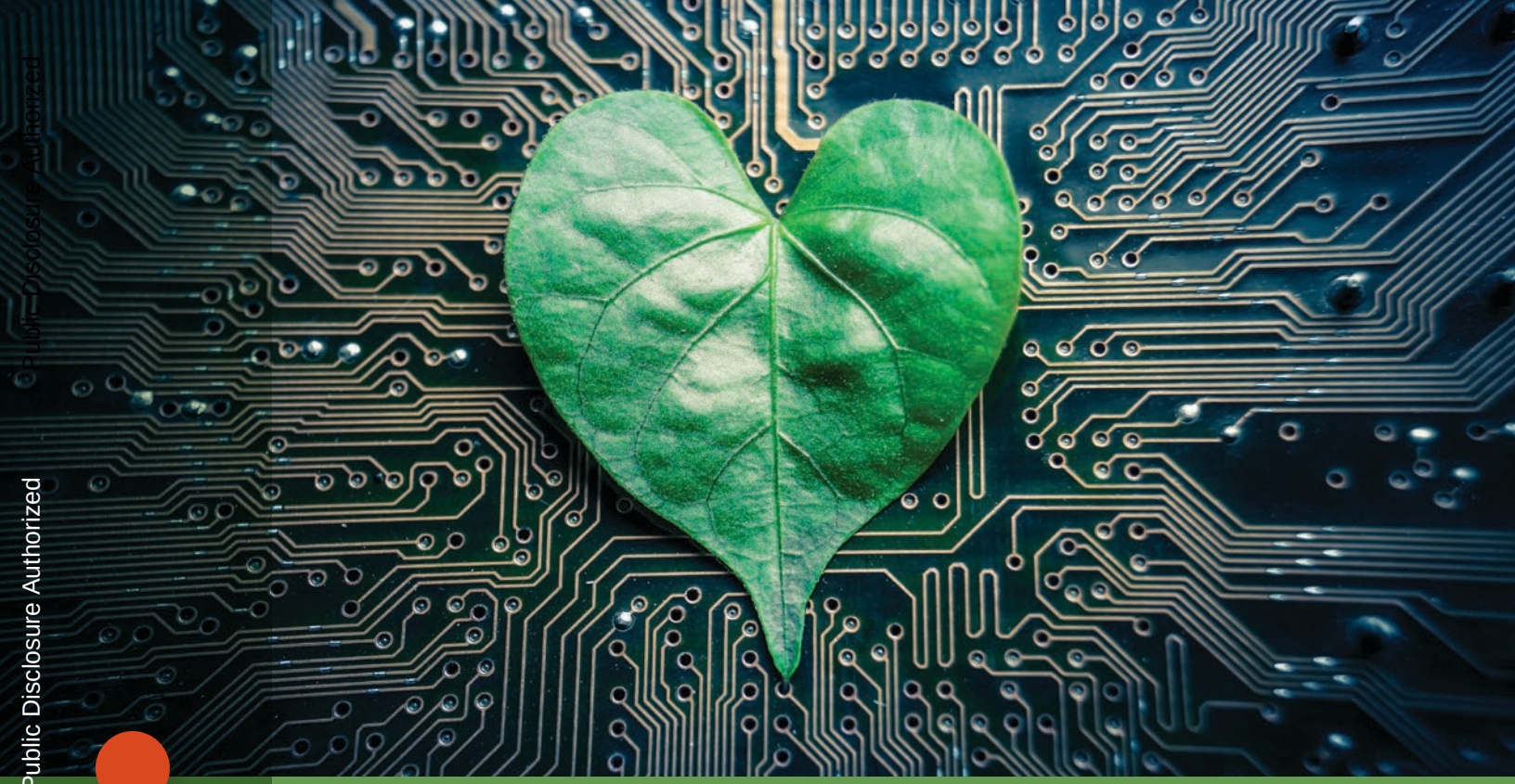

INTERNATIONAL DEVELOPMENT IN FOCUS

Climate-Sensitive Mining: Case Studies

Background Paper for *Building Resilience: A Green Growth Framework for Mobilizing Mining Investment*

Sri Sekar, Kyle Lundin, Christopher Tucker,
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This report is part of a series of background reports underpinning the report on *Building Resilience: A Green Growth Framework for Mobilizing Mining Investment,* which investigates potential for leveraging the mining industry to drive the uptake of climate-sensitive technologies and practices in emerging and developing markets. The series includes four reports: Methodology and Value Chain Analysis, Mining Firms' Climate-Sensitive Initiatives, Climate Sensitive Mining: Case Studies, and Policy Approaches to Climate Change in Mineral Rich Countries.

The research was undertaken by a team comprising Sri Sekar (Mining & Energy Lead), Kyle Lundin (Mining & Energy Research Analyst), Christopher Tucker (Mining Specialist), and Joe Figueiredo (Extractives Policy Associate), all with Deloitte Consulting LLP, with the contribution and under the guidance and direction of Silvana Tordo (Lead Energy Economist, World Bank), and Javier Aguilar (Senior Mining Specialist, World Bank) who co-lead the ELLED Program.

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Extractives-led
Local Economic
Diversification

NOTE

1. A merger between Barrick Gold Corporation and Rangold Resources Limited was completed on January 1, 2019. The new company continues to be known as "Barrick." All references to "Barrick" or "Barrick Gold" or "Barrick Gold Corporation" in this report, refer to the activities and actions of Barrick Gold Corporation prior to the January 2019 merger and do not necessarily reflect the actions or activities of the newly formed company, Barrick.

Abbreviations

ACF	Ambuja Cement Foundation
AEMP	African Energy Management Platform
AUS	Australian dollar
BF-BOF	blast furnace/basic oxygen furnace
BMW	Bavarian Motor Works
CAD	Canadian dollar
CAPEX	capital expenditure
CDP	Carbon Disclosure Project
CO_2	carbon dioxide
CRM	critical raw materials
DRC	Democratic Republic of Congo
EAF	electric arc furnace
ELLED	Extractives-Led Local Economic Diversification
FDI	foreign direct investment
FPO	farmer producer organization
GAO	U.S. Government Accountability Office
GDP	gross domestic product
GHG	greenhouse gas
GPS	Global Positioning System
GSP	gross state product
GVA	gross value added
HFO	heavy fuel oil
ICMM	International Council on Mining & Metals
IFC	International Finance Corporation
IRENA	International Renewable Energy Association
kWh	kilowatt hour
MNRE	Ministry of New and Renewable Energy
MT	metric tonne
MW	megawatt
NOAA	National Oceanic and Atmospheric Association
OPEX	operating expenditure
PPA	power purchase agreement
PPP	public private partnership
PV	photovoltaic

SAG	semi-autogenous grinding
SEDAPAR	Servicio de Aqua Potable y Alcantarillado de Arequipa
UN	United Nations
USD	United States dollar
USGS	United States Geological Survey

1 Introduction

The mining industry is one of conflicting identities. Mining firms can add tremendous value to the resource-rich countries where their mines operate but also to their shareholders. Further, the industry extracts and ferries to the market many of the raw materials that are crucial to industrial and economic progress around the world, creating a magnifying effect to its added value to global GDP. However, the nature of mining activity itself—extracting and processing metals and minerals for commercial use—produces a substantial portion of global greenhouse gas (GHG) emissions, and as such burdens those same beneficiaries of firm value with externalized, unaccounted for, costs. This makes the industry a significant opportunity for broad-based climate improvement in an era where, with the global adoption of the Paris Climate Accords, the world has placed renewed emphasis on mitigating the effects of climate change while keeping the increase in global average temperature below 2°C above pre-industrial levels.

SCOPE OF THIS REPORT

This report is part of a more comprehensive study intended to investigate the potential for leveraging the mining industry to drive the uptake of climate-sensitive technologies and practices in emerging and developing markets. The study includes four background reports—Methodology and Value Chain Analysis, Mining Firms' Climate-Sensitive Initiatives, Climate Sensitive Mining: Case Studies (this report), and Policy Approaches to Climate Change in Mineral Rich Countries—and an overview report on Building Resilience: A Green Growth Framework for Mobilizing Mining Investment.

This report is intended to deliver an account of mining technologies, processes, and strategies that seek to incorporate new, green technologies that have the potential to diversify local and national economies where the mine operates. This report is not intended to provide an ordered ranking of industry trends, mine sites, or the companies engaged in these operations. An analysis of that nature would likely not produce a sufficiently diverse set of case studies to provide an industry-wide perspective. As a result, in selecting the case studies the report prioritizes comprehensiveness and diversity.

2 Case Study Framework

THEMATIC TECHNOLOGY AREAS

The Methodology and Value Chain Analysis (Sekar et al. 2019) report analyzed certain processes and technologies being implemented by mining firms. These were ranked on a two-dimensional scale of (a) Climate Impact and (b) Ease of Implementation (figure 2.1). The confluence of these two factors indicates green mining practices that are scalable and have a propensity to contribute to the development of new green value chains in a host country's economy. Among these activities, the following three overarching thematic areas that rank highly on both axes were selected for detailed analysis and are discussed in this paper.

- Renewable Energy
- Water Management
- Automation & Transportation

These thematic areas cover some of the climate-sensitive activities in which mining firms are currently engaged that are not only contributing the most impact but are also eminently deployable at the mine site.

BENCHMARK METALS AND MINERALS

This report incorporates specific elements of the Methodology and Value Chain Analysis report such as the Value Chain and Subsector Heat Map (figure 2.2), which identifies climate-related pressure points across the mining industry value chain within specific industry subsectors (i.e., mineral categories).

FIGURE 2.1

Categorization of firms' climate initiatives

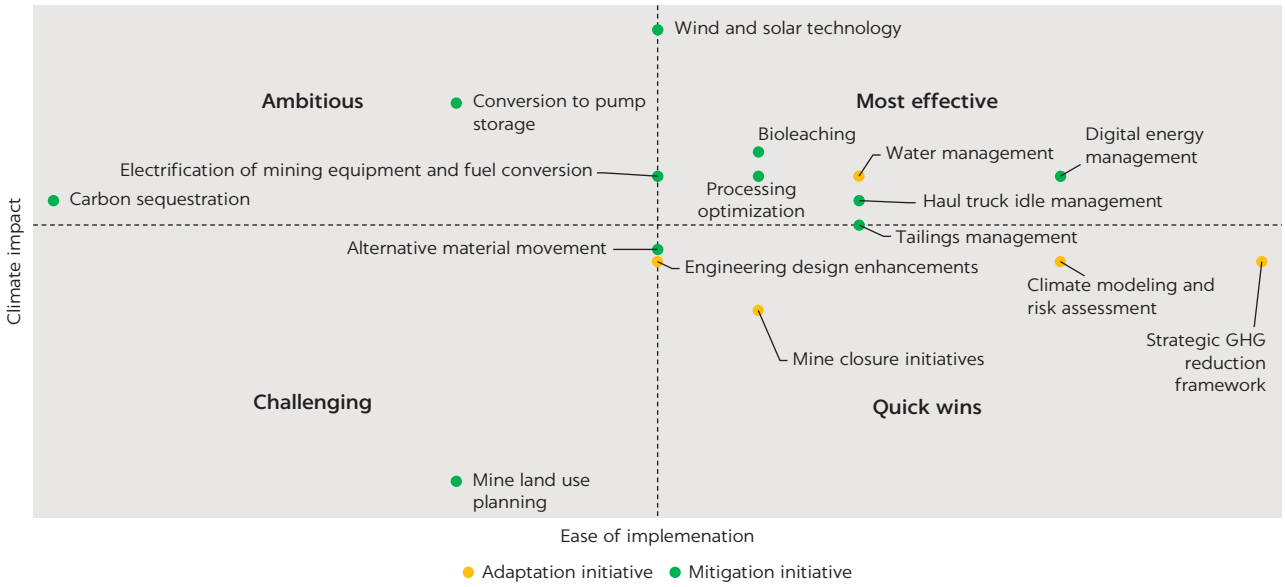


FIGURE 2.2

Value chain and subsector heat map

This report prioritizes trends and mine operations based on the benchmark minerals identified in figure 2.2. For example, mining operations producing a benchmark mineral with potential to contribute to low-carbon value chains, over mined fuels such as coal or uranium. One case study is presented for each benchmark metal or mineral identified in the methodology report, namely Gold, Iron Ore, Copper, and Aggregate/Cement.

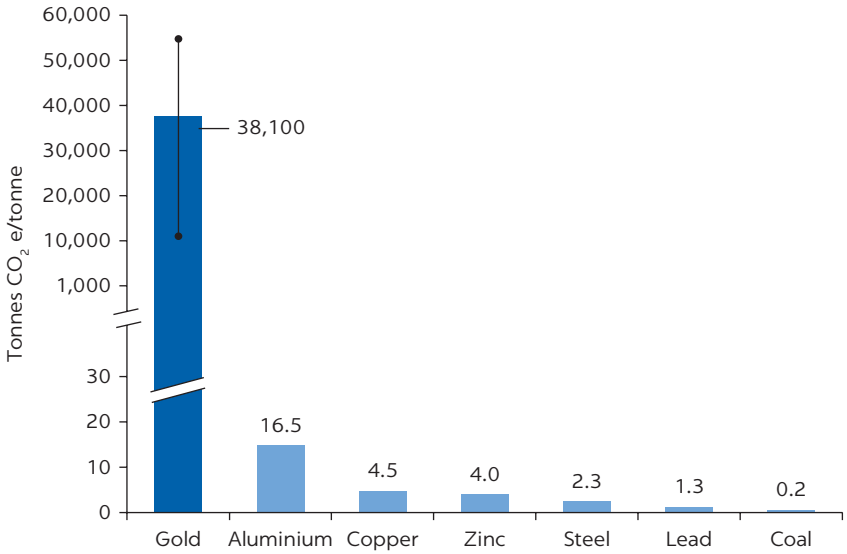
As a forward-looking element the report includes a note on frontier minerals some of which the European Commission labels as "critical raw materials" (CRM) (European Commission 2017). Frontier minerals are those metals and minerals that stand to play a substantial role in the future commodity landscape and are projected to be in increasingly high demand while simultaneously facing a stressed supply chain. Examples of materials that would fall under this definition are cobalt, lithium, and rare earth elements.

BENCHMARK MINERAL PROCESSES

Mining and mineral processing is an energy intensive activity that currently uses about 8 percent of the total global energy supply (van der Voet 2013). As such, the mining and downstream processing industries are significant contributors to global greenhouse gas emissions (figure 2.3). Nevertheless, mineral inputs are critical to the development of renewable energy technologies that help reduce energy related GHG emissions. As accessible, high-grade deposits have been largely exhausted over the last century, miners are moving further afield and working lower-grade deposits. This trend only increases the amount of energy used in hauling rock and processing ore. The current processes for mineral extraction and refining present a large opportunity for technological transformation to low-carbon production methods—many of which were identified in

FIGURE 2.3

CO_2 emissions by commodity



Source: World Gold Council 2018 (https://www.gold.org/goldhub/research/gold-and-climate-change-introduction).

the Methodology and Value Chain Analysis report. Developing electrified mining equipment, shifting to renewable energy sources, and changing mineral processing and mine waste management practices can reduce some of the climate and water impacts from mining as the industry continues to facilitate the shift toward a low-carbon global economy. While new solutions to these challenges are emerging throughout the mining and mineral processing landscape, not every solution is equally applicable to every operation. Mining and processing operations vary significantly by the metals and minerals produced as well as across geographical regions. Understanding the specific climate change risks and opportunities associated with the various types of mineral extraction and processing operations is important. However, as a report from the United Nations Environment Program cautions:

> Important knowledge is still missing in the linkages that exist between different types of resources: metals, energy, water, and maybe others. This refers both to the resources needed in the chain of the metals (e.g., energy for refining) and to the fact that metals are in some cases mined as a by-product of other materials (mostly other metals, but sometimes other materials, e.g., mercury production from natural gas). In scenario explorations for the future, this is essential knowledge. It requires an interdisciplinary approach and the cooperation of researchers from different fields to build up this type of knowledge. (van der Voet 2013)

This section reviews the current state of knowledge with respect to climate change risks and opportunities particular to each benchmark metal and mineral.

Gold

There are many unique aspects to gold mining but three notably worth highlighting (box 2.1). First, due to its high value and relative scarcity, gold can be economically extracted in very low ore grades (e.g., below 1 gram of gold per tonne of ore), depending on global prices, resulting in relatively high volumes of material mined and waste generated. Second, large scale mining of the refractory ores (i.e., ore from which is it more challenging to extract gold due the presence of other minerals) requires more energy- and reagent-intensive processes. As such, it can increase the acid-generating potential of waste products as well as liberate harmful metals such as arsenic into the environment. Third, gold mining uses large amounts of water for processing, dust suppression, and for maintaining tailings waste ponds.

Recognizing the climate implications stemming from gold extraction, industry, governments, and non-government entities are seeking to adopt policies and techniques which can address these challenges. Technology areas that may be particularly applicable to gold in light of the above processing nuances include integrating renewable energy, bioleaching, and water management.

BOX 2.1

Gold mining drivers

- Extraction can be economical even when the ore grade is extremely low
- Chemicals used and released in the extraction and processing of gold can end up contaminating ecosystems if not managed effectively
- Water use in traditional processes for mining and refining gold is high

Copper

Compared to gold and other precious metals, copper is relatively abundant in the earth's crust. Box 2.2 summarizes the drivers of copper mining. Copper is classified as a base metal (along with nickel, zinc, aluminum, lead, etc.) and is widely used in many manufacturing industries due to its high conductivity and relatively low cost. Total global copper production from mining was approximately 22.5 million metric tons in 2016. Major copper producing countries include Chile, China, and Peru, with Chile having the world's largest copper reserves and accounting for almost one third of global production (USGS 2018).

BOX 2.2

Copper mining drivers

- Most copper mines are large, low grade, open pits.
- A large part of operating costs come from energy use associated with moving ore and waste rock as well as mining and mineral processes.
- Copper play a fundamental role in the electrification of industry and transition away from fossil fuels.

In copper mining, energy use accounts for a significant amount of operating costs and is the main source of GHG emissions. These operations' GHG emissions are primarily scope 1 emissions associated with the burning of diesel or other liquid fuels to move ore and waste rock, and scope 2 emissions from electricity use in mining and mineral processing. Approximately 80 percent of copper comes from sulphide ores that are processed using grinding and flotation plants to produce concentrates for smelting (Reemeyer 2016). The remainder comes from mines using heap leaching, solvent extraction and electrowinning to make copper cathode (Reemeyer 2016). Most copper mines are large, low grade, open pits. Typically, these operations process over 50,000 tonnes per day of ore with copper head grades below 1 percent, and sometimes as low as 0.3 percent (Reemeyer 2016). For sulphide ores, electricity is used for crushing and grinding, pumping water and slurries, and operating flotation machines (Reemeyer 2016). For oxide ores, electricity is used in crushing, conveying, pumping solutions, and electrowinning copper metal (ICSG 2018).

Given the copper's abundance within the earth's crust, compared to precious metals such as gold and silver, copper can be mined at a higher grade. As such, less ore and waste rock need to be moved and processed per unit of metal produced. Thus, the overall GHG intensity associated with copper production is lower than that of gold and other precious metals. Nevertheless, the same principles of electrification of mining equipment, alternative material movement (e.g., conveyors over haul trucks), and use of renewable energy sources apply to the production of copper. In addition, because of the relative high volume of copper production, such efforts will significantly contribute to reduction in global GHG emissions.

Given its use in wiring and electrical delivery, copper has a fundamental role to play in the electrification of industry and the transition away from fossil fuels. Electric vehicles are projected to significantly increase their share of both the industrial and consumer markets and the copper requirements of electric vehicles are estimated to be approximately 3–4 times those of traditional vehicles. Hence, copper's role is expected to grow (ICSG 2018). Since copper is common to established and emerging technologies, it represents a mineral that lends itself to establishing local value chains. Whereas, emerging critical minerals such as lithium, cobalt and rare earths require relatively specialized industries and technologies, copper's use is near universal. As such, developing copper value chains in copper-rich regions presents a relatively straightforward route towards

enhancing local economic development while addressing climate change. For example, when a mine such as Goldcorp's Borden project creates a demand among local equipment suppliers for electrified mining equipment, expertise is established in the region. In copper-producing countries this demand holds the potential to make use of existing copper products such as concentrate or copper metal. Developing the intermediate value chains for electric motors (e.g., wire production and components) would require a strategic outlook by both governments and local business.

IRON ORE

Iron is the most used metal globally, primarily in the production of steel, and makes up approximately 5 percent of the earth's crust (Royal Society of Chemistry). Box 2.3 summarizes the drivers of iron ore mining. Due to this very high level of production, the iron and steel industry is the largest energy consuming manufacturing sector and the second-largest industrial consumer of energy, after the chemical sector, producing 5 percent of global GHG emissions (Global Network for Climate Solutions 2012). Of the multiple iron-forming minerals, hematite (Fe_2O_3), is the most abundantly found and also among the highest grade. Due to its relative abundance and comparatively low price per tonne, iron ore must be mined in large deposits to be commercially viable. This also rarely justifies the expense of "digging deep" to access an ore body, no matter how high the grade, due to the volume of material that must be captured to sustain a margin. As a result, most of the world's successful iron ore mines are close to the surface in large, open pits that cover large amounts of land.

This involves a substantial excavation process to move tonnes of earth after it is loosened through blasting or drilling. At a high level, the iron ore extraction and processing flow involves the following processes:

- Excavators and wheel loaders often collect the ore and transport it out of the pit, where trucks take the ore to be crushed and processed.
- Crushing is the first stage in iron ore processing, taking the raw ore and breaking it into pieces that range from only a few millimeters in length to the size of a football.
- Trucking or use of conveyor belt to the processing plant, which sorts and washes the ore until it can be pelletized.
- Pelletization is a process that uses the powder from the extraction process that, until recently, was considered waste, to bind and collate loose ore into small balls of iron ore to be used in the steel production process.
- Storage of processed pellets in a dry stockyard in large piles prior to being loaded onto rail cars and transported to a port to be sent to market.

The next step, steel production, includes both production from raw iron ore and recycling of scrap metal. Recycling of steel strongly affects the energy performance of the sector as a whole, since steel produced from scrap requires considerably less energy than steel produced from iron ore.

BOX 2.3

Iron ore mining drivers

- Due to its relative abundance and comparatively low price per tonne, iron ore must be mined in large deposits to be commercially viable.
- Most iron ore mines are close to the surface, large open pits.
- Iron ore is primarily used in the making of steel. The iron ore and steel industry generates 5 percent of global GHG emissions.

Steel plants are divided into two general categories according to their major source of metal. Plants that produce steel from iron ore using a blast furnace/basic oxygen furnace (BF-BOF) process are referred to as integrated plants. Plants that produce steel by melting steel scrap in the electric arc furnace (EAF) process are referred to as EAF plants. To produce one tonne of crude iron ("pig iron") requires 1.5 tonnes of iron ore and about 450 kilograms of coking coal (Accrue Group Holdings). This latter process using carbon as reducing agent results in approximately 2.8 tonnes CO_2 per tonne of steel (Watson et al. 2008). By shifting iron ore production to use hydrogen as a reducing agent, a significant amount of the process emissions from iron ore production could be reduced (Kundak, Lazić, and Črnko 2009).

Cement and aggregate

Cement and its key ingredient, aggregate, are ubiquitous throughout the world. The drivers of cement production are summarized in box 2.4. Aggregate comprises mostly of rocks and sediment and is a highly local industry as it is available nearly everywhere. Cement is primarily used in the production of concrete and is one of the most common and important construction materials in the world. Concrete is a mixture of mineral aggregates, such as sand, gravel, crushed stones, and cement. Cement consumption and production is tied to construction and correlates to economic activity in general.

Cement production accounts for approximately 6 percent of global GHG emissions (Harvey 2018). The widespread availability of raw materials required for cement production combined with high transport costs relative to cement's value result in little international trade in cement. As of 2011, 96 percent of cement production stayed within the country of production (Armstrong 2012). Thus, cement is generally consumed close to where it is produced.

The majority of CO_2 emissions from cement production are process emissions from the conversion of limestone to lime in the production of clinker. The second source of emissions is the burning of fossil fuels to generate the energy required to heat the raw ingredients to over 1,000 degree Celsius. Initiatives such as clinker substitution directly reduces the thermal energy and process carbon emissions associated with the production of this intermediate product for the same amount and quality of final cement produced (IEA 2017).

Improved grinding technologies also present opportunities for energy efficiency in cement manufacturing. Efficient grinding technologies (e.g., roller presses and vertical mills) offer significant improvements over traditional ball mills. Electricity savings in grinding cement would benefit the overall energy efficiency of the manufacturing process (IEA 2017).

BOX 2.4

Cement production drivers

- Cement and its key ingredient aggregate are widely available.
- Compared to other industries, cement has the highest logistics cost as a percentage of sales. Hence, 96 percent of global cement production remains within the country of production (Armstrong 2012).
- Energy represents 20 to 40 percent of the total cost of cement production (Climate Technology Centre & Network).

3 Case Studies

The following case studies are organized by the key benchmark metals and minerals outlined in the methodology report. They are intended to be comprehensive, not exhaustive, and represent a high-level overview of the sites operations with the potential for replication. The case studies were selected for their geographical diversity, their technological relevance, and their relevance to driving green growth. Table 3.1 below outlines the minerals, technologies, geographies, and companies that are covered by the case studies presented in this chapter. Each company profiled in the case studies was contacted for corroboration and confirmation of facts. Feedback was received from Goldcorp, IAMGOLD, Anglo American, Barrick Gold, and Newmont Mining.

CASE STUDY 1: GOLD

Gold has been mined and used to make goods and as currency for thousands of years. Countries with known resources often stand to reap significant economic benefits from extraction. In 2015, over 60 percent of the 30 largest gold producing countries globally were categorized as low or lower-middle income countries (World Gold Council 2015).

Countries can collect significant direct and indirect gross value added (GVA) from mining companies operating in their jurisdictions. Direct value to

TABLE 3.1 List of case studies in this chapter

BENCHMARK MINERAL	TECHNOLOGY AREA	COUNTRY	COMPANY
Gold	Energy Efficiency and Renewable Energy	Burkina Faso	IAMGOLD Corporation
Iron Ore	Automation and Transportation	Australia	Rio Tinto
Copper	Water Conservation and Infrastructure	Peru	Freeport-McMoRan
Cement/Aggregate	Energy Efficiency and Renewable Energy	India	Ambuja Cement

Case 1 Snapshot	
Gold	**Renewable Energy**
IAMGOLD	**Burkina Faso**
To tackle a technical challenge requiring reliable and competitive source of energy in its Essakane gold mine, IAMGOLD teamed up with Total EREN and AEMP to build the world largest hybrid solar-thermal plant. The plant started operations in March 2018. Support from the Government of Burkina Faso has been instrumental in making this project viable and bodes well for similar future projects. Developing renewable energy assets and skillsets in a nascent power sector can trigger knock-on economic and human capital development.	

governments from gold mining companies, in the form of corporate taxes and royalties, is far outweighed by the 70 percent indirect value gained through taxes on payments to domestic suppliers (e.g., fuel), contractors, and employee salaries (i.e., payroll tax) (World Gold Council 2015). Other benefits can be realized throughout a country's mining value chain when industry pursues local procurement of goods and services. Of the largest global gold producers, lower income countries in Africa and Asia realized the most GVA to national GDP from gold mining from 2003 to 2013 (World Gold Council 2015).

The importance of gold to Burkina Faso

Burkina Faso is the fourth largest African producer of gold, behind Mali and Ghana, with as much as 55 tonnes produced in 2018, an increase of approximately 66 percent from 2012 (Cocks and Aboa 2018). This underlies the gold mining industry's importance to the Burkinabé economy.

According to the International Council on Mining and Metals (ICMM) Burkina Faso's economy is the third most dependent country on the mining industry in the world, ranking just behind Mauritania and the Democratic Republic of Congo (DRC) (ICMM 2017).

While the country also retains significant zinc and manganese deposits, S&P Market Intelligence estimates that the vast majority of active, non-artisanal mining operations in Burkina Faso are predominantly gold-producing. In the past decade, gold has replaced cotton as the country's largest export, with gold responsible for more than 71 percent of exports by value in 2013, according to the U.S. Geological Survey (Burmúdez-Lugo 2016).

A dominant gold sector within an economically vital extractive industry makes Burkina Faso's economic landscape highly sensitive to changes in the manner in which gold is extracted, processed, and produced, in addition to highly susceptible to demand and price fluctuations. Adaptations to processing technology, production techniques, or advances in energy generation or use related to mining firms' activities could have a large effect on the Burkinabé economy. Policy and regulatory changes that influence the adoption of new mining processes and technology would necessarily have a far-reaching impact on economic advancement and have the potential to trigger the localization of new value chains.

The importance of renewable energy to Burkina Faso

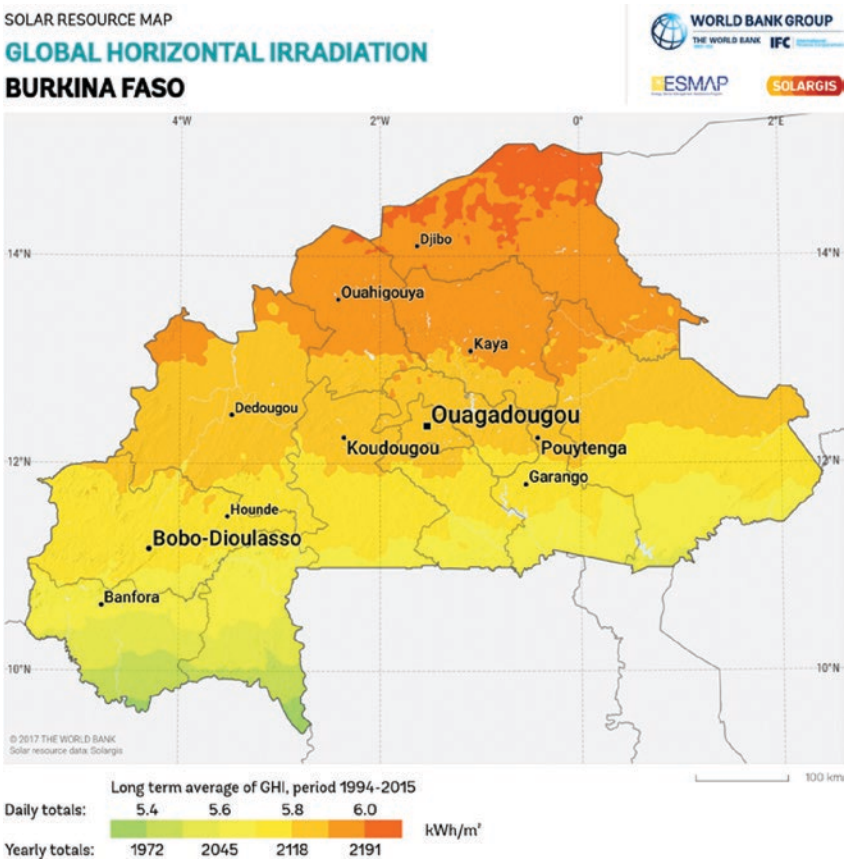
Even compared to other West African countries, Burkina Faso's power sector is nascent. The national electricity grid stops more than 300 kilometers from the Essakane site and there are no connecting transmission lines.

Generation options are limited, with fossil fuels responsible for approximately 86 percent of Burkina Faso's install electricity capacity while the country is forced to import nearly all of the fossil fuel consumed (CIA 2018). It is estimated that approximately 1 percent of the rural population is reliably electrified (CIA 2018). In an effort to foster sector growth, the national government, through the Ministry of Mines and Energy, has drafted and implemented a handful of renewable-friendly policies and made a push to expand the country's renewable portfolio, including recently commissioning the Zagtouli solar PV plant near the capital city of Ouagadougou, a 33 MW facility that is expected to provide 5 percent of the country's generation needs (ESI Africa 2018).

The economically additive nature of the renewable energy industry is particularly acute in Burkina Faso, where there are no naturally occurring fossil fuel resources and where the balance of jobs existing in industry has outpaced the number of jobs in agriculture only within the last few years. Replacing imported fuel resources, and their respective jobs abroad, with locally developed renewable energy resources could create an entirely new technology and employment base in-country. Further, Burkina Faso's potential for renewable energy success is high, with a strong solar radiation profile (map 3.1) receiving direct sunshine for more than 3,000 hours annually and stands to facilitate the country's case for PV investment (Bellini 2018).

MAP 3.1

Burkina Faso's photovoltaic power potential



Source: World Bank Group, https://globalsolaratlas.info/downloads/burkina-faso.

Adding renewable energy capacity offers a stable and scalable alternative to traditional generation options that can be erected in off-grid locations or where there is "bad grid," where the community is connected to the grid, but the service is so unreliable or expensive that they operate as if they are not connected to the grid. The national government has recognized this potential and has committed to making renewable generation a significant part of their push to improve electricity access in rural and urban areas by 2025 (World Bank 2017). To accomplish this goal and take advantage of the country's unique suitability to solar photovoltaic generation technology, the national government has unveiled plans to erect eight solar parks for a combined generation capacity of 100 MW (Bellini 2018).

IAMGOLD's Essakane operation

IAMGOLD's Essakane mine is the largest single gold mine in Burkina Faso, producing more than 430,000 ounces of the more than 1.4 m ounces produced nationally in 2017.[1] This single site accounts for approximately one third of annual Burkinabé gold production. Given gold's prominent role in Burkina Faso's economy and Burkina Faso's renewable energy potential, IAMGOLD's Essakane gold mine represents a compelling snapshot of how the interests of the mining industry and the benefits of green economic growth and economic diversifications opportunities associated with the renewable energy industry are aligned.

IAMGOLD understood that, due to the mine's remote location and the fledgling state of the Burkinabé power sector, Essakane would have to generate its own power. This was no small feat, as the processing facilities, with multiple production lines, primary and secondary crushers, SAG and ball mills, and leach tanks. To generate the amount of electricity required to power a system that processed more than 12 million tonnes of ore annually, IAMGOLD constructed a 57 MW thermal plant. This type of generation is a proven standard for large mining or industrial operations and relies on heavy fuel oil (HFO)—a notoriously high-carbon and inefficient fuel type formed as a derivative of other fuel refining processes that yields approximately 1 kWh for every 11 liters consumed—to provide the generation capacity (SEAI 2017). Due to supply strain constraints and the isolated nature of the mine site in the Essakane case, utilizing HFO meant trucking fuel in over hundreds of kilometers from neighboring countries Benin and Togo. This arrangement required more than 130 haul trucks to drive more than 1,400 kilometers to transport millions of liters of HFO on an annual basis.[2]

IAMGOLD's decision to construct a solar generation facility was prompted by increasing power demand to process harder ore. Relatively soon after the mine was commissioned deeper pits struck a higher proportion of harder rock. This harder ore took longer to grind and crush than the anticipated softer rock, a process that can demand three-to-four times more electricity to process than a softer ore body. Responding to this obstacle, the mine's energy consumption jumped from 14 GWh/month in 2013 to 26 GWh/month in 2015, significantly increasing the mine's HFO consumption to generate the required power.

From 2013 on, the mine looked at multiple options to add additional generation, including connecting to the national grid, to reduce its dependency on HFO (IAMGOLD 2017).

By 2015, solar PV generation had become relatively affordable, on par with traditional fossil fuels, and renewable energy emerged as IAMGOLD's preferred power source. The company was concerned, however, that the intermittency of solar power could result in supply interruptions and jeopardize their continuously-running processing operation. IAMGOLD determined that a 15 MW hybrid solar-thermal plant would be the appropriate solution to reap the cost savings and environmental benefits of solar while ensuring that the solar-thermal integration did not compromise the power supply's reliability.

BOX 3.1

Economic drivers of IAMGOLD's investment

- **90 million** liters of HFO saved over 15 years
- **40 percent** reduction in the price of power compared to HFO
- **~$100 million** saved from reducing the amount of HFO purchased

To IAMGOLD, the economic considerations justifying this additional expense were clear (box 3.1): integrating solar power to their existing thermal asset improved energy reliability by reducing the mine's dependency on imported HFO and reducing fuel costs associated with the purchasing approximately 90 million liters of HFO over the expected 15-year life of the Essakane hybrid plant. At the current spot price of approximately $500 per ton, this corresponds to more than $100 million in fuel savings over the life of the generation asset, not including savings on logistical expenses associated with trucking HFO in from abroad. Further, prior to the plant coming online, HFO power accounted for approximately 14 percent of Essakane's operating costs (IAMGOLD 2017). Compared to thermal costs of between $0.30/kWh and $0.19/kWh over the 5 years prior to the plant's construction, the solar plant is expected to produce power at a rate of $0.17/kWh for the first year and average $0.18/kWh going forward, savings of up to 40 percent (IAMGOLD 2017). In this context, IAMGOLD moved forward with the project sponsor, Total Eren, a global renewable energy independent power producer, and AEMP, a developer and independent power producer, to add solar capacity to its existing power system.

For Burkina Faso, there was an immediate economic benefit and longer term strengthening of the renewable energy value chain stemming from this installation. The Essakane site is the largest private employer in the country, deriving more than 95 percent of its 2,000+ employees from the local population (IAMGOLD 2014). At the time of its opening, the Essakane mine represented the largest private foreign investment in the history of Burkina Faso (IAMGOLD 2010). The Essakane hybrid solar-thermal plant opened in March 2018 and is playing a role in establishing and strengthening local technical expertise in renewable energy. The recent commissioning of another large solar installation in Burkina Faso, the Zagtouli plant, serves a tangible example of the potential for deployment of the technical skillsets set in motion by Essakane. In addition to hiring 70–120 contractors for the project's construction phase, IAMGOLD committed to securing approximately 40 locally-held operational jobs at the solar plant over the 15-year life of the asset (IAMGOLD 2017). This not only creates short term local jobs and skillsets but builds long term renewable energy-related skillsets in Burkina Faso well into the future, a key consideration when the national government plans to make renewable generation at least 50 percent of its energy mix by 2025.[3]

CASE STUDY 2: IRON ORE

Case 2 Snapshot	
Iron Ore	**Automation**
Rio Tinto	**Australia**
Increasing the degree of automation in mining activities, including material movement, has both improved efficiency of mining operations and created an avenue to diversify Australia's economy into high-tech areas; including monitoring and operation of automated vehicles and logistics systems.	

Iron ore represents the second largest commodity market in the world behind crude oil and is integral to the global economy. The commodity has a primary role in the production of everything from daily-use household items to large industrial projects. Iron ore is a high-volume commodity, requiring large mining operations to extract enough of the metal to make the comparatively narrow margin. Due to its high volume nature and that it is often not profitable to dig deep into the earth, even compared to other metals, developing iron ore assets requires high up-front CAPEX (Blas, O'Murchu, and Bernard 2010). This is due to the amount of processing infrastructure required, the large tracts of land covered to extract enough ore to have a commercially viable business, and the necessity of having a well-developed pit-to-port supply chain. Companies must be capable of moving millions of tonnes on an annual basis across increasingly large distances using a variety of machinery and methods. Due to these conditions iron ore is, perhaps more so than other commodities, uniquely matched to the promise of automated operations.

In the coming decades it is estimated that nearly 50 percent of all jobs currently performed manually could be subject to automation (Economist 2018). The mining industry will be at the center of this transformation—where the traditional transportation of ore, waste, and processed metals is highly labor, energy, and emission intensive. While this technological shift represents a possible cost savings for miners by energy efficiency, reducing transportation-related carbon emissions, and curbing waste, it also stands to dramatically change the landscape of the modern workforce, both for the mine and the economy of the host country, where automation is an opportunity to modernize the economy at large by creating new, greener value chains.

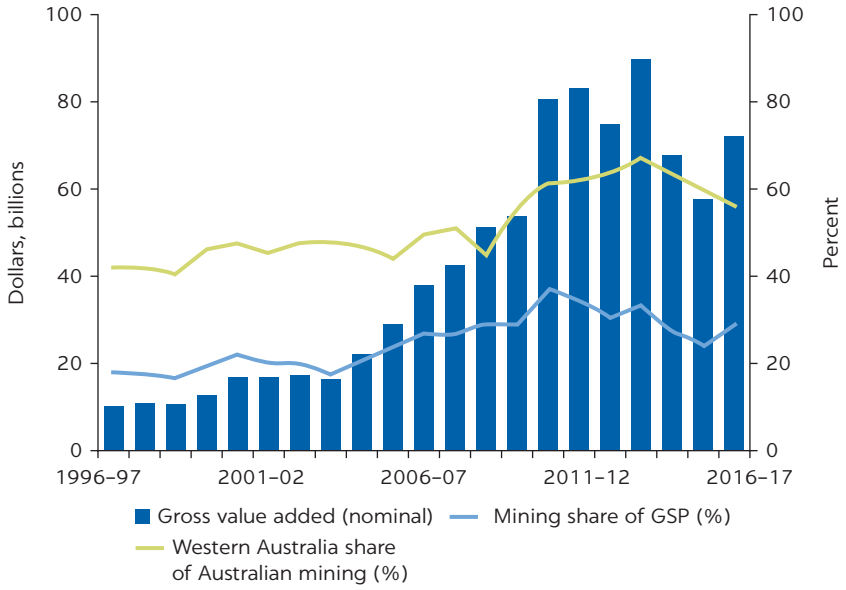
The importance of iron ore to Australia

Australia is among the most successful mining economies in history and perhaps no single mineral or metal is more integral to that success than iron ore. In 2015, Western Australia produced 741 million tonnes of iron ore, approximately 37 percent of global production and second only to China's production levels (Government of Western Australia 2017). The Pilbara region in the state of Western Australia produces more than 98 percent of the country's iron ore (Government of Western Australia 2017). This not only makes Western Australia one of the richest iron ore veins in the world but indicative of Australia's mining industry at large and a key driver of Australia's national and state economies (figure 3.1).

Total mining production accounted for approximately 8 percent of national GDP in 2015 (Frydenberg 2015). The national economy and iron ore are

FIGURE 3.1

Mining's contribution to Australia



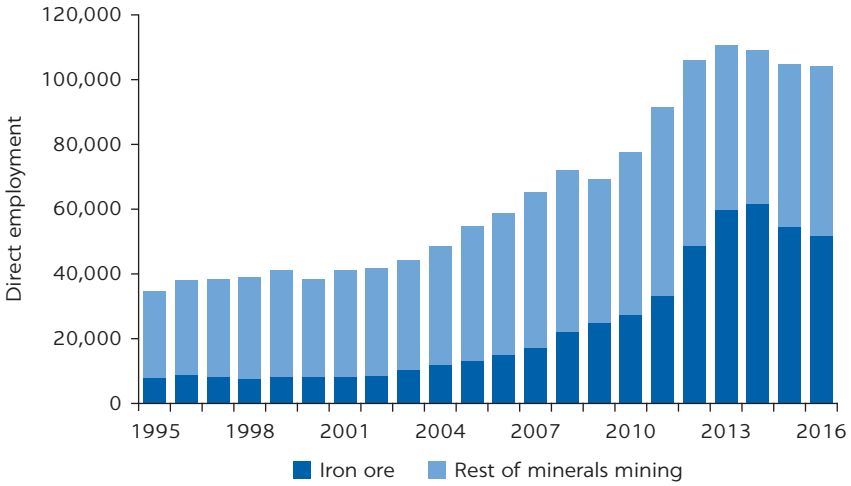
Source: Government of Western Australia, Department of Mines, Industry Regulation and Safety (https://www.jtsi.wa.gov.au/docs/default-source/default-document-library/wa-economic-profile---september-20187cfa10a57ba2628e86e4ff0000981137.pdf?sfvrsn=5e0d721c_6 https://globalsolaratlas.info/downloads/burkina-faso).
Note: GSP = Gross State Product.

intertwined to such a degree that a US$10 swing in the commodity's spot price could increase or decrease national GDP by as much as US$12 billion (approximately .01 percent of total GDP) according to projections from the Australian Treasury for the 2019–20 calendar year (West Australian 2018). Western Australia accounts for the lion's share of Australia's iron ore production and approximately 13 percent of national GDP. Royalties alone accounted for 18 percent of the state's total government revenue in 2017 (Government of Western Australia 2018). The mining sector's share of the Gross State Product (GSP) has increased significantly since the late 1990's, with its total contribution now hovering around 30 percent of GSP (Government of Western Australia 2018).

In Western Australia, the iron ore industry represents significant share of the state's mineral sector employment accounting for approximately 50 percent of all mining jobs (figure 3.2) (Government of Western Australia 2017). Overall, the mining industry accounts for approximately 2 percent of national employment, compared to healthcare, the largest sector, which accounts for approximately 13 percent of the job market (Parliament of Australia 2018). Due to its centrality to the economy of Western Australia, the iron ore sector would be particularly sensitive to policies aimed at supporting the development of a green economy pursued by the local and national governments. Given this dynamic between the state and the sector, targeted green industrial policy enacted by the state may be able to leverage the sector for further diversifying the economy beyond mining. This logic holds true for Australia at large, as there is likely no single mineral or metal in Australia's mining economy that so heavily influences the national economic tenor to the same degree as iron ore.

FIGURE 3.2

Iron ore employment profile



Source: Government of Western Australia Department of Mines, Industry Regulation, and Safety (https://www.jtsi.wa.gov.au/docs/default-source/default-document-library/wa-iron-ore-profile---august-2017.pdf?sfvrsn=2).

The importance of automation to Australia

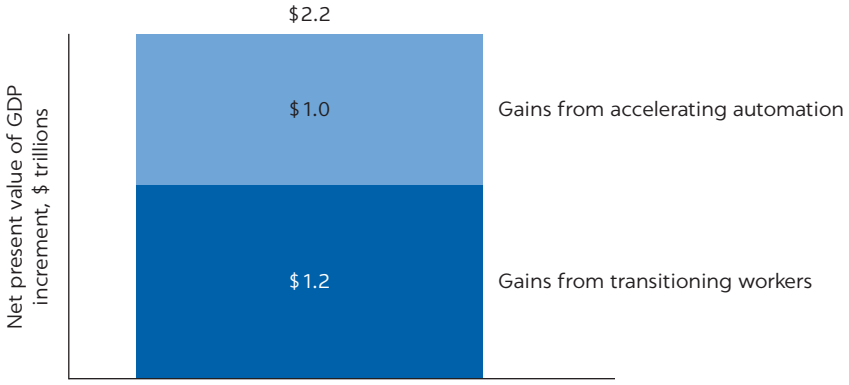
Some analysts estimate that nearly 60 percent of fuel waste in the trucking industry is due to driver over-acceleration (Morris 2015). According to industry analysts, manual transportation systems, including cars, trucks, and rail systems, are starkly inefficient compared to automated systems. The Smithsonian Institute, for example, by merely equipping their fleet of more than 1,000 cars with GPS tracking systems and wireless communications to enable better fleet management, reduced fuel consumption by more than 50 percent (Pyper 2014). This has a corresponding impact on not just cost savings, but the amount of GHG emitted by automated vehicles compared to manually driven vehicles, with some reports estimating that widespread adoption of automation technology in transportation systems could reduce global GHG emission by upwards of 50 percent in 2050, should the necessary societal and technology steps be taken (Fulton, Mason, and Meroux 2017).

With approximately half of all existing jobs susceptible to automation and a renewed emphasis on climate-conscious policies and activities, these timelines coalesce to affirm that the jobs of tomorrow will likely not resemble the jobs of today (The Economist 2018). Value chains—the technical skillsets, infrastructure requirements, and logistical capabilities—are likely to reflect these market adaptations. But, according to a research by AlphaBeta, industry's adoption of automation in Australia has been timid (AlphaBeta 2018).

A report commissioned by Google and authored by economic consultancy AlphaBeta estimated that widespread adoption of automation technology could lead to as much as a $2.2 AUS trillion benefit to Australia's national income, provided that Australia acts soon (figure 3.3). Currently, Australia ranks 10th on a list compiled by The Economist of countries "most ready" for the shift towards an automated economy (The Economist: Intelligence Unit 2018). While this is a globally strong position, it is one of the lowest ranked amongst its peer group of industrialized western nations that would be top competitors for investment, industry, and jobs, with the U.S., Japan, the Republic of Korea, Germany, and Singapore all ranking as more prepared (The Economist: Intelligence Unit 2018).

FIGURE 3.3

Australia's potential gain from automation



Source: Based on AlphaBeta (https://www.alphabeta.com/wp-content/uploads/2017/08/The-Automation-Advantage.pdf).
Note: Automation could deliver a $2.2 trillion dividend to Australia if workers are transitioned successfully and the uptake of automation is accelerated.

Rio Tinto's Mine of the Future

Rio Tinto's "Mine of the Future" operation in Western Australia is a prime example of how automation can mitigate the impacts of a mining operation on climate while developing green value chains of the future and diversifying local economic sectors. Inaugurated in 2008, the Rio Tinto's Mine of the Future automation portfolio holds four primary technological advances (box 3.2): (1) a modern operations center in the Western Australian city of Perth that oversees mining operations remotely; (2) autonomous vehicle haulage system that moves ore around the mine site by relying on a supervisory control system and remote controller from the operations center in Perth; (3) an automated drilling system that can engage multiple drill rigs simultaneously; and (4) AutoHaul®, a long-distance rail transportation system that moves ore to ports of call for export abroad (Rio Tinto 2018). The car industry's dramatic shift from a manually-intensive assembly line to an automated and more efficient production process served partially as the impetus for Rio Tinto's investment in its Mine of the Future technology. Former Rio Tinto Chief Executive Sam Walsh cited the American car industry's failure to rapidly adapt to changing technology and the supply chains of the future as a critical example of how a failure to innovate can lead to a lack of competitiveness in the long term, saying, "Having seen the automotive evolution in the car industry I wanted to ensure that Rio Tinto pushed itself up the technology curve." (Brookes 2018) This drive to avoid technological complacency fueled Rio Tinto's investment in new technologies to create greater

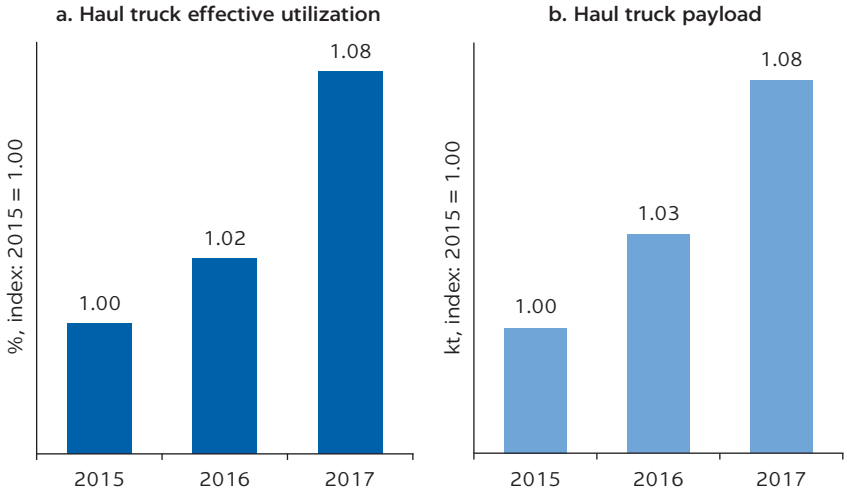
BOX 3.2

Rio Tinto's Mine of the Future

- **State of the art** operations center in Perth, Western Australia
- **Autonomous** haulage systems that transport ore around the mine site
- **Automated** drilling systems that can operate simultaneously from a single point of control
- **Automated** long-haul systems, including rail transport

FIGURE 3.4

Mine of the Future productivity gains



Source: Rio Tinto (https://www.riotinto.com/documents/180618_Presentation_Chris_Salisbury_Iron_Ore.pdf).

efficiencies, ensure long-term competitiveness, increase savings, and reduce the degree of climatological impact.

For Rio Tinto and their automated haul partners Komatsu and Caterpillar, these adaptations have achieved significant efficiencies and cost savings, as shown in figure 3.4.

The fleet of approximately 80 automated haul trucks now move approximately 25 percent of ore and waste material produced across Rio Tinto's Pilbara operations (Jamasmie 2018). The adaptation has proved so successful, with the same or fewer number of trucks able to carry more ore, that Rio plans to roll out as many as 50 additional trucks by the end of 2019 (Rio Tinto 2017). Maximizing route efficiency and curbing the amount of truck idle time have contributed to both increased haul efficiency and reduced carbon-intensive fuel consumption with overall cost reductions of approximately 15 percent compared to a manned truck (Jamasmie 2018). Rio Tinto's mine of the future is not the only example of high-level of automation in the industry. Resolute's Syama Mine in Mali and Vale's S11D operation in Brazil are also notable examples and suggest a growing trend (box 3.3).

In addition to the direct economic benefits of the Mine of the Future productivity gains, including extracting, moving, and selling more ore, generating more royalties, and expanding mine operations, the nature of the technology being used in Rio Tinto's operation has a high potential to establish new, scalable green value chains and drive national economic diversification. While automating labor and time-intensive manual processes may initially reduce the number of manually-performed jobs, it creates new categories of jobs. For example, while the Mine of the Future operation replaced truck driving with an automated haul system, it simultaneously created jobs for more than 200 controllers and schedulers and more than 230 technical planning positions to keep trucks running from more than 1,500 kilometers away (Rio Tinto 2018). These are skilled positions in high-technology areas of the Australian economy that did not exist prior to the Rio Tinto's investment in automation.

BOX 3.3

Notable example of mining automation

Resolute Mining's Syama Mine
Scheduled to begin production in late 2018, Resolute Mining's Syama gold mine in Mali is slated to be the first fully-automated mining operation in the world. Despite up-front equipment costs of nearly $15 million more than manned equipment, Resolute expects to shave total mining costs by as much as 30 percent in addition to seeing notable efficiency gains and reductions in GHG emissions (Mining Technology 2018).

Vale's S11D Iron Ore Mine
Another giant of the iron ore industry, Vale, automated aspects of their S11D Eliezer Batista iron ore mine in southeast Pará, a northern Brazilian state on the edge of the Amazon rainforest. Instead of developing a system of driverless trucks, as Rio Tinto had, Vale approached the automation of mine activities by installing several kilometers of conveyor belts.

In lieu of traditional haul trucks, approximately 30 km of conveyor belts operating 11 meters/second and transporting up to 52,000 tonnes of ore per hour from the pit to the processing plant. Vale estimates that implementing a conveyor system increased ore transport capacity compared to traditional truck haulage which, over the life of the mine, can translate to an efficiency benefit of thousands, if not millions, of tonnes of ore brought to market with less carbon and energy expenditure. The conveyor belt system alone is projected to reduce GHG emissions by 118,000 metric tonnes annually compared to using traditional, diesel burning haul trucks. The new remote monitoring systems are in place to oversee the complex system, spawning non-traditional jobs and technology skillsets that would otherwise not exist with the use of haul trucks, embedding new, greener value chains an technical skillsets in Brazil (Based on company sustainability reports and website material).

These new jobs and skills are likely to not only develop a proficient skill-base within Perth and Western Australia, but in other industries throughout the country. Further adoption of automated industrial processes will increase the economic competitiveness of Australian businesses and build technical skillsets widely applicable to other economic sectors such as manufacturing, energy, industrial, and administrative jobs for which a step up in automation is expected across the world.

CASE STUDY 3: COPPER

Case 3 Snapshot	
Copper	Water Management
Freeport-McMoRan	Peru
Strengthening water resource infrastructure supports developing local technical skillsets in water resource operation and maintenance, mitigates damage to natural resources, and provides an anchor for economic diversification and growth.	

Copper is often viewed as a bellwether for the status of the global economy, earning the nickname "Dr. Copper" due to its longtime position as an indicator of overall market health. This notoriety, coupled with its common usage in cars, mobile technology, and power and utilities, makes copper a key commodity in a crowded field of metals and minerals that power the global economy.

The importance of copper to Peru

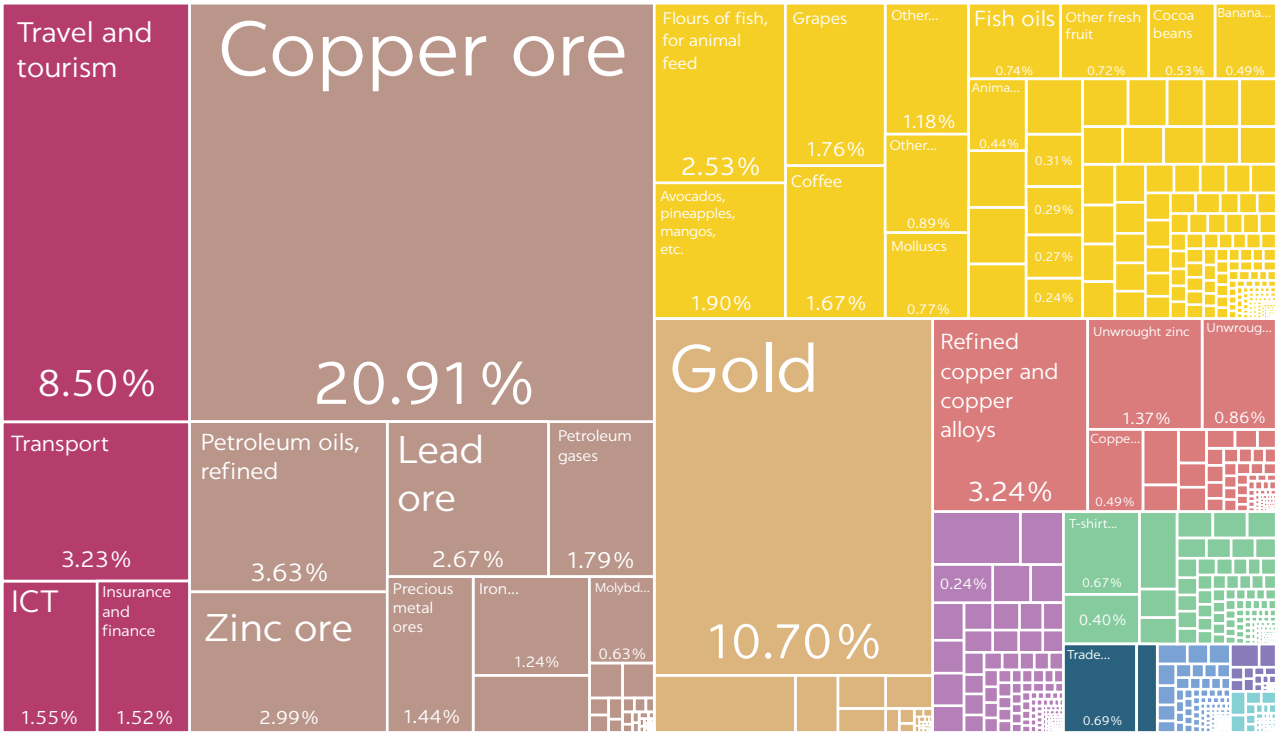
The mining industry and Peru's economic strength are inexorably joined as figure 3.5 suggests. In 2013, more than 4 percent of all employment in Peru was tied to the sector while the majority of countries with large mining presences attribute between 0.5 percent and 3 percent of total national employment to the industry, according to ICMM (ICMM 2017). Behind neighboring Chile, Peru is the second largest copper producer in the world, with approximately 10 percent of total global copper reserves and annual production of nearly 2.4 million tonnes in 2017, according to the U.S. Geological Survey, a figure that accounts for approximately 12 percent of global production for the year (USGS 2018).

Copper ore makes up for nearly one quarter of all Peruvian exports, delivering billions of dollars to the government in the form of receipts and royalties. Mining accounts for as much as 14 percent of national GDP and more than one quarter of national Foreign Direct Investment (FDI) is directed at the mining sector (Ernst & Young 2018). The success of the copper industry has fueled Peru's economic rise over the last two decades, turning it into one of the fastest growing economies in Latin America (World Bank Group 2017).

The importance of water to Peru

The competing demand for scarce water resources is accentuated by the global increase in water stress and growing intensity—and frequency—of climate extremes. According to the U.S. National Oceanic and Atmospheric Association (NOAA) three of the warmest years ever recorded occurred between 2015 and

FIGURE 3.5
Peru's export map 2016



Source: Atlas of Economic Complexity, Center for International Development at Harvard University (www.atlas.cid.harvard.edu).

2017 (NOAA 2018). Further, not only are 1.7 billion people living in areas where water use exceeds replacement, but the UN has estimated that 40 percent of the global population—a figure that is projected to increase—is impacted by water scarcity (HLPW 2018).

Growing water scarcity is of significant concern in Peru and also presents one of the country's greatest conundrums. While Peru's interior has abundant water resources and receives substantial annual rainfall, Peru also faces chronic water stress. Approximately 70 percent of Peru's population lives along the Pacific coast, the most economically developed portion of the country and a landscape dominated by an arid, high-altitude desert receives little to no annual rainfall. Further, of the limited available freshwater, it is estimated that 60 percent is "unusable" due to a variety of factors, including pollution form industrial activities (World Bank 2018). This has placed significant stress on Peru's water infrastructure and their ability to consistently deliver clean, potable water. Increasing demand for water services coupled with a rising population and static supply near large population centers has contributed to a "high" water risk classification from the World Resources Institute (Reig, Maddocks, and Gassert 2013).

Water is integral for sustaining the climate and the health and safety of a population, but it is an equally important economic driver. More than 40 percent of the world's total active workforce rely on jobs that are heavily water dependent (Europa 2017). Nearly the same amount of jobs relies on industries that are "moderately water dependent," meaning that nearly 80 percent of the global workforce works in an industry or jobs that requires water (Europa 2017). Some estimates indicate that an unsecure water sector can reduce national GDP by as much as 6 percent (World Bank 2016). Investing in adequate water infrastructure is a key step towards securing a stable and vibrant economy in a global environment where water scarcity will only increase in the coming years.

A study from the International Finance Corporation (IFC) estimated that Peruvian cities and villages with improved water irrigation infrastructure hired 30 percent more agricultural workers than comparative villages (IFC 2013). It further estimated that investing $1 billion in water-related infrastructure in Latin America may yield 100,000 new, knock-on jobs in fields such as agriculture, maintenance, and technology—all industries where water is a necessary component to economic expansion or where technical skillsets such as water management or engineering may be highly transferrable (IFC 2013). Furthermore, the job return for water investment is higher than a comparative investment in coal-based energy generation or rural electricity infrastructure (IFC 2013).

The national government has moved to act on this front, increasing infrastructure spending on potable water and sanitation throughout Peru to improve access, quality, and consistency and setting a goal of achieving access to running water on a national level by 2021. This initiative is estimated to require upwards of $50 billion soles (~$15 billion dollars) to achieve, as more than 50 percent of the state-owned water utilities across the country are not considered sustainable over the long term (Aquino 2017). The national-level policy drive for improved water infrastructure includes an emphasis on partnering with private industry to bring in international expertise to partner with local industry and build Peru's water management industry from the ground up.

Freeport-McMoRan's Cerro Verde mine

Freeport-McMoRan's Cerro Verde copper mine sits in the foothills of Arequipa, Peru. At more than 800,000 residents Arequipa is the second largest city in the country. Arequipa occupies an arid environment, receiving approximately three inches of rainfall annually, with many months recording no measurable precipitation, and draws more than 90 percent of its water for consumption and agriculture from a single source—the Rio Chili (Fraser 2017). The river also serves as the primary source of water for regional agriculture operations, the Cerro Verde mine, and, until 2015, was the primary discharge location for the City of Arequipa's waste water and municipal sewage.

The relatively high water demands of Cerro Verde further complicate the already-stressed water situation. Freeport-McMoRan's disclosed to the Carbon Disclosure Project (CDP) that Cerro Verde withdrew approximately 62,200 megaliters of water in 2017, the second-highest withdrawal amount among all Freeport-McMoRan's mines, and consumed approximately 1,738,300 megaliters of water across all company operations (CDP 2017).

In 2008, it is in this water-scarce landscape that Freeport-McMoRan charted the Cerro Verde site for expansion, a prospect that threatened to stress the already-fraught water system of Arequipa to the limit and could, potentially, have provoked significant local pushback. In order to proceed with the planned expansion, it was very likely that Freeport would have to adjust their operation or plan to mitigate the possible negative consequences of expanding the mines footprint.

The prospect of expanding Cerro Verde galvanized both Freeport-McMoRan and the local community to push for a joint solution. In advance of the expansion project Freeport-McMoRan began an outreach effort to determine if water scarcity was a topic of concern shared amongst the communities in and around Arequipa (Fraser 2017). This revealed community concern to be twofold. One, that expanding Cerro Verde would increase water scarcity and, two, that expanding the mine would intensify already existing levels of pollution in the Rio Chili (Fraser 2017). Freeport-McMoRan shared these concerns, while also angling to continue using the Rio Chili as its primary water supply. To address water quality and quantity concerns, the company engaged community leaders to develop a plan for how to both improve water quality in the Rio Chili river system and ensure the mine retained its ability to draw water from the river (Fraser 2017).

In 2010 Freeport-McMoRan began to design, and agreed to help finance, a potable water treatment plant to address concerns over quality water (box 3.4). Commissioned in 2012, the La Tomilla II facility provides 24-hour access to potable water for approximately 300,000 Arequipa residents (Fraser 2017). Further, the plant was designed with a modular construction that,

BOX 3.4

Freeport Cerro Verde economic drivers

- **Social license** secured for an expansion that tripled copper production
- **300,000+** residents have access to potable water
- **90 percent** of waste water now treated

should the city's population continue to increase, the plant could be expanded to serve approximately 750,000 households with potable water (Fraser 2017).

In addition to the potable water plant, Freeport-McMoRan acted on a suggestion stemming from the community outreach process to construct a wastewater treatment facility—La Enlozada. This would achieve the dual benefits of treating the high levels of pollution in municipal waste water dumped into the Rio Chili and providing Cerro Verde with a portion of the treated water in exchange for bearing a large part of the $550 million planning and construction cost (Fraser 2017). After construction was completed, approximately 90 percent of wastewater discharged from Arequipa city into the Rio Chili was able to be treated for contaminates (Fraser 2017).

The economic benefit to Freeport was clear, the massive expansion project required more than $4.5 billion in CAPEX and tripled the mine's copper production. It was ultimately successful, with Cerro Verde alone now accounting for 2.4 percent of global copper production in 2017 according to S&P Global (Fick 2016). The company achieved copper production of approximately 500 million tonnes in 2016 and 2017, up from just over 200 million tonnes in 2014 (Reuters 2015). Further, the mine now receives approximately 1 m^3/second of the treated water from the newly constructed facility for use in Cerro Verde's operations (Fraser 2017). This increase, coupled with the strong price of copper, has transformed Cerro Verde into one of Freeport's strongest assets and demonstrates the capacity to derive a tangible financial return on a social investment.

For Peru and Arequipa this project contributed to creating both the infrastructure and technical expertise necessary to run a more robust water sector, and increasing knowledge of the water management and governance process, which will eventually result in a more economically diverse and robust national marketplace. This is bolstered by Freeport-McMoRan's decision to develop these facilities through public-private partnerships (PPP) and in cooperation with local community leaders and local utilities, as well as to engage local entities to help manage and run the facilities. Successfully developing and operating this project demonstrates the potential for private industry to bring FDI to a new segment of the national Peruvian economy and begins to build-in the technical skillsets needed to develop and manage water infrastructure on a national level.

Further, Servicio de Aqua Potable y Alcantarillado de Arequipa (SEDAPAR), Arequipa's regional water management and sewage utility, was heavily involved in the planning and community outreach stages of both the La Tomilla II and La Enlozada (Fraser 2017). Local employees of SEDAPAR are responsible for collecting wastewater, monitoring water quality, and supervising plant operations, generating jobs, teaching valuable water management skillsets in a water stressed region, and facilitating local procurement, further building out the knowledge segments of the value chain for this green initiative (Fraser 2017). Further, Freeport-McMoRan plans to eventually transfer control of both plants to full SEDAPAR control, adding more local jobs and institutionalizing more green value chain knowledge in the process (Fraser 2017).

In addition to providing new jobs and transferrable technical skillsets through constructing two new water treatment facilities, cleaner water in the Rio Chili has the knock-on effect of securing existing jobs. The river is a popular white-water rafting destination, a business that is reliant on clean, safe water in the Rio Chili watershed. Mitigating the amount of pollutants that flow in to the river not only drives job creation for those companies that monitor and manage the water treatment facilities but preserves jobs that are dependent on a reliably clean water supply.

CASE STUDY 4: CEMENT AND AGGREGATE

Case 4 Snapshot	
Cement/Aggregate	**Renewable Energy**
Ambuja Cement	**India**
Implementing renewable biomass technology and sourcing resources locally strengthens local supply chains, encourages alternative business development in green economic areas, and delivers generation with a reduced carbon footprint compared to utilizing HFO as the plants sole fuel source.	

After water, cement is the most consumed commodity in the world. Cement production also contributes approximately 6 percent of total global GHG emissions (Harvey 2018). Cement production is intensely local; aggregate is extracted around the world and often processed nearby, as aggregate is labor intensive to move and in plentiful supply. Cement processing plants exist in almost every country and the market share of large cement companies is more fractured than that of large metal mining companies. As just one example of how diffuse the cement market is, according to CDP, 13 of the largest publicly listed cement companies are responsible for approximately 15 percent of global cement production (Kisic et al. 2018). In comparison to the copper industry, where 13 of the largest companies are responsible for more than 50 percent of global copper production.[4]

The importance of cement to India

India is the second largest cement-producing country in the world, producing more than 270 million tonnes in 2017 (Rowland 2018). While this figure is nearly double the United States, the third largest producer at approximately 86 million tonnes per year, India's production is dwarfed by China, the world's top cement producer with more than 2 billion tonnes annually (McCarthy 2018). This also means that, compared to other nations' cement production-related emissions, India contributes significantly to the global carbon dioxide emission levels of cement, emitting nearly as much cement-related CO_2 as the Russian Federation, Turkey, and the U.S. combined (McCarthy 2018).

India's economic rise has been rapid, demonstrating year-over-year GDP growth of more than 5 percent since 2009, marking India one of the fastest growing economies in the world and sparking a local infrastructure boom (World Bank 2018). This rise has been fueled by a dynamic technology market, a large and rapidly growing local consumer base, and a significant investment in infrastructure, at times as much as 35 percent of GDP (Dangra 2016). Substantial growth in the real estate sector catalyzed the rise of India's cement industry. With real estate projected to attain a market size of $1 trillion by 2030 and contribute approximately 13 percent of India's GDP by 2025, cement is likely to continue to play a large economic role in the Indian economy and contribute a similarly large portion of global cement-related CO_2 emissions (IBEF 2018).

The importance of renewable energy to India

According to IRENA, India has one of the largest renewable energy job markets in the world, with more than 164,400 jobs in solar photovoltaic technology alone, lagging only Japan, the United States, and China (IRENA 2018). Across all

renewable energy generation options, India is home to nearly 7 percent of the global job market (IRENA 2018). Despite the competitive state of the Indian renewable energy market, India's energy needs remain dominantly met by fossil fuels, with traditional coal-fired powerplants accounting for more than 50 percent of energy generation and installed capacity (Government of India, Ministry of Power 2018). Of the available technology options, including solar and wind, biomass—organic material that is combusted to produce steam—could form a more substantial pillar of the energy generation mix due to a large agricultural sector and its wide availability as a cheap and easily accessible fuel source.

India's agricultural sector employs slightly less than half of the national workforce and is covered mostly by farmland (World Bank 2018). Approximately 66 percent of the 1.2 billion population living in disparate and predominantly rural agricultural areas—a geography that also encapsulates almost 80 percent of India's poor (World Bank 2016). Approximately half of the rural poor survive by laboring in an agricultural setting that produces a surplus of as much as 150 million tonnes of biomass every year, according the Ministry of New and Renewable Energy (Government of India, Ministry of New and Renewable Energy 2018).

Biomass can include timber, agricultural waste and byproduct, and a variety of other organic material. India's Ministry of New and Renewable Energy (MNRE) estimates that India's biomass resources, if fully utilized, could generate as much as 18,000 MW of power (Government of India, Ministry of New and Renewable Energy 2018). IRENA estimates that the range of fuel cost per kWh for biomass in India is often less than both solar photovoltaics and onshore wind, despite having one of the most globally-competitive costs of solar. As a result, biomass-powered generation plants have sprung up across India, with MNRE tallying at least 288 biomass power and cogeneration projects, with the construction of each plant employing approximately 100 workers across the construction phase with approximately 25 full-time employees required to operate the plant and an additional 35 employees in the biomass collection and logistics portion of the supply chain (Government of India, Ministry of New and Renewable Energy 2018). This supply chain is also a primary detractor from biomass as a viable generation option. While ample supply is available, the extremely rural nature of the country and the lack of an organized mechanism to collect and transport biomass from disparate fields or forests to a single generation site is challenging.

To capitalize on the clean energy generation and the corresponding economic boon from developing new renewable energy value chains in predominantly rural areas, the national government has actively incentivized biomass development. These initiatives include a 10-year tax holiday for newly constructed biomass plants, aggressive capital subsidies, and excise and customs duty exemptions on a state-by-state basis (India Ministry of New and Renewable Energy 2018). The viability and availability of biomass in the rural Indian market is a scalable opportunity to build renewable infrastructure that both generates electricity, provides local jobs and economic benefit in a technology area that reduces greenhouse gases (GHG) and has the capacity to diversity the economy beyond biomass as farmers derive additional income.

Ambuja Cement's Rabriyawas processing plant

Ambuja Cement, a subsidiary of Lafarge Holcim, operates 5 integrated plants and 8 grinding plants throughout rural India, producing more than 22.9 million

BOX 3.5

Ambuja Cement economic drivers

- **Strong and local** biomass supply chain established
- **500+** farming families brought into the biomass supply chain

tonnes of cement of 2017 (Ambuja Cement 2018). This makes Ambuja the second largest cement producer in India, with almost 10 percent of the country's total production capacity.

Ambuja's Rabriyawas processing plant is located not far from the Pakistani border in District Pali, Rajasthan, India. Having identified the opportunity to leverage biomass in its fuel mixture to reduce GHG emissions and save on energy expenditures at its Rabriyawas plant, Ambuja Cement moved to secure a supply of biomass for its alternative fuel operations. As is standard in the industry, Ambuja began by purchasing biomass from third-party providers. These were private, for-profit Indian businesses allowing Ambuja to secure a steady supply of biomass while contributing to the regional economy through local procurement. However, the Ambuja Cement Foundation (ACF), the company's corporate social responsibility arm, determined that greater value creation may be attained by engaging local farmers to join the biomass market, moving to co-locate much of the plant's biomass supply and foster significant local procurement with suppliers in a new market. Rabriyawas's rural location became an asset in this regard, the surrounding farmland providing fertile ground for biomass sourcing at a local level. ACF established a farmer producer organization (FPO) to directly supply the Rabriyawas plant with biomass, securing a dedicated local supply chain to supply biomass to power part of the Rabriyawas processing facility.

To date, more than 500 farming families have taken advantage of this structure and sold biomass to the plant, including sugarcane waste, cotton stalk, and other crop residues and successfully established elements of the biomass value chain within rural parts of Rajasthan (LafargeHolcim 2016). This program proved so popular with local communities that Ambuja exported the framework to other cement processing plants in rural areas (box 3.5). In 2016 alone FPO's surrounding multiple plants sold more than 12,500 tonnes of biomass to Rabriyawas kiln. Company-wide, more than 50,000 MT of biomass was supplied to Ambuja by FPO chapters, nearly doubling from the 24,000+ MT produced the year before (Amubja Cement Foundation 2018).

Demonstrating the viability of this biomass supply model mitigates one of the primary disadvantages of instituting a biomass generation system. It also demonstrates the viability of this procurement model in the rural Indian countryside, an area often devoid of local or foreign investment. A scalable farmer-supply system could provide biomass across India's remote interior, driving economic diversity by creating from scratch biomass-centered green supply chains.

CASE SNAPSHOT: CRITICAL RAW MATERIALS AND FRONTIER MINERALS

Frontier Mineral Snapshot	
Frontier Minerals	**Global**
Identifying minerals that are likely to hold significant market importance in the future is key to assisting mineral-rich countries in developing policy frameworks and economic development plans to maximize green-growth and economic diversification in new and growing mineral classes.	

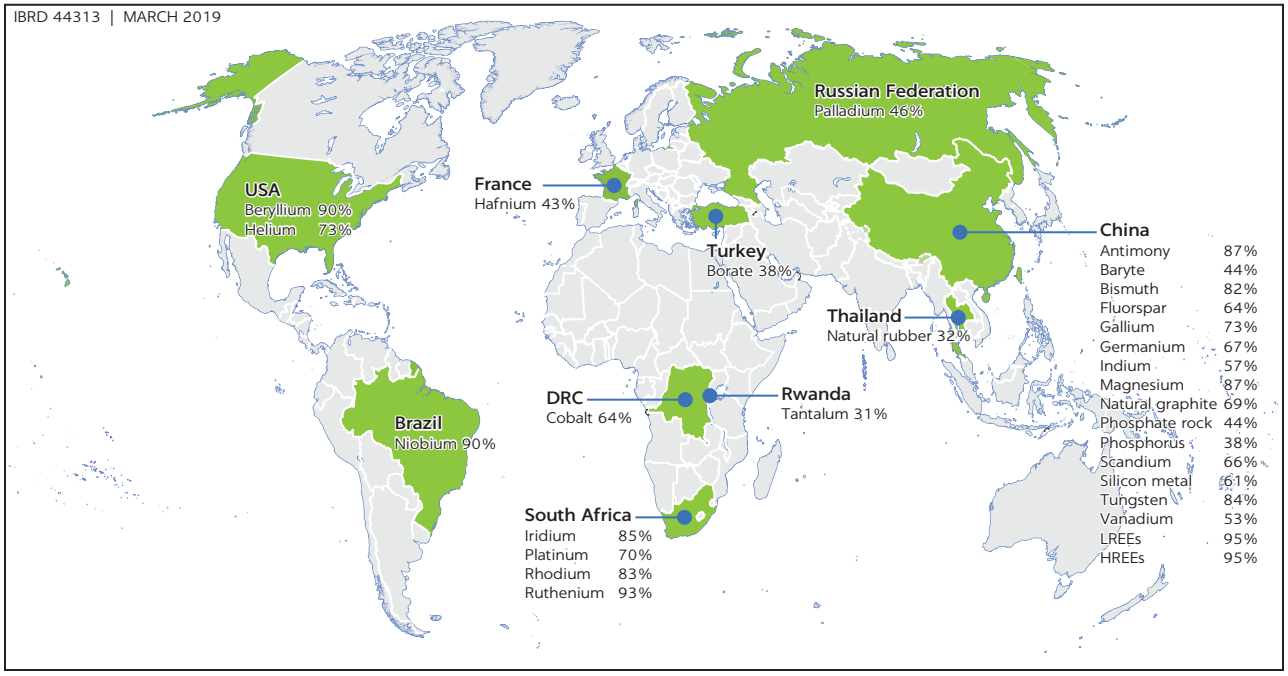
Frontier minerals and CRM are defined as those that have high economic importance and substantial supply chain risks. These factors make the material important in a high-functioning economy and, potentially, difficult to obtain, either from limited sources or sources that may not be able keep up with demand either through strategic choice, geopolitical instability, or lack of infrastructure. In turn, this combination of factors drives up the price of these minerals. There are many minerals that fit this definition, but this report will briefly outline cobalt, lithium, and rare earth elements. Map 3.2 shows countries with the largest supply of critical raw materials (CRM).

Cobalt's burgeoning demand is primarily tied to technological advances in rechargeable lithium batteries that are found in everything from cellular phones to cars. As of the writing of this report, Cobalt, for example, traded at approximately $70,000 per tonne, compared to approximately $55,000 per tonne the year prior. The dramatic rise in demand, projected by some sources to jump more than 40 percent in 2018 alone, has severely stressed an already fractious supply chain for the metal (Ferris 2018). The Democratic Republic of Congo (DRC) contains more than 60 percent of known cobalt reserves, an amount more than six times that of Australia, the second largest reserve of cobalt (USGS 2018).

Similarly, lithium is used in batteries that power many of todays most advanced technologies, with Australia being the largest current producer with approximately 50 percent of global production. However, Bolivia and Chile have two of the largest untapped reserves of lithium in the world, with Bolivia's reserves alone exceeding Australia's by nearly three-fold (USGS 2018). This emphasizes the critical nature of establishing green value chains that can fostering replicable, scalable climate-sensitive technology solutions for yet-untapped markets.

MAP 3.2

Countries with the largest supplies of CRM



Rare earth elements are integral to technologies across the media, communications, clean energy, health, and defense fields. A collection of 17 metallic elements that are physically and chemically similar, rare earth elements are essential to producing some of the world's strongest magnets (e.g., neodymium magnets) that play a central role the defense platforms of multiple industrialized nations. China plays a dominant role in supplying this market, with a 2010 U.S. Government Accountability Office (GAO) report determining that China produced 97 percent of global rare earth ore and 89 percent of rare earth alloys and controls a significant portion of known global reserves (GAO 2016).

Why mineral-rich developing economies should care

The rising demand for cobalt, rare earth elements, lithium, and other CRM will prompt a rise in extractive activities to increase supply, putting cobalt and rare earths at the forefront of exploration and production in coming years and decades. As companies and governments seek to solve current supply chain restrictions and find stable sources outside of China, the DRC, and Australia, the search for these metals and minerals may find its way to the doorstep of new markets—and likely countries—if it has not done so already.

The strong demand for these materials suggests that CRM such as cobalt, even with reserves predominantly focused in DRC, have the capacity to drive economic diversification across a broader range of localities than metals and minerals with more limited production geographies. In 2017, according to metrics from S&P Global Market Intelligence, the top 20 cobalt-producing mining operations showed a marked difference between the top 20 iron ore producing operations: 90 percent of the top 20 iron ore producing mines are in either Australia or Brazil, while 11 different countries occupy the list of the top 20 cobalt production sites.[5] The same can be said of rare earth minerals given the similar demand and dominant reserve positions a multitude of countries. Countries that currently have large cobalt reserves (although significantly smaller than those of DRC) include Zambia, Tonga, Cuba, the Philippines, and Madagascar. Similarly, countries with large rare earth deposits include Brazil, India, South Africa, and Vietnam and those with substantial lithium reserves include Australia, Argentina, Bolivia, Chile, and China.[6]

The demand for these types of minerals is so intense that countries that rely on rare earths for key defense technologies and companies that require the materials for commercial products are actively seeking to diversify the supply. The U.S. Department of Energy lists supply diversification a top priority when addressing CRM and states that part of their approach includes "...encouraging other nations to expedite alternative supplies."(U.S. Department of Energy 2011) Companies such as Apple and BMW have expressed interest in working directly with cobalt mining companies in an effort to shore up access to a steady supply of the metal (Farchy and Gurman 2018). If demand continues at the current pace, and companies and governments continue to demonstrate a willingness to venture further afield for cobalt, lithium, and rare earth elements, emerging market countries whose relatively small reserves would not have been profitable for companies to extract just a decade ago may benefit.

Furthermore, the royalty structures applied to mining operations across local, state, and national levels are often tied to the market value of the dominant mineral or metal being mined. As the demand for both cobalt and rare earth elements continues to be driven by technology advancements and the supply chains

continue to be constrained by a lack of effective substitutes and sole-source providers, the market value is projected to increase steadily over the coming decades. Countries such as the DRC have already moved to classify Cobalt as a "strategic" mineral, a designation that increases royalties from 2 percent to as much as 10 percent in an effort to generate additional revenue from the in-demand metal (Reuters 2018).

NOTES

1. Information provided by IAMGOLD as part of consultation for the preparation of this case study.
2. Retrieved through consultation with IAMGOLD.
3. Sustainable Energy for All (SE4ALL), https://www.se4all-africa.org/seforall-in-africa/country-data/burkina-faso/.
4. Compiled from data available through S&P Market Intelligence.
5. Compiled from data available through S&P Market Intelligence.
6. Compiled from data available through S&P Market Intelligence.

4 Conclusion

...knowledge is still missing in the linkages that exist between different types of resources...

– UN Environment Program

The mining industry has historically been resistant to dramatic change. Volatile commodity prices, high CAPEX requirements, the uncertainty of exploration, and large debt burdens create a cycle of boom and bust that has traditionally rewarded companies that make measured decisions over the life of its mining operations. Adapting to climate change is no exception to this reality, and industry's implementation of climate-sensitive initiatives and activities is not yet well-established, with large solar arrays, smart water management systems, and emissions-reducing technology only beginning to take hold on an industry-wide level over the last decade. Similarly, green industrial policy is a relatively new policy option in the arsenal of national governments. Taken together, as these case studies highlight, the mining industry's nascent but growing use of climate-sensitive initiatives in their operations and governments' burgeoning prioritization of green industrial policy have begun to influence how each side behaves.

Gold's importance to Burkina Faso and the national potential for renewable energy make this a compelling example of how broad-based technology transfer in one sector can drive economic diversification on a national level. By erecting the physical infrastructure required to develop a robust renewable energy industry and proofing the financial viability of power purchase agreements in a country with a high risk-profile, gold has delivered value to Burkina Faso beyond a direct contribution to the bottom line.

Copper's strong relationship with Peru and the potential for water infrastructure and water-related technical expertise to have a scalable and diversifying impact on a national economy is high. To some degree, access and availability of a clean water supply is integral to economic advancement, something that is particularly acute in water-stressed environments. Peru, and the infrastructure put in place through PPP by Freeport-McMoRan, emphasize that relationship,

and demonstrate the larger potential of companies investing in long-term water assets and the capacity of national governments to influence, or demand, the types of investment these permanent assets require.

Iron ore can be a lever on which the Western Australian or national government relies to drive larger, greener gains in economic diversification. Iron ore remains the most dominant Australian commodity in a competitive commodity landscape and companies such as Rio Tinto have already had success designing and implementing new automating technologies. These technologies have increased productivity, reduced carbon emissions, and created new, greener, economic value chains in Western Australia.

Cement and aggregate are thriving in the Indian market. Farmer biomass supply organizations and biomass generation technology represents a mechanism through which India can reach across its rural expanse to develop a scalable and economically diversifying green value chain that puts infrastructure and financial support in local communities.

All of these commodities, and the mining industry at large, have the potential to drive economic diversification in green technology areas. However, companies and policy makers have yet to fully capture this opportunity. Climate change initiatives, such as the Paris Agreement and the Taskforce for Climate-related Financial Disclosure are well known to policy makers in emerging and developing economies leaders, and mining companies' boardrooms of global corporations. Yet the first-hand concerns of local communities in these economies are more directly focused on the tangible, immediate local economic and social impacts of mining operations.

Overall, mining companies are more decentralized than other types of businesses with more consistency across operations: mine sites very much reflect the specific nature of their host rock and host communities. As such, climate concerns only begin to become material issues at a mine site when they reflect issues such as water scarcity and local value creation. Bringing together the motives of industry, the interests of government, and the climate-sensitive capacity of technology may be a more effective way of looking at the issues of climate change in mining and national economic diversification, rather than addressing such issues as separate matters.

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The mining industry, which provides input to almost every product and service in the world, is a critical component of sustainable growth in mineral-rich countries and the economy at large. This report is intended to deliver an account of mining technologies, processes, and strategies that seek to incorporate environmental sustainability considerations and have the potential for local value creation and green growth. The analysis focuses on three areas—renewable energy, water management, and automation and transportation—that are considered to have the broadest impact on environmental sustainability and in-country value creation through economic linkages. A reference case study is presented for each of the four benchmark minerals: gold mining in Burkina Faso, iron ore in Australia, copper in Peru, and cement in India. The report is part of a series of background reports that inform the research on *Building Resilience: A Green Growth Framework for Mobilizing Mining Investment*.

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