provide a better understanding of the situation in the Andean region.

6.1. Data management and information systems

The implementation of digital solutions in the extractive sector poses a challenge in many domains, but especially in information management. The design and implementation of systems for the collection, storage, and management of information require not only actions on the part of companies, but also the establishment of regulations addressing topics such as ownership, privacy, and security of information handling. For instance, a lack of standards in terms of information formats will prevent interoperability among companies, communities, and governments. Similarly,

data security without a proper framework could lead to the theft and misuse of information.

In fact, a relevant concern about the rapid growth in IT technology is privacy. The sharing and tracking of information can lead to disclosure and loss of control over data, which is detrimental for both people and organizations. This is a major reason why it (the protection of privacy) represents a challenge for governments, policy makers, and society (Morrar, Arman, & Mousa, 2017)

Moreover, such systems require capable human resources, so training in the relevant technical fields is a must for strengthening capacities. These fields include the administration, storage, and processing of statistical information, as well as those related to the adoption of the automating systems that use state-of-the-art tools and to the improvement of the sector's information management and energy planning models.

Through the use of information systems, companies and local governments can harmonize a method for generating technical, economic, and social information using standardized concepts, promoting comparability at both the regional and global levels.

For instance, in Colombia ANM has adopted digital solutions to fulfil the duties that the Law 1753 assigns to the agency.[24] ANM is charged with (1) designating the geographic areas with high mining potential[25] within the Strategic Mining Reserve Areas (Áreas Estratégicas Mineras, AEM), and (2) choosing the interested actors that can obtain the corresponding mining titles. The agency has partnered with a private technology company to develop a PoC in blockchain technology that will facilitate the execution of these duties. The usability, credibility, confidentiality, accessibility, and integration of data will provide more information certainty not only for the agency but for international customers and investors as well.

Likewise, subnational governments, such as municipalities, could use the tools to support decision-making and the development of local planning. For instance, information could be used to relate sectoral growth and demographic characteristics to the social patterns of the local communities. This would deepen understanding of social patterns and how companies and the local population use infrastructure and services. In addition, this type of information could serve as inputs for generating forecasts concerning geographic and environmental risks or socioeconomic impacts, forecasts that could support planning processes for both companies and subnational governments.

[24]The Law 1753 of 2015, whereby the National Development Plan is issued, states that the National Mining Authority shall determine the minerals of strategic interest for the country, for which, based on available geoscientific information, it may indefinitely delimit special areas that are free (PND, 2015).
[25]Resolution 18-0102 of 30 January 2012, by which minerals of strategic interest to the country are determined to be of strategic interest to the country, lists the following minerals as being of strategic interest to the country: gold, platinum, copper, phosphate minerals, potassium minerals, magnesium minerals, metallurgical and thermal coal, uranium, iron and coltan (MINEM, 2012).

6.2. Transparency and traceability

The environmental and social performance of the extractive sector has been and continues to be at the center of public discussion, because of the economic, environmental, and social impacts at both the local and regional levels. Accordingly, environmental and social performance indicators have been used for many years, but their scope has been restricted by the lack of availability of and means of sharing information. Digitalization opens the door to multiple opportunities for improving the data collection systems that serve for indicators tracking, analysis, and dissemination.

For instance, during the interviews that were conducted as part of the research for this report, tools to mitigate environmental impacts and achieve socio-productive inclusion in the full supply chain by providing full traceability were mentioned. This could be done through interconnection among various aspects, including geo-information on landscape, satellite monitoring, georeferencing of rural properties, blockchain systems, and the design of risk maps, which cross-reference maps with operations, making it possible to identify the areas more prone to negative environmental impacts.

In the extractive sector, information systems could leverage transparency and traceability by establishing, for instance, economic, environmental, or even social benchmarks. Such systems could help in assessing the performance of existing and new utility models by supplying the base information needed to identify opportuni-

Box 9. Sustainable mineral supply and traceability

Digital sustainability initiatives have been implemented around the world. For example, SveMin (Swedish Association of Mines, Mineral and Metal Producers) has created a traceability system called **TraceMet.** The objective was to develop a functional IT system to trace certified metals from mining to end use, with the key criteria being the carbon footprint and the amount of recycled material.[26]

Another example is the creation of new frameworks for responsible sourcing. In the case of cobalt, which used in the manufacturing of lithium-ion batteries, the major producer is the Democratic Republic of Congo. There, the key actors face a trade-off involving providing a long-term supply versus reducing the risks associated with cobalt sourced from locations with environmental and human rights problems **(Mugurusi & Ahishakiye, 2022).**

Mugurusi & Ahishakiye (2022) analyzed the link between existing blockchain technology frameworks in the cobalt industry and ESG performance of companies. The use of these frameworks is intended to help companies audit their chain-of-custody journeys and ultimately their sustainability performance, based on traceability's being a mechanism to monitor and analyze sustainability aspects.

[26]More information can be found on the website of the project: www.svemin.se/en/project-traceable-metals-for-a-sustainable-future/

ties for increasing efficiency. In brief, information systems are crucial for monitoring and verification; furthermore, the generation of consistent information could help in assessing performance across the sector. In order to ensure an impartial, effective, secure system, governments through their specialized ministries should take responsibility for the administration and regulation of these systems and the establishment of the rules of operation, as well as the monitoring and verification of information.

6.3. Digital ecosystems

The concept of the digital ecosystem cannot be restricted to one set of interconnected information technology resources functioning as a single unit within an organization. Rather, it is increasingly clear that it involves a range of stakeholders interacting through digital channels. In this way, a digital ecosystem should be understood not only from the point of view of digital resources, but also as a set of suppliers, users, regulators, etc. whose impact is not linear and whose interdependencies exist through mutual feeding, use, and monitoring.

In the interviews phase, the importance of the creation of digital ecosystems was a recurrent topic. In the extractive sector, three main stakeholders can be distinguished that potentially make up the digital ecosystem: extractive companies, local communities or the public at large, and the public sector. On the extractive companies' side, the systems for generating, transmitting, and storing information for conducting operations, tracking performance indicators, and informing decision-making are part of this digital ecosystem, particularly the dissemination of information on their environmental and social performance to the public, whether on their own initiative or in response to regulation.

Governments also use the information provided by companies for monitoring the operations of the latter as part of their regulatory duties, as well as for creating information systemas about energy, production, and economic aspects. In addition, governments function as guarantors of privacy and security in terms of the storage and transmission of information.

One project is currently underway in Colombia, where Ecopetrol is currently working on pilot programs with 5G technology. The company had to apply for a special permit to utilize this type of network, because there are no regulations concerning this technology in place. In the process Ecopetrol worked closely with the Ministry of Science, Technology, and Innovation to help develop a safety framework for adopting IT solutions in the country, which served as a guiding example for the implementation of 5G technologies.

Among the other important aspects are the innovation systems and platforms that serve as drivers for new technological development in the region by drawing in local talent. According to WEF (2017a), innovation ecosystems not only unleash the innovation process within companies, they, if extended to communities and govern-

ments, could be powerful tools in generating information for decision-making.

For instance, an innovation ecosystem could feed digital platforms integrating KPIs that could be used to link companies' operations to local development. An innovation ecosystem thus has the potential to improve sustainability and local growth while simultaneously opening up investment possibilities (WEF, 2017a). These in turn could translate into growth opportunities for suppliers that can help with meeting projected demand for employment and subsequently for housing, utility provision, roads, and other services. The result would be improved planning at all levels: companies and local communities and governments.

Governments have a vital role here as facilitators. They are uniquely positioned to establish platforms that encourage the sharing of the widest variety of data (on topics ranging from the whole value chain to social development) among different key actors to enable decision-making while safeguarding privacy.

Box 10. LTE network in Toquepala Mine, Peru

The Toquepala copper mine, located in Tacna on the border with Chile, has a conventional open pit operation that began in 1960. It is operated by Southern Peru Copper, a subsidiary of Grupo Mexico.

In May 2021, it was announced that the mine had acquired a Long-Term Evolution (LTE) network that will enable 4G connectivity in its operation, making it the second mine in the world to have a dual core 5G network from Huawei, a company that is supporting Toquepala's technological transition. This technology is expected to drive the introduction of autonomous trucks, smart shovels, remote critical operations, and augmented reality, among other innovations (Huawei, 2021) (HUAWEI, 2021).

Peru already has six LTE networks, but this new one will be built on a standalone 5G core that will be the first of its kind in the country. For the time being, the network will be used with 4G technology; when the relevant legislation is passed, the network will switch to 5G (Huawei, 2021).

6.4. Barriers to innovation

Despite the incentives at all levels to adopt digitalization, a critical issue that the Andean region is facing is the establishment of specific policies and regulations that incentivize companies to transition to digital solutions. This could be understood as being related to behavior, which is part of the innovation process between competing companies.

Latin America, for example, faces what can be called the innovation paradox, which is a situation in which both the public sector and especially the private sector underinvest in innovation activities, regardless of the high returns innovation can yield.

Crespi (2015) analyzes the rationale behind a company's decision not to invest when

the company is confronted with a highly profitable investment opportunity. The author suggests that this is because there are several anomalies in the market when dealing with innovation. For example, once something is produced by a company, it becomes available to all of its competitors to use for their own benefit. Companies do not want to invest in a type of good or service that will not be proprietary. This is where the anomaly arises: companies know that innovation is profitable, but prefer to wait for someone else to do it first.

This is precisely why **public policies and institutions need to push the innovation process forward, coordinating and stimulating the digital ecosystem.** An example would be the promotion, by government agencies that manage innovation, of programs that foster competitiveness and improve the economic and environmental performance of a sector while generating social benefits.

According to the information gathered during the interviews, one of the biggest challenges that the companies in the extractive sector face is overcoming the risk aversion that slows the adoption of disruptive digital technologies. In particular, when considering new technologies, the question comes up of whether a specific technology has been thoroughly evaluated beforehand. A relevant case in this respect is Chile, where pilot centers were created as external entities with government subsidies to vet different technologies. In addition, the use of the technologies was certified, which reassured companies that were considering the adoption of those technologies. Box 11 describes Ecopetrol's implementation in Colombia of a strategy to find local solutions through an innovation initiative that made the company more resilient in the face of the COVID-19 health emergency.

In the case of Chile, the Senate Commission on Future Challenges, Science, and Innovation[27] produced a report titled "Chile has a future from its territories" (CDF, 2022) that addresses various scenarios for future growth. One of the sections deals with developments in AI, which in Latin America are perceived as disjointed, because in no country is there a vision of specific objectives. In the case of Latin America, less than 5 percent of governments' public budgets are allocated to research and development; moreover, the efforts of academia, industry, and governments are not fully aligned, so there is still a long way to go in the region.

Finally, it has been observed that **efforts between industry and academia are not coordinated,** because industry uses open innovation systems with the objective of bringing technology to market. However, these initiatives do not consider near-term technologies that have a sufficient level of maturity to be incorporated quickly. Industries do not have clear strategies on how to build these solutions; they assume that knowledge will be generated abroad, but they do not know how it will be generated locally.

[27]For further information, visit https://www.senado.cl/appsenado/index.php?mo=comisiones&ac=-ficha&id=941

Box 11. Ecopetrol's resiliency strategy

In 2020, the oil and gas sector faced a huge decrease in demand that severely impacted the price of commodities, leading to economic losses for the sector. Nevertheless, Ecopetrol, the biggest oil and gas company in Colombia, managed to make a profit that year, thanks to the changes the company had been implementing since the 2014 oil crisis when the company was pushed to optimize its processes (Semana, 2021).

The flexibility and resilience Ecopetrol demonstrated during the COVID-19 pandemic showed how solid the company had become. From January to March 2021, its revenues were USD 821.7 million. Due to the company's transition to digital solutions, 85 percent of the workforce was able to work remotely without affecting productivity. Felipe Bayon, Ecopetrol's president, explained to the journal Semana that the company had invested around USD 120 million in technological innovation (Semana, 2021).

Digital technology has transformed Ecopetrol in a pioneering company. Its "Digital industries" space has seen the development of more than 450 solutions related to blockchain, AI, and machine learning that have helped in many ways, e.g., with assignment of employee bonuses, logistics, and wastewater treatment and reuse. The most remarkable solution was the creation in 2018 of "bots," informatic programs that automatically performed repetitive activities involving the internet that nowadays are used to perform key daily operational activities regarding finance and accounting (Semana, 2021).

As part of Ecopetrol's social commitment, at the beginning of 2022 it launched an open innovation initiative called "Reto 100 x100" in order to find the people and digital ecosystems that could solve 100 problems that the company is currently facing regarding AI, analytics, and robotics. This initiative provides growth opportunities to local entrepreneurs in Colombia and assists the development of the new digital ecosystem vital to the country's transition to the 4.0 technologies. In this way everybody benefits: the company, local businesses, and the whole country (Ecopetrol, 2022).

The challenges, as the company calls them, are to be developed throughout the entire value chain, (i.e., refining, exploration, production, and transport) and are supported by "CEmprende," the biggest entrepreneurial and innovation center in Colombia. The first two challenges launched promoted safe workplace behavior and counted how many employees were working inside the company's premises in real time (Ecopetrol, 2022). Moreover, Ecopetrol is keen to undertake many other projects and discover other new technologies.

One of the objectives is that academia be funded so it can generate the knowledge that is needed. However, resources for colleges and universities are scarce, because governments must attend to the needs of the entire country. For example, during the COVID-19 health emergency state funds for innovation and research were not directed to mining but to public health. A government's science and innovation policies must play a role in generating the public-academic conversation, in addition to generating other countrywide strategy conversations that anticipate where the country's context is headed.

In Colombia, Ecopetrol creating an Entrepreneurship and Innovation Center for the public where children can learn about cybersecurity and other topics related to STEM careers. At the same time, this center will foster the development of pilot programs and capacity building around emerging business ideas for the new low-carbon economy that are open to all actors: academic, public, and private organizations. These public-private partnerships offer the opportunity for collaborations in which the best of both sides enrich and support all actors. Such collaboration has already influenced Ecopetrol to create pilot programs around green hydrogen production, leading to the building of the first Proton Exchange Membrane electrolyzer in the country.

Another example of public-private partnerships is seen in Peru, where the Energy and Mines Ministry (Ministerio de Energía y Minas, MINEM) together with CMSP and SAMMI are working to develop new initiatives for digitalization adoption. Although still in the early phases, the initiatives are improving the financing opportunities for those companies in the sector that have not adopted these technologies.

Governments must ensure that the actors are aligned so that future efforts are focused in order to progress quickly, because this is not happening presently. The risk is great that the majority of personnel are formulating solutions and using tools that already exist, but that no push is being made toward generating new mechanisms to replace current ones and evolving other tools to achieve disruptive solutions.

Likewise, governments must ensure that the benefits generated by innovation in digital technologies are maximized from a social perspective. The financial benefits of increasing efficiency and productivity resulting from technological innovation should not be captured only by companies. Instead, companies, governments, and communities must work toward achieving a shared value. The positive outcomes of the use of these technologies can also increase local social revenues and prevent environmental degradation (IGF, 2018).

07

Conclusions

The energy transition is making a direct impact on the demand for goods supplied by the extractive sector. The mining sector will have to adapt to the demand for increasingly specific and scarce minerals and metals, while the oil and gas sector will need to respond to the demand for including the production of alternative fuels, for instance hydrogen and biofuels, in its energy portfolio. **The extractive sector should look at the adoption of digital technologies in the coming years as a strategic action that would enable the sector to meet the challenges posed by the energy transition.**

Digitalization has generated new opportunities that are not limited to increasing operational efficiency, as they also hold the promise of boosting environmental and social performance. The adoption of digital technologies has an enormous potential to leverage the social license, mainly through the enhancement of transparency, something more and more people in the Andean region are demanding. With an eye to sustainability and the social performance of projects, companies and governments should rely on communications strategies that involve digital media and technologies with the aim of promoting public and corporate transparency, accountability, and public participation.

By extension, **the adoption of digital technologies has the potential to leverage the social license in diverse aspects, mainly through enhancing transparency, as some cases across the region involving the usage of cell phone communication have shown.** Digital technologies can be powerful tools for ensuring accountability, where companies assume responsibility for their actions and spillovers whether they have either positive or negative impacts—or both—on society. The strategies involving digital technologies may build relationships between companies, communities, and governments. In the coming years, disclosing sustainability and social data will be increasingly crucial to providing an accurate overview of the efforts being directed toward the improvement of sustainability performance.

If the transition is responsibly managed, technological advances could improve the quality of life in local communities. At the same time, these advances could create barriers to employability for those who do not have the necessary skills. This could result in the displacement of personnel from the nearby locality to other areas and vice versa. Therefore, digitalization strategies must not only be oriented to improving the economic performance of the companies, they must be complemented with actions mitigating negative social impacts, in particular the displacement of jobs. A policy that integrates training with new opportunities for displaced workers could offset the negative impacts of digitalization.

Moving beyond the immediate community and even the country in which a company operates, **social and environmental performance, along with the economic indicators of the extractive companies, are becoming mandatory measuring sticks from the point of investors.** Moreover, in light of the growing demand for metals and minerals needed for the energy transition in the coming decades, the mining sector must be able to meet the environmental and economic demands of investors who are mandated to finance their projects.

The extractive sector in South America is being affected by all of these changes. In

Peru, Ecuador, and Colombia in the Andean region as well as in Chile companies have begun to adopt technologies that will enable them to remain competitive. Nevertheless, the digitalization of mining in particular in the region continues to lag.

In the case of the Andean region, **the low level of technological adoption presents major challenges for the deployment of digital solutions, particularly in the case of companies that either rely on legacy physical capital or operate on a small scale.** For new and large-scale companies, the integration of digital technologies is not a decision, it is intrinsic from the conception of an extractive project to its operation.

Some cases of the full adoption of digital solutions have been observed in the region, i.e., large companies that have recently begun operating and are using fully digitalized processes. In contrast, companies that have been established for decades face the dilemma of continuing with conventional technological methods that are sufficient to keep their operations running or jumping into the new era, which entails investing in technologies and assuming the risks associated with their implementation.

In this context, governments should play a key role by enacting regulations that address technology-related concerns such as ownership, privacy, and security in information handling. The sociopolitical situation of each country can be both a barrier to and an enhancer of the adoption of digital technologies. **Governments should formulate policies that ensure the security of information sharing and storage, so that innovators can capture the benefits of the innovations**. In addition, governments should establish development hubs that serve as pilot centers for new technologies and as specialized educational training centers that serve as interlocutors between academia and industry. These have been useful for advancing technology adoption in Colombia. This could trigger public-private synergies that accelerate the adoption of not only digital technologies, but of other types of technology as well.

As more companies in the region, such as Ecopetrol in Colombia and Anglo American in Peru, take the lead in digitalization, more acceptance of such technologies could occur. There is a growing interest in adopting these solutions to improve the sector's competitiveness and to increase the economic benefits for countries in which the sector's companies operate. The governments of Andean countries have realized that public-private collaboration must drive the changes that support the sector's efforts to improve its social and environmental impacts. For this part, companies in the extractive sector have come to see digitalization not only as a productivity strategy, but also as a tool for bringing about more collaboration and engagement among stakeholders while considering social and environmental needs.

Annexes

Acknowledgments

In preparing this report, we relied heavily on the information various specialists in the field of digital technologies in the extractive sector provided to us.
We are grateful for the participation in the interviews by the following people, who kindly shared their time and expertise on various aspects of this report's subject:

Table 3. Interview participants

Organization	Participants
Cluster Minero Andino (SAMMI; Andean Mining Cluster)	Daniel Escalante
Innovación Minera del Perú (Peruvian Mining Innovation)	Pamela Antonioli De Rutté
Private companies	
Anglo American	Carlos Manuel Ojeda Chávez
Ecopetrol	Carolina Ocampo-Maya Ernesto José Gutiérrez María Clara Otalvaro Rendon
Nokia Digital Industries Latin America North	César Augusto Vásquez
Public organizations	
Agencia Nacional de Minería, Colombia (National Mining Agency)	Cristina Andrea Becerra Bustamante María Alejandra Espinosa Curtido
Cluster Minero del Sur (CAF; Southern Mining Cluster)	Benjamín Quijandría Diaz
Local governmental and nongovernmental entities	
Asociación Colombiana de Minería (Colombian Mining Association)	Ana María Zamora
Linkminers	Emilio Gómez de la Torre Gutiérrez

Organization	Participants
Consultancy firms	
Cumbre del Sajama Consultants	Ana María Araníbar Jimenez
GERENS	Vinio Floris
LQG Energy and Mining Consulting	Ricardo Labo
Academia	
Pontifical Catholic University of Chile	Juan Carlos Salas

Table 4. Interview questions

Main question	Secondary questions
1. Why is digitalization important for your company?	• Economic reasons? • Social reasons? • Policy reasons? • Environmental reasons?
2. Where are the innovative digital opportunities happening across the value chain in your company?	• Procurement of inputs? • Processes? • Storage? • Transport?
3. What are the key technology trends that are being observed in your sector?	• In what digital solutions is your company a leader in Latam, e.g., robotics, remote viewing, VR, autonomous machinery? • In what digital solutions is your company a laggard in Latam? • What is the rate of adoption of the digital solution (XYZ) compared to other international efforts? Low/medium/high?
4. Who are the key players in your sector leading the adoption of digital solutions?	• What companies are leading?
5. When are/did these digital solutions happening/happen?	• What would be the ideal conditions for deciding to implement a digital transformation?

Main question	Secondary questions
6. What are the major challenges to this? **Are you aware of policies and regulations that have had a positive impact in the adoption of digital solutions in your sector?**	• Unfamiliarity/Resistance to change? • Budget/Finance? • Cost/risk of pioneering? • Employment, upskilling, or high-skilled professionals availability? • Local infrastructure and technological development? • Regulation and policies (e.g., patents)?
7. How would innovation/digitalization benefit the local community?	• Local development (higher economic activity)? • Education? • Income? • Gender equality?
8. Key lessons learned from adopting and implementing digital technologies in your companies?	• What did the company want to get from the digitalization? • What were some unexpected benefits or challenges for the company?

Table 5. Readings by topic

Energy transition

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