

Methodology and Value Chain Analysis

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

Sri Sekar, Kyle Lundin, Christopher Tucker,
Joe Figueiredo, Silvana Tordo, and Javier Aguilar

INTERNATIONAL DEVELOPMENT IN FOCUS

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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 ELLEDED Program.

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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

CO ₂	carbon dioxide
ELLED	Extractives-Led Local Economic Diversification
GHG	greenhouse gas
ICMM	International Council on Mining & Metals
kWh	kilowatt hour
LNG	liquefied natural gas
MW	megawatt
PPA	power purchase agreement
REE	rare earth elements
TBTU	trillion British Thermal Units
USGS	United States Geological Survey

1 Introduction

Rising global temperatures, the increasing frequency of severe weather events, changing precipitation patterns, and other measurable shifts in global climate have tangible impacts on societal and economic factors alike. The mining industry is not insulated from these impacts and, due to its global economic footprint, the industry is sensitive to the increasingly variable nature of our climate. In the face of this change, mining firms have developed and implemented a variety of climate-sensitive mining practices that attempt to mitigate the mining industry’s impact on climate change while adapting industry practices to operate more effectively in the face of a changing climate.

These practices are rooted in the fact that the mining industry is in a unique position to not only meet the new climate challenges, but to reap the benefits of the opportunities presented by climate change—namely, making timely investments in areas that can address climate challenges while delivering real sustainable economic value for host nations, while securing for themselves a stronger social license to operate. The industry overall is an extremely resilient one, owing in part to preexisting robust processes mining firms have put in place to prepare their physical and human capital to operate well in extreme environments. That being said, mining operations can be quite vulnerable to particular climate-related risks, including water scarcity (e.g., production shut downs, costs of water, competition for scarce resources) and extreme weather events which can lead to pit and underground flooding, pumping and dewatering costs, and increased erosion. Yet climate change also presents business opportunities—such as energy cost reduction, renewable power production, newly accessible mining sites, and overall operational efficiencies. Ultimately, water-energy nexus impacts are context specific, and can’t be generalized. The same notion applies to the climate-mining nexus. As such, this report proposes a methodology to prioritize value chain segments within multiple mining subsector for in-depth analysis.

THE PURPOSE OF THIS REPORT

The methodology proposed in this report is intended to provide the reference framework for policy makers to investigate the potential the segments of the mining industry primed to drive the uptake of climate-sensitive technologies and practices in emerging and developing markets, such that those policy makers might identify areas for policy interventions that can generate sustainable economic growth. By establishing the scope and scale of the inquiry, detailing initial inputs, and defining the methodological rigor while proving its robustness, this report will inform the report on *Building Resilience: A Green Growth Framework for Mobilizing Mining Investment* and its background reports.

2 Defining the Methodology

After examining and prioritizing the individual climate risk and opportunity “Priority Areas” through a thorough analysis of each subsector’s value chain, this report explores the Priority Areas to select a group of readily observable production and procurement technologies, innovations, and strategies, collectively described as “initiatives,” that capture industry tactics to both mitigate climate impact and adapt their practices to account for a changing climate. The initiatives will be analyzed according to their relative ease of implementation and the degree to which they impact the climate-sensitive agenda, and further categorized as mitigation (initiatives that seek to mitigate mining activities’ impact on climate) and adaptation (initiatives that reflect industry adaptation to a changing climate).

It is important to note that the initiatives identified in this paper are intended to serve as the baseline for further research—they are not meant to serve as an exhaustive list of potential industry practices. This is particularly important given the dynamic environment of disruptive innovations that affect industry practice. Additionally, the underlying data that forms the basis of the analysis in this report is limited to either data made publicly available by mining industry stakeholders in the public sector (e.g., US Geological Survey) or disclosed by mining firms in response to a growing ecosystem of climate-related mining compliance mechanisms such as the UN Sustainable Development Goals and the Carbon Disclosure Project. This initial research is essentially a launch-point for discovery of similar, supporting, and adjacent practices.

PRIORITY AREAS

To support the identification of public and private sector mining practices to mitigate the industry’s impacts on or adapt its operations to climate change this report first seeks to establish what the specific priority areas in the industry should be. The first step in establishing these priority areas is to categorize mineral and metal mining subsectors that are sufficiently unique in operation and requirements to warrant individual treatment, and have developing

country relevance. To this end, this report focuses on the following unique subsectors, which also reflect industry-accepted groupings from the International Council on Mining & Metals (ICMM):

- Precious Metals,
- Ferrous Metals,
- Base Metals, and
- Construction Minerals/Limestone/Cement.

Both precious and base metals are relatively high value commodities with particular significance/presence in the developing world, and due to their high value, they warrant exploration and extraction activity even when the ore grade is very low relative to other subsectors. Ferrous metals, by contrast, present more of a common, ubiquitous type of operation where commercially viable ore grades are roughly 19–20 percent, have low value due to a market glut, yet continue to have a strong presence in emerging markets (roughly 35 percent of 2017 world production not including China). Lastly, construction minerals such as sand,

BOX 2.1

A note on next-gen commodities

Cobalt

This report recognizes that cobalt plays an important role as a base metal, but it chose not to include it as the reference commodity for the ICMM base metal category. This is primarily because cobalt is often a byproduct of copper mining, and as such its extraction process is closely linked, yet its value is approximately 10 times that of copper. Moreover, analysts at Benchmark Mineral Intelligence estimate that 73 percent of cobalt will be sourced from the Democratic Republic of the Congo by 2023 (Deign 2018). Given its extreme geographic concentration, close nexus to copper, and high value relative to other base metals, cobalt was not used as a reference commodity. However, this report acknowledges the growing role of cobalt in the global energy economy, as it is a major component in the cathode in lithium ion batteries—a product that figures prominently in grid-scale renewable energy and electric and hybrid vehicles. In fact, China, the world’s largest consumer of cobalt, utilizes approximately 80 percent of its cobalt in the production of batteries (USGS 2018). Given the commodity’s growing prominence, while it is not featured as a reference metal in subsequent analysis, it will figure into the broader discussion and in the final report.

Rare earth elements (REE)

REEs present a similar case to cobalt in that their production is extraordinarily geographically

concentrated—95 percent of 2017 REE production came from China (Tyrer et al. 2013). In addition, the REE industry is relatively small for metals—all 17 REEs combined form an industry that is approximately \$20 billion in size as of 2013, with \$5 billion being the maximum size of any of the individual REE industries. This is in comparison to a \$350 billion iron ore industry and a \$160 billion copper industry (Tyrer et al. 2013). REEs are also distinct from the reference commodities used in the report’s subsector analysis in that only 50 percent of REE’s metal value is accrued in the mining stage while the other 50 percent is accrued in downstream processing—that is in comparison to copper, where 75 percent of the metal’s value is due to mining, and gold where 90 percent of the value is owed to mining (Tyrer et al. 2013). As such, REEs are more of a *processing* story than it is a *mining*, and that made for an imperfect fit for the process-oriented analysis reflected in figure 3. That said, the magnetic potential of REEs has made them a critical resource in vital and growing sectors of the global economy, such as high tech, renewable energy, and defense. Due to its extraordinary relevance, while REEs are not included as a stand-alone segment of its heat map, subsequent parts of the project will address important climate innovations in the industry, especially in downstream processing.

gravel, and limestone—many of which are used to make the finished product, cement—are a huge industry, extremely local due to their low unit-value, and the market for the minerals is driven by a growing local economy. In summary, these subsectors are all uniquely relevant to the developing world, and have nuances in each of their value chains to warrant individual examination.

To increase quantitative analytical rigor—increasing the chances of “apples-to-apples” comparisons—this report uses a *reference commodity to represent each of the subsectors*: for precious metals the reference metal is gold, for ferrous metals it is iron ore, for base metals it is copper, and for construction minerals the reference mineral is sand and gravel, and for the purposes of the final processing analysis, the reference finished product for construction minerals is cement. Box 2.1 provides additional criteria for the choice of reference commodities.

The reference commodities for each of the categories were selected based on both qualitative and quantitative criteria:

- a. Gold was selected to represent precious metals because it serves as a benchmark for financial markets, has a vast quantity of publicly available data, and boasts by far the largest commodity market in the precious metal segment.
- b. Copper has the largest market in terms of mined base metals (most widely used metal in the electrical industry and building construction), and its price has long served as a benchmark indicator for economic health, with price fluctuations in sync with overall manufacturing and construction. Copper is also considered a “mineral of the future,” perhaps because of its use in battery electric vehicles that require three to four times as much copper as traditional fossil fuel-powered vehicles.
- c. Iron ore was selected to represent ferrous metals because the ferrous metal classification is defined by whether a metal contains a high iron content. By this definition, iron ore was an apt choice to represent the broader category of metals.
- d. With respect to the inclusion of the construction and industrial mineral segment, this was done to capture growth in emerging markets—these commodities are critical to the infrastructure construction sector, and quintessentially local—the low per-unit price of these minerals makes overseas shipment prohibitively expensive. The scale of the industry in terms of the quantity mined is also mammoth in size; the United States Geological Survey (USGS), for instance, measures production in terms of millions of metric tons while it measures the production of most other commodities in thousands of tons.

With the relevant unique industry subsectors identified, it is necessary to analyze the subsectors’ value chain, broken down by individual segments. Here, two sets of segments are important—first the overarching stages of the end-to-end mining life cycle, and then the activities within the high-level stages. Listed below are the stages of the mining lifecycle, followed by a description and the activities entailed in each area. Moreover, the stages described below also provide the scoring and analytical methodology employed to identify the corresponding areas of climate risk and opportunity as it relates to the five identified mining and mineral subsectors. Both climate and economic factors were considered; with climate factors encompassing primarily energy and water intensity of operations, and economic factors represented by the most recent annual percentage metal/mineral produced in the developing world. It is worth noting that the energy proxy variable used in this report—energy intensity of each process in trillion BTU/yr—is

targeted at minimizing the difference between direct emissions (e.g., those driven by emissions from extraction and hauling equipment) and indirect emissions (e.g., those driven by electricity consumption). Qualitative assessments were also applied based on the unique nature of operations for each subsector, and that in turn had an impact on the overall selection of the priority areas for further examination. Detailed scoring results are provided in appendix A.

1. **Mine Design, Planning, and Development:** This stage encompasses the initial portion of the mining lifecycle—from concept, to the exploration of resources, design and planning of the facility, and planning for its ultimate closure.

Methodology: This report begins by analyzing the value of and ore grade at which the extraction of any of the identified minerals or metals would be commercially viable. The analysis leads to implications as to the likelihood that miners would be incentivized to engage in riskier and larger-scale activity, such as exploring harsher locations that are newly accessible due to global warming (e.g., arctic areas). Similarly, the incentive provided by highly valuable metals/minerals and low ore grade influences whether small scale/artisanal mining would occur, or the likelihood and *magnitude* of tailings operations, underground mining, and risks posed at mine closure—all activities that present substantial risks to, or whose operations are impacted by risk from climate change. For each of these knock-on impacts or considerations, a qualitative assessment was used to apply a likelihood of occurrence score between 2 (most likely) and 0 (not at all likely). Lastly, the energy intensity of each subsector’s drilling/exploration activities, measured by trillion British Thermal Units (TBTU) consumed per year,¹ was also researched while controlling for each subsector’s economic relevance to developing countries by applying a multiplier. This last multiplier was rooted in the proportion of 2017 global production of the reference commodity attributed to emerging markets. This multiplier was not, however, applied to the construction mineral subsector, which was considered as uniquely local—for example, sandstone’s price/value prevents companies from being able to cost-effectively ship the commodity long distances.

2. **Mine Operations—Extraction:** This stage encompasses all activities necessary to extract the subject metal or mineral from its ore body. This includes all of the equipment and power required to blast, dig, ventilate, and dewater during mining operations. The equipment and materials used for these operations include diamond and rotary drills, explosives, hydraulic shovels, fans, and pumps.

Methodology: While there are multiple factors to assessing the climate risks that threaten and are posed by extraction operations, in a quest for a data-rich analysis, energy intensity (as measured by TBTU/yr) of operations was chosen as the primary measure for climate risk/impact in mining operations. It tapered the climate analysis to the specific mineral/metal by accounting for the subsector’s economic relevance to the developing world through the application of a multiplier. This accounts for the fact, for instance, that the developing world produces less of the world’s production in gold in percentage terms, than it produces copper.

3. **Mine Operations—Materials Handling/Equipment:** These operations encompass all in-pit activities related to the mobilization of mine inputs and outputs. The equipment used for these activities include service trucks, front-end loaders, bulldozers and pick-up trucks.

Methodology: Since so much of this activity is powered by diesel fuel (and some electrical equipment including conveyors, pumps, and hoists), energy intensity in TBTU/yr was selected as the primary quantitative measure of climate impact and risk. Once again, we also applied the overall emerging markets relevance factor to measure the scale of the climate mitigation or adaptation (to reduced fuel supply) opportunity.

4. **Processing:** This stage is comprised of all activities required to transform run-of-mine material into the final mined product. This includes crushing the initial material into coarse particles, grinding them into fine particles, and using physical or chemical methods to separate the valuable material from the non-valuable substances. This stage also includes the roasting, smelting, and refining required to transform the raw material into the final substance (e.g., cement, aluminum, or steel).

Methodology: As with other operations, TBTU/yr was retained because it is the metric most reported and aligned with climate impacts, followed closely by the economic scale of the particular subsector in emerging markets. The analysis used a factor of the two to determine the segment's overall relevance for climate purposes.

5. **Water Risk and Intensity:** The analysis also included the consideration of a subsector's particular exposure to water related risks (e.g., availability, competing uses, permeable aquifers) and the intensity of water use in operations. Water use and risk were considered a climatic factor that particularly runs throughout the mine's operations from exploration through processing, operations, and closure, the report includes it as its own operational "stage" that impacts the entire assessment.

Methodology: Due to the relative dearth of water-related data per value chain segment, a qualitative assessment was used to determine the water risks and intensity of water use per subsector metal or mineral. Specifically, it assigned a commodity a 3 (highest score) for water risk if it is frequently mined in arid or semi-arid environments or an environment extreme rainfall and permeable aquifers. Whereas a 0 (lowest score) was assigned for water risk to a commodity if it's typically mined in areas with a moderate level of rainfall, and the mine site can easily control its flow.

It should be noted here that none of the stages or factors above were considered in isolation when arriving at the priority areas for analysis. Rather, this report takes a holistic approach, with an understanding of how, for instance, mine planning and design choices impact other parts of the value chain, how water plays a role throughout, and how economic indicators illustrate any particular value chain segment's significance. Figure 2.1 provides an illustrative summary of the methodological factors for the report's value chain analysis.

MITIGATION AND ADAPTATION INITIATIVES

A framework was developed to plot a range of climate-sensitive initiatives identified from within the Priority Areas established through the mining value chain and subsector analysis. This framework prioritizes the initiatives along two axes: (1) Ease of Implementation and (2) Climate Impact, as an initiative that is both simple to implement and has a high positive impact on the climate would be an industry practice that governments and donors would be eager to encourage. The individual criteria of those two overarching categories are outlined below,

FIGURE 2.1
Subsector and value chain prioritization methodology

		Gold	Base/copper	Iron ore	Other/ construction mineral
Mine design/planning	Exploration/drilling	TBTU/yr × EM relevance factor*			
	Ore grade/recovery	Recovery ratio			
	Hazardous/harsh environment potential	Likelihood of activity qualitative assessment (0 = Not at all likely; 2 = Very likely)			
	Small scale/artisinal mining				
	Tailings/alluvial				
	Underground mining potential	(Validated by independent research)			
	Closure and decommissioning				
Extraction	Blasting/extraction	TBTU/yr × EM relevance factor			
	Digging/excavation				
	Ventilation				
	Dewatering/suction				
Processing	Crushing	TBTU/yr × EM relevance factor			
	Grinding				
	Separations				
	Final processing (roasting, smelting, refining)				
Materials handling/ equipment	Diesel equipment	TBTU/yr × EM relevance factor			
	Electric equipment				
	Pumps				
Water risk and intensity	Intensity	Qualitative assessment of intensity of risk and operations based on, e.g., ore grade, subsurface operations, likelihood of extreme conditions (0 = Low risk; 3 = Very high risk)			
	Risk				

Commodity	Factor
Gold	60%
Base/copper	100%
Iron ore	60%
Other/construct.	N/A

EM Relevance based on proportion of 2017 global production attributed to emerging markets. construction minerals is un-applied due to local nature of market.

100% Fixed at reference commodity with highest attribution to emerging markets.

Note: TBTU = trillion British Thermal Units.

with a description provided for each. These criteria were produced after engaging with industry specialists and performing extensive industry research and are intended to capture the overall intention of the their respective axis category and, as are the other elements of this report, grounded in publicly available data. They do not represent an exhaustive list of elements that would influence, for example, the ease of implementation for a specific climate-sensitive initiative, but rather identify focus areas that would commonly impact the calculus of the decision maker when deciding whether to implement the initiative or gauge how significant it is from a climate impact perspective.

Detailed scoring are presented in appendix B.

EASE OF IMPLEMENTATION

Following extensive research and the evaluation of government reports, private company reports, and industry leader self-reporting, the ease of implementation metric evolved to be viewed through the intentionally broad lens of “how

challenging is it to execute and implement this initiative from end-to-end.” Through the analysis of similar reports, industry standards, and leading practices, this definition came to include a variety of factors that, taken as a whole and within the broad intent of this assignment, would be able to provide a general prioritization of which initiatives are “easiest” to implement.

To preserve the general applicability of the criteria against which the initiatives are being measured, the majority of the ease of implementation criteria are scored on a binary scale, with the exception of Innovation Maturity. This serves to indicate engagement with subject matter leaders, and use of industry knowledge—whether the respective indicator makes it more or less challenging to implement this initiative.

For example, does the size of the mining enterprise that is considering the initiative impact the relative ease with which that company can invest the necessary funds to execute the initiative? Some initiatives, due to economies of scale and other considerations, may be implemented by anyone, regardless of size, while some initiatives may be inherently more or less implementable by a mining company of small or large revenue. If an initiative cannot be implemented with relatively equal ease by companies across the size spectrum then the size of the company is an exclusionary factor in determining whether a company can implement the initiative and, in a general sense, that initiative is more challenging to implement than an initiative that can be implemented effectively by companies of every size. This example would then receive a zero (0) to indicate that that size of the company does impact the ability of this initiative to be implemented, and the initiative is generally less easily implemented than initiatives that prompt the opposite conclusion as a result.

It is noted that some categories within this analysis may necessarily penalize initiatives that are inherently more challenging to implement by companies of a certain size or capability. However, by applying evaluation criteria across multiple initiatives from a truly global array of options, the possibility of distortion should be minimal and acceptable within the intended scope and purpose of the analysis.

CLIMATE IMPACT

The climate impact metric is centered around the proven Triple Bottom Line approach of “People, Planet, and Profit,” designed to determine the relative impact of an initiative on the climate by qualitatively assessing the impact from across these three primary indicators. Relying on research and feedback from industry specialists, the elements of the Triple Bottom Line are broken down further into factors that capture the drivers that would influence the Triple Bottom Line areas. These elements are scored on a scale of 0–2, with the high (2) end of the scale indicating that something is more of a Triple Bottom Line impact than an initiative with a zero (0) score. Analyzing an initiative through this lens follows the same approach in the ease of implementation section; that whether a criteria generally increases, decreases, or has no effect on an initiative will indicate the degree to which that initiative has an impact on its assigned Triple Bottom Line score and, by extension, the climate, depending on how the criteria is being framed. Determining whether something “increases” or “decreases” will be evaluated using status quo as the benchmark. For example, if an initiative actively decreases greenhouse gas (GHG) emissions of the company

FIGURE 2.2
Initiative prioritization methodology

		Criteria	Description	Assumption	Scoring	
Ease of implementation (0-6)		Company size	Does the size (defined by revenue) of the firm impact investment decision?	Smaller or larger companies would be better able to implement an initiative depending on the economies of scale	0 = Yes 1 = No	
		Mine size	Does the size of the mine impact investment decision?	Economies of scale would factor in to implementing the initiative on a small or large size mine		
		Return	Does the investment require an extended timeframe to recoup?	It is easier to make the business case for an investment with a short-term return timeline		
		Mine lifecycle	Does the current lifecycle of the mine impact investment decision?	Some interventions would need to be made before mine construction or it may not make financial sense to invest in an initiative in a mine close to closure		
		CAPEX investment	Does the investment require CAPEX?	CAPEX investment is traditionally difficult to approve in the mining industry		
		Innovation maturity	Is the technology or the initiative commercially or institutionally viable?		1 = Yes 0.5 = Partially 0 = No	
Climate impact (0-6)	People (0-2)	Job creation	Does the initiative create more jobs at the mine and/or in the surrounding community?		2 = Increase 1 = Status quo 0 = Decrease	
		Tax revenue	Does the initiative increase local tax revenue?			
	Planet (0-2)	Mitigation	GHG avoidance	Does the initiative decrease GHG emissions?		2 = Decrease 1 = Status quo 0 = Increase
			Energy intensity	Does the initiative decrease energy use intensity (EUI) of the mine?		
		Adaptation	Water intensity	Does the initiative decrease water intensity?	Decreasing water intensity lowers vulnerability associated with water scarcity brought on by climate change	
			Climate risk	Does the initiative decrease insurance premiums?	Insurance premiums are a proxy for the risk associated with a climate event brought on by climate change	
	Profit (0-2)	OPEX	Does the initiative decrease operating expenses?			
		Revenue	Does the initiative increase revenue?			
		Company valuation	Does the initiative increase economically accessible mineral reserves/deposits?	Commercially viable deposits impacts the public valuation of the company	2 = Increase 1 = Status quo 0 = Decrease	

Note: CAPEX = Capital Expenditure; GHG = Greenhouse Gas; OPEX = Operating Expenditure.

implementing it, it would receive a two (2) to signify its positive impact on mitigating climate impact. Figure 2.2 provides an illustrative description of this two-axis methodology and a summary of the scoring framework.

NOTE

1. Note here that for an operations/energy consumption benchmark this report uses the USGS assessment of US mining operations. Although this measure does not specifically address developing markets directly, on a relative and averaged basis, the intensity across subsectors should be the same irrespective of the geographical context in which the operations are taking place.

3 The Value Chain and Subsector Heat-Map

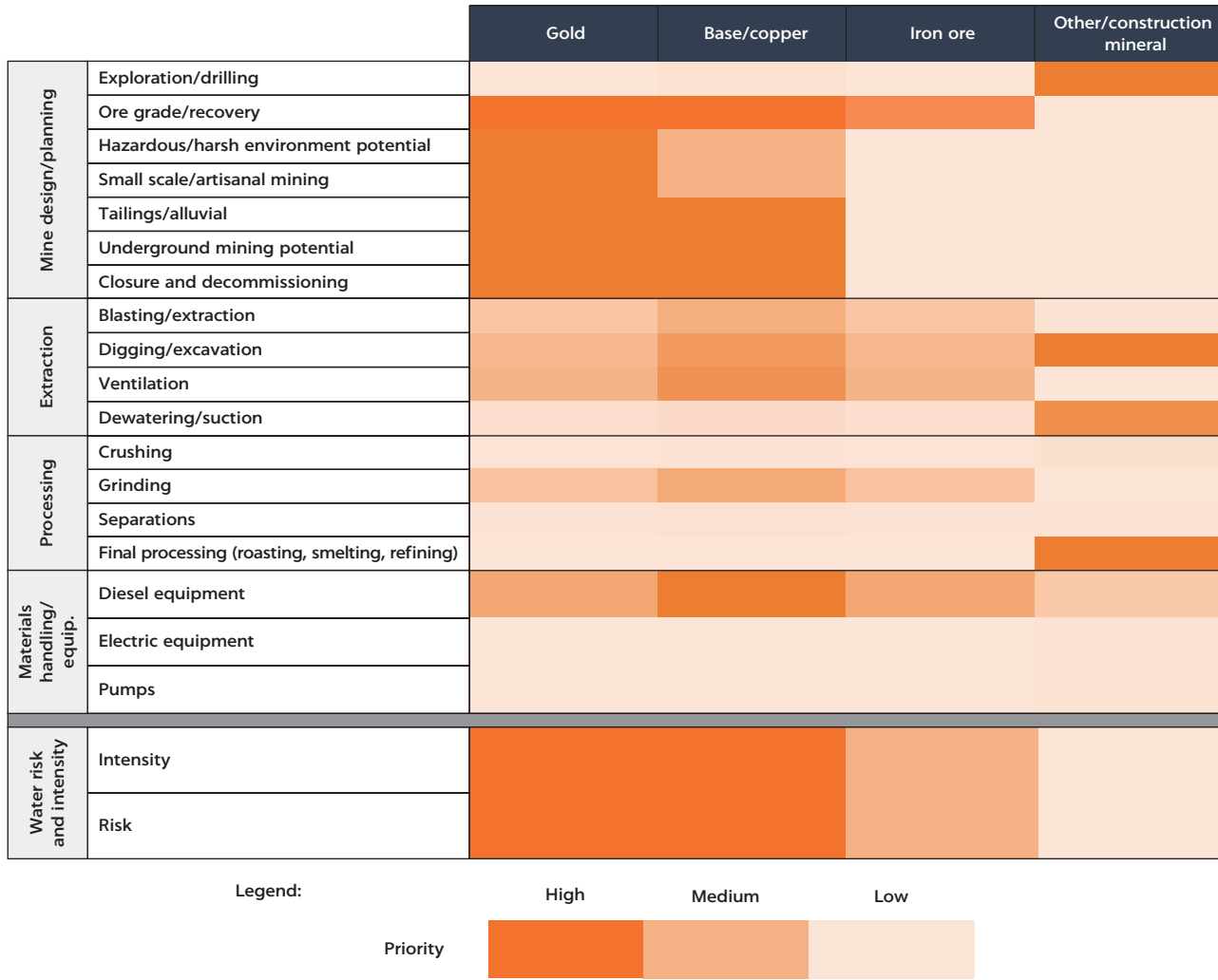
The methodology described in this report helped identify broad themes, or Priority Areas—comprising a combination of industry subsectors and corresponding value chain segments particularly vulnerable to or primed for the risks and opportunities presented by climate change. These Priority Areas reflect an effort to avoid *generalization*—the findings and recommendations reflected in the forthcoming series of reports require context, and this prioritization helps provide the relevant circumstances of each recommendation. This report goes on to provide examples of current initiatives being undertaken in the industry to address and/or take advantage of the risks and opportunities encompassed in each Priority Area.

These Priority Areas not only inform where firms are motivated to and are already making climate-sensitive investments, but should provide critical insights to policy makers as to which climate-related policies discussed in subsequent reports in this series might be best suited to incentivize the types of investment that might spur green growth, and how such policies might be targeted. Gold and Copper mines, as the heat map below displays for instance, present outsized risks to local aquifers. As such, policy makers in gold and copper-rich areas might have an interest in developing and making available water-related data, passing robust siting standards, and even providing benefits to those miners willing to install water treatment infrastructure as a part of the mine development process. Similarly, countries and regions in which cement processing plants are located have an incentive to pass standards targeted particularly at those energy intensive plants, offering benefits (e.g., feed-in-tariffs or opening the way for direct power purchase agreements) to those plants willing to invest in renewable resources.

CLIMATE IMPACT

The value chain and subsector analysis and corresponding scoring exercise led to a heat-map, which helped visualize the areas of critical concern for the industry. That heat-map is presented in figure 3.1.

FIGURE 3.1
The value chain and subsector heat-map



This visualization technique provided insights into what segments of the industry are particular pressure points for the industry as it relates to climate change in the developing world context. Based on our analysis, for instance, gold mine siting and development is a crucial area for climate risk and—more importantly—opportunity for the industry. Similarly downstream processing in the construction mineral industry has a particularly onerous climate impact. These insights yielded five high-level themes described in detail below:

- a. **The frontier of mining—planning for the risks associated with scale and new geographies.** Warming temperatures, for instance, have led to more accessible mining sites—driving mining exploration activities to harsher climates. High value commodities like gold and high demand metals like copper were more often found to drive activities such as subsurface mining (with its corresponding increased energy and water requirements, and peculiarities

around mine closure) and small/artisanal mining in developing countries (e.g., dredging river beds). These higher-risk activities require thoughtful planning, and we've presented in this paper a sample of activities currently being undertaken by mining sector actors that address these new challenges.

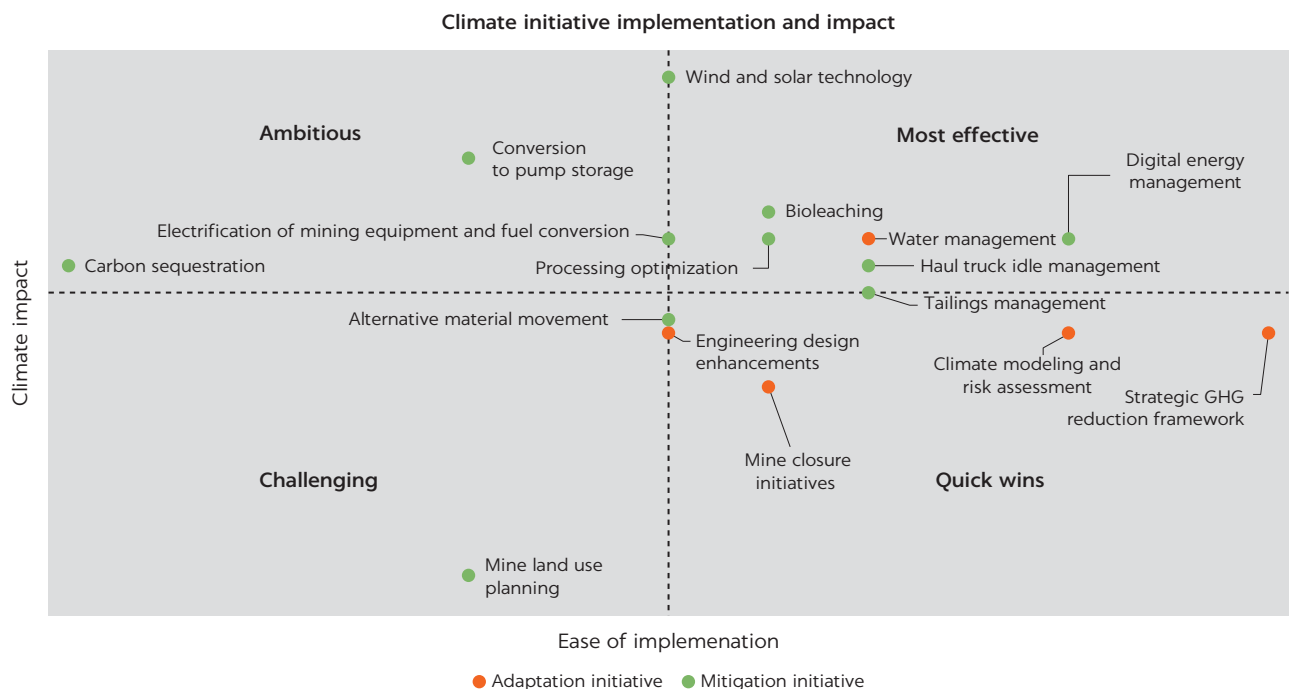
- b. Energy intensive extraction processes.** Within mining operations, extraction activities were far and away the most energy intensive, and thus the largest contributor to greenhouse gas (GHG) emissions. The digging and ventilation activities in subsurface base metal mines particularly drove energy consumption, as did the dewatering/suction activities in quarries and construction mineral extraction. Industry stakeholders have been taking a holistic view of how they may reduce energy costs in these activities, and this involves everything from adopting a climate reporting and accountability framework, the procurement of new equipment, deploying renewable energy, and exploring how approaches to procurement might be modified to incentivize the purchase of climate-sensitive alternatives. Current and notable efforts are described in greater detail below.
- c. The mobility of materials—procurement and management of material handling.** Material movement within the mine and from “pit to port” are primarily fueled by inefficient and high-emitting diesel fuel. The climate impact of this hauling equipment—bulldozers, pickup trucks, dump trucks, etc.—presents an opportunity for mining companies to reorient their procurement processes toward electric consumption vehicles, use alternatives to trucks, and optimize their logistics chains, and to drive best practices down to local suppliers and subcontractors in developing and emerging economies. One outcome that we seek to promote within this research project is the transfer of high-value climate-related skill and technology from diversified majors, to smaller in-country operators and suppliers. It is worth noting that these outcomes might be driven by purchasing behavior or by a holistic approach to procurement and novel contractual arrangements.
- d. Downstream processing—the intense impacts of final processing.** The goal of this research projects is to identify actionable recommendations to the mining sector to mitigate stakeholders' climate footprint, and to adapt their operations to a changing environment. Toward that end, if the scope of this effort were to be confined solely to mining activities, it may miss an opportunity to deliver comprehensive value—as such, final processing activities were included in this analysis. That includes the roasting, smelting, and refining process that takes the raw material and transforms it to the finished good—for example, aluminum, steel, and cement. While for the most part processing activities are proportionately slight in climate impact or less exposed to climate risk, there are a few exceptions—notably the final processing of cement, which contributes to 5 percent of global GHG emissions (Rubenstein 2012). This report reviews process improvements that could mitigate this disproportionate impact.
- e. The new world of water.** For the final overarching Priority Area, or thematic area of climate risk/opportunity for the mining sector, water scarcity, water competition, rising water levels, and extreme water-related weather events

were considered critical climate factors for mining operations in the developing world. The impacts of these interconnected risks ranged from having to restrict water usage and sources in mining operations to increased community unrest. The analysis revealed that more mature organizations have approached this risk through a comprehensive water management plan.

4 Climate Mitigation Initiatives

Applying the initiative scoring methodology outlined in the previous section yielded the results in figure 4.1. The initiatives are organized into two distinct classes—those that align most appropriately with climate mitigation (taking an active step towards reducing the negative effects of climate change) and those that are climate adaptations (actions taken as a result of climate change). Digital Energy Management is one of the simplest initiatives to implement with a respectable climate impact across the Triple Bottom Line focus areas. Similar conclusions can be drawn in the Water Management initiative, Haul Truck Idle Management—an initiative that operates both by upgrading haul trucks to

FIGURE 4.1
Initiatives categorization



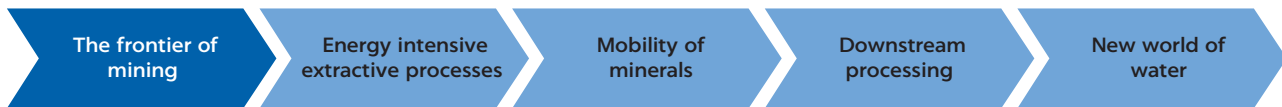
autonomous drive and using technology to better manage energy usage in the trucking and transportation segments of the mining value chain. These initiatives are in contrast to those such as Carbon Sequestration and Mine Land Use Planning, where a significant piece of the planning process is centered on converting Open Pit mines to underground mining operations, a capital-intensive process that is often reserved for when commodity prices are at historically high levels.

Overall adaptation initiatives appear slightly less challenging to implement than mitigation initiatives, while simple technological innovations are often both the easiest to implement and have the highest likelihood of positive climate impact in the mining industry. The full range of initiatives analyzed in this report, companies implementing them, and descriptions of their impact are provided below, each aligned within the Priority Areas this report identifies.

The following subsections align the initiatives prioritized in figure 4.1 to the overarching priority areas discussed earlier in the report. To facilitate the tracking of the intersection of initiatives and priority areas, the following graphic will be used.



THE FRONTIER OF MINING—PLANNING FOR DEVELOPMENT IN EXTREME ENVIRONMENTS AND USING RISKY TECHNIQUES



Climate modeling and risk assessment

Vale has commissioned independent studies to assess their exposure and vulnerability under certain climate scenarios. Similarly, Anglo American has modeled climate scenarios to forecast potential hazards for its operations, even modeling specific scenarios on a site-by-site basis, to better adapt to the rigors of climate change. Identifying and evaluating the consequence and likelihood of climate impacts at sites enables the mapping of critical controls such as slope stability monitoring, dust and fire suppression, and pit dewatering equipment. Multiple companies are developing regional and site-specific models to map the long term impact of climate change and forecast possible impacts on their interests and the communities surrounding them and better inform the companies on how to adapt.

Engineering design enhancements

The increasing frequency and intensity of severe weather events has triggered the mining industry to review construction standards for across their asset portfolios. Increased levels of flooding, inconsistent precipitation

amounts, and historically uncharacteristic fluctuations in temperature have encouraged companies like Norsk Hyrdo and Kumba Iron Ore to review their forecasting data and adapt their construction standards to complement the shifting atmospherics, in some cases facilities are even raised to accommodate projected sea level rises.

Tailings and mine waste management

Goldcorp's EcoTails technology that aims to significantly reduce freshwater consumption during the tailings process. There are multiple strategies to contain tailings and mitigate their climate impact. Among them is dry stacking, an initiative used in colder climates to guard against the potential of tailings mixing with freshwater. Additional technologies to reduce the amount of tailings produced and reclaim water used in the tailings process include tailings centrifuges that remove water and leave behind a clay that can be easily transport or used for land reclamation. Effective waste rock and tailings management including pit and underground backfill and capping is critical to managing acid rock drainage and post-closure stability at site.

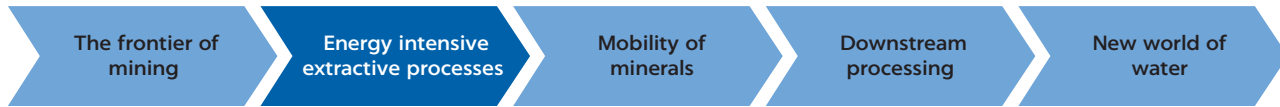
Mine closure initiatives

Risks at the post-closure stage of mine life include health and safety risks (due to ingress of the mine site), environmental risks (e.g., acid-rock drainage, toxic metal discharge), and financial risks when insufficient security has been provided to host governments. Planning for passive closure in order to minimize the amount of active (and costly) management and monitoring required is a leading practice from both a risk and an economic perspective. Understanding changing climatological and hydrological regimes is key to this process. In wet climates, maintaining tailings dams and/or treating water to acceptable limits in perpetuity is both risky and costly. In drier climates, challenges in establishing post-closure vegetation can result in increased erosion, dust and further instability.

Mine land use planning

Mining activity uses land at every stage of the mining cycle—exploration, construction, operation, closure and post-closure. There are many opportunities to reduce land-use impacts and associated emissions and many of these represent good environmental practice. Reducing the overall footprint of mining areas can have a significant impact in reducing land-use emissions at the construction stage. For example, a switch to underground mining significantly reducing the overall environmental footprint of the project, as compared to an open pit operation. Barrick is currently seeking a partner for the Pascua-Lama mine, located on the border between Argentina and Chile, which contains 21.3 million ounces of measured and indicated gold resources (Barrick 2018). Other companies like Codelco have entertained the possibility of making the move underground, only to be stymied by fluctuating copper prices. Biodiversity programs at the planning, operational and closure phases, can be developed to monitor and mitigate negative impacts on the environment and even plan to have a net-positive impact on land use and biodiversity.

ENERGY INTENSIVE EXTRACTION



Strategic GHG reduction frameworks

Mining companies of all sizes are developing and updating on an annual basis a framework for company-wide or site-specific climate sustainability enhances companies' accountability for their climate impacts and provides the opportunity to baseline key performance indicators that enable setting of achievable, science-based goals. Organizations can use reporting to inform their risk analysis strategies and boost their business. A growing number of companies, including those such as Rio Tinto and Goldcorp, use sustainability reporting to drive greater innovation through their businesses and products and create a competitive advantage in the market. Developing a sustainability report can help emphasize the links between financial and non-financial performance, help set benchmarks and assess climate performance with respect to laws, regulations, and voluntary initiatives.

Electrification of mining equipment and fuel conversion

The electrification of mining equipment enables production that consumes low carbon power by eliminating the use of diesel fuel. An example of this practice is Goldcorp's all-electric mine at its Borden Lake deposit, 200 km southwest of Timmins, Canada. Goldcorp's new mining technology will range from battery-operated drilling and blasting equipment, to electric bolters, personnel carriers and ultimately a battery powered haul truck.

The company's battery and electric mobile equipment will eliminate all greenhouse gases (GHGs) associated with the movement of ore and waste rock, equal to roughly 50 percent of the total GHGs on site, or 5,000 t/y of CO₂, and will reduce maintenance and energy costs (Jamasmie 2016). The use of an efficient on-demand ventilation system will provide added benefits—the Borden mine will require 50 percent less ventilation than a baseline diesel underground mine and avoid more than 7,500 t of CO₂ and eliminate 3 million liters of diesel fuel, 1 million liters of propane (Jamasmie 2016).

Converting haul trucks from diesel to liquid natural gas (LNG) can actualize significant savings and cut GHG emissions (Caterpillar 2017). A prime example is popular Caterpillar's 785C Mining Truck, where customers can expect to see between 20 percent and 40 percent fuel savings while LNG produces approximately 27 percent less GHG than diesel fuel (EIA 2018).

Digital energy management

Operational improvements can reduce energy consumption in mines by 10–20 percent and investment in energy efficiency technologies can boost that to 50 percent or more (Choudhry et al. 2015). There are a multitude of innovative investment strategies that can enable the realization of this savings (De Souza 2015). For example, ventilation systems in underground mines are often controlled manually and run at full power 24-hours a day; ventilation can account for

up to half of total power requirements of a mine and 30 percent of production costs. Automated systems can operate ventilation according to the production requirements of a mine, adjusting to specific area needs. Investment savings is equal to 5–15 percent of total energy consumption and paybacks are between 3 and 5 years (Choudhry et al. 2015).

Wind and solar technology

Many mines are located in remote sites that are not grid-connected. Electricity is often produced by diesel gensets. Driven by high fuel costs, the price for electricity generation is normally high. Renewable energy generation such as wind and solar, technologies that can operate in almost any environment and are proven to provide stable generation, is an optimal add-on to diesel-gensets and can generate considerable fuel and electricity cost-savings as well as GHG savings.

In 2012, the Diavik Diamond Mine in Lac de Gras, Northwest Territories, Canada implemented a 9.2 MW off-grid, wind-diesel-hybrid system. In 2013, diesel consumption reduced by 3.8 million liters and provided 8.5 percent of the mine’s power needs. The project is joint venture between Rio Tinto and Dominion Diamond Corporation; \$31 million investment fully funded by Rio Tinto and Dominion Diamond with a payback estimated at 8 years (Kirby 2014).

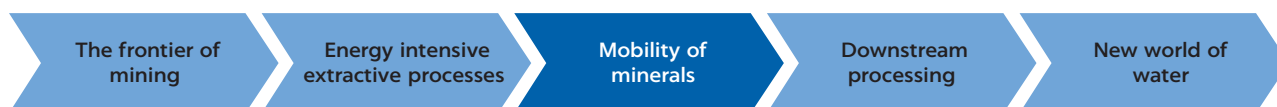
Capital intensity can be offset by working with local or international service providers (e.g., through a power-purchase agreement [PPA]). Broader energy needs planning can be incorporated into micro-grid investment where insufficient infrastructure exists in-country.

Conversion to pump storage

To compensate for intermittent wind and solar power, old mines can be converted to pumped hydro storage facilities by creating above and below ground storage reservoirs. During the day, water is pumped from the below grade reservoir in the refurbished mine to the above ground reservoir. When electricity is needed on the grid, water is released into mine shafts and turns turbines that generate electricity.

The Prosper-Haniel hard coal mine in the state of North-Rhine Westphalia is set to convert into a 200-MW pumped storage hydroelectric reservoir, which will have enough capacity to power more than 400,000 homes (Williams 2017). A closed mine in Australia has been similarly converted and is expected to be capable of producing more than 300-MW (Gough 2016).

THE MOBILITY OF MATERIALS—PROCUREMENT AND MANAGEMENT OF MATERIAL HANDLING



Haul truck idle management

Major industry players such as BHP and Rio Tinto have moved to modernize and improve productivity of its haul truck fleet by adding autonomous vehicles such as Caterpillar’s 793F and Komatsu’s 830E and 930E trucks. Modifying traditional

trucks or purchasing new, automated versions, can actualize upwards of 20 percent productivity in some cases, reducing the amount of time trucks are idle and thereby curbing fuel consumption and GHG emissions significantly (Flannery 2017). For Rio Tinto's operations in Australia, implementing these developments has reduced unit costs by 15 percent (Wayne 2017). This initiative also includes adapting other features of the truck to be more technologically adept; including remote truck monitoring to streamline heating and air-conditioning usage and to turn off the trucks when not in use, reducing idle tailpipe emissions.

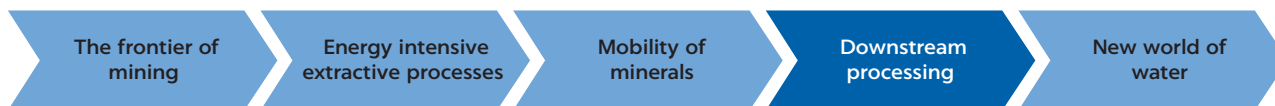
Alternative material movement

Low-loss conveyor belts use advanced compounds and fibers to reduce resistance between the belt and the drives. Reduced resistance saves energy. By switching from steel to aramid fibers, a Bulgarian power plant cut the weight of its conveyor belt by a third, saving about 18 percent in energy costs (Teijin Aramid 2014). Two primary examples are evident.

The Rail-Veyor system is a specific type of conveyor that incorporates a remotely operated electrically powered series of two wheeled railcars driven by power stations located along on a light-rail track. Because the cars are remotely operated and compact in size, they can be used as an enabling technology for rapid development and high-speed production at the working face (Business Wire 2011).

The 2.11-mile RopeCon cable conveyor system at Alcoa's Mount Oliphant mine in Jamaica generates 1,200 kW of green energy per hour. Alcoa has saved about \$1.5 million in energy costs since it began using the system in 2007. This conversion to an alternative method of material movement saves approximately 1,200 truck journeys a day along with the associated emissions of CO₂.

DOWNSTREAM PROCESSING—THE INTENSE IMPACTS OF FINAL PROCESSING



Process optimization

The final stages of the mining value chain are often some of the most energy and GHG intensive. This presents an opportunity for technological optimization to have a substantial, climate-sensitive impact. Behind water, concrete is the most abundantly consumed material in the world, and the mining of aggregate to supply the material to meet that demand is proportionally large. The GHG footprint of concrete production is substantial, accounting for approximately 5 percent of global man-made CO₂ emissions and emits as much as 80 percent of its weight in carbon dioxide during the manufacturing process (Berg 2016). Implementing energy-saving innovations such as high-efficiency grate coolers, improved pre-heating, and modernizing combustion systems can reduce the amount of energy required to manufacture cement and greatly reduce carbon emissions.

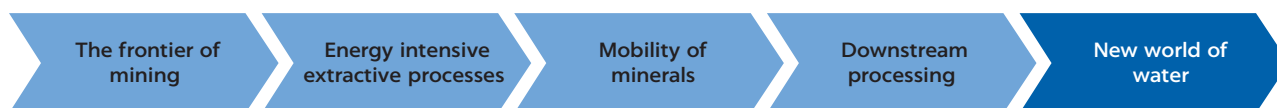
Further, the smelting portion of the aluminum mining value chain produces a disproportional amount of GHG, with some estimates at approximately double

the GHG of the combined emissions from the mining, alumina production, anode/paste production, and ingot casting segments of the aluminum value chain. Recently, aluminum giant Alcoa has joined with the technology company Apple to develop a process that would replace carbon with another conductive material that, when burned in the smelting process, would produce oxygen instead of carbon dioxide. If fully implemented this innovation could fully eliminate GHG emissions from the aluminum smelting process (Fulton and Sainz 2018).

Bioleaching

The process of extracting metals from ores using microorganisms native to the environment. Notably, it is used to extract copper from sulfide ores, a process that would not necessarily be profitable with more traditional extraction technology. Bioleaching has the dual benefit of both allowing mining companies to profitably access lower level ore grades than previously pursued while having the capacity to clean up toxic and contaminated mining sites, including uranium. Codelco, a state-run mining company in Chile and the world's largest copper miner, has so successfully utilized bioleaching that Chile now produces upwards of 10 percent of its copper using the technology (Gentina and Acevedo 2016). Globally, bioleaching is projected to sustainably produce more than 20 percent of the world's copper supply (MIT 2015).

WATER AND WASTE MANAGEMENT



Water management strategy

Goldcorp's Zero Water initiative is a prime example of how mining companies are adopting strategies and technologies to significantly reduce the water consumption, a tactic that both reduces the company's cost and curbs negative environmental and climate impact. Companies are adapting to water scarcity and new climate realities with innovative strategies to ensure a consistent water supply, recycle brackish water for use in mining processes, and preserve as much freshwater during the extraction and production process as possible. Additional strategies include developing site-specific water reclamation plants, as implemented by Anglo American. For example, the eMalahleni Water Reclamation plant in South Africa has treated more than 30 billion liters of contaminated water and supplied more than 22 billion liters of water to the local municipality (ICMM 2011). Similar endeavors have yielded strong water reclamation and recycling results amongst companies like Barrick Gold, Rio Tinto, and Freeport-McMoRan. Mapping watershed-level requirements at the mine planning stage, including other water users, can inform and contribute to the mitigation of risks associated with competition over scarce resources, as well as identify opportunities for collaboration and infrastructure investment (e.g., supporting provision of fresh drinking water, providing agriculture irrigation infrastructure).

5 Conclusions

This report has identified climate-sensitive Priority Areas at the cross section of mining value chain segments and mining industry subsectors that represent areas of focus for selecting industry initiatives that reduce or positively impact the climate footprint of mining operations in both the areas of climate mitigation and adaptation. The segments and the climate-sensitive initiatives have been selected with an emphasis on diversity—diversity in geography, technology, and implementation capabilities. This is intended to ensure that companies of different sizes are included in the analysis carried out in subsequent reports. Similarly, multiple geographical regions will be selected to best represent the geographic diversity of global mining climate-sensitive initiatives.

Appendix A

Value Chain and Sub-Sector Prioritization Scoring

The heat-map provided in chapter 3 is intended to identify Priority Areas of climate sensitivity or opportunity in value chain segments across a variety of mining subsectors. Areas of sensitivity and opportunity were analyzed primarily through an energy intensity and water intensity lens (i.e., for the purposes of this effort, broader environmental concerns such as deforestation, ecological contamination, and subsidence do not meet the “climate-sensitive” criteria). Using that lens, both a quantitative and qualitative analysis were conducted: process-heavy activities such as drilling and blasting were measured in their energy intensity by trillion British Thermal Units (BTU) consumed per year. Whereas qualitative measures, such as the likelihood of certain mining activities were ranked on a scale of 0 (not at all likely) to 2 (very likely). Water intensity and risk were similarly viewed qualitatively due to the absence of sufficient data. Using secondary sources, reference minerals or metals were assigned a high (3), medium (2), or low (1) intensity or risk score. Finally, an emerging market relevance factor was applied to each of the process-heavy activities, based on the percentage of 2017 world production of the reference commodity attributed to emerging markets. The commodity whose production is most attributable to emerging markets was assigned a 100 percent factor, and the remaining commodities were assigned a relative weighting based on that figure. This factor was not applied to the construction mineral analysis. Due to the uniquely local nature of the industry, applying an emerging market relevance criteria would disproportionately distort the results. The formulas underlying each of the scores in figure A.1 were presented in chapter 3.

FIGURE A.1
Value chain and subsector prioritization scoring

		Gold	Base/copper	Iron ore	Other/ construction mineral
Mine design/planning	Exploration/drilling	2.4	4	2.4	36
	Ore grade/recovery	0.001%	0.16%	19%	90%
	Hazardous/harsh environment potential	2	1	0	0
	Small scale/artisinal mining	2	1	0	0
	Tailings/alluvial	2	2	0	0
	Underground mining potential	2	2	0	0
	Closure and decommissioning	2	2	0	0
Extraction	Blasting/extraction	9.6	16	9.6	1
	Digging/excavation	13.2	22	13.2	30
	Ventilation	14.4	24	14.4	0
	Dewatering/suction	1.8	3	1.8	25
Processing	Crushing	6	10	6	28
	Grinding	177.6	296	177.6	3
	Separations	13.2	22	13.2	15
	Final processing (roasting, smelting, refining)	0	0	0	512.3
Materials handling/ equipment	Diesel equipment	72.6	121	72.6	34
	Electric equipment	0	0	0	3
	Pumps	0	0	0	3
Water risk and intensity	Intensity	3	3	2	1
	Risk	3	3	2	1

APPLIED MULTIPLIER - EM RELEVANCE

Gold	60%
Base/copper	100%
Iron ore	60%
Other/construct.	N/A

EM Relevance based on proportion of 2017 global production attributed to emerging markets. construction minerals is un-applied due to local nature of market.

100% Fixed at reference commodity with highest attribution to emerging markets.

Appendix B

Initiatives Categorization

The categorization of identified climate-sensitive initiatives is detailed below in figure B.1. A scoring scale (0, 0.5, 1) was used to simplify the scoring process while allowing for some variance in scoring outcome. Some criteria are scored on a binary (0, 1) scale, while those criteria scored on a non-binary (0, 0.5, 1) scale are those that could be evaluated with an additional, non-binary scoring element added with a reasonable level of accuracy. Further, those criteria scored against whether they “increase” or “decrease” are determined to be increasing and decreasing from the benchmark of their status quo.

The questions underlying the scoring, and the corresponding criteria, are outlined in chapter 2, figure 2.2 (Initiative Prioritization Methodology). Scores are the product of substantial desk research, and expert consultation, as well as professional judgment. Some criteria are inherently more subjective than others. However, combining and applying a consistent and transparent methodology and a rigorous scoring process sought to limit research bias to the extent possible.

FIGURE B.1
Scoring results

Category	Initiative	Ease of implementation (EOI)						EOI Score (0-6)	Sustainability impact (0-6)									Sust. impact score (0-6)
		(Yes = 0; No = 1)					(Yes = 1; Partially = 0.5; No = 0)		People (Increase = 2; Status quo = 1; Decrease = 0)		Planet (Decrease = 2; Status quo = 1; Increase = 0)			Profit				
		Size (enterprise)	Size (mine)	Mine lifecycle	CAPEX investment	Return			Initiative maturity	Mitigation		Adaptation		Risk	OPEX	Revenue	Valuation	
							Job creation			Tax revenue	GHG emissions	Energy intensity	Water intensity					
Mitigation	Wind and solar technology	1	1	0	0	0	1	3	2	2	2	1	1	2	2	1	1	4.83
Mitigation	Alternative material movement	1	1	0	0	0	1	3	0	1	2	2	1	1	2	1	1	3.33
Mitigation	Digital energy management	1	1	1	0	1	1	5	1	1	2	2	1	1	2	1	1	3.83
Mitigation	Electrification of mining equipment and fuel conversion	1	1	0	0	0	1	3	1	1	2	2	1	1	2	1	1	3.83
Mitigation	Mine land use planning	1	0	0	0	0	1	2	1	1	1	0	1	1	0	0	0	1.75
Adaptation	Strategic GHG reduction framework	1	1	1	1	1	1	6	1	1	1	1	1	2	1	1	1	3.25
Mitigation	Carbon sequestration	0	0	0	0	0	0	0	2	1	2	1	1	2	0	1	1	3.67
Mitigation	Conversion to pump storage	1	0	0	0	0	1	2	2	2	2	0	0	2	1	2	1	4.33
Mitigation	Processing optimization	1	1	0	0	1	0.5	3.5	1	1	2	2	1	1	2	1	1	3.83
Mitigation	Bioleaching	1	1	1	0	0	0.5	3.5	0	1	2	2	1	1	2	2	2	4.00
Mitigation	Haul truck idle management	1	1	0	0	1	1	4	0	1	2	2	1	1	2	2	1	3.67
Adaptation	Tailings management	1	1	1	0	0	1	4	1	1	1	1	2	2	1	1	1	3.50
Adaptation	Water management	1	1	1	0	0	1	4	1	1	1	1	2	2	2	1	1	3.83
Adaptation	Climate modeling and risk assessment	1	1	1	1	0	1	5	1	1	1	1	1	2	1	1	1	3.25
Adaptation	Engineering design enhancements	1	1	0	0	0	1	3	1	1	1	1	1	2	1	1	1	3.25
Adaptation	Mine closure initiatives	1	1	0	1	0	0.5	3.5	1	1	1	1	1	2	0	1	1	2.92

Note: CAPEX = Capital Expenditure; GHG = Greenhouse Gas; OPEX = Operating Expenditure.

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The mining industry, which provides input to almost every product and service in the world, is a critical element toward 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*.