Innovation and Competitiveness in the Copper Mining Global Value Chain

Developing Local Suppliers in Peru

Prepared for the Inter-American Development Bank by:
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ABSTRACT

Peru is the second largest producer and exporter of copper in the world. However, the country's sector has weak background linkages and the emergence of innovative suppliers able to provide high-value products and services is still incipient. This article explores the opportunities to leverage Peru's international positioning in the mining industry to foster the development and innovation capacities of local suppliers. Based on data analysis and interviews with local industry stakeholders, this research —which uses the global value chain framework— finds that the incorporation of a larger number of high-value local suppliers into the copper value chain is limited by weaknesses in the national innovation system. In addition to this, it notes that the national copper policy places little emphasis in the need to innovate and add value. In order to generate a critical mass of strong and innovative suppliers, Peru must create solid institutions and coordination mechanisms to develop the sector. At the same time, it should favor the insertion of domestic suppliers into the value chain and incentivize these to innovate and scale. The article presents recommendations in these areas, as well as best practices from other mining countries that have successfully overcome these challenges.

JEL Codes: O38 L22, L23, L24, L38, L52, L71, L78

Keywords: copper, mining, copper value chain, Peru, backward linkages, local suppliers, innovation, global value chains, upgrading

Acronyms

AEPME	Asociación de Empresas Privadas Metal Mecánicas del Perú (Association of Private Metalworking Companies of Peru)
APRIMIN	Asociación de Proveedores Industriales de la Minería, Peru (Association of Mining Industry Suppliers)
CIF	Cost, Insurance, and Freight
CORFO	Corporación de Fomento de la Producción, Chile (Production Promotion Corporation)
CONCYTEC	Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica, Peru (National Council of Science, Technology and Technological Innovation)
EPC	Engineering, Procurement, and Construction
EPCM	Engineering, Procurement, and Construction Management
EV	Electric Vehicle
FOB	Free on Board
GDP	Gross Domestic Product
GVC	Global Value Chain
ICE	Internal Combustion Engines
ICSG	International Copper Study Group
IDB	Inter-American Development Bank
INEI	Instituto Nacional de Estadística e Informática, Peru (National Institute of Statistics and Informatics)
IP	Intellectual Property
IRENA	International Renewable Energy Agency
IT	Information Technology
LME	London Metals Exchange
METS	Mining Equipment, Technology, and Services
MINCUL	Ministerio de Cultura, Peru (Ministry of Culture)
MINEM	Ministerio de Energía y Minas, Peru (Ministry of Energy and Mines)
OECD	Organisation for Economic Co-operation and Development
PRODUCE	Ministerio de Producción, Peru (Ministry of Production)
R&D	Research and Development
SUNAT	Superintendencia Nacional de Aduanas y de Administración Tributaria (National Superintendency of Customs and Tax Administration)
SX-EW	Solvent Extraction-Electrowinning
TC/RC	Treatment Charges/Refining Charges
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
UTEC	Universidad de Ingeniería y Tecnología (University of Engineering and Technology)
WIPO	World Intellectual Property Organization

1. INTRODUCTION

Peru is the world's second largest copper producer and exporter, and the sector is an important driver of the country's economy. This paper explores how the country can leverage this strong position to foster innovative activities and develop local suppliers. The global copper mining industry is concentrated in a small number of countries. Latin American economies dominate global production, with Peru trailing only Chile. The strength of Peru's copper mining sector is based on large reserves with low-cost extraction compared to other global locations. Over the past 15 years, these advantages have raised the country's relevance to the global industry, and copper's importance to the local economy. By 2017, copper represented 50 percent of mining exports, 31 percent of all goods exports, and 5 percent of Peru's gross domestic product (GDP) (MINEM, 2019).

Global demand for the commodity is set to increase in coming years as a result of fundamental shifts in downstream industries, from rising demand for electric cars to electrification of national energy supply and rapid urbanization in the developing world. However, historically, increasing demand and prices have not translated into substantial gains for the resource-rich economies. It has been very difficult for countries like Peru to capture the value of exploiting these commodities to drive growth and development. Much of the industry is operated by foreign firms with few linkages to the rest of the economy. Functional upgrading into processing activities is no longer an attractive path, as it offers only marginal value gains (see the *Value Chain Stages* section). As a result, host countries have sought alternative pathways to capture value from the sector, including fostering backward linkages, a key strategy. Today, numerous host economies are promoting the development of local suppliers that can offer products and services to the mining sector.

Yet, supplying the sector is notoriously challenging. The copper mining market is concentrated in a small number of lead firms with mature global supply chains. Critical inputs are dominated by a few firms with strong relationships with buyers, while lower value inputs tend to be highly competitive and require significant scale. Copper mining companies are highly risk adverse, exhibiting a strong preference for proven solutions, sourcing innovations for critical systems only from their trusted supply base. New suppliers are typically considered only for solutions to issues miners have yet to resolve. And, establishing new solutions is hampered by information asymmetry and limited opportunities to test and install new technologies. While miners rely on their suppliers to bring innovations to the sector—miners are poor innovators, in general—they simultaneously resist disclosing information about anything where innovation is most needed and are constrained by high stoppage costs to pilot new solutions in operating mines.

Dominated by leading multinational miners, Peru's copper mining sector reflects these broader global trends. There are only a few innovative suppliers providing value-added products and services to the industry and they are concentrated in services, consumable products, metal structures, and niche capital equipment segments. Local supply has a comparative advantage in these segments, benefiting from proximity, high volume to value shipping costs, and specific geological conditions. Many potential local suppliers in other areas lack the organizational capabilities, scale, and scope to participate in the industry.

Integrating more and higher value-added Peruvian suppliers into the copper mining industry is undermined by the still weak national innovation system. The suppliers that have successfully innovated in the sector have done so largely as a result of individual efforts rather than a consolidated national strategy. These firms have tapped into the small pools of human capital, training employees internally or abroad, and investing their own limited funds on research and development (R&D). Furthermore, they have leveraged knowledge bases in foreign universities and with foreign suppliers to develop new products and services and gain access to the market. Peruvian copper mining policy has focused heavily on regulation, with little emphasis on the need to innovate and upgrade. With little guidance or commitment from government regarding the future of the industry, existing efforts are taking place in silos, with little coordination or dialog on how to increase the availability of qualified human capital, reduce the bureaucracy related to R&D financing, or increase effective collaboration between research institutes, universities, and suppliers. These elements are all required to boost innovation activities by Peruvian suppliers and secure meaningful access to the copper global value chain (GVC).

If Peru is to develop a critical mass of backward linkages, changes need to be made at the policy level to circumnavigate the strong industry governance structures that limit access of local suppliers to the GVC and boost the number of innovative suppliers. Institutionally, the country needs to develop a strong, long-term national strategy supported by decisive leadership. Access to the chain needs to be strengthened by increasing opportunities for information sharing and supporting the development of industry-specific organizational skills for mining suppliers. Finally, significant attention needs to be paid to developing the innovation capabilities of local firms.

This study uses the GVC framework to more fully understand the potential opportunities for Peruvian suppliers in the chain. Several data sources were used for the analysis, including the United States Geological Survey (USGS), UN Statistics Division Comtrade, and supply–use matrices from leading copper producing countries (Australia, Canada, Chile, Peru, and United States). In Peru, firm-level production, investment, and export data were analyzed from the Peruvian Ministry of Energy and Mines (MINEM), the National Superintendence of Customs and Tax Administration (SUNAT), and the National Statistics Institute of Peru (INEI). Primary quantitative sources were complemented with research from secondary sources, including a review of existing academic, trade, and policy literature as well as annual reports and private sector databases. In addition, over 20 interviews were carried out with mining companies, mining suppliers, government officials, and educational institutions/research centers in Peru (see appendices for a detailed methodology).

The early sections of this report focus on unpacking the global dynamics of the copper mining industry to understand how these trends impact Peru. This includes mapping the copper GVC, analyzing the geography of the chain, assessing the industry's governance structures and their influence on procurement at the global and local level, and reviewing the opportunities available for innovation in the industry. Next, the focus shifts to Peru's evolving sector, identifying where and how local firms are successfully participating and innovating and understanding the existing national innovation system as it relates to copper mining. Finally, a set of policy recommendations are provided focusing on fostering increased participation and innovation by Peruvian suppliers.

2. THE COPPER MINING GLOBAL VALUE CHAIN

While copper has been traded globally for centuries, over the past 30 years, it has grown in importance as a key input for manufacturing and construction. Today, it is the third most consumed industrial metal after iron and aluminum (USGS, 2019a) and is present in almost every aspect of daily life, from lighting homes, to electrifying cars and connecting cities, to preventing the spread of bacteria (antimicrobial). As a result of this boom, the red metal has become a key industry in South America. It is a significant contributor to GDP and exports and is a major driver of economic growth and development in Chile and Peru, accounting for 10 percent and 5 percent of GDP, respectively (MINEM, 2019; Banco Central de Chile, 2019). South America leads global copper production and exports, and Chile and Peru combined account for close to 44 percent of global production.

While the price of copper has fluctuated considerably over the past decade, demand has increased steadily. During the 2004–2012 period, strong demand and trading led to very high prices for copper, and for commodities in general, which has become widely known as the "supercycle." In February 2012, commodity prices crashed, which had a major impact on the industry's outlook and approach to new development. Further, there is now increased pressure on miners to reduce their environmental and social impacts as global awareness of climate change has risen, increasing the complexity of their operations. As a result, few firms have focused on exploration and new mine development since 2012, with most focusing on productivity improvements, consolidating their high-value assets, and divesting low-grade projects. Currently very few new projects are set to come into operation before 2023.

Although the commodity's price remains subject to global economic uncertainty, there are strong expectations for growth over the next decade as a result of fundamental shifts in its major end markets. Major structural changes that affect demand include (i) electrical vehicle (EV) substitution for internal combustion engines (ICE), (ii) increased electrification and green energy, and (iii) construction and public infrastructure expansion in response to global urbanization. EVs use up to four times as much copper as ICE cars. At least 20 countries have set formal targets for EV adoption, with China one of several nations to announce a desire to phase out traditional ICE entirely (Thornton, 2019). Electricity's share of total global energy consumption is expected to double between 2020 and 2050 (IRENA, 2018). Renewables are expected account for a major share of this as they are estimated to use 12 times as much copper as previous power generation, such as coal power (Copper Development Association, 2018). The world's urban population is estimated to increase by approximately 50 percent between now and 2050 (to 6.6 billion from 4.3 billion currently) (Ritchie and Roser, 2018; Schipper, Lin, Meloni, et al., 2018). The movement of people into cities is driving the need for new housing and boosting construction, particularly in emerging economies,[1] and on its own this migration is expected to double copper demand over the next 30 years (Schipper et al., 2018; Drzik, 2019). In the short term, China's Belt and Road Initiative is expected to boost demand. This initiative aims to consolidate the country's global relationships by improving connectivity, shipping, road, rail, and energy infrastructure across Eurasia and much of Africa.[2]

These trends of tightening supply and growing demand suggest that copper is entering a new upward cycle that will offer producer countries such as Peru major opportunities to develop a more robust copper mining sector.

Value Chain Stages

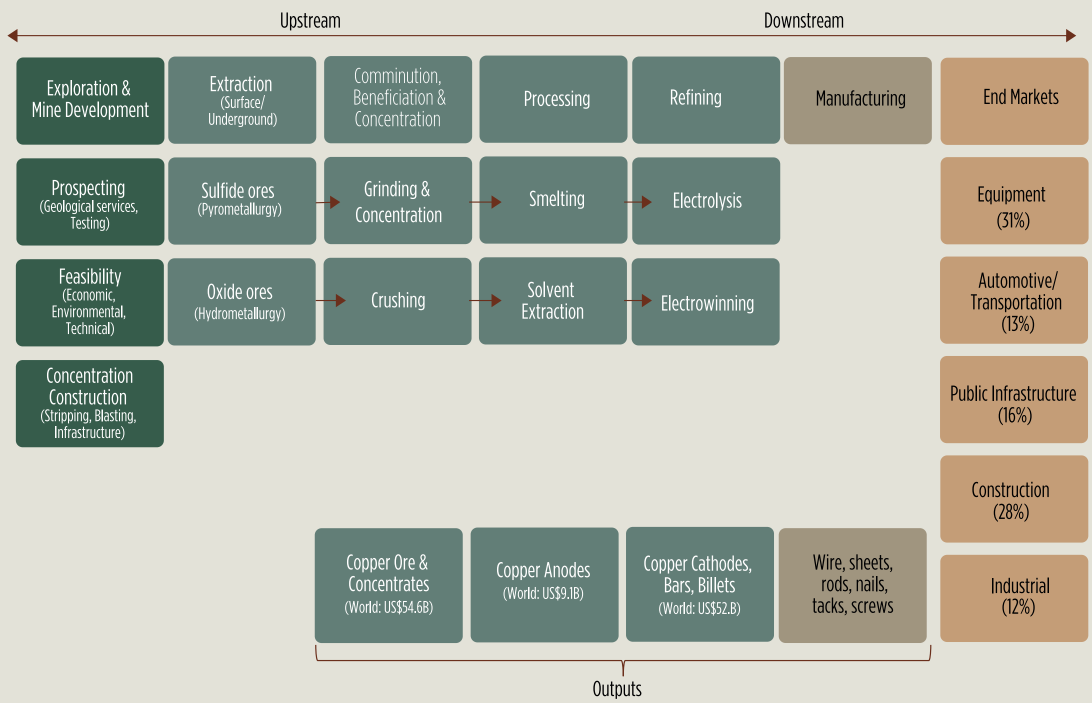
The copper mining GVC is characterized by a few stages that can be disaggregated, low levels of geographic fragmentation, and high levels of capital intensity. Introducing new assets to the global sector takes a long time and requires significant investment. Once in operation, mines can be active for more than 80 years. Inputs (goods and services) primarily support extraction and processing and are not incorporated into the final product; manufacturing inputs are components of the final product. While upstream the sector is relatively concentrated, the GVC feeds a large variety of downstream industries (e.g., automotive, construction, energy, healthcare, and manufacturing). The following analysis focuses primarily on the upstream and midstream stages of the chain (Figure 1).

Five key upstream and midstream stages: (i) exploration and mine development; (ii) extraction; (iii) comminution, beneficiation, and concentration/; (iv) processing; and (v) refining. *Extraction activities* vary between open pit and underground mining, depending on the location and geological conditions of the reserves. *Processing activities* vary according to the type of copper ore mined: sulfide or oxide. Sulfide ores are processed using mature and widely known pyrometallurgical operations: comminution, beneficiation, and concentration (output: copper concentrate, typically around 30 percent pure), smelting (output: 95 percent pure copper anodes), and electrolytic refining (output: 99.9 percent pure copper cathodes).

1 Per capita consumption of copper is correlated with GDP growth until GDP per capita reaches roughly US$20,000, with leading industrialized countries consuming the highest amount (Mills, 2015).

2 China's Belt and Road Initiative has already boosted demand for copper. In the first five years (2013–2018), it consumed some 1.25 million tons of copper (equivalent of 4 percent of global refined output) as energy and rail infrastructure expanded in developing countries (BHP, 2018). Estimates suggest that direct and indirect demand will increase by 6.5 million tonnes between 2019 and 2027 (Lewis, 2018).

Figure 1. Copper Mining Global Value Chain



Source: Authors' elaboration.

Oxide ores are processed using a hydrometallurgical method whereby mineral heaps are drenched with sulfuric acid (solvent-extraction via heap leaching), followed by electrowinning of the resulting copper sulfate to produce copper cathodes. The solvent-extraction electrowinning (SX-EW) process results in as high or higher grade copper than that produced by traditional electrolytic refining. SX-EW technology was widely introduced in the 1980s and 1990s, allowing oxide reserves to be efficiently exploited. The two processes are often viewed as complementary because smelting produces significant quantities of sulfuric acid as a by-product, which can then be used for heap leaching. However, SX-EW can be undertaken separately, with low capital and scale requirements, which facilitates the competitive production of cathodes[3] and allows refined copper to be produced competitively where only oxide reserves are available.

Fragmentation of the chain: GVC activities are undertaken by a small number of actors using one of four primary business models: (i) exploration only, (ii) exploration and extraction (miners only), (iii) vertically integrated (miners + processors), and (iv) processing (processors only).

i. **Exploration only:** Firms that engage only in exploration activities, generally referred to as juniors, specialize in high-risk activities, particularly early-stage exploration to find new reserves. These firms usually remain engaged with a site until a discovery is deemed economically viable.

3 EW is five times as energy intensive (8MJ/kg) as electrorefining (1.6MJ/kg) and thus its competitiveness depends on the availability and cost of energy (Dresher, 2001).

ii. **Exploration and extraction:** Most major mining companies today undertake exploration activities to identify new potential assets[4] in addition to developing and operating mines and beneficiation plants. Leading miners that are primarily engaged only in these stages of the value chain include First Quantum and Teck Resources.

iii. **Vertically integrated:** Most miners also process some amount of their output. For example, Anglo American, BHP,[5] Codelco, Freeport McMoRan, Glencore, Grupo Mexico, and Rio Tinto own considerable smelting and refining capacity. Nonetheless, their share of processed copper (i.e., anodes and cathodes) is low compared to pure processing firms.

iv. **Processing:** Processors have large-scale smelting and refining capacity. These firms do not engage in mining activities, but some may own minority shares in mines to secure inputs.[6] The largest of these include Jiangxi Copper Corp (China, 900,000 tonnes), Jinchuan (China, 800,000 tonnes), Hidalco (India, 500,000 tonnes), Sumitomo (Japan, 575,000 tonnes), and Aurbis (Germany, 450,000 tonnes) (ICSG, 2018). In addition, a small share of Japanese processors also manufacture copper components for downstream industries, including JX Nippon, Mitsubishi, Sumitomo and Mitsui.

v. **Value addition in the Copper GVC:** Concentrates from the mines may either be sold directly on to processors/smelters through long-term (annual) or spot market contracts, or the miner may retain ownership of the product and pay treatment charges (TC), refining charges (RC), and marketing fees to the downstream processors (OECD, 2015). Traders (independents, miners, and processors) play a key role in facilitating both pre-processing sales and post-refining sales. Contracts are typically negotiated based on the price of copper cathodes on the London Metal Exchange (LME). Cathode is usually sold based on cost, insurance, freight (CIF). Further, time of delivery, payable metals, concentrate content, the presence of gold/silver, and penalty charges for deleterious materials are all factored into the price.[7] The value of concentrate is the equivalent of the LME cathode price minus TC/RCs and transportation, and insurance may or may not be included.

The value addition of copper processing fluctuates considerably because it is a direct function of concentrate supply and smelting capacity, plus potential price participation if the copper price increases over a negotiated threshold.[8] The cost of smelting and refining is thus a percentage of the final cost of copper cathode (Barr, Defreyne, Jones, et al., 2005). Since the 1990s, this cost has varied considerably, peaking around 25 percent (2005) and declining to approximately 7 percent in

4 Majors' spending on exploration activities is highly volatile. Exploration is generally considered expendible and therefore is typically cut in downturns.

5 BHP does not own smelting capacity, but several of its major mines, including Escondida (Chile) and Olympic Dam (Australia), have SX-EW operations and produce copper cathodes.

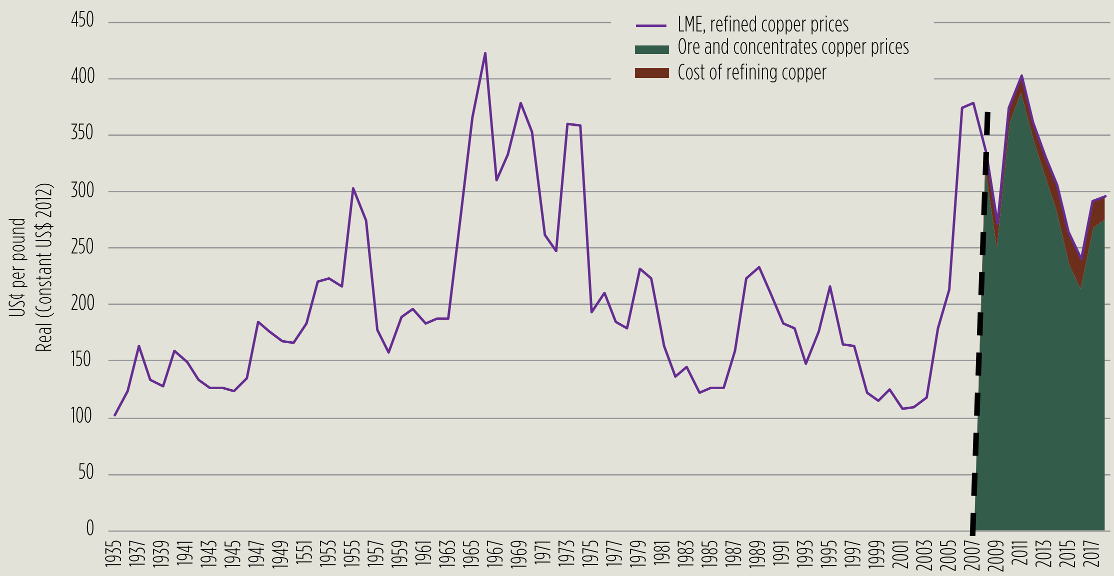
6 Large smelters in Japan have acquired shares of mine production to ensure supplies. Chinese smelters have recently announced they will follow this pattern, seeking to acquire shares in major mining countries, including Chile and Peru. Asian processors are taking on larger stakes in the projects in which they are engaging. For example, Sumitomo increased its stakes in Morenci to 28 percent and Cerro Verde (21 percent) and recently acquired a 30 percent share of Quebrada Blanca II. Mitsubishi has followed a similar pattern with stakes in Antamina (10 percent), Los Bronces (20 percent), and Los Pelambres (15 percent). The company also acquired a 40 percent share in Peru's new Quellaveco mine.

7 If the cathode brand is not accredited by the LME or COMEX (Commodity Exchange Chicago), then the buyer can usually negotiate a discount.

8 Price participation allows the processor to increase the TC/RC charges if the overall price of copper increases beyond a previously negotiated threshold.

2018 (Figure 2). This decline is the result of an increase in global smelting capacity over the past two decades, with major increases in China in particular (ICSG, 2018; Outotec, 2019). Smelters prefer to operate at peak capacity and thus are willing to charge lower prices to secure concentrate. These cost dynamics show that there is currently little value in functionally upgrading into smelting and refining.

Figure 2. Refined Copper Prices, 1935–2018, and Cost of Smelting and Refining Copper, 2008–2018



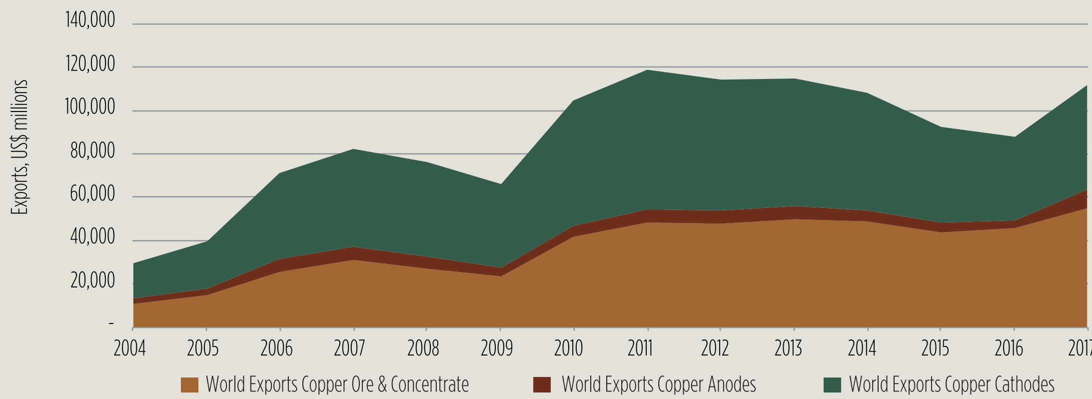
Source: Authors' elaboration based on copper price from Cochilco (Cochilco, 2017) and treatment and refinery charges from S&P Global Intelligence (cited in Outotec, 2019).

Geography of the Copper Mining Global Value Chain

The global footprint of the copper mining GVC is limited relative to other industries as a result of reserve locations, geological conditions, and capital intensity. Upstream, the global industry is dominated by Latin America (led by Chile and Peru), which accounts for 44 percent of copper production, and downstream by Asia (led by China and Japan), which imports 75 percent of traded copper concentrate and produces 56 percent of the world's refined copper.[9] Over the past decade, as a result of declining smelting and refining prices, the share of copper concentrate trade/total trade value has steadily increased from 36 percent in 2006 to 49 percent in 2017 (Figure 3). Trade in anodes or blister copper (smelted but not refined) is minimal (approximately 15 percent the value of concentrate trade), with Chile providing the most consistent export supply.

9 The figures in this section are based on export value rather than export volume due to inconsistent volume reporting.

Figure 3. Global Copper Trade by Value Chain Stage, 2004–2017



Source: UN Comtrade, 2019, downloaded 23/05/2019.
Notes: HS02 260300 (copper ore and concentrate); 7402 (unrefined copper, copper anodes for electrolysis) and 740311 (copper cathodes). All exporters.

Production is highly concentrated as a result of the location and economic viability of reserves. Of the world's reserves, 50 percent are located in just five countries, led by Chile and Peru, with the next five accounting for a further 25 percent (USGS, 2019a). However, the economic viability of these reserves varies. China, Zambia, and the Democratic Republic of the Congo (DRC) produce substantially higher global shares than their reserves as a result of lower costs; Australia, Indonesia, and Mexico produce substantially less. Economic viability is driven by a combination of technical and political factors, including ore grade, accessibility, and government policies with respect to royalties. Of these producers, the leading exporters of concentrate are Chile, Peru, Indonesia, Australia, and Canada (Figure 4, Table 14 in appendices), together accounted for 72 percent of global trade in 2017. The majority of this is exported to Asia for smelting and refining.

Figure 4. Leading Exporters and Importers of Copper Ore and Concentrate

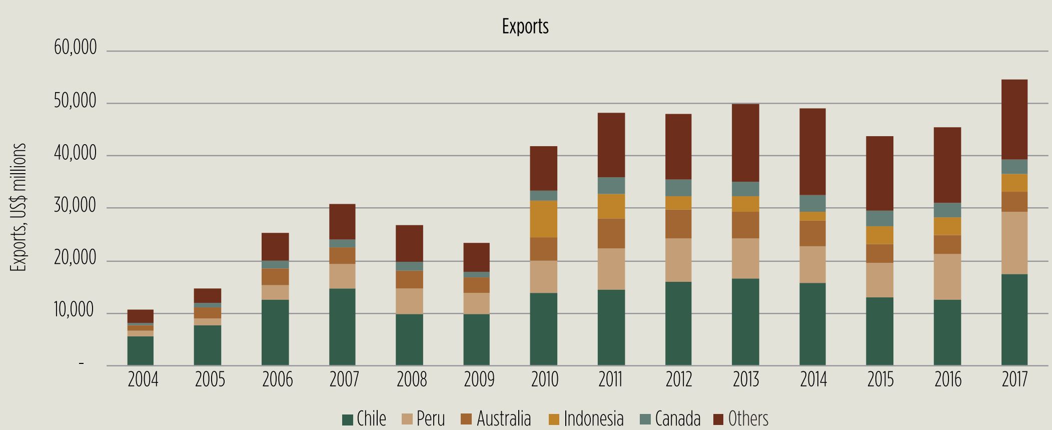
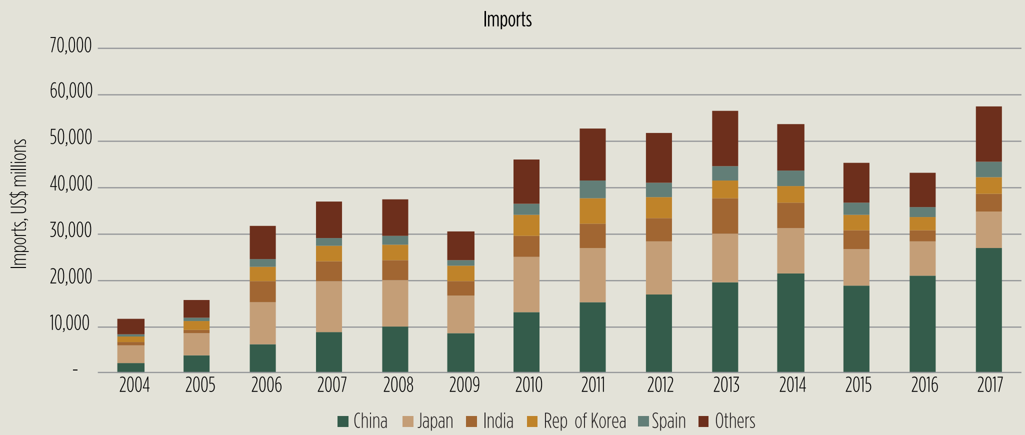


Figure 4. Leading Exporters and Importers of Copper Ore and Concentrate *(continued)*



Source: UN Comtrade, 2019, downloaded 23/05/2019.
Notes: HS02 260300 (copper ore and concentrate). All exporters.

Asia has about half of the world's processing capacity (smelting and refining). The top four importers of concentrate are China, Japan, India, and South Korea, which together import approximately 75 percent of the world's traded copper concentrate. The majority of their refined output is used domestically or regionally in manufacturing operations. As the world's factory, **China is singularly the most important downstream actor in the copper GVC**. As the world's third largest copper miner (8.5 percent), it consumes its own internal production as well as the majority of globally traded refined copper. China leads smelter (40 percent) and refined copper (38 percent) (see Table 20 in the appendices)[10] production, importing half of globally traded concentrate (47 percent, 2017) and anodes (48 percent, 2017, Table 18 in the appendices), and 38 percent of world refined copper. In the past, Japan played a more significant role in processing. Since 2004, however, it has steadily lost market share to China and has increased its exported refined copper as manufacturing has shifted away. Other importers of refined copper include major manufacturing hubs in Asia, Europe, and the United States. China, the United States, Germany, Italy, and Taiwan collectively account for 66 percent of traded refined copper.

Based on these trade flows, the most significant countries in the copper GVC can also be divided into three major groups: (i) miners only, (ii) processors only, and (iii) integrated producers and refiners.

i. **Miners only:** The countries primarily produce unprocessed copper ores and concentrates and include relative newcomers to the industry. Peru is the most important country in this segment, along with Indonesia and Mongolia. These three countries account for less than 2 percent of global refinery capacity and over 75 percent of their export revenues are generated from unrefined copper.

10 The second and third largest smelters are Japan with just 8 percent of smelter capacity and Chile with just 7 percent (ICSG, 2018).

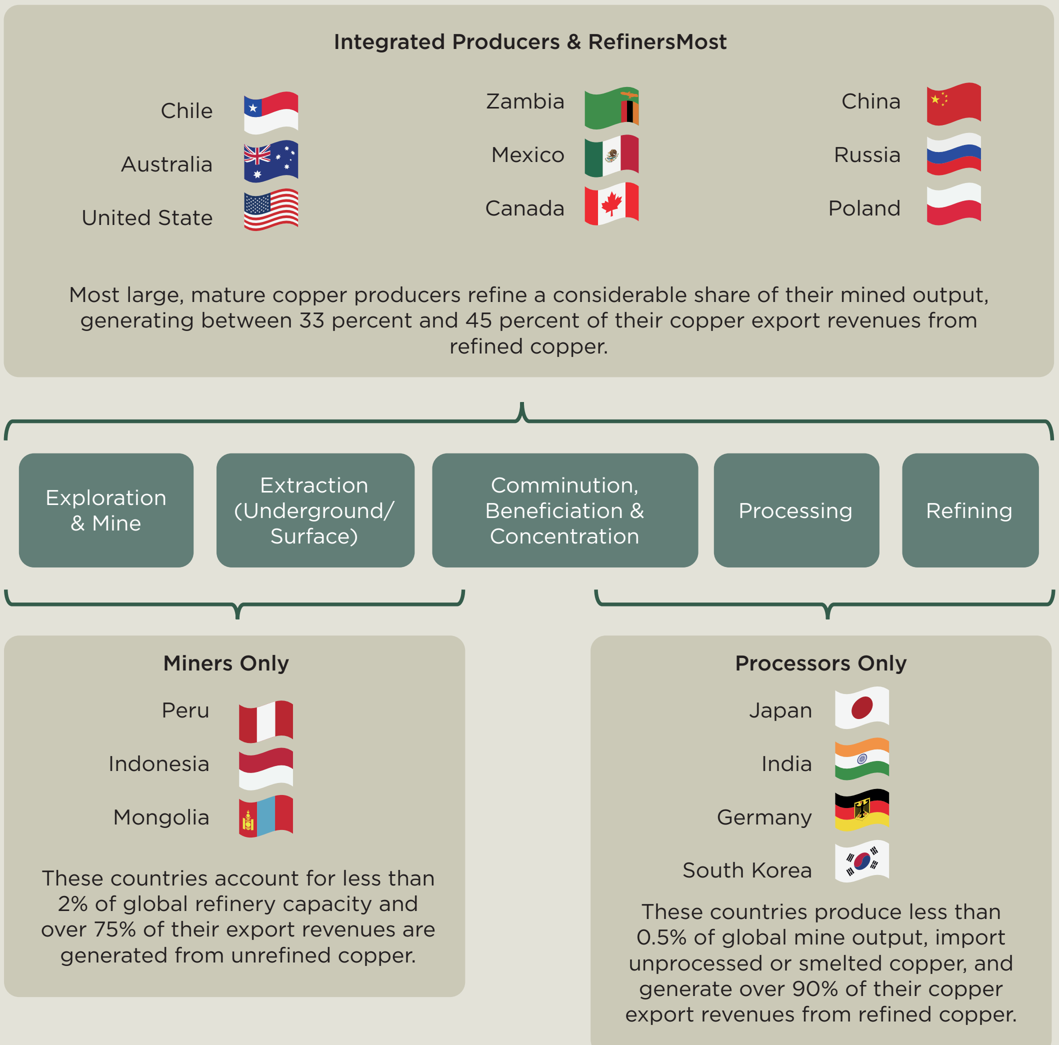
Figure 5. Leading Exporters and Importers of Refined Copper

Source: UN Comtrade, 2019, downloaded 23/05/2019.
Notes: HS02 740311 (copper cathodes). All exporters. nes = not elsewhere specified.

ii. Processors only (produce less than 0.5 percent of global mine output): Processing countries import unprocessed or smelted copper and generate over 90 percent of their copper export revenues from refined copper. The key processing countries are Japan, Germany, India, and South Korea.

iii. Integrated producers and refiners: Most large, mature copper producing countries refine a considerable share of their mined output. Chile, Australia, the United States, Zambia, Mexico, and Canada generate between 33 percent and 45 percent of their copper export revenues from refined copper. In these countries, most smelting and refining capacity was installed prior to 2005. China, Russia, and Poland do not export any unprocessed copper.

Figure 6. Distribution of Copper Countries, by Value Chain Role, 2018



Source: Authors' elaboration based on USGS (2019a) for production and refinery capacity and UN Comtrade (2019) for exports.

Governance and Lead Firms

The copper mining GVC is dominated by a relatively small number of lead firms: miners, engineering firms, and major equipment manufacturers. The power dynamics between these firms greatly shape the potential for smaller firms to participate in the industry. The largest five miners account for 38 percent of production. While several of these lead firms are diversified in more than three commodities (e.g., BHP, Glencore, and Grupo Mexico), pure-play copper firms have become increasingly important (e.g., Codelco, Freeport McMoRan, and First Quantum). These firms have mines in leading production sites around the world, including a very strong presence in South America, especially Chile and Peru. The headquarters of these firms are primarily in major mining countries;

of the top 10, two are in each of Australia and Chile, and one in Canada (Table 1). Most of the major miners are engaged in all of the upstream and midstream stages of the value chain, from exploration to refining. In each stage, these firms depend on a large number of input providers, with outsourcing is as high as 60 percent in some countries.[11]

Since the end of the supercycle in 2012, leading miners have operated conservatively, focusing on consolidating high-value assets, divesting low-grade projects, and limiting exploration and new project development. There are currently very few new projects set to come into operation before 2023. Major new mines include Codelco's Chuquicamata Underground (130,000 tonnes, 2019), First Quantum's Cobre Panama (350,000 tonnes, 2019), Anglo American's Quellaveco (435,000 tonnes, est. 2022), and Teck Resources's Quebrada Blanca II (316,000 tonnes, est. 2022). However, projected increases in demand for copper has resulted in renewed exploration and development activity (Jamasmie, 2017). Forecasted projects will add 3.5 million tonnes in Chile (total investment of US$59.0 billion) and 2.1 million tonnes in Peru (total investment of US$58.5 billion) over the next decade (Cochilco, 2018; MINEM, 2018).

Table 1. Leading Global Miners

	Copper Production (MT)	Copper Revenue (EBITDA)	Origin	Key Mines in Latin America	Key Mines in the Rest of the World	Value Chain Segments
Codelco	1,806	4.7	Chile	Chuquicamata (100%, operator) El Teniente (100%, operator) Radomiro Tomic (100%, operator) El Abra (49%) Las Bronces (20%)		Exploration Extraction Smelting Refining SX-EW
BHP	1,753	6.5	Australia	Escondida (57.5%, operator) Antamina (33.75%, joint-control) Cerro Colorado (100%, operator) Spence (100%, operator)	Olympic Dam (100%, operator)	Exploration Extraction SX-EW
Freeport McMoRan	1,733	6.5[a]	United States	Cerro Verde (53.6%) El Abra (51%)	Grasburg (81.5%, operator) Morenci (78%)	Exploration Extraction Smelting Refining SX-EW
Glencore	1,454	4.7	Switzerland	Antamina (33.75%, joint-control) Collahuasi (44%) Antapaccay (100%, operator)	Ernest Henry (70%, operator) Mount Isa Mines (100%, operator) CSA Mine (100%, Operator) Katanga (86.3%, operator)	Exploration Extraction Smelting Refining SX-EW Trading

11 Most firms refine copper using solution extraction and electrowinning techniques. Only a few, including Rio Tinto (Kennecott mine), Freeport McMoRan (in the United States and Spain), and Glencore, use traditional smelting and refining processes.

Table 1. Leading Global Miners *(continued)*

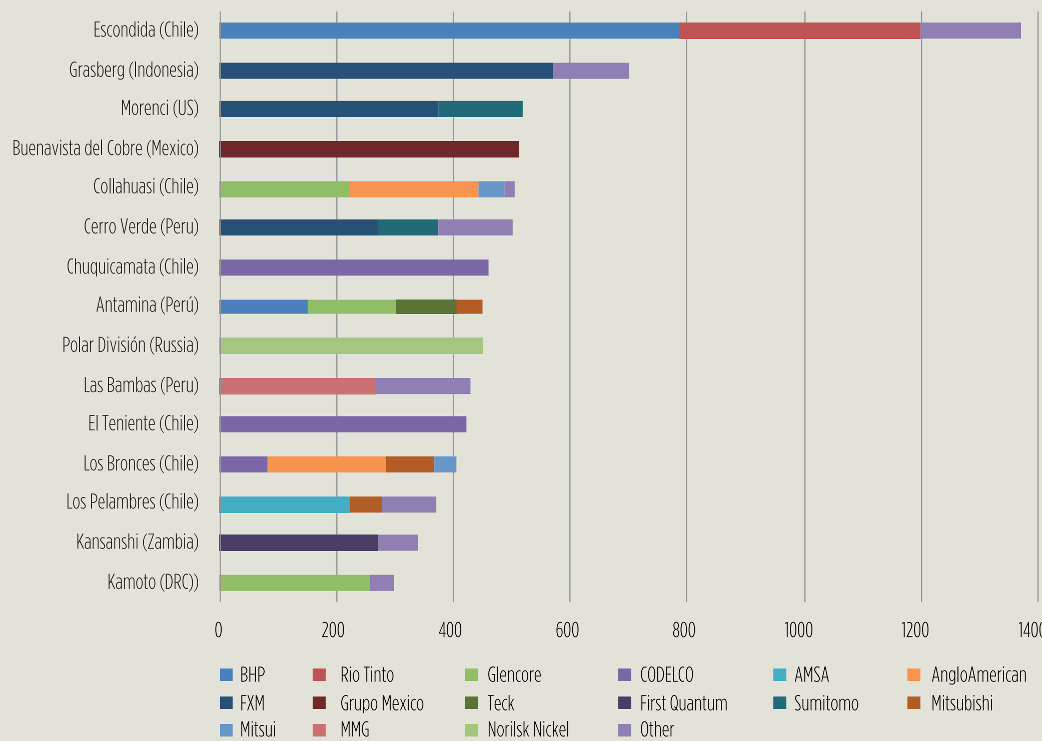
	Copper Production (MT)	Copper Revenue (EBITDA)	Origin	Key Mines in Latin America	Key Mines in the Rest of the World	Value Chain Segments
Grupo Mexico	1,200	2.3[b]	Mexico	Buenavista del Mexico (100%) Toquepala (100%) Cuajone (100%) Caridad	Mission, Ray & Silver Bell Mineria Los Frailes	Exploration Extraction Smelting Refining SX-EW
AMSA	725	2.2	Chile	Antucoya (70%) Centinela (70%) Los Pelambres (60%) Zaldivar (50%)		Exploration Extraction Smelting SX-EW
Anglo American	668	1.9	United Kingdom	Los Bronces (50.1%, operator) Collahuasi (44%, joint-op) El Soldado (51%, operator)		Exploration Extraction Smelting
Rio Tinto	634	2.8	Australia	Escondida (30%, joint-control)	Oyu Tongi (33.5%, joint-control) Kennecott (100%, operator)	Exploration Extraction Smelting Refining
First Quantum	606	1.7	Canada	Cobre Panama (90%, operator) Las Cruces (100%, 74,000 tonnes)	Sentinel (100%) Kansanshi (80%) Cayeli (100%)	Exploration Extraction Smelting
Norlisk Nickel	436	6.2	Russia		Polar division, Kola MMC GRK Bystrinskoye, Harjavalta Nkomati	Exploration Extraction Smelting Refining
Vale	395	1.1	Brazil	Sossego Salobo Sudbury		Extraction
Teck Resources	294	2.8	Canada	Antamina (22.5%) Andacollo (90%) Quebrada Blanca (90%)	Highland Valley (100%)	Exploration

Source: Annual reports and company websites.

[a] All mining revenues. [b] Calculated based on 65 percent share of copper in output.

With projects dominated by large, capital-intensive and long-life mines, joint venture operation is common as a risk mitigation strategy. Of the world's 15 largest copper mines, only three are wholly owned by one company (Figure 7). Joint ownership structures vary, including collaboration between two or more miners, together with processors that usually own a small percentage of the mine (joint miner investments), and partnerships between miners and processors. The ownership structure for most of the recent projects has been miners working with processors. In joint miner investments, typically, one of the miners operates the project. In a few exceptional cases new companies are created to operate the mine drawing on resources from across the owners. Peru's two largest mines, Antamina and Cerro Verde, are both joint miner operations. In more direct miner-processor arrangements, the miner generally operates the mine, with processors participating to secure access to raw materials. Ownership and operation patterns affect how mines procure their inputs. When large miners operate projects, they tend to rely more heavily on centralized global procurement strategies. Mine-specific companies will have their own procurement team, however, as procurement personnel is drawn from the companies that own the mines, these will tend to continue to favor their preferred suppliers. Processors, on the other hand, have very little influence over procurement for upstream stages.

Figure 7. Top 15 Copper Mines, by Capacity, 2018



Source: Author's elaboration based on International Copper Study Group, Directory of Copper Mines and Plants, 2018. Ownership shares from annual reports.

In addition to miners, engineering firms play a major role in shaping industry dynamics and determining which suppliers participate in the mine development stage of the value chain. Based on either EPC (Engineering, Procurement, and Construction) or EPCM (Engineering, Procurement, and Construction Management)[12] contracts, engineering firms are engaged in all aspects of mine development, including facilitating the procurement of mining equipment and infrastructure. Leading engineering firms include Bechtel, Fluor, Hatch, SNC-Lavalin, Ausenco, and Worley. During the supercycle, these firms took on a particularly important role, dominating mine development; however, in the down period that followed, miners sought more control over the development process to keep costs down. As a result, increasingly, miners themselves are making procurement decisions (Douglas, 2016).

12 See Table 13 in the appendices for major differences between these contract types.

Among the mining supply base, capital equipment manufacturers hold considerable power as a result of their investments in innovation and the development of new equipment and systems to drive mine productivity. The development of larger, more efficient and more productive equipment, such as continuous miners and autonomous rigs, and the development of integrated systems solutions for different stages of the mining value chain, provide original equipment manufacturers an advantageous position vis-à-vis their clients, which are eager to benefit from these productivity enhancements (Bamber, Fernández-Stark, and Gereffi, 2016). This advantage has been further enhanced by consolidation in the sector and the dominance of a handful of firms in the production of each product category, particularly in the surface mining equipment sector where the top 10 firms, including Caterpillar and Komatsu, account for over 60 percent of the market (Sleight, 2015). The underground mining equipment sector is less concentrated, with more potential for new firm entry (Scott-Kemmis, 2011).

Procurement Patterns of Lead Firms

In the mining sector, procurement includes both products and services and spending is divided between operational expenditures and capital expenditures. Annual expenditures on goods and services is significant. Australia's mining sector made procurements worth US$20.2 billion in 2016 (Australian Bureau of Statistics, 2016) and Peru's mining sector procurements reached US$9 billion in 2017 (INEI, 2017a). In Chile, procurement in the copper mining sector alone accounted for US$12.2 billion (Banco Central de Chile, 2019).Annual capital expenditures vary more considerably based on new mine investment or expansion.[13] Taken together, mine development accounts for the highest share of procurement within the value chain. Purchasing is carried out by two key actors: miners and engineering firms. Figure 8 disaggregates these purchases by value chain stage: exploration; mine development; extraction; comminution, beneficiation, and concentration; and processing and refining.

Despite the capital intensity of the industry, services account for approximately half of the operational spending in the copper mining sector. In Chile, for example, services account 54 percent of procurement value (Table 2). Services are dominated by high-value activities. For example, engineering services are the most important category of inputs, accounting for approximately 20 percent of industry spending. This is followed by professional and technical services (8 percent), including IT, financial, and legal services. Indeed, considering all minerals and metals, services account for a growing share of value added in the mining industry, increasing in all major mining locations over the past decade. By 2015, services accounted for 23 percent of value added in global mining exports and 21 percent of those of Chile (OECD, 2020). These services are provided by a wide range of suppliers and are mostly produced domestically, albeit potentially by foreign subsidiaries. Product consumption is concentrated in generic inputs of electricity, fuel, and water, which together account for approximately 25 percent of all inputs, varying according to price fluctuations. These inputs are typically sold by a small set of firms. Beyond utilities and fuel, chemicals and explosives,

13 This excludes expenditures recorded as gross fixed capital formation. See Figure 19 in the appendices for Gross Fixed Capital Formation in Chile (2008–2017).

capital equipment, and consumables are the three most important categories of product inputs and make up about 17 percent of spending.

Figure 8. Major Services and Intermediate Product Inputs in the Copper Global Value Chain

	Exploration	Mine Development	Extraction (Surface/ Underground)	Comminution, Beneficiation and Concentration	Processing and Refining
SERVICES	• Topographical, geological, geochemical and geophysical services • Financial services • Repair and maintenance • Rental of specialized industrial equipment • Transportation services • Building and maintenance of roads	• Engineering services for design, development and installation of plant and equipment • Feasibility analysis services: technical, environmental, social • Drilling and blasting services • Land movement, construct leach pads, drilling platforms, process pads, tailings dams • Construct access roads and infrastructure • Legal services	• Equipment maintenance and repair • Lease of specialized equipment and machinery • Blasting and drilling services • Engineering services	• Transportation of concentrate to port (truck/ rail/pipeline) • Equipment maintenance and repair • IT services	• Financial services • Equipment maintenance and repair • Commodity contracts specialized services • Engineering and architectural services
PRODUCTS	• Specialized equipment • Fuel • Structural metallic products • Iron and steel	• Capital equipment (fixed; e.g., SAG grinder, etc.) • Structural metallic products (e.g., shafts, towers, flotation tanks, pipelines, etc.) • Cement and other construction products • Fuel	• Capital equipment (mobile) and parts • Explosives • Tires • Lubricants • Consumables (beds of the trucks, shovel blades) • Fuel and energy	• Consumables (grinding balls, SAG liners, conveyors) • Chemicals (reactive agents: collectors, frothers, and modifiers (e.g., lime) • Water • Electricity	• Capital equipment and parts • Copper concentrate and anodes • Electricity • Chemicals • WaterSX-EW • Sulfuric acid • Oxidating agents (e.g., ferrous agents/ bacteria)

Sources: Authors based on Australian, Chilean, Peruvian, and U.S. supply use tables (Australian Bureau of Statistics, 2016; Banco Central de Chile, 2019; BEA, 2012; INEI, 2017a).
Notes: Australian SU Industry Codes: 082 Non-ferrous metallic minerals, 100 Exploration and Mining Support Services; Chile Industry Codes: 15 Mineria de Cobre; Peru – SU Industry Code: 004001 Extraccion de minerals metalicas. US SU NAICS Codes analyzed – 212230 Copper, Nickel, Lead and Zinc Mining, 331410 Nonferrous Metal (except Aluminum) Smelting and Refining.

Table 2. Products and Services Required by the Chilean Copper Mining Sector, 2016[14]

	Share of Services	Share of Total
Total Services		**54%**
Architectural and engineering services	35%	19%
Professional and technical services	15%	8%
Transportation and logistics	13%	7%
Labor contracting services	11%	6%
Utilities services	7%	4%
Repair and maintenance services	9%	5%
Equipment leasing, without operator	6%	3%
Other	4%	2%
Total Products	**Share of Products**	**46%**
Utilities	42%	19%
Chemicals and explosives	15%	7%
Capital equipment and parts	13%	6%
Fuels and lubricants	12%	5%
Consumables	8%	4%
Metallic and structural products	5%	2%
Other (incl. quicklime)	4%	2%
Transportation equipment	2%	1%

Source: 2016 supply use table (Banco Central de Chile, 2019).
Note: Industry code: Minería de Cobre (15), user prices. Purchases of mineral products are excluded in this analysis.

The primary buyers for developing and operating a mine differ by value chain stage and contracting arrangement. The majority of spending is carried out during mine development and extraction. While procurement for extraction activities is carried out almost primarily by the operating miner, mine development may be carried out in-house by the miner or using engineering firms under EPC/EPCM contracts (Mining IQ, 2015). EPC contracts are turn-key operations, whereby engineering firms directly procure all inputs. Under EPCM contracts, the engineering firm provides the miner with short lists of suppliers and the miner is directly responsible for procurement (see Table 13 in the appendices). The choice of contract depends on a variety of factors, including the degree of risk, size of project, and availability of technical expertise (Brahm and Tarziján, 2015). As a result of

14 Chile was chosen as the example because its supply use data is limited to copper mining sector and is highly disaggregated, covering 181 categories of products and services (Banco Central de Chile, 2019). Further, the Chilean copper mining industry is comprehensive, including all upstream and midstream stages of the value chain and both oxide and sulfide refining processes. Also, as the largest global producer and second largest refiner, the data is representative of the global industry. Finally, the Chilean mining sector is characterized by very high levels of outsourcing. For example, 62 percent of all labor is employed by suppliers (compared to low levels in the United States and Canada) (Fernández-Stark, Cuoto, and Bamber, 2019). These factors allow for greater insight into potential areas of supply than in mining countries with high levels of vertical integration. One important caveat: 2016 was characterized by low exploration spending and mine development activity, with the major miners ratio of exploration to revenue at a 12-year low of 1.8 percent (S&P Global Market Intelligence, 2018).

this structure, both miners and engineering firms affect and control supplier access to the industry. Engineering companies tend to have strong relationships with lead suppliers since they buy large amounts of products and services for a wide range of industries, beyond just the mining sector. In 2018, Fluor's client procurement totaled US$16 billion (Fluor, 2019).

Sourcing practices are driven by reliability, quality, and safety. Miners tend toward strategic, long-term relationships with preferred suppliers on whom they can rely to deliver on these requirements. This has contributed to the consolidation of the supply sector around a small number of entrenched firms.[15] Miners are typically very conservative in hiring new suppliers because of the high costs of operational failure on cash flow and profitability, even when other more innovative solutions may be available (Deloitte, 2018). This is most notable in the capital equipment segment where sourcing is oligopolistic, often concentrated around two or three suppliers with approximately 50 percent of the market (Comisión Nacional de Productividad, 2017). Over the past 10 years, most mining companies have shifted toward centralized procurement to maximize economies of scale and share the cost of equipment over multiple mines as they have sought to cut costs, boost productivity, and reign in debt accrued during the boom. Since 2008, Anglo American, AMSA, BHP, Rio Tinto, and Freeport McMoRan, among others, have established global procurement operations. BHP's shift helped contribute to US$12 billion in productivity savings since 2012 (BHP, 2018). Combined, these procurement practices make it extremely difficult to become a capital equipment supplier for the industry.

Less strategic procurement categories are considerably more competitive, with thousands of suppliers. Codelco has close to 6,000 suppliers (Codelco, 2016). To manage the associated transactional costs, in recent years, the use of digital portals has increased, including in-house ones such as BHP's Global Contract Management System and third-party portals such as Ariba (SAP) or Achilles. To be included in these portals, suppliers must meet extremely demanding operational, safety, and environmental requirements. Typically these include significant pre-qualification audits of risk management procedures (e.g., valid insurance coverage, medical checks for all relevant personnel, and contingency procedures), operational reviews for equipment and systems compliance, financial guarantees for projects, and compliance with international legal requirements such as the *Foreign Corrupt Practices Act* and trade in conflict minerals.

Local Procurement Practices

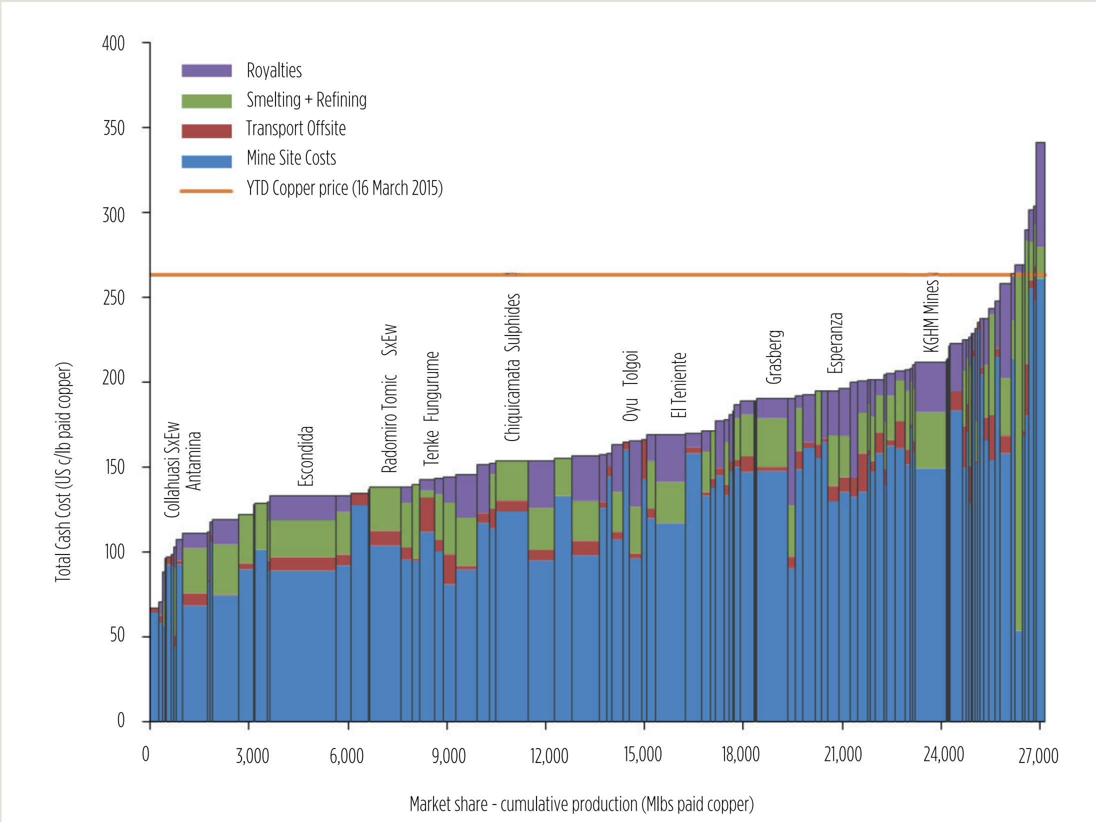
Within the industry, there has been a tendency for global miners to source primarily from their established global supply base, with little effort made to connect with local suppliers (Fessehaie and Morris, 2013; Katz and Pietrobelli, 2018). As a result, some host countries have emphasized promoting the incorporation of local suppliers into the value chain as backward linkages.[16] Mine site costs account for the highest share of expenditures in the industry, and offer a potentially lucrative

15 Cochilco identifies six critical supplies for the copper mining industry: quicklime, grinding balls, extraction trucks, shovel loaders, off-road tires, and flocculants. In each of these cases, in the Chilean market, the three leading suppliers account for over 75 percent of the market (Cochilco, 2016).

16 Backward linkage to local suppliers is part of a broader set of initiatives by host countries to capture additional value from natural resources sectors. Initially efforts focused on royalties and taxes, followed by functionally upgrading into the processing stages of the chain.

opportunity if firms can meet the miners/engineering firm requirements (Figure 9). Success in driving the development and participation of these suppliers has varied by country. More developed copper mining countries, such as Australia and Canada, have quite successfully built strong local mining equipment, technology, and services (METS) sectors, which today contribute substantially to exports in addition to supporting local mining operations. Chile's METS sector is slowly gaining momentum. Other developing countries have not yet been as successful, and there is weak local suppliers' participation in numerous African and Latin American countries.

Figure 9. Copper Supply Cost Curve, 2015



Source: SNL Metals and Mining, 2015 (cited in Outotec, 2019).

Local suppliers typically face multiple challenges to market entry as a result of both the nature of procurement in the industry and shortcomings in their local institutional context. The scale and capital intensity of the industry and the longevity of investments mean that miners tend to buy from large, established suppliers with broad capabilities, a global reputation, and with whom they have existing relationships. This may even occur in highly competitive low-cost categories where miners prefer to buy from familiar suppliers in their home countries (Field Research, 2019).[17] Local suppliers

17 Australian miners BHP and Rio Tinto have been accredited with supporting the internationalization of local suppliers (Scott-Kemmis, 2011).

in developing countries, on the other hand, tend to be considerably smaller, technically specialized, and with lower access to finance and organizational capabilities than their global peers (Katz and Pietrobelli, 2018). Furthermore, as new entrants, they do not have the trusted relationships required to gain access to mines to pilot their technologies/services (Pietrobelli, Marin, and Olivari, 2018). Even if the firms can deliver the required product/service, they are often unable to comply with the guarantees and prerequisites to become preferred suppliers (Banchile Inversiones, 2016).

Numerous policies and programs have been implemented over the past decade to help foster the insertion of local providers. Models to increase local procurement have ranged from those focused on promoting access through improved information availability to strict local content requirements (OECD, 2017b). Aid agencies and multilateral finance institutions have been strong proponents of these policies, including the OECD, the World Bank, and GIZ. These organizations have developed multiple guidelines and tools to drive these strategies (Ramdoo and Cosbey, 2019). In Australia, the Participation Plan requires miners to submit detailed plans on how they intend to identify local firms to participate in the procurement process, including timely distribution of information to local suppliers. This is coupled with numerous initiatives to improve local capabilities, such as efforts to bring universities and industry together to develop Centers of Excellence in key locations (Australian Goverment, 2019). In Ghana, the 2012 mining code stipulates specific product and services categories that must, by law, be procured locally. This was initially limited to just eight categories, but was increased to 19 in 2016 and is expected to continue to grow. In other cases, such as Argentina's transportation sector, economy-wide restrictive services policies ensure local procurement takes place (Ramdoo and Cosbey, 2019).

These policies have met with varying degrees of success. A common response to local content requirements has been to incorporate local suppliers into non-value chain inputs and activities, such as sourcing clothing or footwear, security, catering, or accommodation (Esteves, Coyne, and Moreno, 2013). There has been less success in incorporating local firms into value chain activities, such as drilling, blasting, or providing specialized inputs. Efforts to introduce firms into capital equipment spaces are stymied by very capable global suppliers (Bamber, Fernández-Stark, and Gereffi, 2016). There has been greater success incorporating local suppliers into adapting foreign equipment for the local environment (Stubrin, 2017) and producing consumables and wear parts (Bamber, Fernández-Stark, and Gereffi, 2016).

While the goal of these policies is to increase domestic value added, most policies focus only on local firms. Nonetheless, a core GVC tenant is that domestic value added can be generated by both foreign and local firms when products and services are being developed and/or manufactured domestically. In the mining sector, where procurement practices tend to favor large, global actors, their presence in the domestic market can contribute to domestic value added and to knowledge transfer as a result of labor rotation between local and foreign firms. Engineering services in Chile are illustrative. Supply use tables from 2016 indicate that 88 percent of engineering and architectural services were generated domestically in Chile (Banco Central de Chile, 2019) with only 22 percent imported compared to 78 percent of value added services in LAC (OECD, Unpublished). Chilean engineering skills have developed significantly as a result of local–foreign interactions over the past three decades. At the height of the copper boom in 2010/11, five copper centers of excellence for foreign engineering firms were located in Santiago de Chile and employed primarily Chileans (Fernández-Stark, Bamber, and Gereffi, 2010).

Figure 10. Local Value Added by Firm Type

Source: Authors' elaboration.

Approaches to Innovation in the Copper Mining Global Value Chain

Capital intensity, long investment cycles, and high costs to halt operations force miners to adopt only proven technologies and major innovations tend to be incorporated during mine development or expansion (Batterham, 2004; Field Research, 2019). It can be extremely costly and complex to pilot new alternatives, even if they could be transformative and lower costs in the long term. Miners are much more willing to adopt innovations that address unsolved (demand-driven) challenges that they face (Field Research, 2019); however, the mechanisms to share this information with potential new suppliers do not always exist. As a result, new suppliers have driven few major innovations in the industry over the past half-century.

Despite the industry's conservative procurement profile, the sector the adoption of new technologies and innovation have accelerated in recent years. However, unlike in other GVCs, technological advances have been driven not by lead firms (miners) but by their large suppliers. These suppliers are large multinational firms from developed countries that spend significantly more on R&D than miners (OECD, Unpublished). Local firms tend to be marginalized due to their weaker organizational capacity, scope, and scale. In order to create value adding opportunities for local firms within the chain, some mining countries have adopted a new approach focused on enhancing a more collaborative relationship between miners and local suppliers. Successful models are emerging that have embedded this value chain relationship within national innovation systems, including non-value chain actors, such as universities, research centers, investment funds, and incubators, as well as regulatory actors. The following section highlights key innovations introduced in recent years, followed by a discussion of emerging models.

Key Areas of Innovation

With essentially one output, innovations in the copper mining sector focus on improving the process of mining and processing; that is, process innovations to make it more productive, safer, more sustainable, and cheaper. Table 3 details R&D focus for the industry in recent years by value chain stage. In addition to these more traditional areas, innovations in digital and green technologies emerging in other sectors have been reshaping the way the industry operates. Digital tech includes precision mining such as sensors in mine shovels, decision automation in extraction (such as autonomous diggers and haul trucks) and processing activities, and 3D virtual reality and simulators for exploration, mine development, and operator training (e.g., Digital Bird Eye's View [Teck, 2018]). Augmented reality is being adopted to support field maintenance and repair operations. New processing plants are now widely automated and/or controlled remotely. These technologies enable operators to be removed from the mine site, improving safety and enhancing efficiency. Over half of the major international industry events between 2017 and the first semester of 2019 focused specifically on Industry 4.0 and digital innovation (Fernández-Stark, Cuoto, and Bamber, 2019). Clean or green tech includes developing electrical mining vehicles to reduce emissions, in situ mining to extract metals from ore deposits without removing the host rock, and eliminating the use of fresh water in general and all water in some cases (e.g., Anglo American's waterless technology project [Anglo American, 2018, 2019; Leonida, 2019]).

Table 3. Key Areas of Innovation in the Copper Mining Global Value Chain, 2010–2015

GVC Segment	Activity	Patents (2010–2015)	Main Technological Trends	Main Companies/R&D	Main Universities
Exploration and Mine Development	Exploration	315	• Work with lasers • Seismology, prospecting, and seismic or acoustic detection Tunnels or galleries • Methods or guidelines for reading or recognizing printed or written characters or to recognize patterns • Systems that use reflection or re-irradiation of the electromagnetic waves that are not radio waves	• Caterpillar Inc. • Shell Oil Co. • ExxonMobil Upstream Res Co. • Foro energy Inc. • Tech resources PTY Ltd. • Sandvik Mining & Constr OY. • Halliburton Energy Serv Inc. • Safemine Ag.	• University of Sydney • California Technology Institute • Chinese University of Mining and Technology • University of Jianghan • Catholic University of Chile • University of Akron • University of Nevada • Southeastern University • University of Utah Research Foundation • University of Western Ontario
	Planning	43	• Procedures for underground or surface mine operation • Diverse details related to the equipment that creates the fractures or completely frees the ore material from the vein	• Sandvik Mining & Constr OY • BHP Billiton Innovation PTY • Sandvik Intellectual Property • Atlas Copco Rock Drills Ab • FCI Holdings Delaware Inc. • Rag Ag • Trimble Navigation Ltd • Soletnache Freeyssinet • Sandvik Tamrock OY	• University of Sydney
Extraction	Operation	212	• Drills especially adapted to change drilling direction, with means for collecting substances • Manufacture of composite layers, parts, or objects based on metallic dusts, sintered with or without compacting	• Baker Hughes Inc. Halliburton Energy Serv Inc. • Kennametal Inc. Longyear TM Inc. Potter Drilling Inc. Schlumberger Technology bV • Smith International • TDY IND Inc.	• Chinese University of Mining and Technology
	Tailing	70	• Destruction or transformation of solid wastes • Flow mixers • Sludge treatment • Devices for the above • Water treatment • Nature of the pollutant	• Basf Ag • Suncor Energy Inc. • Kurita Water IND Ltd • FLSmidth & Co A/S • Changchun gold Res INST • Du Pont • Fort Hills Energy LP • Nippon Sodaco • Total E&P Canada Ltd • Chinanat Gold Group	• University of Freiberg • University of Nankín

Table 3. Key Areas of Innovation in the Copper Mining Global Value Chain, 2010–2015 *(continued)*

GVC Segment	Activity	Patents (2010–2015)	Main Technological Trends	Main Companies/R&D	Main Universities
Comminution, Beneficiation, and Concentration	Grinding	113	• Presses specially adapted to specific ends • General layout of separation in the plant • Control systems especially adapted to crushing and disintegration • Metalworking	• FLSmidth & Co A/S • Unimin Corp. • Outotec OYJ • Metso Minerals France SA • Schlumberger Technology bV • Tech Resources PTY LTD • Arter Technology bV • KDH Humboldt Wedag gMbH	• McGill University • University of KwaZulu-Natal • University of Queensland • University of Santiago de Chile • University of Melbourne
	Crushing	77	• Preliminary treatment of ore or scrap • Methods or ancillary devices or accessories especially adapted to crushing and disintegration • Means of transport specially adapted to underground conditions	• Tech Resources PTY Ltd • Takraf gMbH • Unimin Corp. • Joy MM Delaware Inc. • Thyssenkrupp Foerdertechnik • Suncor Energy Inc. • Arter Teknolodzhi Ltd • Harnischfeger Tech Inc. • Codelco	• Chinese University of Mining and Technology • University of Houston • University of Melbourne
	Flotation	88	• Expected effects of flotation agents • Specified materials treated by flotation agents, specific applications	• Barrick Gold Corp. • Basf Ag • BHP Billiton SSM Dev PTY Ltd • Cytec Tech Corp. • Evonik Industries Ag • Ex Tar Technologies Inc. • Georgia-Pacific Chemicals LLC • Sumimoto Metal Mining Co.	• Technical University of Aquisgran • University of Manchester • McMaster University • University of Osaka • University of Utah Research Foundation
Processing	Smelting	119	• Mitigation of climate change from production	• Outotec OYJ • Tanaka Precious Metal IND • Dowa Metals & Mining Co. Ltd • Jx Nippon Mining & Metals Corp. • Precious Metals Recovery PTY Ltd • Mitsubishi Materials Corp. • Kosaka Smelting & Refining Co. • Nippon PgM Co. Ltd • Outokumpu OY • Umicore Ag & CO Kg	• Central South University, China • National Technology Institute of Japan • Beijing University of Science and Technology • Espirito Santo Federal University • Jiangxi University of Science and Technology • Northeastern University of China • University of Tokyo • University of Utah Research Foundation
	Leaching	291	• Ion exchange in which a complex or a chelate is formed; Use of a substance as an ion exchanger that forms complexes or chelates. • Treatment of a substance to improve its exchange or iron properties forming complexes or chelates	• Freeport McMoRan Corp • Jx Nippon Mining & Metals Corp • Outotec OYJ • Nippon Mining Corp • Cognis IP Man gMbH • Basf Ag • Cytec Tech Corp • Outotec Finland OY	• University of British Colombia • University of Alberta • Universidad Autónoma Metropolitana de México • University of Cape Town • Central South University, China • Donghua University • James Cook University • University of Kingston
	Solvent Extraction	141	• Solid waste management technologies • Obtaining metals from rare earths • Obtaining noble metals • Metal composites from rare earths	• Cognis Ip Man gMbH • Commw Scient IND RES ORG • Cytec Tech Corp. • Freeport McMoRan Corp. • Jx Nippon Mining & Metals Corp. • Nippon Mining Co. • Outotec OYJ • Process Res Ortech Inc.	• University of Nevada • University of British Colombia • Central South University, China • Chung Yuan Christian University • University of KwaZulu-Natal • Catholic University of Louvain • Complutense University of Madrid • University of Nantes • Northwestern University • University of Osaka

Table 3. Key Areas of Innovation in the Copper Mining Global Value Chain, 2010–2015 *(continued)*

GVC Segment	Activity	Patents (2010–2015)	Main Technological Trends	Main Companies/R&D	Main Universities
Refining	Refining	77	• Obtaining copper • Technologies related to metals processing • Solid waste management technologies • Electrolytic production • Recovery and refining of metals via solutions electrolysis	• Jx Nippon Mining & Metals Corp. • Pan Pacific Copper CO LTDA • Nippon Mining Co. • Phelps Dodge Corp. • Freeport McMoRan Corp. • Outotec OYJ • Xiangguang Copper CO LTDA. • Sumitomo Metal Mining Co.	• University of Chile • Free University of Brussels • University of Osaka • University of San Luis • University of Santiago de Chile • University of British Colombia
	Electrowinning	61	NA	• Alcan INT Ltd • Aluminum Corp of China Ltd • BHP Billiton SA Ltd • Elkem AS • Green Metals Ltd • Moltech Invent SA • Pechiney Aluminium	• University of Seoul Research and Development Foundation • University of Alabama • Boston University • University of British Colombia • Free University of Brussels

Source: Author's elaboration based on Fundación Chile, 2015.

Role of Actors in Innovation in the Copper Mining Global Value Chain

Unlike other GVCs, lead firms are not the major drivers of innovation. Miners themselves invest very little in R&D and instead rely on other value chain stakeholders to develop new technologies. Innovation is thus driven to a large extent by suppliers (Urzua, 2013). Since 2007, while R&D spending for miners has been close to zero (Deloitte, 2018), major suppliers have invested significantly. For example, in 2017, Caterpillar, Komatsu, Hitachi, and Sandvik each spent upwards of 4 percent of their revenue on R&D (Pricewaterhouse, 2018).[18] That year, Caterpillar alone spent US$1.9 billion on R&D (Caterpillar, 2019). Indeed, when acquired technology is taken into account (ratio of R&D in intermediate goods and services to internal R&D/sales), the sector is found to be highly innovative (Smith, 2005). Suppliers are the companies that carry out experimental and pilot projects, develop prototypes, and improve production models (Katz & Pietrobelli, 2018). Innovation and its later adoption by the industry therefore depends to a large degree on miners' relationships with their suppliers.

Innovative suppliers of METS are primarily based in developed countries—not necessarily mining countries. The United States (e.g., Bechtel, Caterpillar), Canada (e.g., Maclean, SNC-Lavalin), Japan (e.g., Hitachi), and Germany (e.g., Liebherr, Siemens) have been important players in innovation in the extraction stages of the chain, while Finland (e.g., Metso) and Sweden (e.g., Atlas Copco) have contributed significantly in the processing stages. Among mining countries, Australia has successfully developed a dynamic, innovative METS sector that contributes domestically and in global markets. METS firms collectively spent US$2.7 billion on R&D in 2018 (Austmine, 2019). South Africa and Chile have also developed a small number of innovative suppliers dedicated to local and regional markets (e.g., Minnovex). Most copper mining countries, however, including many in LAC (e.g., Ecuador and Peru), Africa (e.g., Democratic Republic of the Congo and Zambia), and Asia (e.g., Indonesia and Mongolia) rely almost exclusively on imported technologies.

18 Comparing R&D spending as a share of revenue between the different types of firms can be misleading because miners have very high sales.

In recent years, several mining countries, including Australia and Chile, have begun to establish new innovation hubs, creating opportunities to development more technologically advanced local firms to generate greater value from their participation in the industry. These innovation hubs encourage GVC actors to interact with non-GVC actors in the national innovation system sector.[19] Through these arrangements, GVC-related knowledge complements local knowledge development channels, such as local industry associations and universities (De Marchi, Giuliani, and Rabellotti, 2018). In particular, these hubs have focused on collaboration models involving multiple stakeholders, moving away from single actor in-house innovation (Bryant, 2015; Expande Minería, 2019; Monitor Deloitte, 2016, 2017; Upstill and Hall, 2006).

Models have varied from collaboration between two actors (e.g., mine/supplier and university) to highly collaborative and open innovation models (Table 4). Five innovation approaches are common in the sector: miners only, suppliers only, miner–supplier, start-ups, and multi-stakeholder collaboration with researchers and start-ups.

Table 4. Innovation Approaches in the Mining Industry

Innovation Approaches	Knowledge Developers				Description	Examples
	Miners	Suppliers	Research Centers	Start-ups		
Miners only	X				Mining firm uses internal human capital to develop innovative solution; typically focused on areas where suppliers lack incentives to carry out R&D and is typically of an incremental nature.	Nippon JX is developing new leaching technologies to apply to copper sulfide resources (JX Nippon Mining & Metals, n.d.).
Suppliers only		X			Supplier drives innovation process independent of buyers.	Caterpillar developed a 120-person in-house data analytics team to develop new data applications for the sector. Innovations include augmented reality field technician glasses, predictive maintenance models, and autonomous trucks (Caterpillar, n.d.a).
Miner–supplier collaboration	X	X			Miner and supplier collaborate to develop a solution, with each possibly committing different resources (e.g., time, money, and pilot phase testing).	Teck Resources partnered with MineSense to develop the bucket-mounted ShovelSense™, which can determine waste rock from ore, rolling out the first full-scale trial in 2017 (Teck, 2018).

19 "A system of innovation is the sum of all market and non-market actor networks that foster the creation, transfer, adoption, adaptation, and diffusion of knowledge through learning processes that are individual, collective, and organisational" (Oyeyinka and Gehl Sampath, 2007). Central to the innovation systems approach is that firm-level innovative capacity depends on the density and quality of the relationships among and between enterprises and supporting institutions (Lundvall, 2007).

Table 4. Innovation Approaches in the Mining Industry *(continued)*

Innovation Approaches	Knowledge Developers				Description	Examples
	Miners	Suppliers	Research Centers	Start-ups		
Start-ups				X	Start-up develops disruptive solution; sells service product or entire company to miner or supplier.	CodelcoTech was established in 2017 to become the global pioneer in accelerating the integration of mining experience and know-how with new technological capabilities. The mining subsidiary acquired numerous innovation startups, including BioSigma and IM2 (Codelco, 2017).
Multi-stakeholder collaboration	X	X	X	X	Miners and/or suppliers collaborate with research centers, and start-ups to develop new processes or products.	Rio Tinto's multimillion dollar Mine of the Future program involves alliances with Komatsu and five research centers across Australia, including University of Sydney's Faculty of Engineering and Information Technology. The program has developed autonomous diggers, among other products, for the mining industry (The University of Sydney, n.d.). Mining3 in Australia is an industry-driven research institute, bringing together miners, suppliers, and researchers focused on developing new and innovative solutions for the industry (Mining3, 2019)

Source: Authors' elaboration.

For example, Rio Tinto embedded its key Mine of the Future research laboratory in The University of Sydney's Engineering Faculty to draw on innovative resources at the school. Large suppliers have recognized the importance of tapping into innovative talent emerging from the start-up world, particularly to tap into high technology firms in robotics and advanced automation. Caterpillar set up Cat Ventures to invest in early-stage rounds (US$0.5 million to US$5.0 million) in innovative firms (Caterpillar, n.d.b); Siemens established Next47 to do the same. Other firms that provide control and automation services to the mining industry, including ABB, GE, Honeywell, and Rockwell Automation, have followed similar patterns of investing in and acquiring start-ups (Frederick, Bamber, Gereffi, et al., 2018).

The most collaborative models bring multiple miners, suppliers, industry associations, and local and foreign research institutions together with innovative start-ups and investors. Australia's Mining3, for example, brings together the global players with Australian public and private research institutions to develop new solutions for the industry. Chile's Expande program—spearheaded by Fundación Chile, a quasi-public organization dedicated to develop new technologies—provides a platform whereby miners publish key challenges they face and any firm or organization is welcome to submit a potential solution for evaluation (Fundación Chile, 2019a). Two complementary venture capital funds, Aurus Fund and Chile Global Ventures, offer risk financing to support start-ups with accepted solutions (Fundación Chile, 2019b; Aurus Capital, 2019).

Box 1. Appropriability and Intellectual Property Protection

The rise of collaborative innovation in the mining sector raises the issue of appropriability (Miozzo, Desyllas, Lee, et al., 2016). With large mines dominating the power relationship, smaller suppliers with low bargaining power may be disincentivized from developing innovative solutions in partnership with miners if they will later be captive to those miners, unable to sell their products or services to other organizations. These dynamics require strong contractual terms and institutionalization of process to manage conflicts and protect each party. Mining companies are often unwilling to collaborate because of concerns about disclosing information regarding their competitive advantage and intellectual property (Deloitte, 2018). Resolving these conflicts remains a challenge, particularly in developing countries and even for countries with more advanced systems, such as Australia and Chile. Appropriability continues to be dealt with on a case-by-case basis (Field Research, 2019).

Similarly, intellectual property protection has been a challenge. While there has been an increase in patenting within the sector (Daly, Valachi, and Raffo, 2019; Field Research, 2019) —there were more patent applications filed in the past five years than in the past 30 years*— this has been primarily used to support the internationalization of suppliers. The use of patents has been most important for markets with strong intellectual property protection frameworks and suppliers from these markets. Global firms use patents well. For example, Caterpillar has roughly 22,000 granted or pending patents globally (Caterpillar, n.d.b). However, many mining countries —especially developing economies— continue to have weak intellectual property protection frameworks. In these contexts, miners tend to disregard patents in their procurements process. Local suppliers are therefore disincentivized from registering patents for their innovations. In these situations, other appropriability mechanisms, from confidentiality agreements and lead time advantage to nondisclosure agreements, may offer alternative ways to protect innovations (Miozzo, Desyllas, Lee, et al., 2016).

* In the past, in the mining industry patenting was dominated by firms, but recently there has been an increase in patenting by universities (Daly, Valachi, & Raffo, 2019), illustrating the rise of innovation being drawn from non-value chain actors.

3. OPPORTUNITIES FOR PERUVIAN SUPPLIERS IN THE COPPER MINING GLOBAL VALUE CHAIN

Peru is the world's second most important copper producer, with significant unexploited reserves and a robust pipeline of potential investments in new mines. Over the past two decades, as the industry has grown, a local supply chain has emerged; however, it is dominated by foreign suppliers, with very low participation of Peruvian suppliers in value-added inputs. The relatively weak presence of local suppliers in the industry reflects global industry dynamics combined with generally undeveloped capabilities of local firms. The opportunities for their insertion by the miners are primarily in areas where new solutions are required. This places significant demand on innovative capacity; however, the still weak innovation system in Peru hampers the development of these suppliers.

With copper demand likely to continue to rise in the future, a renewed investment cycle is imminent in Peru and current procurement is likely to rise. Procurement in 2017 reached US$9 billion, excluding categories characterized by oligopolistic supply (e.g., fuel and utilities). The approximate market size in Peruvian mining for goods is US$2.3 billion and for services is US$4.4 billion. Services tend to be acquired locally, albeit from foreign affiliates (OECD, unpublished). New mine development would provide a significant boost in demand for a range of services, from feasibility to engineering and construction services. Increased demand provides significant opportunity for the country; however, neither the current local supply base nor the national institutions are prepared to take advantage of that potential.

Policies are required to better position the country to strengthen its backward linkages to the chain. Institutionally, the country needs to develop a strong, long-term national strategy, supported by a policy champion. Current government policy is overly focused on social and environmental regulation, with no focus on upgrading or innovating in the industry. Efforts need to be made to strengthen access to the chain by increasing opportunities for information sharing and supporting the development of industry-specific organizational skills for mining suppliers. Peru does not have local content or procurement targets that apply to the mining industry (OECD, 2017b). Though mining firms agree to prioritize local procurement and report on their progress, global supply dynamics prevail in Peru and foreign suppliers continue to be favored over local ones. This preference is due to a lack of information about existing local firms and relatively weak firm capabilities. Significant attention needs to be paid to developing the innovation capabilities of local firms.

Peru in the Copper Mining Global Value Chain

Peru is a major actor in upstream stages of the copper GVC, with strong participation in exploration and extraction, and a presence in early mineral processing. Peru is the world's second largest exporter of copper ore and concentrate, and copper accounts for one-third of the country's total exports (UN Comtrade, 2019). With 81 million tonnes, Peru has the third largest proven copper reserves in the world after Chile and Australia (USGS, 2019a). Peru's reserves are inexpensive to extract at approximately US$1.10/lb compared to US$1.48/lb in Chile, Australia, and Canada and a global average of US$1.42/lb (BBVA Research, 2019). As a cheap destination with ample supply, the global growth in copper demand has thus spurred the development of the industry in Peru.

Figure 11. Peru's Position in the Copper Global Value Chain, 2017

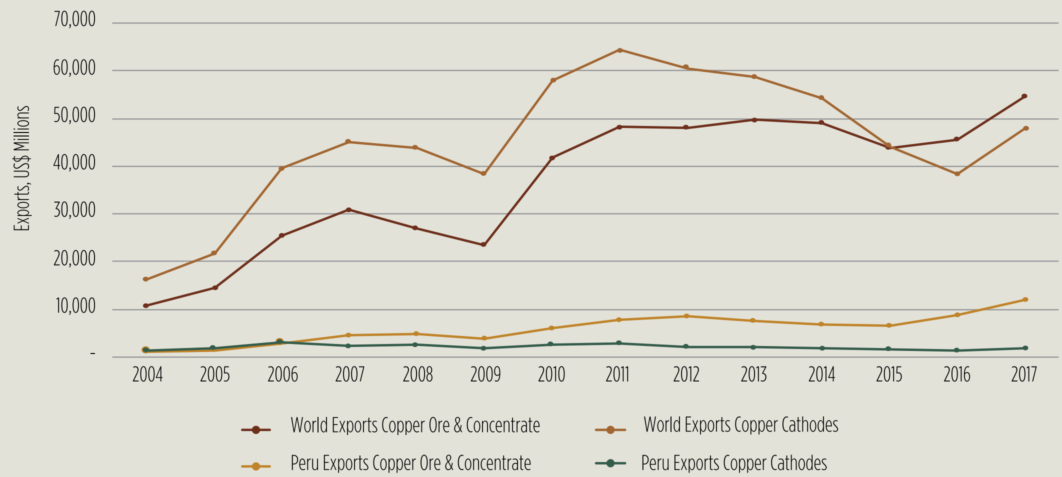
Source: Authors' elaboration based on UN Comtrade (2019).

Peru's output has increased significantly, from 1.28 million MT to 2.44 million MT between 2008 and 2018, consolidating its position as the second largest producer of copper after Chile.[20] Peru's contribution to global production (12 percent) is aligned with its share of global reserves (11 percent). The low cash costs have allowed the country to rapidly increase its output where that of other producers has remained steady.

Almost all of Peru's ore and concentrate production is exported, with only a small share destined to the country's one operating smelter-refinery in Ilo. The majority of reserves currently exploited in Peru are sulfide ores, requiring flotation to produce concentrate. Only a few mines (e.g., Cerro Verde and Toquepala) extract oxide ores that can be directly processed using SX-EW to produce cathodes. The country is thus overrepresented in the upstream stages of the chain, accounting for 22 percent of global copper concentrate exports in 2017. This concentrate is destined primarily to Asia, which accounted for 82 percent of Peru's copper exports in 2018. Chinese smelters absorb the majority (64 percent), followed by Japan (9 percent) and South Korea (6 percent) (UN Comtrade, 2019).

20 Despite this growth, Peru still produces less than half of the global leader, Chile, which produced 5.8 million MT in 2018 (USGS, 2019a).

Figure 12. Peru in the Copper Global Value Chain, Exports by Value, 2004–2017



Source: UN Comtrade (2019).
Notes: HS02 260300 (copper ore and concentrate); 7402 (unrefined copper, copper anodes for electrolysis) and 740311 (copper cathodes). Peru/All exporters. Downloaded 23/05/2019.

Production is concentrated in a small number of large- (>200,000 tonnes) and medium-sized (45,000–200,000 tonnes) mining companies. The top 10 mines account for 96 percent of all copper produced. The three largest mines, which are world class mines (among the global top 10), are owned by consortia of primarily foreign majors and operated by local mine-specific companies: Cerro Verde (U.S.–Japan–Peru), Las Bambas (China), and Antamina (Australia–Switzerland–Canada–Japan). Southern Peru Copper (Mexico–U.S.) is the largest single firm mine operator in the country. Only one Peruvian firm, Buenaventura, has a significant position in the country's copper mining sector; it owns 20 percent of Cerro Verde and operates the medium-sized El Brocal, which accounts for 2 percent of national copper output. Of all copper mining production, 70 percent is located in southern Peru (MINEM, 2019).

Large reserves have attracted considerable exploration activities. In 2017, Peru captured 7 percent of global spending on exploration in all non-ferrous metals (S&P Global Market Intelligence, 2018). Cumulatively, since 2008, approximately US$5.6 billion has been spent on exploration in the country. While exploration spending slowed following the decline in copper prices in the early 2010s, it increased to US$412 million in 2018 from a low of US$377 million in 2016 (MINEM, 2019). Leading copper miners have been active in the search for new mining sites alongside juniors.

As expected with the majority of copper being produced by foreign firms, feasibility and mine development are led primarily by foreign firms. Of the 26 projects in Peru's copper portfolio, only three are owned by Peruvian firms—Trapiche (Buenaventura, 65,000MT), Mina Justa (Marcobre, 110,000MT), and Anubia (Arutani, 20,000MT)—with the remaining projects owned primarily by majors. Projects owned by Southern Peru Copper account for 17 percent of projected new output. Consistent with a poor global pipeline within the next five years, only two projects are currently under construction. Quellaveco, jointly owned by Anglo American and Mitsubishi, is the largest new project nearing commissioning. It will produce 225,000MT at full capacity in 2022. Two others—Tia Maria and Mina Justa—are in the final stages of engineering design; however, Tia Maria is still held up by social concerns and is awaiting construction permits (BBVA Research, 2019) (Figure 13).

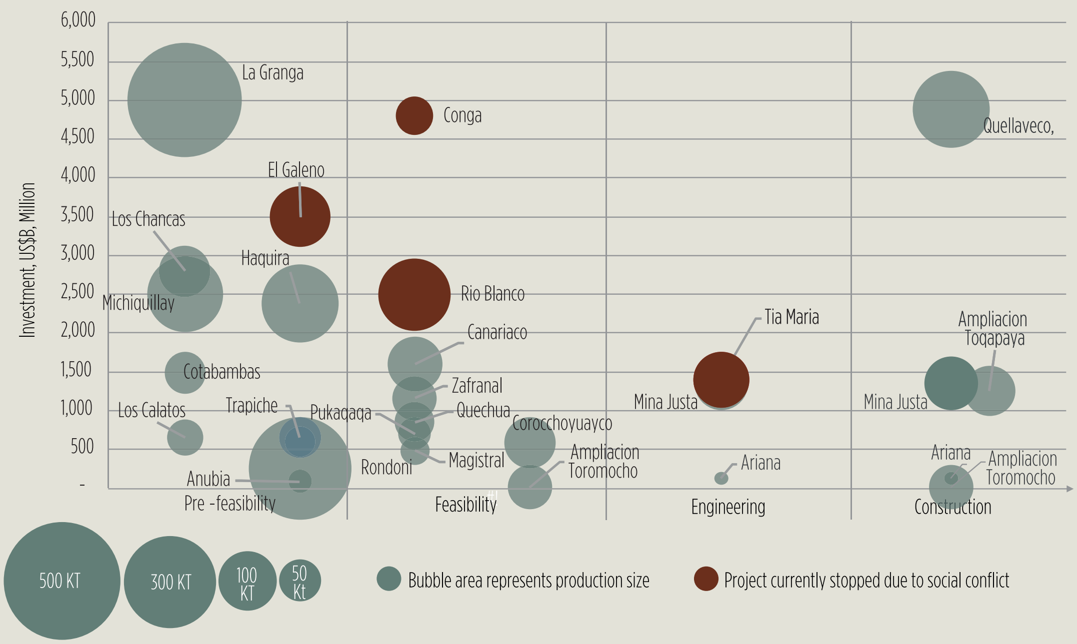
New investment projects include a smelting-refinery plant in Ilo by Southern Peru, which would double the country's smelting capacity. The investment is estimated to be US$1.35 billion. The plant is awaiting a production permit. There are also new projects that will produce SE-EW cathodes, including Tia Maria, which would produce 120,000 tonnes of copper cathode.

Table 5. Peru's Leading Copper Mines

Mines	Ownership	Processes	Output (MT)	
			2017	%
Cerro Verde	Freeport McMoRan, Sumitomo, Buenaventura	SE-EW	501,815	21
Las Bambas	MMG, Guoxin, CITIC Metal Co.	Flotation	452,950	19
Antamina	BHP, Teck Resources, Glencore, Mitsubishi	Flotation	439,248	18
Southern Peru Copper	Grupo Mexico	Smelting; Refining; SE-EW	306,153	13
Antapaccay	Glencore	Flotation	206,493	8
Toromocho	Chinalco	Flotation	194,704	8
Constancia	Hudbay	Flotation	121,782	5
Milpo	Nexa Resources	Flotation	46,691	2
Marcapunta-Norte/El Brocal	Buenavantura	Flotation	45,778	2
Cerro Corona/ La Cima	Gold Fields	Flotation	31,460	1
Other mines			98,510	4
Total			**2,445,584**	**100**

Source: MINEM (2019).

Figure 13. Key Investments in the Copper Mining Sector in Peru, by Stage of Mine Development



Source: Authors' elaboration based on MINEM (2019).

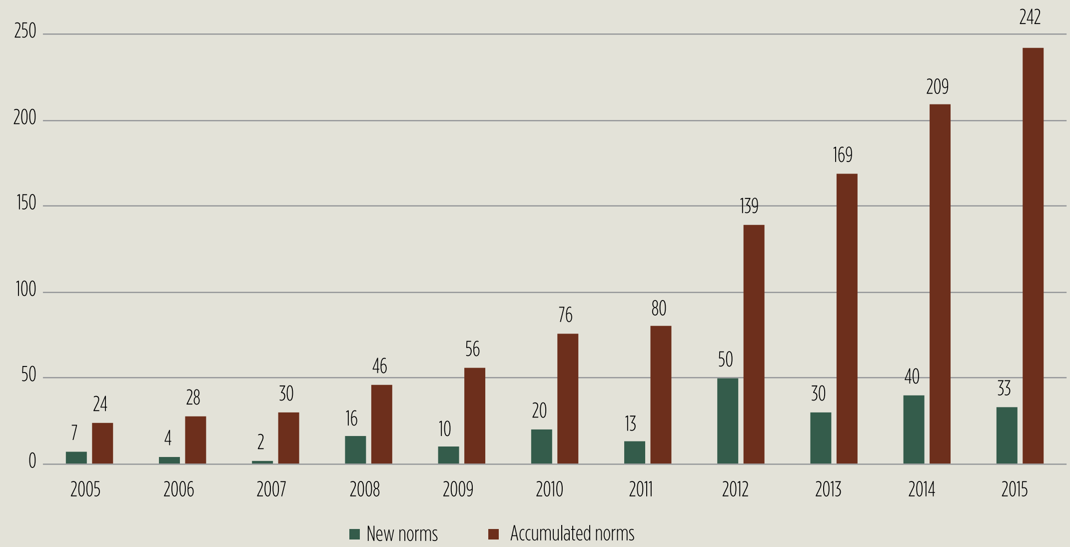
Institutional Framework

The institutional framework that supports mining activities in Peru suffers from a lack of organization that affects the competitiveness of the sector. In the past, mining in Peru was overseen by the Ministry of Energy and Mines (MINEM). However, since 2007, two other entities have been given oversight of sector activities: the Agency for Environmental Assessment and Enforcement and the Ministry of Labor. The overlapping regulations among government actors has resulted in a lack of industry leadership, excessive bureaucracy, and high degrees of redundancy (Field Research, 2019).

These institutional changes have rapidly led to overregulation of the industry. Between 2005 and 2015, the number of regulations increased more than 10-fold, from 24 to 242 (Figure 14). This has been accompanied by a simultaneous increase in the number and complexity of procedures required to obtain operating permits, which must be processed by a large number of organizations, including the General Directorate of Mining, the General Directorate of Mining Promotion, MINEM, the Ministry of Agriculture, and the Ministry of Culture (Tras100d, 2017).

Regulatory changes have been particularly stringent with respect to social and environmental impacts and have resulted in increased uncertainty in the industry. Indeed, delays in environmental approvals has forced MINEM to establish work-around regulations, including one that allows mining activities to begin without a current environmental approval certificate, as well as to extend the validity of certifications from one to three years. In lieu of oversight, firms are expected to self-regulate during these periods (BBVA Research, 2019).

Figure 14. Relevant Norms in the Copper Mining Industry, 2005–2015



Source: Molina (2019).

The rise of social conflicts in mining areas in Peru has also resulted in an increase in regulatory burden. Throughout the years, the government has made numerous attempts to resolve the conflicts, however, these have been predominantly short-term solutions. The most important institutional change was the approval of the *Prior Consultation Law* in 2011 that requires prior consultation with Indigenous communities before any infrastructure or projects, especially mining and energy projects, are developed in their areas.[21] Achieving a social license to operate has thus become one of the most important challenges that the mining industry faces in Peru (EY, 2018). According to the Office of the Ombudsman, there were 199 active social conflicts in 2018, of which 83 are directly related to the mining sector (Office of the Ombudsman, 2018).

Social conflicts, especially in mining areas, are affecting business costs and decision-making. In Peru, social conflicts with neighboring communities have halted three mining projects worth approximately US$2.8 billion that would have been a substantial contribution to aggregate mining production. MINEM has estimated that the projected annual production of the three mining projects would be around 374,000 tonnes of copper, 680,000 ounces of gold, and 3,000 tonnes of molybdenum (MINEM, 2019).

21 The *Law of the Right to Prior Consultation with Indigenous or Native Peoples* (Law 29785) was recognized by Convention 169 of the International Labor Organization, which created the procedure of the right to prior consultation with indigenous or native peoples regarding legislative or administrative measures that directly affect them.

Copper Mining Procurement in Peru

As a leading producer of various minerals, including copper, expenditures in the Peruvian mining industry is high. In 2017, for the sector as a whole, expenditures reached US$9 billion in goods and services.[22] Slightly more was spent on goods than services. Goods spending was concentrated on fuels and utilities, followed by chemicals and explosives and capital equipment, which collectively account for 80 percent of spending. Services spending is focused transportation and logistics, professional and technical services, and labor contracting (82 percent). Excluding categories characterized by oligopolistic supply (e.g., fuel and utilities), the approximate annual market for mining goods is US$2.3 billion and for mining services is US$4.4 billion in Peru. Based on copper mining accounting for approximately half of Peru's mining output and it being carried out by capital-intensive global miners, copper is estimated to account for approximately half of mining expenditures, representing a considerable market for suppliers. Table 6 provides details on the products and services purchased by mines in Peru.

Table 6. Peruvian Mining Sector Expenditures, 2017

	US$ millions	Share of Total	Share of Products
Total Procurement	**8,991**	**100%**	
Total Goods	**4,504**	**50%**	**100%**
Utilities	913	10%	20%
Chemicals and explosives	934	10%	21%
Capital equipment and parts	464	5%	10%
Fuels and lubricants	1,257	14%	28%
Consumables	182	2%	4%
Metallic and structural products	326	4%	7%
Other	424	5%	9%
Transportation equipment	3	0%	0%
Total Services	**4,487**	**50%**	**Share of Services**
Architecture and engineering	217	2%	5%
Professional and technical	1,178	13%	26%
Transportation and Logistics	1,620	18%	36%
Utilities	57	1%	1%
Repair and maintenance	138	2%	3%
Labor contracting	862	10%	19%
Equipment leasing, without operator	267	3%	6%
Other	149	2%	3%

Source: Authors' elaboration based on 2017 Peruvian supply use matrix (INEI, 2017).

22 Including all expenditures for mining registered in the national current accounts, excluding that noted as gross fixed capital formation. The amount is comparable to spending in Chile (US$12 billion, 2016) and Australia (US$20 billion, 2016).

Of course, procurement varies by the stage in the value chain and is driven primarily by variations in capital expenditures. Capital expenditures are most significant during mine development and/or expansion (46 percent of the total procurement costs), with the building of mine infrastructure and mineral processing plants collectively accounting for 37 percent in 2018. As the mine prepares for extraction, a further 10 percent is spent on acquiring mobile mining equipment such as drills, shovels, and haulage trucks. As a result, annual capital expenditures fluctuate with the development of new mines. For example, the expansion of Cerro Verde (2015), which doubled production, included US$4.6 billion in procurement (MINEM, 2019), processors,[23] investment in the Las Bambas (2015) mine development totaled US$10 billion, and Southern Peru Copper invested US$1.2 billion in a major expansion underway at Toquepala (Gestión, 2017). Mining investment for new project development and expansion is projected to be a total of US$21 billion between 2018 and 2021, and by 2028, reaching a total of US$58.5 billion (Millan Lombrana and Quigley, 2018). This market expansion offers potential for more procurement, although new mine investment depends on a sustained copper price. Figure 15 illustrates mine procurement expenditures in 2018 by value chain stage, including the top mine spenders.

Figure 15. Mining Capital Expenditure by Value Chain Segment, 2018

	Exploration (11%)	Mine Development (46%)	Extraction (10%)	Comminution, Beneficiation & Concentration	Processing & Refining
	Other Expenditures (32%)				
	• Exploration (11%)	• Mining Development & Preparation (9%) • Infrastructure (23%) • Benefication Plant (14%)	• Mining Equipment (10%)	NA	NA
Top Mine Spenders	• Zafranal (US$28M) • Buenaventura (US$27M) • Antapaccay (US$20M)	**Mining Dev. & Preparation** • Marcobre (US$101M) • Yanacocha (US$94M) **Infrastructure** • Quellaveco (US$166M) • Southern Peru (US$73M) • Cerro Verde (US$57M) **Beneficiation Plant** • Southern Peru (US$434M) • Chinalco (US$189M) • Antamina (US$112M)	• Cerro Verde (US$142M) • Antamina (US$92M) • Southern Peru (US$86M)	NA	NA

All Mining Capital Expenditure US$ billion

2010	2011	2012	2013	2014	2015	2016	2017	2018
3.3	6.3	7.4	8.8	8	6.8	3.3	3.9	4.9

Source: Authors' elaboration based on MINEM (2019).

23 Cerro Verde's direct imports of capital goods and construction materials, excluding those acquired from foreign subsidiaries in Peru, accounted for approximately 25 percent of that expenditure (Aduanas-SUNAT, 2017).

With the Peruvian copper mining industry dominated by large multinational corporations, local procurement patterns reflect those of the global industry. Prior to 2019, there was little collaboration among firms to foster backward linkages in the country. Purchasing by miners is led by the principles of quality, safety, and reliability, while compliance with environmental standards has become increasingly relevant. Generally, supplier preference is based on the risk/cost assessment. Risk is determined by the critical nature of the product and how difficult it is to secure. High-risk/high-cost inputs are procured using long-term (3–5 years) purchasing strategies to lock in costs and secure supply. These inputs are only contracted from reliable, experienced, and, generally, global suppliers. Supply of low-risk/low-cost inputs is characterized by high competition. In these cases, miners seek to reduce their transactional costs while limiting contracts to just one to two years, and proven low-cost products are favored. In either case, suppliers must be approved and registered on internal procurement platforms to bid on new contracts (Field Research, 2019). Procurement decision-making is generally managed by specialized teams based in corporate offices in Lima or abroad. Miners indicate that the high willingness of local suppliers to customize solutions to meet their needs improves their attractiveness to the industry. In addition to these generalized practices, it is common for miners in Peru to have specific local procurement programs for their immediate areas of impact around the mines to maintain their social license to operate. These programs include labor contracting and maintenance.

Procurement of new, innovative products is done generally on a demand-driven basis. Unsolicited solutions are not reviewed. Once a mine has adopted a particular technology or process, innovations are not encouraged (Field Research, 2019). The cost of disrupting operations to introduce a new process are often prohibitive and operating mines typically only seek new solutions for non-mission-critical activities. Any short-term mission critical events are handled by trusted, large, foreign suppliers. On the other hand, miners are open to innovation where it solves a problem they have not yet resolved, offering the greatest opportunity for new suppliers. Nonetheless, miners are typically reluctant to publicly disclose where they have challenges in their operations, leading to information asymmetries (Field Research, 2019).

Mining Supply Chain in Peru[24]

While Peru's copper mining sector was initially supplied by foreign firms from global or Chilean headquarters, today, there is a relatively robust and growing local supply chain (Field Research, 2019). In 2017, the 10 leading copper miners directly imported goods and services valued at just US$446 million (Aduanas-SUNAT, 2017).[25] Several of these copper miners report procuring as much as 90 percent of their inputs locally (Field Research, 2019).[26] The local supply chain consists of

24 This section is based primarily on field research with miners, suppliers, and industry experts in Peru and Chile. Results were triangulated for veracity.

25 This value includes both operational and capital expenses. In 2017, the largest import categories were 8474 (15 percent, machinery for sorting, screening, separating, washing, crushing, grinding, and parts), 8704 (12 percent, off-road transportation equipment), 4011 (9 percent, off-road tires), 8431 (7 percent, parts for mobile equipment), and 8429 (5 percent, extraction equipment) (Aduanas-SUNAT, 2017). Comparatively in 2012, just eight of these 10 mines imported double that (US$906 million) (Aduanas-SUNAT, 2017).

26 For example, Hudbay's 2017 annual report notes, "In Peru, our top 50 suppliers accounted for 84 percent of our spending, and 95 percent of our spending was with suppliers based in Peru" (Hudbay, 2017).

three main sets of suppliers: subsidiaries of global mining suppliers, subsidiaries of global mining suppliers based in Chile, and Peruvian suppliers. Foreign suppliers whose operations are a strong presence in Peru include mining equipment suppliers and engineering firms. Lead global suppliers such as Atlas Copco, Bechtel, FLSmidth, Fluor, Hatch, Komatsu-Joy Global, Metso, Outotec, and Sandvik all have a local presence either in Lima or Arequipa in southern Peru.[27] These foreign suppliers, with the exception of a few cases (e.g., Molycop and Austen Engineering), are distributors and do not carry out any production activities in the country. Chilean suppliers include engineering services companies such as JR Ingenieros, metal-mechanics firm Corporación Aceros de Pacífico, and water treatment firms such as Disal. Peru accounts for 45 percent of Chilean local mining supplier exports (Corporación Nacional Alta Ley, 2017). Finally, after more than two decades in the copper mining industry, there is a growing number of Peruvian suppliers. The remainder of the report focuses on these firms and the role they play in the industry.

Domestic Peruvian Mining Suppliers

In Peru, there are domestic suppliers for a wide range of activities in the exploration, mine development, and operation stages of the copper GVC, contributing both products and services to the industry. However, as a whole, their participation in the industry is limited and no strong area of focus has yet emerged. The strongest presence of local suppliers is in services, metallic structures, consumables, and niche capital equipment. Local supply has a comparative advantage in these segments, benefiting from proximity, high volume to value shipping costs, and specific geological conditions. Overall, these firms are relatively small, typically subcontract with larger suppliers rather than directly with the mine, and only a few have successfully internationalized (Bamber, Fernández-Stark, and Gereffi, 2016). Mid-size firms have tended to diversify across several markets, including oil and gas (in Peru) and infrastructure in order to reduce their exposure to the volatile commodity sector. Generally, it is very difficult for local suppliers to enter the mining GVC due to their lack of scale and scope, access to finance, and relatively weak organizational structure playing against them. Table 7 details select suppliers that were analyzed in the scope of this report.

Table 7. Select Peruvian Mining Suppliers

Company	Products or Services	Activities, Products, or Services and Changes Over Time	Mining GVC Stage
Exsa	Manufacturing explosives and explosive services	Exsa has been in business for more than 60 years. It changed its business model from just manufacturing explosives to providing extraction solutions to mines. It also serves the Chilean market.	Extraction
Famesa	Manufacturing explosives	The company, which was founded 64 years ago, manufactures and commercializes explosives, blasting accessories, and agents for mining. It exports to all continents.	Extraction

27 Caterpillar also has a strong presence in the country, although this is through its local dealer Ferreryos.

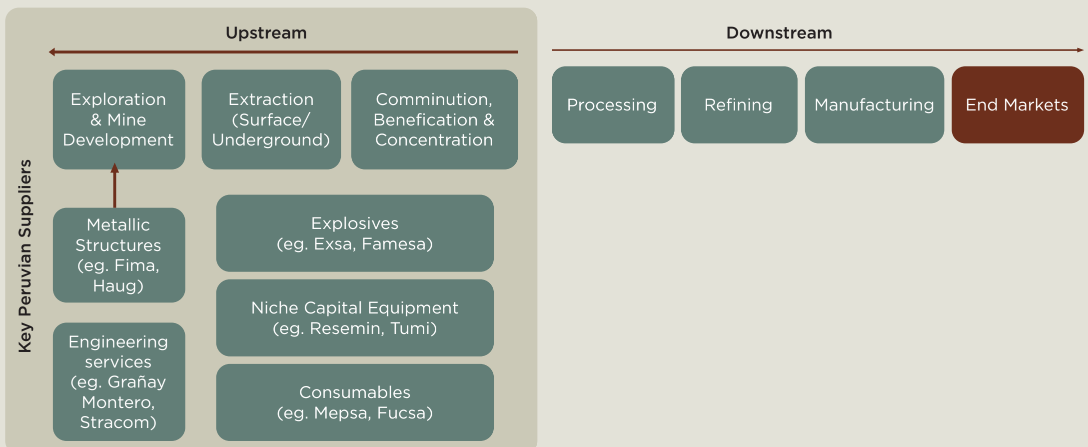
Table 7. Select Peruvian Mining Suppliers *(continued)*

Company	Products or Services	Activities, Products, or Services and Changes Over Time	Mining GVC Stage
GyM	Integrated mining services	GyM is a large and diversified engineering company with a big presence in Latin America.	Exploration and mine development (EPC/EPCM)
Linkminers	Marketing services to mining suppliers	Linkminers connects mining suppliers with mining companies through a web platform where mines present their current needs and suppliers offer solutions.	All stages
Mepsa	Mining parts manufacturer	Mepsa, created in 1964, provides consumables for mining equipment, such as steel grinding balls. The majority of its exports go to Chile.	Extraction, communition, beneficiation, and concentration
Mimco	Manufacturing and installing metallic structures	Mimco is a Peruvian company created 14 years ago. It serves several markets and in recent years has penetrated the mining sector, offering the sales and installation of electric rooms.	Exploration and mine development
Minconsulting	Mining engineering services	The company, which was founded in 2014, focuses on feasibility studies. In partnership with a foreign company, it also sells mining software.	Exploration and mine development
NDT Innovations	Non-destructive testing services for equipment and assets	NDT opened in 1996 and started exporting its services in 2004. The company offers non-invasive testing to detect defects in equipment before any damage is done.	Extraction, communition, beneficiation, and concentration
Proesmin	Mining services related to environmental issues	Proesmin is one of three Peruvian services companies that offers services during all stages of the value chain.	Exploration and mine development; Extraction; Communition, beneficiation, and concentration
Qaira	Drone services to mines	Qaira was born as a start-up from an idea developed by a Universidad Católica del Peru student. The company monitors mines with drones.	Extraction
Resemin	Manufacturing drilling jumbos for underground mining	Since 1979, Resemin has been working in the mining sector. The company exports its products to all continents.	Extraction
SRK Consulting	Mining engineering services	SRK Consulting was formed by the 2011 merger between SBS Ingenieros, a Peruvian company created in 1985 (70 percent), and SRK Global, an international company (30 percent).	All stages
Stracon[a]	Mining and construction services	Stracon was part of Graña y Montero until 2018. It provides mining services to several countries in the Americas, including Canada and Mexico.	Exploration, mine development, and extraction
Tecsup	Mining engineering services	Tecsup is a college in Peru that offers tech degrees. At the same time, they possess a consulting and laboratory arm offering services to mining. It also serves the Chilean market.	Exploration, mine development, extraction, communition, beneficiation, and concentration
Tumi	Manufacturing raise boring equipment	Founded in 1982, the firm developed the SBM 400 SR, a machine that significantly reduced digging time and costs. It now exports its machines to 22 countries.	Extraction

Source: Authors' elaboration.
Note: All of these mining suppliers (except Stracon and GyM) were interviewed by the research team. Interviewees were selected to include as wide a range of suppliers as possible, including for both goods and services. An initial database of firms was drawn up based on the research team's past experience in the sector. This list was complemented by a database supplied by the Inter-American Development Bank's Peru office and by using the snowball technique, having interviewees identify suppliers or peers.
[a] Stracon was acquired by Ashore Group.

Most local suppliers produce standardized products and services, with limited impact on value-added in the industry, such as transport, catering, and security. These are typically highly localized sourcing segments that are largely insulated from foreign competition. Nonetheless, approximately one-third of local suppliers to the large-scale copper mining sector indicate that they have had to undertake some innovative activities and upgrade their products and services in order to compete in the sector (INEI, 2017b). Within this group, there are a small number of firms that are undertaking innovation activities that directly contribute to domestic value added. The most successful of these innovations are those that have responded directly to the current needs of the industry; solely supply-driven solutions have had lower penetration among miners.

Figure 16. Peruvian Suppliers in the Copper Global Value Chain



Source: Authors' elaboration.

Services

According to miners, services account for the highest number of local suppliers, although many of their operations are in non-value adding supportive services such as catering, accommodation, and security. Services in the mining sector in Peru account for just 15 percent of value-added, compared to 21 percent in Chile and 26 percent in Australia (OECD, Unpublished). In 2017 mine procurement of services accounted for 50 percent of total spending (see Table 6). This figure is in line with Chile, where services totaled 54 percent of total mine expenditures. In terms of value-added activities, local firms (e.g., Proesmin, MinConsulting, and SRK Consulting) provide a range of services for the pre-feasibility and feasibility activities within exploration and mine development stage of the chain, particularly with respect to environmental, social, and geotechnical factors, where local expertise is an asset. These firms have tended to expand their service offerings over time. For example, some are now licensing and customizing foreign software, and SRK Consulting went from providing environmental services to providing due diligence in site exploration. Several large engineering and construction firms also operate in mine development, including Graña y Montero (GyM) and Stracon, which have successfully internationalized. For example, GyM affiliate Vial y Vives is contracted by Bechtel to build the processing plant for Quebrada Blanca II, while Stracon was a major partner in the development of Cobre Panama for First Quantam. The latter was the first copper project to be developed in Panama and required the firm to develop a local workforce to undertake the work (Stracon-GyM, 2018).

Box 2. Proesmin and Mining Services

Proesmin is Peruvian company, founded in the early 2000s, that provides engineering solutions to the copper mining sector. Services focus principally on the exploration stage of the mining GVC, including pre-feasibility, feasibility, and mine planning. The company has developed a unique geographic information system, detailing all of the current and potential mining projects in Peru. This information has allowed them to specialize in helping clients to pre-emptively manage potential environmental and social challenges in the early stages of development and identify new mining opportunities. The firm collectively employees approximately 140 workers, the majority of whom hold university degrees and approximately 15 percent with masters degrees. A large share of the employees are focused on R&D and innovation activities. The company invests a significant share (~25 percent) of its annual revenues on these activities. All R&D is carried out in-house.

The firm began as a mining supplier and, over the past decade, has diversified into a number of other industries. The company operates both in Peru and abroad, having completed some 500 projects in Peru and 50–60 in Latin America and Asia. In addition, it has established two joint ventures to serve related activities. One, PowerCem with a Dutch partner, focuses on environmental remediation, and the other, UniVergi, is a solar energy, water and effluent services company.

Source: Field Research (2019).

In the operations segment of the chain, in addition to standardized services, such as labor contracting and equipment maintenance, there are several more innovative local suppliers that have been able to introduce new services to improve productivity. While some of these suppliers entered the sector with new-to-market innovations, others began with standardized services and upgraded their offerings once they had established their credibility among buyers. Renova developed a local retreading service that helped reduce new tire consumption by 18 percent at the Antamina mine (Antamina, 2017). NDT Innovation introduced a new-to-market innovation with non-invasive technologies to offer preventative maintenance services. As more companies moved into the field, they shifted from analyzing steel-based products to detecting plastics failures, a technique which is unique in the global market. Several of these firms have successfully upgraded into international and industrial markets. NDT and Proesmin, for example, have projects in all major copper mining locations around the world as well as in a range of other industries. Serving multiple geographic locations has helped further their understanding of how to tailor their services for specific contexts and gain a reputation in the local market.

A second group of service suppliers are also emerging following the global trend of servicification of the mining industry. Product manufacturers adopting an equipment-as-a-service business model include firms in a range of different activities. For example, Exsa, a leading Peruvian explosives supplier, has moved toward a full-service model, whereby it manufactures the explosives, manages on-site storage, and controls detonation in the mine. Qaira both builds drones to monitor mine operations and provides the monitoring service to miners. In addition to developing innovative business models, several of these firms have also steadily been working on new products. Exsa launched new product Quantex in 2015, which helps reduce mine blasting costs by up to 20 percent and Qaira developed an autonomous charging station (Field Research, 2019).

Products

The presence of Peruvian suppliers in product supply is concentrated on metallic structures, consumables, and niche capital equipment. Companies supplying metallic structures provide inputs for processing plants, such as flotation cells, ball and bar mills, classifiers, and vibrators. These companies, which include Fabertek, Fima, Haug, Andes Peru, and Mimco, also serve multiple other sectors, including construction, infrastructure, and oil and gas, and act as suppliers for original equipment manufacturers (Bamber, Fernández-Stark, and Gereffi, 2016). Consumables suppliers provide products that are regularly replaced in operations, such as rubber tires, dump bodies, conveyor belts, metallic grinding balls, and semi-autogenous grinding mill liners. These products, which are typically lower value and stock needs to be available, account for approximately US$150 million to US$200 million in annual operational expenditures. A large number of foundries, including Sider, MEPSA, Fundicion Ventanillas, and Funcal, provide steel balls for grinding and semi-autogenous grinding mill liners. Others, such as Rosetti, Suminco, and Infasa, produce a range of consumables, including conveyor belts and dump bodies. Since these are standard products for existing equipment, innovation among this group of suppliers is limited. Upgrading in these products has consisted primarily of improving product quality and factory processes and extending into regional markets. Collectively, leading foundries exported close to US$45 million in 2017 to Argentina, Bolivia, and Chile, among others (IDB, 2018).

Niche capital equipment is an area that has grown as a result of specific local technical and geological knowledge. There are very few local suppliers but they have emerged by responding to specific local needs and type of mining carried out in the industry. In particular, underground equipment manufacturers such as Resemin and Tumi Boring have been successful. Both firms have steadily upgraded their products, exporting to numerous locations around the world. Today, most of Resemin's revenue is derived from exports. Resemin is also one of the few firms in Peru to patent its innovations in global markets. The firm started as a parts supplier and steadily began to introduce new products and equipment to the market. Tumi, likewise, developed its own products and is one of just a handful of firms around the world serving the bore raising niche. These firms continue to sell their products, but they have also been moving toward an equipment-as-a-service business model (Field Research, 2019).

Box 3. Resemin: A Peruvian Original Equipment Manufacturer Upgrading Story

Founded in 1989 as a spare parts distributor and manufacturer, Resemin today has become a leading supplier of drilling equipment in the underground mining equipment sector, with global sales of over US$65 million in 2012. The company provides equipment to the domestic market and exports to more than 12 countries. With more than 220 machines in operation globally, Resemin has established sales offices and service centers in key global mining centers, including Argentina, Chile, India, Mexico, and Zambia. The company's global expansion was driven primarily by demand from major firms who were relocating their mining executives from Peru to other parts of the world. In addition to providing direct sales, primarily in Latin America, Resemin provides contracting services for underground drilling.

The third largest firm in its product segment globally, Resemin is one of the few companies in Peru that designs, manufactures, and assembles its equipment in Peru and provides aftermarket services in all key markets. Major components, such as engines, are imported from global Tier 2 component and subassembly providers. Initially, the firm used subcontractors to manufacture parts, but it soon moved production inhouse to improve quality. By 2001, Resemin had gained sufficient experience to enter production of final equipment, launching its first owndesigned equipment that year. Relatively unsophisticated, the first drilling rig made by Resemin benefited from reverse engineering and adaptations of machines already in the market. Since then, the company has shifted to original designs, and its machines have become increasingly sophisticated within the context of hardwearing, easy, and safe to use and specifically suited to remote operating environments. In 2014, Resemin launched the Muki, an innovative and powerful drilling rig for operating in very small underground seams (<1.8 meters), reducing production costs, increasing productivity, and improving the safety of underground mining. This machine had been introduced in most major mining countries in the Americas by 2017. By 2015, the firm employed approximately 500 people in Peru and another 1,500 employees globally.

Source: International Mining (2015), Roca (2013), and Semana Economica (2017).

Table 8 details the key strengths and weaknesses of these local firms in supplying the copper GVC. They have a comparative advantage based on their strong local knowledge, proximity to clients, and their willingness to be flexible to meet specific client needs. Larger foreign suppliers can be reluctant to provide high degrees of customization as their business models are based on scale. Areas of weakness derive from their lack of scale, organizational skills, poor standards compliance, and low investment in innovation. Key institutional problems undermine further growth, including access to qualified human capital and a lack of coordinated industry support mechanisms.

Table 8. SWOT Analysis of Peruvian Mining Suppliers

Strengths	Weaknesses
• Strong local knowledge (geological, cultural, institutional) • Flexibility • Proximity to clients	• Scale • Weak business management skills • Difficulty meeting global industry standards • Lack of reputation and/or sector contacts • Lower investments in innovation • Shortage of qualified personnel • Poor coordination and collaboration • No supportive industrial policy for local supplier development
Opportunities	**Threats**
• Established and growing local copper mining market with rising global demand for copper • Expansion to international markets • Customization for local market	• Foreign competition • Regulation (environmental, social) • Increase in centralized global sourcing • Social conflict • Uncertain global trade environment

Source: Authors' elaboration.

Peruvian Supplier Capability Development[28]

Peruvian mining providers use different strategies to develop their capabilities to offer products and services to the mining sector. These approaches can be grouped in two general categories:

1. Developing internal capacity (including in-house R&D departments) by recruiting and developing human capital.
2. Tapping into external expertise and knowledge at local and foreign universities, foreign suppliers, or through strong relationships with buyers.

While providers tend to focus on one of these strategies, it is common for companies to combine several approaches. For example, a company may have a strong internal R&D department, but for some projects, it partners with a foreign university to acquire new knowledge. The use of these strategies among Peruvian suppliers is discussed below.

Internal Capability Development Strategies

Innovative mining suppliers tend to draw on highly skilled human capital to drive their capability base for innovation and upgrading. Numerous firms have employees with masters and doctoral degrees in engineering in technical fields from Peru and abroad. While this is particularly notable in services firms (Proesmin primarily employs engineers with masters degrees), it is true of manufacturing companies as well (e.g., 15–20 percent of Resemin's staff are engineers). Employees are mostly Peruvian

28 This section was based on interviews with suppliers and secondary research. Interview results were triangulated for veracity.

with degrees from local and foreign universities, although these employees are then trained in-house and/or are sent on work-rotations abroad to further develop their skills. For example, SRK Consulting places new employees in operations in Australia or the United States for up to two years. These employees may also undertake graduate degrees during this time, with financial support from the company. Exsa, likewise, invests in foreign training for their employees. Development of managerial know-how has also been an important tool. Firms such as MinConsulting and Exsa both highlight the importance of business management degrees in supporting business innovation.

Firm founders or managers typically also have past experience in the industry, working for mining companies or suppliers. This is particularly useful in identifying opportunities to develop innovative solutions. Tecsup was founded by mining executives to both develop training programs for the sector as well as to offer consulting and local laboratory services. Resemin's founder worked for foreign equipment manufacturing before establishing his own company. Linkminers was founded by a consultant responsible for leading Antamina's supply development program.

In-house R&D departments: Several of the larger, well known Peruvian mining suppliers, such as Exsa, Resemin, and Tumi, have created strong R&D centers. These are the companies that concentrate patents in Peru. Exsa invests around US$2.2 million annually in their R&D department, which employs nine highly qualified workers and is located in the Lurin plant; the company holds at least three patents. Famesa Explosivos spends 0.75 percent of its revenue on R&D, yet the company holds the highest number of patents awarded in Peru (CARMAR, 2018). Resemin's in-house team designs the company's equipment, similar to Tumi, which created its sophisticated underground mining equipment with workers in its Peruvian workshop.

Some of the services providers are also investing heavily in their internal R&D departments. Proesmin possesses a strong internal R&D department and has invested more than US$5 million in its development. NDT has its own R&D department and, in the last two years, has spent more than US$2 million on innovation. Green Mining has emphasized its internal R&D capabilities and has patented much of its work, but outside of Peru. Overall, services firms noted that they have concentrated their protection efforts in constantly innovating in their services rather than in patenting them. So, the number of patents does not show a strong correlation with the level of innovation of local mining suppliers.

External Capability Development Strategies

Innovating firms have sought out collaborative partnerships with universities, however, these are typically with foreign universities rather than Peruvian ones. Local mining suppliers generally report that local universities do not offer strategic and applied research that can practically contribute to firm growth. Nonetheless, there are a few exceptions. Innovative firms like NDT and Qaira have close links to universities, including Universidad Católica and Peru's University of Engineering and Technology (UTEC). It is more common for firms to partner with foreign universities, particularly those in Australia (e.g., University of Queensland) and the United States (e.g. MIT and University of Houston). Partnering with universities is one model firms use to access national and international funding for innovation. For example, Qaira won a seed capital innovation award from MIT to help develop the company.

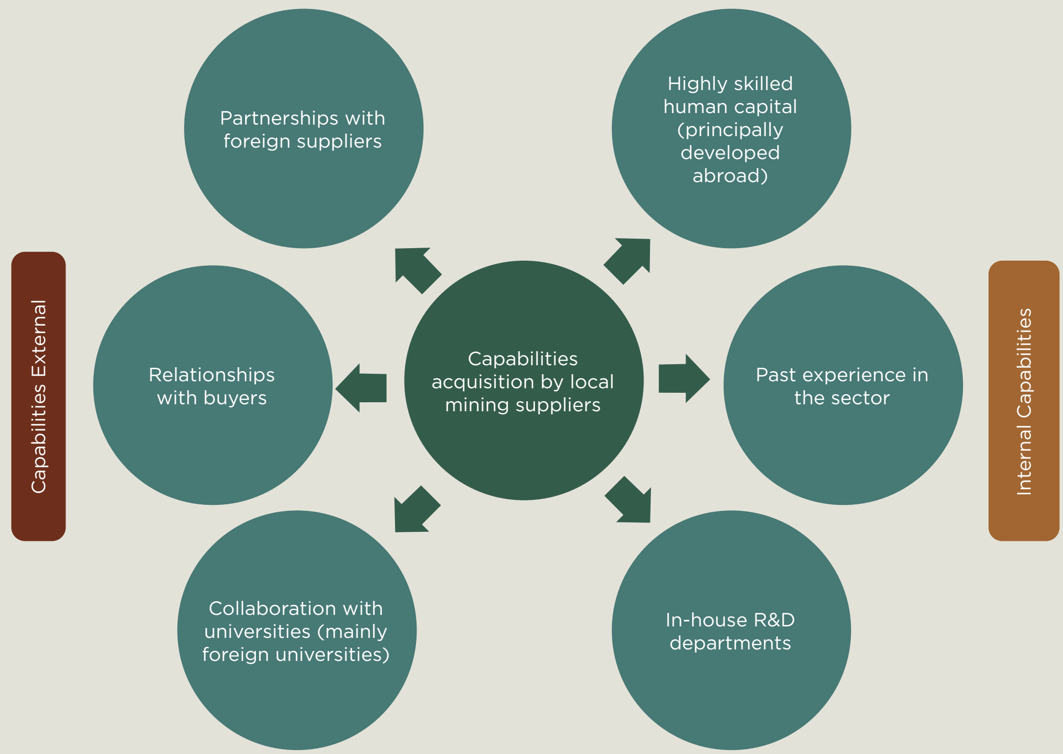
Relationships with foreign suppliers are considered critical in terms of gaining market access in Peru and abroad and in developing additional capabilities. These partnerships help improve local supplier credibility vis-à-vis buyers, in addition to opening up opportunities for inter-firm learning and incremental innovation in adaptation of foreign technology for the local market. For example, MinConsulting became an authorized provider for software from two key foreign suppliers that had previously only been available from foreign locations. As the local provider and systems integrator, Minconsulting was able to further develop its capabilities and now provides all customization for this software in Peru. Exsa's relationships with U.S.-based Nelson Brothers has provided it with the base chemical technology on which to build adaptations for the local market. There is considerable interaction in the process of establishing which chemicals are optimal for the Peruvian context (high altitude, low temperatures), allowing the firm to develop additional knowledge on how to develop explosives for a range of different locations. SRK's acquisition by a foreign firm was key to gaining market access, increasing its visibility in Peru and beyond. In addition, international exchange between foreigners and Peruvian staff helped increase service quality in Peru and improve SRK's position in the local market. Working with foreign firms has also helped improve organizational and services provision to higher global standards, which improves potential to expand abroad. For example, through its alliance with leading global supplier ABB, Mimco received specific development advice to improve its quality and processes, allowing it to access the Peruvian mining industry.

Relationships with buyers are generally based on limited interactions under which the buyer provides the suppliers with specifications and standards and the suppliers develop solutions to meet those specifications. This is particularly true for product suppliers; service suppliers tend to have a higher degree of interaction in developing their solutions. For example, Minconsulting noted that it has weekly meetings with its buyers. Nonetheless, product suppliers also emphasize that their experience working in the mine on a regular basis is a major contributor to their base knowledge of mine needs for new solutions (e.g., Proesmin, Resimin, Tumi, and Exsa). Testing or piloting new products and services is more limited, although miners and suppliers agree that there is some (limited) space to test innovations where there is a trusted relationship (e.g., Exsa) or where the testing is non-intrusive (e.g., Qaira). Overall, there are very few joint development initiatives for innovative products in which any significant transfer of knowledge between miners and their suppliers takes place. There was only one supplier development program, operated by Antamina until recently, that focused on supporting the capability development of local suppliers; however, rather than providing technical know-how, the program mostly focused on indicating areas in which new solutions would be welcome and providing testing facilities (Field Research, 2019). Linkminers, a new platform, seeks to reduce information asymmetry between miners and suppliers but does not currently focus on developing supplier capabilities.

There is virtually no capability development as a result of interaction among domestic suppliers, which typically operate in silos and have no industry representation beyond one focused exclusively on metal-mechanics firms[29] and a brand-new Department for Suppliers at the National Society of

29 Asociación de Empresas Privadas Metalmecanicas del Peru was established in 2013 and currently has 25 members (AEPME, 2019).

Figure 17. Summary Table of Key Capability Development Mechanisms



Source: Authors' elaboration.

Mining, Oil, and Energy.[30] Most firms do not consider participation in the range of other professional organizations or associations beneficial to their business development. The lack of an efficient and coordinated national innovation system in Peru has limited the capability development of the local suppliers. The next section analyzes the system.

National Innovation System in Peru

The relatively weak innovative activities by firms in the sector is, in part, the result of an underdeveloped national innovation system. National innovation policy in Peru is still relatively incipient and the country continues to perform relatively poorly on most global innovation indicators (Table 9). CONCYTEC, the leading institution responsible for science, technology, and innovation systems, was only established in the country in 2006 (CONCYTEC, 2019). While stakeholders agree that significant progress has been made over the past five years to establish a more coherent innovation ecosystem (Field Research, 2019), important gaps remain that need to be addressed to boost its efficacy. As a result, national spending on R&D remains low. Between 2015 and 2017, the country expe-

30 Of note, the Department for Suppliers primarily represents miners' interests, rather than the industry as a whole.

rienced a rise of just 0.004 percent in R&D expenditure as a share of GDP. Peru also performs poorly compared to both its regional peers, as well as the global average. In 2017, Peru spent 0.12 percent of its GDP compared to 0.36 percent in Chile (2016), 0.76 percent in Latin America (2016), and 2.2 percent globally (2016) (World Bank, 2019a).

Table 9. Research, Development, and Innovation System Indicators

Indicator		Peru	Chile	Global Average or Total	Countries with Similar Rank	Source
R&D spending (% of GDP)		0.12% (2017)	0.36% (2016)	Average: 2.2% (2016)	Cambodia, Venezuela, St. Vincent & Grenadines, Tajikistan	UNESCO
Patent applications, residents		100 (2017)	425 (2017)	Total: 2,161,000 (2017)	Armenia, Latvia, Lebanon, Syria, Venezuela	World Bank; WIPO[a] Patent Report: Statistics on Worldwide Patent Activity
Science and technology journal citations Scientific and technical articles		1,008 (2016) 114/129 (2018)	6,746 (2016) 39/129 (2018)	Total LAC: 96,586 (2016)	Ghana, Kenya, Sri Lanka, Cuba	World Bank; National Science Foundation, Science and Engineering Indicators; WIPO
Researchers in R&D (headcount/million inhabitants)		47.4 (2017)	793 (2016)	Average: 1,500 (2015)	Burkina Faso, Cabo Verde, Chad, Ethiopia	UNESCO
Researchers in R&D by sector of employment (headcount/ million inhabitants)	Business enterprise	2.4	25	NA	NA	UNESCO
	Government	7	12			
	Higher education	71.1	58			
	Private non-profit	4.5	5			
	Unspecified	15	—			
University/industry research collaboration (rank among 129 countries, 2019)		98	55		Benin, Kuwait, Tunisia	WIPO
Global Innovation Index (rank among 129 countries, 2019)		69	51		Tunisia, Saudi Arabia, Brunei, Colombia	WIPO
International Property Rights Index (score/rank among 125 countries, 2018)		5.2/69	6.9/29		Greece, Sri Lanka, Philippines, Tanzania	Property Rights Alliance
Global Competitiveness Index (progress score out of 100, 2018): Skills Pillar Innovation Capacity Pillar		 83 89	 42 53		Skills: Kyrgyzstan, Panama, Mexico, South Africa Innovation Capacity: Ecuador, Kazakhstan, Guinea, Albania	World Economic Forum (WEF)

Sources: Cornell University, INSEAD, and WIPO (2018); Property Rights Alliance (2019); UNESCO (2019a; 2019b); World Bank (2019a).
[a] WIPO = World Intellectual Property Organization.

Key shortcomings include the lack of human capital and research institutions adequately prepared to undertake, manage, and incentivize innovation, as well as limited institutionalization and coordination of existing actors to maximize their contributions (BBVA Research, 2019; CONCYTEC, 2017; Field Research, 2019). Despite a relatively high and growing number of graduates in STEM professions,[31] there continues to be a limited number of qualified personnel to work in both public and private institutions in the country because of poor quality programs and an inefficient distribution of graduates in appropriate fields (British Council, 2016). A rise in new, private, low-cost universities has contributed to a significant increase in enrolment (Yamada and Oviedo, 2016); however, these universities were largely unregulated prior to 2014 when the government introduced reforms to improve university quality. Furthermore, even more established universities do not perform at world class levels, and close to one-third of Peruvian universities have no research centers (British Council, 2016).[32] The establishment of Innovation and Technology Centers is a recent effort to create new innovation research centers. However, these centers have been criticized for a lack of market-oriented focus, poor infrastructure, and weak administration (Lampadia, 2017). Moreover, with less than a decade of innovation policy experience at the national level, there are still too few policymakers in a position to adequately design and manage incentive projects (Seclén, 2017).

Importantly, as the innovation ecosystem has slowly emerged, public, private, and academic organizations have operated in silos, with little coordination across actors undermining potential for synergies and applied research. Among research centers, only 26 percent have linkages with the private sector and only 37 percent have any connection to local, regional, and/or the national government (Belapatiño and Perea, 2018). Peru is ranked 98 of 129 economies (2018) for collaboration between the private sector and universities in the Global Innovation Index (Cornell University, INSEAD, and WIPO, 2018). Even within the public sector, there is a lack of coordination and public awareness of initiatives as a number of different ministries launch their own innovation programs. For example, by 2018, only 30 percent of private sector firms engaged in innovative activities were even aware of the availability of fiscal incentives that were launched in 2015 (Gestión, 2019). Many of these initiatives are yet to be institutionalized and are still subject to the decisions of the particular government in power.

Peruvian Mining Innovation System[33]

Within this context, the innovation ecosystem supporting the mining sector in Peru is relatively new and fragmented, emerging in parallel with broader national efforts to shift the country toward higher value added activities. Indeed, the sector is significantly underrepresented in the emerging national innovation initiatives compared to its economic importance to Peru. With no clear policy champion, the industry lacks an effective national strategy. Public policy has focused primarily on regulating the sector, particularly with respect to environmental and social concerns, rather than

31 According to UNESCO's database, 29.6 percent of the 241,000 tertiary graduates in Peru are in STEM-related fields compared to 32 percent in India, 29.3 percent in South Korea, 26 percent in the United Kingdom, but just 20 percent in Chile (UNESCO, 2019b).

32 According to the QS World University Rankings, there are no Peruvian universities among the top 400 universities in the world.

33 Information in this section was drawn from a combination of primary and secondary research. Interview results were triangulated for veracity.

setting a long-term strategy for upgrading and innovation in the future. While numerous efforts are emerging, this remains piecemeal, with different institutions undertaking individual siloed and often duplicate efforts, including a working group at the Ministry of Economics and Finance charged with increasing productivity (Gestión, 2018), a similar initiative at the Ministry of Production (PRODUCE) developing a Technological Roadmap for the mining sector, and MINEM's Mining Vision 2030. These initiatives group a range of different stakeholders but do not necessarily include key strategic actors for the industry. The result of this lack of coherence has been very little contribution of the state to innovation in the mining sector in general and Peruvian mining suppliers in particular.

The government has launched some transversal policies and programs that could encourage innovation in mining suppliers (Table 10) but these have had a low impact on the industry. The most relevant programs for the development of innovative mining suppliers include:

1. Innovate Peru
2. 2015 R&D Fiscal Credit
3. Accelerated patent development programs

However, very few Peruvian mining suppliers have taken advantage of these initiatives to date. Only 51 percent of innovative firms in Peru serving natural resources industries even know about the public programs (INEI, 2017b) and the ones that are familiar with these instruments are reluctant to apply because of the high levels of bureaucracy. The only program highlighted by interviewees as having played a useful role in their development was Innovate Peru; high-tech start-ups such as Qaira have benefited from this program. The R&D credit has had very little impact to date with low awareness (Gestión, 2018). Only 49 projects were approved across the entire economy (i.e., not just the mining sector) in the three years of operation. By comparison, in Chile in 2018, where a similar R&D credit was introduced in 2012, the mining sector alone received the same amount in R&D credits as the entire economy in Peru (US$10 million) (Gestión, 2018). Accessing credits requires firms to submit applications to the tax revenue authority, SUNAT, which is a deterrent. SUNAT has a reputation among suppliers for being overly diligent, and suppliers believe such applications expose them to the risk of repeated audits. In addition to the high levels of bureaucracy, there is limited experience and knowledge among public sector officials for how to adequately design and manage innovation policies and projects.

Table 10. Government and Private Sector Policies and Programs

Program/ Policy	Description	Responsible Institution	Mechanism	Effectiveness
Entrepreneurship (Support for creation of new firms/start-ups)				
Start-Up Peru: Dynamic Entrepreneurs	Co-financing up to approximately US$41,000 (S./140,000) for new firms with innovative technological solutions in the commercialization phase.	Innovate Peru (PRODUCE)	To be eligible, firms must have sales above US$36,000 (S./120,000). Firms receive support for software improvement, intellectual property registration, marketing strategies, and product upgrading.	NA
Start-Up Peru: Innovative Entrepreneurs	Co-financing up to approximately US$15,000 (S./50,000) for teams of 2 to 4 people with innovative products/services/business models.	Innovate Peru (PRODUCE)	Financing includes market studies and focus groups to validate business model feasibility, prototype development and enhancement, and networking events.	NA

Table 10. Government and Private Sector Policies and Programs *(continued)*

Program/ Policy	Description	Responsible Institution	Mechanism	Effectiveness
Innovation (Development of new innovative products and services)				
Innovate Peru	Created through the Supreme Decree N°003-2014-PRODUCE, the program focuses on increasing innovation and facilitating the adoption of new technologies for enterprises.	PRODUCE	The program manages four different funds that are assigned by nation-wide open competitions. The funds are aimed at Competitiveness Innovation (FINCyT 2), R&D for Competitiveness (FIDECOM), Science, Technology, and Innovation (FOMITEC), and Micro and Small Enterprise projects.	As of 2018, the program had co-financed more than 3,000 R&D and entrepreneurship projects.
National Science, Technology, and Innovation Plan for Competitiveness and Human Development (Law N°28303)	A 15-year (2006–21) cooperation agreement between regional governments, government institutions, private schools, and firms. The main goal is to facilitate the development of innovative products and processes.	CONCYTEC	The plan focuses on different strategies that include promoting highly innovative processes, securing foreign financing, diffusing innovative practices, directly assisting firms in matters regarding innovation, and facilitating cooperation between private agents.	NA
R&D Fiscal Credit	Law 30309, the Promotion of Scientific Investigation, Technological Development, and Innovation, is a fiscal incentive to promote investment in R&D by the private sector. The law entered into effect in 2016 and will remain in effect until 2022. In 2019, this law was modified to improve its use by small and medium enterprises.	CONCYTEC	100% tax deduction of R&D and innovation expenses for all companies. In addition, companies that are approved through CONCYTEC can apply for up to 75% additional reduction. This additional credit has an annual limit of US$1.5 million.	In the first three years of the program, 49 projects received this credit, for a total of US$30 million (s./108 million). Surveys indicate that only 30% of companies were aware of this benefit by 2019.
Local Participation (Regulations and mechanisms to encourage hiring local firms)				
Commitment to Sustainable Development (Decree 042-2003-EM)	In 2003, local content was introduced in Peruvian legislation for the first time in Decree 042-2003-EM, known as the Commitment to Sustainable Development. This decree includes a list of commitments that all mining firms must adopt when they undertake mining exploration.	MINEM	Mining firms and their contractors commit to preferentially hiring local people as well as providing training. Equally, they must preferentially purchase local and regional goods and services and support entrepreneurs to promote diversification. This decree establishes that firms are required to submit to MINEM an Annual Consolidated Declaration on these commitments. Local content requirements are part of mining firms' Environment Impact Assessment plans. In addition, the local content clauses of the decree were included in the privatization agreements between mining firms and the government.	NA
Export Promotion (Oriented to helping local suppliers export to regional/global clients)				
Exporter Route	The Ministry of External Commerce and Tourism offers a specialized assessment for micro and small exporter firms in order to introduce them to the global market and connect them with potential clients.	Ministry of External Commerce and Tourism	The assessment consists of several steps that include virtual training programs, nation-wide seminars, and international conventions.	NA

Table 10. Government and Private Sector Policies and Programs *(continued)*

Program/ Policy	Description	Responsible Institution	Mechanism	Effectiveness
Private Sector Initiatives				
Antamina	In 2012, Antamina, the largest producer of copper and zinc in Peru, started the program Developing Suppliers of Excellence for the Mining Industry of Peru. There were two main objectives: (i) to improve the productivity of the mining firm and (ii) to develop the capacity of suppliers to provide increasingly complex services for the industry and, potentially, for other industries as well.	Antamina	Local suppliers were tasked with identifying and developing innovative solutions and approaches to resolve high-value challenges the company was facing (i.e., existing operational problems, inefficiencies, or anomalies faced by mining operations). Antamina offered capable suppliers the opportunity to co-design solutions, leading to the development of cooperative relationships. Following a process of strategy selection, the Logistics and Operations Departments then offered the opportunity to chosen suppliers to test their solutions before awarding contracts.	The program is no longer in operation.

Source: Authors' elaboration.

There are emerging research centers focused on mining, although these initiatives are limited and still relatively recent. Most of these are driven by private universities; of the 47 public–private research institutes established under the Innovation and Technology Centers program by 2018, only one is focused on mining, with initiatives generally coalescing around environmental issues related to mine closure (Instituto Tecnológico de la Producción, 2019; Universidad del Pacífico, 2019). Leading private universities, including Universidad Católica de Peru, Universidad Pacifica, Universidad Nacional de San Agustin, and UTEC have research efforts under way to support the industry; however, funding for these initiatives is limited as is their direct application to the industry. Public universities in key mining localities receive financing for innovation through the mining canon;[34] in 2018, these universities received US$48 million for scientific research on any topic. The private sector is reluctant to work with local universities to drive innovation, citing that the university research agenda is too heavily focused on theoretical issues, with limited applicability to the current state of the industry. The majority of firms interviewed that engage with universities for research do so with foreign universities, not local institutions.

Underlying these issues is a shortage of human capital to staff research initiatives for innovation in the copper mining sector within university programs, independent research centers, or in firms themselves. University programs have typically produced engineers with basic sets of skills rather than oriented specifically toward the mining industry. Though efforts have been to address this shortage, they are limited and focus on meeting the operational rather than the innovative needs of the industry. The most notable examples are the creation of UTEC in 2011, a university oriented toward training highly qualified engineers with managerial skills; Tecsup (1982), which is focused on providing workers with technical abilities and specific knowledge for the industry, such as mainte-

34 The canon is based on the government income from mining. In 2018, the majority of these funds (70 percent) were destined to research, development, and innovation.

nance, risk management, and environmental issues; and Centro Tecnologico de Mineria, which also trains technicians for the industry. Some 80 percent of Tecsup graduates go on to work in the mining industry, while the teaching staff regularly engage in consulting with the sector, ensuring that they remain up to date with key demands.

The lack of qualified human capital combines with poor access to finance to undermine research among private sector actors, amplified by the uncertainty of whether local suppliers will have market access for their innovations. Appropriate human capital for in-house innovation is a widespread challenge. Interviewees frequently cited that it is difficult to find personnel with the skills they require, forcing them to train staff in-house or send them abroad. There is a strong perception among policymakers that the mining industry has the financial resources to undertake innovation and research activities alone. However, this exposes a lack of understanding of the respective roles of the value chain actors. Large, well-financed mining lead firms around the world typically do not carry out innovation activities; these are rather concentrated among mining suppliers. The lack of financial resources among Peruvian mining suppliers, especially the small- and medium-sized firms, has likely contributed to the weak uptake of the R&D fiscal credit offered by the government.[35] Finally, local suppliers have a limited presence in the Peruvian mining sector; the large multinational mining companies that dominate the sector in Peru generally perceive local firms to have a weak reputation for quality and supply. With these weak linkages to the sector, local firms have limited opportunities to test innovative solutions in real-time conditions, making it difficult to enhance their products and services and their applicability to the industry and raising uncertainty as to whether or not they will be able commercialize their innovations.

Finally, there are weak mechanisms in place to encourage the private sector to engage with other stakeholders in the industry. A central underlying issue for mining suppliers is the lack of a representative association that can communicate their interests to other actors. Overall, there are few explicit linkages in which local providers can understand the current challenges faced by the mining companies. This information asymmetry has made it difficult for suppliers to develop appropriate innovations. Leading miner Antamina launched a Suppliers Development program in 2012 to help close this gap (the program was discontinued).[36] This program was largely modeled on that of BHP's World Class Supplier program in Chile, which consisted of putting the challenge to local suppliers to identify and find innovative solutions and approaches to resolve high-value challenges (i.e., existing operational problems, inefficiencies, or anomalies faced by mining operations). Antamina's program was never institutionalized to the same extent as the Chilean program (see Box 4 in the next section) but it inspired the private platform Linkminers, which works with mining companies to identify challenges and publishes these for potential suppliers to bid on. Established in 2017, to date Linkminers has published 50 challenges and registered 450 mining suppliers (Field Research, 2019).

35 In order to receive the R&D fiscal credit, companies need to be turning a profit and be paying sufficient taxes.

36 A new project, Mining Innovation Hub, was launched at the end of 2019 by Buenaventura, Nexa Resources, Goldfields, and the National Society of Mining, Oil, and Energy to support innovative activities. The goal is to accelerate solutions that can enhance the productive efficiency of mining in Peru (Hub Innovación Minera del Peru, 2019).

Table 11. Summary of Key Challenges for Innovation

Technical	Commercial	Institutional
• Shortage of human capital • Poor quality human capital • Universities too theoretical, not focused on applied research • No research centers focused on mining industry	• Information asymmetry regarding opportunities for innovation • Poor coordination and collaboration across value chain actors • Weak access to innovation finance • Lack of experienced innovation managers • Cyclical nature of the industry • Risk innovation	• No strategic direction from government • High levels of bureaucracy in using instruments • Lack of policymakers with experience in innovation instruments • Relatively weak intellectual property protection • No coordination among industry stakeholders

Source: Authors' elaboration.

Poor coordination issues are pervasive across the innovation ecosystem for mining. Universities are usually not aligned with the private sector, nor is the government coordinating with companies and universities. There have been efforts to overcome this—such as the PRODUCE Technology Roadmap—but to date there is little evidence of their success. As a result, the mining innovation ecosystem remains fragmented and numerous actors are working in silos and developing their own interventions to boost innovation. Ultimately, this means that Peruvian value creation from innovation in the copper mining sector continues to be very limited.

4. POLICY RECOMMENDATIONS

In order to develop strong and innovative local mining suppliers, Peru needs to focus on:

1. creating strong institutions and coordination mechanisms (governance) to support the development of the sector;
2. facilitating the entry of local suppliers to the mining GVC; and
3. incentivizing innovation and upgrading of the local providers.

Below, we present a series of recommendations in these three areas. At the same time, we show examples on how copper mining countries have overcome these challenges.

Strong Institutions and Coordination Mechanisms

It is important to establish a strong and prioritized strategy for the future of Peru's participation in the mining industry. Public policy has been dominated by environmental and social concerns with little focus on how to upgrade the copper mining GVC or how mining can be used effectively as an engine for growth within the economy. Developing this vision will require the government to identify and empower the appropriate national ministry to champion the sector's development and to ensure that ministry has staff are qualified to manage innovation initiatives. Currently, there are multiple, redundant initiatives underway in the country, with a varying array of actors participating, from initiatives at the Ministry of Economics and Finance, PRODUCE, and MINEM, to CAF (the Development Bank of Latin America), supported Arequipa Mining Cluster, leading to inefficient and/or incoherent outcomes and a strong sense of uncertainty among investors.

A single multi-stakeholder council with clear leadership and consisting of the major actors from the public, private, educational, and civil society sectors should serve as an overarching institution to establish the goals for the future growth of the mining industry. This council needs to be institutionalized in such a way that it can withstand political cycles, ensure a long-term approach to the sector strategy, and achieve explicit targets (Box 4).

Box 4. Alta Ley: A Vision for the Future of Chilean Mining

The Alta Ley National Mining Program promotes innovative mining to improve the industry's competitiveness and productivity while simultaneously creating the conditions for an R&D ecosystem with local capacities and knowledge to emerge.

This program was created after the document "Minería y Desarrollo Sostenible de Chile: Hacia una Visión Compartida" (Chile Mining and Sustainable Development: Toward a Shared Vision) was drafted by former Chilean President Ricardo Lagos and a group of experts in October 2015. The main objective of this document was to bring together all industry stakeholders to create a consensus to work together toward the upgrading of the industry.

The principal objectives are to increase productivity, drive innovation, improve security, protect the environment, develop local providers, and increase the exports of products and services associated with mining. To reach those goals, several actors have been working together, including mining companies, mining providers, the Chilean State, academia, and R&D centers. In order to reach each of the objectives by 2035, a very detailed technology roadmap was established that followed four stages:

1. Forging and validating the vision
2. Identifying technological challenges and prioritizing core challenges
3. Creating workshops to draft the roadmap
4. Validating roadmap actions

See the goals in the figure below.

2015 Baseline and Goals for 2035

	2015 Baseline	Goal 2035
	On average 5.5 million tonnes of copper produced annually over the past 10 years.	On average 7.5 million tonnes of copper produced annually over the next 20 years.
	40 percent of production in first cost quartiles for industry on global level.	80 percent of production in first cost quartiles for industry on global level.
	65 world class suppliers.	250 world class suppliers.
	US$537 million in exports of mining-related goods and services.	US$4 billion in exports of mining-related goods and services.

Sources: Corporación Nacional Alta Ley (n.d., 2014) and Fundación Chile (2015).

At the same time, the formation of an industry association to represent mining suppliers should be supported (Box 5 describes Australia's industry association). These suppliers are currently not adequately represented within the policy framework in the country, making it difficult for the group to collectively highlight major barriers to their participation and innovation in the industry. A collective body would facilitate miners' efforts to engage with local suppliers, create a platform for potential collaboration to help suppliers achieve scale, and help to channel efforts at internationalization. Under its mandate to promote Peruvian services abroad, PromPeru, for example, could work with the industry association to promote their capabilities in regional and global markets.

Box 5. Austmine: Australian METS Industry Association

Austmine, established more than 30 years ago, is one of the oldest industry associations representing mining suppliers. The organization has helped raise the profile of Australian METS both domestically and abroad. Key initiatives have included annual surveys to measure the size of the industry and its economic impact, represent Australian suppliers at global trade fairs, organize trade missions to major mining locations, and advocate on the sector's behalf with the government. These efforts led to the METS sector being named as one of five prioritized growth sectors, paving the way for the creation of a public–private Industry Growth Center exclusively focused on improving the innovative capacity in the country's mining sector. By 2019, the Australian METS sector exported annually over US$10.1 billion in products and services to every corner of the globe and invested US$2.7 billion in R&D. Austmine represents over 500 members. In Chile, there are two industry associations representing suppliers: APRIMIN, which primarily represents large, often for-eign suppliers such as capital equipment suppliers, and Minnovex, which is a group of highly innovative local suppliers to the industry. In Canada, local suppliers are represented by MSTA and SAMSSA, with the latter specifically focused on the global export market for products and services.

Sources: APRIMIN (2019), Austmine (2019), Minnovex (2019), MSTA Canada (2019), and SAMSSA (2019).

Entry of Local Suppliers to the Mining GVC

Policies need to be implemented both to improve the organizational and technical capabilities of local suppliers and to reduce information asymmetry between miners and local suppliers. While procurement patterns of miners in Peru make entry and participation in the industry for local firms difficult, opportunities exist for technically capable firms. Firms would benefit from training about the organizational and technical requirements of mining companies, such as global certifications on quality, health and safety, procurement processes, and export procedures as well as more generalized business management support through small business development centers. Also, a set of initiatives are required to reduce information asymmetry and ensure full and fair opportunities for local firms to participate in the industry. Peru has advanced local content policy for its extractive sector by requiring firms to commit to prioritizing local content under the Sustainable Development

Legislation (put in place for the first time in 2003). This approach can provide considerable information to the government regarding local procurement opportunities. However, current requirements are vague and lack enforceability, and the institutional complexity in Peru undermines the analysis and transmission of this information to relevant stakeholders. In practice, initiatives need to be undertaken to mandate mining companies to increase the transparency of their procurement needs, to improve the availability of information about the capabilities of local suppliers, and to create opportunities to directly link these two. Examples include public online procurement platforms and/or supplier matchmaking days. Supplier databases can be organized by ethnic groups, gender, geographic locations, among other characteristics, to help miners to meet relevant public obligations and internal corporate social responsibility commitments. By applying pre-qualification tools, these supplier portals can also help identify key technical gaps for supplier development programs, such as relevant certifications. Box 6 details how Australia helped drive a market for its local suppliers without implementing set content requirements.

Box 6. Australian Participation Plan

In 2000, Australia adopted the Australian Participation Plan under the Enhanced Project By-Law Scheme, which requires firms to submit detailed plans on expected opportunities for supplying products and services and how they intend to identify local firms to participate in the procurement process, including the distribution of information in a timely manner to local suppliers. Templates for the plan and compliance reporting are provided by the government. This incentive plan allowed firms submitting a participation plan to qualify for tariff reduction on equipment that had to be imported. In 2013, submission of participation plans became a requirement for all projects over US$375 million, as trade liberalization was eroding the incentive to develop a plan.*

The government-funded Industry Capabilities Network, founded in 1985, has become a key method for firms to meet these requirements. This network, which now includes over 80,000 suppliers, works with extractive industry companies to detail their procurement needs and to match them with potential local suppliers. This service is free for users.

Source: Department of Industry Innovation (2013).

* Firms are required to report during construction and for the first two years of operations of a new facility.

Incentivizing Innovation and Upgrading

Promoting innovative local suppliers in the industry requires significantly more support. First, as miners only do not buy turn-key innovation from local small suppliers (supply-driven), opportunities for miners to disclose key challenges to potential suppliers need to be created. Suppliers can then use this as a base to develop innovative solutions. Linkminers is seeking to address this gap; their model could form the basis for a national level program as has happened in Chile.

Developing innovation capabilities requires initiatives related to human capital, R&D infrastructure, and commercialization.

First, there is a need to address the shortage of qualified human capital in key areas of mining expertise. While initial efforts are underway, such as through UTEC and Tecsup, additional resources can be generated through the availability of scholarships to study abroad in relevant fields. Graduate degree programs at universities such as the Colorado School of Mines and the University of Queensland develop relevant STEM capabilities and offer opportunities to work in applied research centers.

Second, copper mining–specific R&D infrastructure in Peru needs a significant boost. Local suppliers highlight that local universities are not yet adequately prepared to undertake applied research for the industry, with the majority of research being too theoretically focused. In the mid- to long term, training of R&D personnel at foreign universities can help to shift the culture toward one of greater application.[37] In the short to mid-term, the need for applicable research can be addressed by

1. creating a new public–private R&D center in one of the key mining regions, such as Arequipa,[38] to be staffed by a combination of experienced foreign and younger local researchers; and
2. incentivizing firms to engage in R&D activities with foreign universities.

Mining3 is an industry-focused research organization in Australia. Its mission is to develop solutions to provide both incremental and major increases in productivity and overcome key global mining challenges. The organization partners with members from industry (8-year terms), universities, and suppliers of products and services to develop these solutions. The research program is directly linked to mining challenges identified by the miner members, and a technology transfer plan ensures these solutions are implemented in the sector (Mining3, 2019).

Another major R&D infrastructure concern is the lack of appropriate testing facilities to prove new technologies and services at scale. Miners are generally reluctant to open mines for testing, but simultaneously will not consider procuring untested technologies. As copper mining is dominated by large mines in Peru, there are limited opportunities for firms to trial solutions first in smaller operations. The government could play a role in establishing a test facility for these innovations, as Chile has under the Alta Ley project. The Mining Technology Testing Center (M2TC) is co-financed by CORFO, four leading Chilean universities, and Minnovex, the industry association for mining suppliers. The center allows suppliers to test technologies, access expert advice and apply global mining standards. Successful technologies receive certifications that are recognized by the industry (Centro Nacional de Pilotaje de Tecnologías para la Minería, 2019) Within 12 months of operation, 50 prototypes were being tested.

Third, local suppliers need to be able to commercialize their innovations, which requires options for R&D financing, ways to protect intellectual property, and the ability to manage innovation projects. R&D financing includes, but is not limited to, R&D fiscal incentives and the mining canon. While

37 In addition, "research facilitators" can be introduced to help local small and medium enterprises, in particular, connect to the right research centers. This role was introduced by the National Innovation and Science Agenda in Australia to help build linkages between universities and the private sector (OECD, 2017a).

38 Copper mining is concentrated in southern Peru, which is where 70 percent of copper production and 50 percent of all future mining projects are located.

there needs to be increased awareness of these incentives and perhaps a restructuring of the way in which canon financing is distributed, focus should be placed on educating private and public actors about the range of opportunities from accelerators such as UP Emprende to angel and venture funds. Also, the profiles of mining suppliers need to be raised among risk capital actors (Expande Minería, 2019). Likewise, there is a need for training regarding protection and ownership of intellectual property in the mining sector. Courses on patent filings have been introduced by different actors, however, miners in the region are not well known for respecting patents and firms may not be well positioned to defend against patent infringement. One of the areas where local providers play an important role is in the services sector, and in this case patent development is not as relevant. For services, constant incremental innovation and location specificity can be sufficient to maintain an edge in intellectual property. Finally, as innovation and R&D are relatively recent in Peru, there is a shortage of qualified innovation managers with experience enabling R&D within the industry. While many firms may be too small to hire for specific roles, training courses should be developed targeting mid-level managers within the sector.

Table 12. Select Policy Recommendations

Institutionalization	Participation: GVC Entry	Innovation and Upgrading
• Develop a long-term national strategy for the copper mining sector • Identify a national policy champion • Support the development of an industry association for suppliers • Establish a multi-stakeholder council to support long-term plans for the sector; include export promotion agency PromPeru to better coordinate internationalization efforts for innovative firms • Strengthen policymaker knowledge in designing, developing and managing innovation policy	• Increase efforts to support value-added mining services suppliers • Develop instruments to strengthen suppliers capabilities: – Business and organizational skills – Compliance with global standards – Registration procedures and bidding on mining project • Facilitate harmonization of mine-access requirements to reduce duplication of effort • Support firms to obtain certification • Reduce information asymmetry between buyers and local suppliers: – Mandate transparency requirements regarding procurement opportunities – Support development of online portal to link suppliers and buyers – Create supplier matchmaking forums	• Establish/strengthen mechanisms to support demand-driven innovation (e.g., portals, events, and studies) • Improve availability of human capital in the key areas using scholarships to send students abroad • Support a short-term strategy of local suppliers to work with foreign universities on R&D until local universities establish know-how • Create an R&D center exclusively focused on applied research for copper mining • Support establishment of a testing facility • Increase awareness of R&D credit and reduce bureaucratic requirements for application • Strengthen capabilities related to commercialization of innovation with training programs on financing innovation, protecting intellectual property, managing innovation programs

Source: Authors' elaboration.

5. APPENDIX

Methodology

This research paper follows the global value chain methodology developed by the Duke Global Value Chain Center. It used a mixed-methods approach, combining both quantitative and qualitative primary and secondary sources. To understand the global industry dynamics and how these may affect procurement patterns in Peru in the mining sector, multiple academic, trade, and gray literature sources covering private sector engagement in the industry were analyzed. Sources included the annual reports of 12 leading copper mining companies (multiple years), miner and supplier websites, sustainability reports, and private sector databases (e.g., Orbis), as well as relevant industry publications, including the World Copper Fact Book, Mining.com, Mining Global, and *Global Mining Review.*

The position of different countries in the copper global value chain was determined using multiple indicators, including reserves, production, exports, and imports of different copper products. Reserves and production information was sourced from the United States Geological Survey[39]; production and capacity data were complemented by data from the World Copper Factbook published by the International Copper Study Group,[40] while international trade statistics were downloaded from the United Nations Statistical Division Comtrade Database.[41]

Between March and May 2019, more than 20 semi-structured, one-hour interviews were carried out with

- mining companies in Peru
- Peruvian mining suppliers

39 USGS, www.usgs.gov.

40 The International Copper Study Group (ICSG) was established in 1992 to promote international cooperation on issues concerning copper by improving the information available abouy the international copper economy and by providing a forum for intergovernmental consultations on copper.

41 www.comtrade.un.org

- mining industry experts in Peru and Chile
- government officials (current and former)
- education institutions

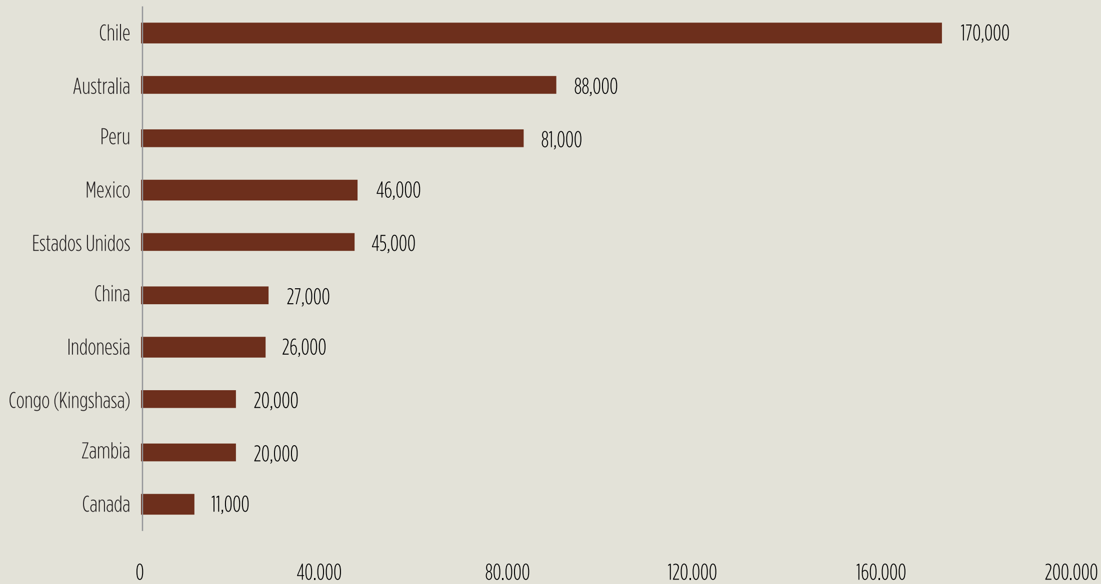
This information was supplemented with approximately 20 semi-structured interviews carried out between 2015 and 2018 with similar groups of actors, including key industry associations focused on the metal-mechanics sector. All interviews (2019 and previously) used the same structure, allowing for comparability. Supplier interviewees were selected to include as wide a range of suppliers as possible, including goods and services. An initial database of firms was drawn up based on the research team's past experience in the sector and this was complemented by a database supplied by the Inter-American Development Bank Peru office and by asking interviewees to identify suppliers or peers (snowball technique). In addition, the database of projects funded by Innovate Peru was reviewed. The keywords "mineria" and/or "cobre" returned 14 finalized projects and 10 projects underway.

Databases used:

- London Metals Exchange: evolution of the price of copper cathode
- United Nations Statistics Division Comtrade Database: International trade statistics used to identify country positions in the copper global value chain. HS codes analyzed: HS 2002 - 260300, Copper Ore and Concentrate; HS-2002, 7402, Unrefined copper, copper anodes for electrolysis; HS-2002, 7403, Refined copper.
- Copper Alliance World Copper Factbook 2018: Indicators of production capacity by country, leading mines, leading smelters, and leading refineries.
- United States Geological Survey 2018: Indicators of global copper reserves, extraction, and refining.
- National Supply Use Tables to identify total annual operational procurement and categorize goods and services supplied to the industry from:
  - Australia (2016)
  - United States (2012)
  - Chile (2013, 2016)
  - Peru (2017)
- Anuario Minero Peru for detailed statistics on the Peruvian mining industry (years covered, 2010–2018): Indicators included production, exports, investment by value chain stage.
- SUNAT–Customs Data (2012, 2017). Imports and exports for all copper exporting companies: values, volumes, destination/origin, HS2-6D.
- UNESCO Institute for Statistics. Science, Technology and Innovation Indicators. Indicator: R&D Spending.
- WIPO Global Innovation Index. Indicators: Patent Applications, University and Research Collaboration.
- World Bank Open Data. Indicator: Scientific and Technology Publications.
- Property Rights Alliance Intellectual Property Rights Index.
- World Economic Forum Global Competitiveness Index.

Tables and Figures

Figure 18. Copper Reserves per Country, 2018 (MT, million)



Source: USGS (2019a).

Table 13. Comparison between EPC and EPCM Contracts

	EPC	EPCM
Accountability	Contractor fully accountable	Owner has multiple points of accountability
Risk	Contractor holds risk	Owner holds risk
Time	Fixed date for completion	No fixed completion schedule
Price	Fixed price contract	Schedule of rates or cost plus
Procurement	Contractor responsible for procurement	Procurement as agent for the owner only
Quality/performance guarantee	Contractor guarantees performance of completed facility	Contractor does not provide performance guarantees
Owner's involvement	Contractor in control	Owner in control
Defective work or service	Contractor to rectify any defects	Assists owner to manage rectification of defects

Source: Sarcich and Moore (2014).

Table 14. Top 10 Exporters of Copper Ore and Concentrate, By Value, 2005–2017

	Export Value (US$ millions)							Export Share (%)						
	2005	2007	2009	2011	2013	2015	2017	2005	2007	2009	2011	2013	2015	2017
World	**14,609**	**30,823**	**23,396**	**48,164**	**49,832**	**43,744**	**54,639**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Chile	7,642	14,683	9,866	14,534	16,651	12,999	17,404	52	48	42	30	33	30	32
Peru	1,410	4,614	3,921	7,797	7,601	6,600	11,999	10	15	17	16	15	15	22
Australia	1,950	3,226	2,976	5,616	4,969	3,659	3,669	13	10	13	12	10	8	7
Indonesia	–	–	–	4,700	3,007	3,277	3,440	–	–	–	10	6	7	6
Canada	910	1,450	1,211	3,283	2,886	3,001	2,749	6	5	5	7	6	7	5
Brazil	304	1,032	803	1,573	1,826	1,984	2,485	2	3	3	3	4	5	5
Spain	–	–	–	1,395	1,422	1,131	2,087	–	–	–	3	3	3	4
Mexico	–	–	289	1,171	1,486	1,159	1,891	–	–	1	2	3	3	3
U.S.	363	1,052	985	2,308	2,601	3,083	1,715	2	3	4	5	5	7	3
Mongolia	326	811	–	–	–	2,280	1,613	2	3	–	–	–	5	3
Argentina	762	1,358	1,126	1,442	–	–	–	5	4	5	3	–	–	–
Philippines	–	–	–	–	968	–	–	–	–	–	–	2	–	–
Portugal	291	599	384	–	–	–	–	2	2	2	–	–	–	–
Turkey	–	335	–	–	–	–	–	–	1	–	–	–	–	–
Bulgaria	–	–	–	–	–	–	–	–	–	–	–	–	–	–
South Africa	116	–	309	–	–	–	–	1	–	1	–	–	–	–

Source: UN Comtrade (2019). HS 2002 - 260300, Copper Ore & Concentrate; All Exporters. Downloaded 23/05/2019.

Table 15. Top 10 Exporters of Copper Anodes (Smelted Copper, Unrefined), By Value, 2005–2017

	Export Value (US$ millions)							Export Share (%)						
	2005	2007	2009	2011	2013	2015	2017	2005	2007	2009	2011	2013	2015	2017
World	**3,385**	**6,326**	**4,209**	**6,341**	**5,914**	**4,730**	**9,075**	**23**	**21**	**18**	**13**	**12**	**11**	**17**
Zambia	–	152	–	–	–	643	3,623	–	0	–	–	–	1	7
Chile	1,311	3,077	1,986	3,101	3,545	2,140	2,406	9	10	8	6	7	5	4
Bulgaria	690	1,039	446	864	1,028	761	1,089	5	3	2	2	2	2	2
Philippines	–	–	–	–	–	–	316	–	–	–	–	–	–	1
Slovakia	–	–	145	443	148	219	296	–	–	1	1	0.3	1	1
Namibia	88	142	214	342	–	113	275	1	0.5	1	1	–	0	1
Spain	241	227	176	296	248	229	241	2	0.7	1	1	0.5	1	0.4
Belgium	–	73	–	383	295	113	168	–	0	–	1	1	0.3	0.3
South Africa	–	–	–	–	–	150	139	–	–	–	–	–	0.3	0.3
Finland	130	87	208	210	184	–	124	1	0.3	1	0.4	0.4	–	0.2
Germany	–	–	–	–	68	–	–	–	–	–	0.0	0.1	–	–
Mexico	102	258	104	–	–	–	–	1	1	0.4	–	–	–	–
Armenia	43	–	60	115	90	66	–	0	–	0.3	0.2	0.2	0.1	–
U.S.	93	80	99	98	67	48	–	1	0.3	0.4	0.2	0.1	0.1	
Peru	203	175	127	121	51	–	–	1	1	1	0.3	0.1	–	

Source: UN Comtrade (2019); HS-2002, 7402, Unrefined copper, copper anodes for electrolysis. All Exporters. Downloaded 23/05/2019.

Table 16. Top 10 Exporters of Refined Copper (All Categories), By Value, 2005–2017

	Export Value (US$ millions)							Export Share (%)						
	2005	2007	2009	2011	2013	2015	2017	2005	2007	2009	2011	2013	2015	2017
World	**24,768**	**51,134**	**42,263**	**73,286**	**64,900**	**48,233**	**51,995**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Chile	10,679	20,569	17,244	26,134	18,849	14,173	14,754	43	40	41	36	29	29	28
Russia	1,051	1,881	2,493	–	1,620	3,085	3,646	4	4	6	–	2	6	7
Japan	1,005	3,307	3,107	4,073	4,359	3,232	3,230	4	6	7	6	7	7	6
India	596	1,659	1,048	2,141	2,354	1,936	2,460	2	3	2	3	4	4	5
Zambia	633	2,105	2,250	6,174	6,607	4,446	2,448	3	4	5	8	10	9	5
Australia	1,179	2,172	1,612	3,337	2,975	2,479	2,179	5	4	4	5	5	5	4
China	–	–	–	–	2,264	–	2,055	–	–	–	–	3	–	4
Peru	1,747	2,398	1,862	2,755	2,112	1,506	1,776	7	5	4	4	3	3	3
Poland	1,148	1,753	1,697	2,923	2,561	1,670	1,575	5	3	4	4	4	3	3
Rep. of Korea	–	–	–	–	–	1,665	1,499	–	–	–	–	–	3	3
Canada	899	2,090	1,033	–	–	1,351	–	4	4	2	–	–	3	–
Bulgaria	–	–	–	1,840	–	–	–	–	–	–	3	–	–	–
Philippines	–	1,294	–	–	–	–	–	–	3	–	–	–	–	–
Indonesia	–	–	–	2,544	–	–	–	–	–	–	3	–	–	–
Germany	641	–	1,022	1,837	1,811	–	–	3	–	2	3	3	–	–

Source: UN Comtrade (2019); HS-2002, 7403, Refined copper. All Exporters. Downloaded 23/05/2019.

Table 17. Top 10 Importers of Copper Ore & Concentrate, By Value, 2005–2017

	Import Value (US$ millions)							Import Share (%)						
	2005	2007	2009	2011	2013	2015	2017	2005	2007	2009	2011	2013	2015	2017
World	**15,683**	**36,955**	**30,435**	**52,860**	**56,496**	**45,271**	**57,534**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
China	3,721	8,833	8,479	15,339	19,509	18,781	26,897	24	24	28	29	35	41	47
Japan	4,819	10,861	8,230	11,513	10,646	7,818	7,970	31	29	27	22	19	17	14
India	812	4,369	3,021	5,284	7,443	4,094	3,903	5	12	10	10	13	9	7
Rep. of Korea	1,734	3,347	3,294	5,634	3,938	3,501	3,580	11	9	11	11	7	8	6
Spain	800	1,609	1,250	3,668	3,077	2,594	3,117	5	4	4	7	5	6	5
Germany	1,003	2,438	1,671	3,104	2,383	2,081	2,224	6	7	5	6	4	5	4
Philippines	–	–	910	–	1,128	–	1,761	–	–	3	–	2	–	3
Bulgaria	514	1,001	719	1,772	1,951	1,338	1,682	3	3	2	3	3	3	3
Brazil	461	1,056	683	1,117	1,058	973	851	3	3	2	2	2	2	1
Zambia	–	–	–	–	1,389	–	843	–	–	–	–	2	–	1
Finland	442	772	434	976	–	643	–	3	2	1	2	–	1	–
Sweden	351	784	506	830	–	466	–	2	2	2	2	–	1	–

Source: UN Comtrade (2019); HS 2002 - 260300, Copper Ore & Concentrate; All Importers. Downloaded 23/05/2019.

Table 18. Top 10 Importers of Copper Anode, By Value, 2005–2017

	Import Value (US$ millions)							Import Share (%)						
	2005	2007	2009	2011	2013	2015	2017	2005	2007	2009	2011	2013	2015	2017
World	**3,324**	**7,623**	**4,967**	**9,488**	**9,353**	**7,222**	**10,287**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
China	463	1,222	1,202	3,762	4,563	2,969	4,889	14	16	24	40	49	41	48
Belgium	882	1,598	1,123	2,100	1,570	1,385	1,650	27	21	23	22	17	19	16
India	–	–	–	115	124	482	880	–	–	–	1	1	7	9
Germany	150	247	292	710	960	388	716	5	3	6	7	10	5	7
Canada	526	637	359	153	398	389	619	16	8	7	2	4	5	6
Rep. of Korea	158	792	232	605	534	378	489	5	10	5	6	6	5	5
Austria	68	184	133	387	157	216	296	2	2	3	4	2	3	3
Namibia	–	–	–	–	–	131	232	–	–	–	–	–	2	2
Japan	11	179	125	–	–	–	183	0	2	3	–	–	–	2
Poland	15	198	252	229	129	103	103	0	3	5	2	1	1	1
Sweden	75	–	–	–	77	–	–	2	–	–	–	1	–	–
Spain	–	–	–	120	–	–	–	–	–	–	1	–	–	–
Netherlands	37	–	–	–	–	–	–	1	–	–	–	–	–	–
U.S.	420	1,122	389	–	–	–	–	13	15	8	v	–	–	–
Australia	–	161	357	488	582	306	–	–	2	7	5	6	4	–

Source: UN Comtrade (2019); HS-2002, 7402, Unrefined copper, copper anodes for electrolysis. All Importers. Downloaded 23/05/2019.

Table 19. Top 10 Importers of Refined Copper (All Categories), By Value, 2005-2017

	Import Value (US$ millions)							Import Share (%)						
	2005	2007	2009	2011	2013	2015	2017	2005	2007	2009	2011	2013	2015	2017
World	**27,021**	**55,407**	**43,095**	**75,367**	**68,615**	**55,200**	**57,190**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
China	4,483	10,705	15,921	25,194	23,965	20,936	20,629	17	19	37	33	35	38	36
U.S.	3,471	5,944	3,053	5,938	5,565	3,912	5,115	13	11	7	8	8	7	9
Germany	2,559	6,326	3,481	6,498	5,412	3,922	4,110	9	11	8	9	8	7	7
Italy	2,432	5,568	2,799	5,641	4,283	3,644	4,022	9	10	6	7	6	7	7
Other Asia, nes	2,332	4,529	2,560	4,228	3,313	2,779	3,610	9	8	6	6	5	5	6
Turkey	883	2,139	1,491	3,126	2,730	2,208	2,438	3	4	3	4	4	4	4
Malaysia	679	1,530	1,077	2,037	3,932	2,027	2,148	3	3	2	3	6	4	4
Rep. of Korea	1,573	3,142	2,566	3,234	2,241	2,230	2,020	6	6	6	4	3	4	4
United Arab Emirates	11	31	360	1,492	3,079	1,333	1,826	0	0	1	2	4	2	3
Vietnam	200	640	496	797	752	950	1,451	1	1	1	1	1	2	3
France	1,910	3,161	1,316	2,037	1,751	1,147	1,289	7	6	3	3	3	2	2
Brazil	621	1,630	1,038	2,066	1,824	1,078	1,156	2	3	2	3	3	2	2

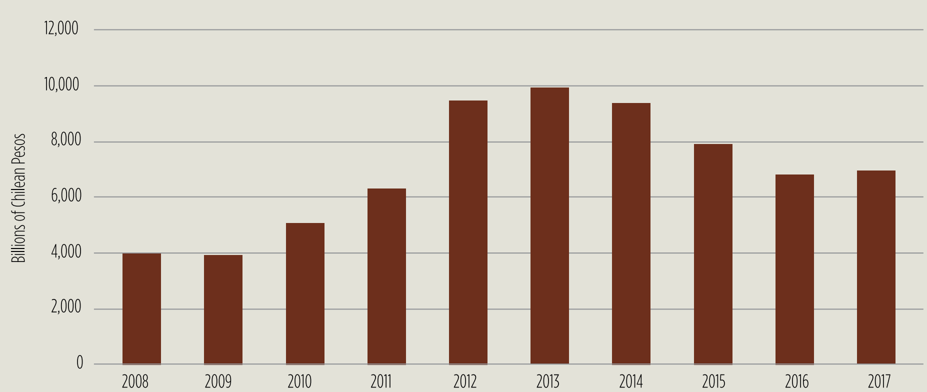
Source: UN Comtrade (2019); HS-2002, 7403, Refined copper. All Importers. Downloaded 23/05/2019.
nes = not elsewhere specified.

Table 20. Distribution of Refined Copper Production Worldwide, by Country, 2017

Country	Share of Refined Copper Production (%)
China	37.8
Chile	10.4
Japan	6.3
United States	4.6
Russia	3.9
India	3.5
D.R. Congo	3
Germany	3
South Korea	2.9
Poland	2.2
Mexico	2.1
Zambia	2
Spain	1.8
Belgium	1.7
Australia	1.7
Kazakhstan	1.4
Peru	1.4
Canada	1.4
Other countries	9

Sources: ICSG (2018) and Natural Resources Canada (2019).

Figure 19. Evolution of Gross Fixed Capital Formation in Chilean Mining, Current Prices, 2008–2017



Source: Banco Central de Chile (2019b).

6. REFERENCES

Aduanas-SUNAT. (2017). *Data Aduanas (exportaciones e importaciones)*.

AEPME. (2019). *Asociados*. Retrieved from https://aepme.pe/no-sidebar-full-width-2-2-2/.

Anglo American. (2018). *Picture this: The waterless mine.* Retrieved from https://www.angloamerican.com/futuresmart/our-industry/technology/picture-this-the-waterless-mine.

Anglo American. (2019). *Futuresmart Mining*. Retrieved from https://www.angloamerican.com/~/media/Files/A/Anglo-American-PLC-V2/presentations/2019pres/baml-smart-mine-conference-presentation.pdf.

Antamina. (2017). *Sustainability Report 2016*. Retrieved from http://www.antamina.com/wp-content/uploads/2018/01/sustainability-report-antamina-2016.pdf.

APRIMIN. (2019). Nuestra Asociación. Retrieved from http://aprimin.cl/site/corporativo/nuestra-asociacion/.

Aurus Capital. (2019). Portfolio. Retrieved from https://www.aurus.cl/.

Austmine. (2019). Austmine Survey. Retrieved from http://www.austmine.com.au/About.

Australian Bureau of Statistics. (2016). Supply Use Table. Retrieved from https://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5217.02016-17?OpenDocument.

Australian Goverment. (2019). Australian Industry Capabilities: Mining, Oil and Gas. Retrieved from https://www.austrade.gov.au/International/Buy/Australian-industry-capabilities/Mining.

Bamber, P., Fernández-Stark, K., and Gereffi, G. (2016). Peru in the Mining Equipment Global Value Chain: Opportunities for Upgrading. Durham, NC: Duke University Global Value Chains Center Center. Retrieved from https://gvcc.duke.edu/cggclisting/peru-in-the-mining-equipment-global-value-chain-opportunities-for-upgrading/.

Banchile Inversiones. (2016). Chile 2016 Mining Report. International Investor.

Banco Central de Chile. (2019). Cuentas Nacionales 2013–2018: Matrices de Oferta-Produccion 2016. Retrieved from https://si3.bcentral.cl/estadisticas/Principal1/Informes/anuarioCCNN/index_anuario_CCNN_2018.html?chapterIdx=-1&curSubCat=-1.

Barr, G., Defreyne, J., Jones, D., and Mean, R. (2005). *On-site Processing vs. Sale of Copper Concentrates*. Perth: CESL.

Batterham, R. (2004). Has minerals industrial technology peaked? In E. Dowling, & J. Marsden, *Improving and Optimizing Operations: Things That Actually Work!* (pp. 93–127). Colorado: Society for Mining Metallurgy.

BBVA Research. (2019). Peru. Situation of the Mining Sector. Retrieved from https://www.bbvaresearch.com/wp-content/uploads/2019/03/Peru_MiningSector.pdf.

BEA. (2012). Supply Use Framework, 2012.

Belapatiño, V., and Perea, H. (2018). Perú: Innovación Una Agenda Pendiente. Lima: BBVA Research.

BHP. (2018). Annual Report. Retrieved from Melbourne: https://www.bhp.com/-/media/documents/investors/annual-reports/2018/bhpannualreport2018.pdf.

Brahm, F., and Tarziján, J. (2015). Does complexity and prior interactions affect project procurement? Evidence from mining mega-projects. *International Journal of Project Management*, 33(8), 1851–1862. doi:https://doi.org/10.1016/j.ijproman.2015.08.005.

British Council. (2016). The Reform of the Peruvian University System: Internationalisation, Progress, Challenges and Opportunities. Retrieved from https://www.britishcouncil.pe/sites/default/files/the_reform_of_the_peruvian_university_system_interactive_version_23_02_2017.pdf.

Bryant, P. (2015). The Case for Innovation in the Mining Industry. Retrieved from http://www.ceecthefuture.org/wp-content/uploads/2016/01/Clareo_Case-for-Innovation-in-Mining_20150910_lo.pdf.

CARMAR. (2018). Famesa Explosivas es la Empresa con más Patentes de Innovación en el Perú. Retrieved from http://www.carmarltda.com/noticias/famesa-explosivos-la-empresa-mas-patentes-innovacion-peru/.

Caterpillar. (2019). Let's do the work: 2018 Annual Report. Retrieved from http://reports.caterpillar.com/ar/2018_Caterpillar_Annual_Report.pdf?_ga=2.147796339.519615306.1571239263-2131962283.1558553880.

Caterpillar. (n.d.a). Data Analytics. Retrieved from https://www.caterpillar.com/en/company/innovation/customer-solutions/data-analytics.html.

Caterpillar. (n.d.b). Caterpillar Ventures: Portfolio. Retrieved from https://www.caterpillar.com/en/company/innovation/caterpillar-ventures/portfolio.html.

Centro Nacional de Pilotaje de Tecnologías para la Minería. (2019). Centro Nacional de Pilotaje de Tecnologías para la Minería. Retrieved from https://pilotaje.cl

Cochilco. (2016). Copper-Mining Critical Supplies Market Analysis.

Cochilco. (2017). Precio del Cobre Refinado, Nominal y Real. Retrieved from https://www.cochilco.cl/Precio%20Metales/1.3_Cobre_Nominal-Real_anual_BML-COMEX_1935-2016.xlsx.

Cochilco. (2018). Investment in the Chilean mining industry: Portfolio of projects, 2018–2027. Retrieved from https://www.cochilco.cl/Research/Project%20portfolio%202018%20-%202027%20(final)%20(ENG%20version).pdf.

Codelco. (2016). Categorías de empresas proveedoras. Retrieved from https://www.codelco.com/prontus_codelco/site/artic/20160630/imag/foto_0000000320160630114556.png.

Codelco. (2017). Companies: Subsidiaries and Associates. Retrieved from https://www.codelco.com/memoria2016/en/pdf/mem2016codelco-companies.pdf.

Comisión Nacional de Productividad. (2017). Productivity in the Chilean Copper Mining Industry. Retrieved from https://www.comisiondeproductividad.cl/wp-content/uploads/2018/08/Productivity-in-the-Chilean-Copper-Industry.pdf.

CONCYTEC. (2017). I Censo Nacional de Investigación y Desarrollo a Centros de Investigación 2016. Retrieved from http://portal.concytec.gob.pe/index.php/publicaciones/censo-nacional-id.

CONCYTEC. (2019). ¿Quiénes somos? Retrieved from https://portal.concytec.gob.pe/index.php/concytec/quienes-somos.

Copper Development Association. (2018). Copper Is Among the Best Conductors of Electricity and Heat. Retrieved from https://copperalliance.org.uk/about-copper/applications/energy-and-renewables/.

Cornell University, INSEAD, and WIPO. (2018). The Global Innovation Index 2018: Energizing the World with Innovation. Ithaca: Cornell University, Fontainebleau: INSEAD, and Geneva: WIPO.

Corporación Nacional Alta Ley. (2014). Minería y Desarrollo Sostenible de Chile. Hacia una Visión Compartida. Retrieved from https://corporacionaltaley.cl/publicaciones/mineria-y-desarrollo-sostenible-de-chile-hacia-una-vision-compartida/.

Corporación Nacional Alta Ley. (2017). Proveedores de la Minería Chilena: Reporte de Exportaciones. Retrieved from https://corporacionaltaley.cl/wp-content/uploads/2019/09/Reporte-Exportaciones-2012-2016-VD.pdf.

Corporación Nacional Alta Ley. (n.d.). Quiénes Somos. Retrieved from https://corporacionaltaley.cl/quienes-somos/.

Daly, A., Valachi, G., and Raffo, J. (2019). Mining Patent Data: Measuring Innovation in the Mining Industry with Patents. Geneva: WIPO.

De Marchi, V., Giuliani, E., and Rabellotti, R. (2018). Do Global Value Chains Offer Developing Countries Learning and Innovation Opportunities? *European Journal of Development Research*, 30(3), 389-407.

Deloitte. (2018). Tracking the Trends 2018. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-ttt-report-2018.pdf.

Department of Industry, Innovation, Science, Research and Tertiary Education (DIICSRTE). (2013). Strengthening Australian Industry Participation. Sydney: DIICSRTE. Retrieved from http://ris.finance.gov.au/files/2013/02/03-Strengthning-Australian-Industry-Participation-RIS.pdf.

Douglas, R. (2016). EPC or EPCM Contracts. Vancouver, Canada: Ausenco. Retrieved from https://www.ausenco.com/en/epc-epcm-whitepaper.

Dresher, W. (2001). How Hydrometallurgy and the SX/EW Process Made Copper the “Green” Metal. Retrieved from https://www.copper.org/publications/newsletters/innovations/2001/08/hydrometallurgy.html.

Drzik, J. (2019). Infrastructure Around the World is Failing. Retrieved from https://www.weforum.org/agenda/2019/01/infrastructure-around-the-world-failing-heres-how-to-make-it-more-resilient/.

Esteves, A., Coyne, B., and Moreno, A. (2013). Local Content Initiatives: Enhancing the Subnational Benefits of the Oil, Gas and Mining Sectors. Retrieved from https://resourcegovernance.org/sites/default/files/Sub_Enhance_Benefits_20151125.pdf.

Expande Minería. (2019). Open innovation in mining. Retrieved from https://expandemineria.cl/wp-content/uploads/2019/02/OpenInnovation-OK-1-1.pdf.

EY. (2018). *Peru's Mining & Metals Investment Guide 2019/2020*. Lima: EY.

Fernández-Stark, K., Bamber, P., and Gereffi, G. (2010). Engineering Services in the Americas. Durham, NC: Duke University Global Value Chains Center Center. Retrieved from: http://www.cggc.duke.edu/pdfs/CGGC-IDB_CORFO_Engineering_Services_in_the_Americas_July_1_2010.pdf.

Fernández-Stark, K., Cuoto, V., and Bamber, P. (2019). The Mine of the Future and the Role of Women: The Case of Chile. Washington DC: World Bank Group.

Fessehaie, J., and Morris, M. (2013). Value Chain Dynamics of Chinese Copper Mining in Zambia: Enclave or Linkage Development? Retrieved from https://link.springer.com/article/10.1057/ejdr.2013.21.

Field Research. (2019). Peru Field Research Copper Mining Industry. Lima: Field Research.

Fluor. (2019). Global Procurement and Supply Chain Contribute to Clients' Project Success. Retrieved from https://www.fluor.com/services/procurement.

Frederick, S., Bamber, P., Gereffi, G., and Cho, J. (2018). The Digital Economy, Global Value Chains and Asia. Durham, NC: Global Value Chain Center and Seoul, Korea: Korea Institute for Industrial Economics and Trade. Retrieved from https://gvcc.duke.edu/cggclisting/the-digital-economy-global-value-chains-and-asia/.

Fundación Chile. (2015). From Copper to Innovation: Mining Technology Roadmap 2035. Retrieved from https://corporacionaltaley.cl/wp-content/uploads/2019/09/Roadmap_ingles_completo.pdf.

Fundación Chile. (2019b). Chile Global Ventures. Retrieved from https://chileglobalventures.cl/.

Fundación Chile. (2019a). Fundación Chile. Retrieved from https://fch.cl/en/proyecto/expande/expande/.

Gestión. (2017). Southern Copper planea invertir cerca de US$ 1,200 millones en el 2017. Retrieved from https://gestion.pe/economia/empresas/southern-copper-planea-invertir-cerca-us-1-200-millones-2017-134356-noticia/.

Gestión. (2018). MEF conforma mesa ejecutiva para mejorar productividad del sector minero energético. Retrieved from https://gestion.pe/economia/mef-conforma-mesa-ejecutiva-mejorar-productividad-sector-minero-energetico-nndc-246129-noticia/.

Gestión. (2019). BID Plantea que se Brinde Crédito Fiscal a Empresas para Impulsar Innovación en Perú. Retrieved from https://gestion.pe/economia/bid-plantea-brinde-credito-fiscal-empresas-impulsar-innovacion-258156-noticia/?ref=gesr.

Hub Innovacion Minera del Peru. (2019). http://www.hubinnovacionminera.pe.

Hudbay. (2017). Positioned for Growth, 2017 Annual and CSR Report.

ICSG. (2018). The World Copper Factbook 2018. Retrieved from https://www.icsg.org/index.php/component/jdownloads/finish/170/2876.

IDB. (2018). Directorio Proveedores Mineros Peruanos. Lima: Inter-American Development Bank, Peru.

INEI. (2017a). Cuadro Oferta Utilización - Año 2017. Lima: INEI.

INEI. (2017b). Perú: Encuesta Nacional de Innovación en la Industria Manufacturera 2015. Lima: INEI.

Instituto Tecnológico de la Producción. (2019). Bienvenidos al CITE. Retrieved from https://www.itp.gob.pe/nuestros-cite/.

International Mining. (2015). Resemin addresses narrow vein drilling with Muki. *International Mining* 6. Berkhamsted, United Kingdom.

IRENA. (2018). Global Energy Transformation: A Roadmap to 2050. IRENA.

Jamasmie, C. (2017). BHP to step up copper exploration, expansions to meet electric vehicles sector's rising demand. Retrieved from https://www.mining.com/bhp-step-copper-exploration-expansions-meet-electric-vehicles-sectors-rising-demand/.

JX Nippon Mining & Metals. (2019). Corporate Profile. Retrieved from https://www.nmm.jx-group.co.jp/english/company/.

JX Nippon Mining & Metals. (n.d.). Development of Technology for Mineral Resources. Retrieved from https://www.nmm.jx-group.co.jp/english/industry/technology/resource.html.

Katz, J., and Pietrobelli, C. (2018). Natural Resource Based Growth, Global Value Chains and Domestic Capabilities in the Mining Industry. *Resources Policy*, 58, 11–20. doi:10.1016/j.resourpol.2018.02.001.

Lampadia. (2017). Revisión de la Situación Actual de la Red de Centros de Innovación Tecnológicos (CITE) en Perú. Retrieved from https://www.lampadia.com/assets/uploads_documentos/0b63c-resumen-ejecutivo-informe-onudi-.pdf.

Leonida, C. (2019). Mining Without Water. Retrieved from https://theintelligentminer.com/2019/05/09/mining-without-water/.

Lewis, B. (2018). BHP Sees Major Copper Demand Boost from China's Widening Belt and Road. Retrieved from http://www.mining.com/web/bhp-sees-major-copper-demand-boost-chinas-widening-belt-road/.

Lundvall, B. Å. (2007). National Innovation Systems—Analytical Concept and Development Tool. *Industry and Innovation*, 14(1), 95–119. doi:10.1080/13662710601130863.

Millan Lombrana, L., and Quigley, J. (2018). Peru's Mining Investment Boom Leaves Political Woes Behind. Retrieved from https://www.bloomberg.com/news/articles/2018-10-01/peru-s-mining-investment-boom-leaves-political-turmoil-behind.

Mills, R. (2015). China Copper Con. Retrieved from https://www.kitco.com/ind/Mills/2015-03-06-China-Copper-Con.html.

MINEM. (2018). 2018 Anuario Minero Peru. Lima: MINEM.

MINEM. (2019). 2019 Anuario Minero Peru. Lima: MINEM.

Mining IQ. (2015). Mining Procurement: 3 Trends You Need to Know. Retrieved from https://www.miningglobal.com/operations/mining-procurement-3-trends-you-need-know.

Mining3. (2019). Mining3. Retrieved from https://www.mining3.com.

MINNOVEX. (2019). ¿Quiénes somos? Retrieved from https://minnovex.cl/minnovex/

Miozzo, M., Desyllas, P., Lee, H.-f., and Miles, I. (2016). Innovation Collaboration and Appropriability by Knowledge-intensive Business Services Firms. *Research Policy*, 45(7), 1337–1351. doi:https://doi.org/10.1016/j.respol.2016.03.018

Mitsubishi Corporation. (2019). Our Business. Retrieved from https://www.mitsubishicorp.com/jp/en/bg/group.html.

Molina, O. (2019). Sector Minero en el Perú: Competitividad e Innovación. Lima: Universidad del Pacífico.

Monitor Deloitte. (2016). Business Ecosystems in Exploration. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/co/Documents/energy-resources/Business_Ecosystems_in_Exploration_Report_EN%20-%20Final.pdf.

Monitor Deloitte. (2017). Innovation in Mining Latin America 2017. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/latin-america-innovation-in-mining.pdf.

MSTA Canada. (2019). What we do. Retrieved from https://mstacanada.ca/about-us/what-we-do.

Natural Resources Canada. (2019). Natural Resources Canada. Retrieved from https://www.nrcan.gc.ca/home.

OECD. (2015). Addressing Information Gaps on Prices of Mineral Products. Paris: Organisation for Economic Co-operation and Development. Retrieved from https://www.oecd.org/tax/tax-global/case-study-mineral-product-sales.pdf.

OECD. (2017a). Boosting R&D Outcomes in Australia. Paris: OECD. doi:https://doi.org/10.1787/93d19106-en.

OECD. (2017b). Local Content Policies in Minerals-exporting Countries, Case Studies. Paris: OECD. Retrieved from http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=-TAD/TC/WP(2016)3/PART2/FINAL&docLanguage=En.

OECD. (Unpublished). The Mining Global Value Chain and the Impact of Embodied Services. Paris: OECD.

Office of the Ombudsman. (2018). Reporte Mensual de Conflictos Sociales N.° 176. Lima.

Outotec. (2019). Copper Market and TC/RCS. Helsinki: Outotec. Retrieved from https://www.outotec.com/company/newsletters/smelting-newsletter/smelting-newsletter-2-2018/copper-market-and-tc-rcs/.

Oyeyinka, B., and Gehl Sampath, P. (2007). *Latecomer Development*. UK: Routledge.

Pietrobelli, C., Marin, A., and Olivari, J. (2018). Innovation in Mining Value Chains: New Evidence from Latin America. *Resources Policy*, 58, 1–10. doi:https://doi.org/10.1016/j.resourpol.2018.05.010.

Pricewaterhouse. (2018). The Global Innovation 1000: Top Spenders on R&D 2017. London, UK: Pricewaterhouse.

Property Rights Alliance. (2019). Countries. Washington, DC: Property Rights Alliance. Retrieved from http://www.internationalpropertyrightsindex.org/countries

Ramdoo, I., and Cosbey, A. (2019). Local Content Policies in the Mining Sector: Scaling Up Local Procurement March 2019. Winnipeg, Canada: International Institute for Sustainable Development. Retrieved from https://www.iisd.org/library/local-content-policies-mining.

Ritchie, H., and Roser, M. (2018). Urbanization. UK: Our World in Data. Retrieved from https://ourworldindata.org/urbanization.

Roca, A. (2013). Máquinas que Conquistan. *Poder, September 13, pp.30–34.*

S&P Global Market Intelligence. (2018). World Exploration Trends. Retrieved from https://mineralsmakelife.org/wp-content/uploads/2018/03/World-Exploration-Trends-Report-2018.pdf.

SAMSSA. (2019). SAMSSA. Retrieved from https://samssa.ca.

Sarcich, H., and Moore, T. (2014). EPC -v- EPCM. Contract & Procurement Optimisation 501. Retrieved from https://www.slideshare.net/helensuni/epc-v-epcm-contracting-a-comparison

Schipper, B., Lin, H., Meloni, M., Wansleeben, K., Heijungs, R., and der Voet, E. (2018). Estimating Global Copper Demand until 2100 with Regression and Stock Dynamics. *Resources, Conservation and Recycling*, 132, 28–36. doi:https://doi.org/10.1016/j.resconrec.2018.01.004.

Scott-Kemmis, D. (2011). The Formation of Australian Mining Technology Services and Equipment

Suppliers. Sydney, Australia: University of Sydney, United States Study Center. Retrieved from https://www.ussc.edu.au/publications/The-formation-of-Australian-mining-technology-services-and-equipment-suppliers.

Seclén, J. (2017). Políticas de Ciencia, Tecnología e Innovación en el Perú. Entrevista a Francisco Sagasti. 360: *Revista De Ciencias De La Gestión*, 1(2), 133–137. doi:https://doi.org/10.18800/360gestion.201702.008

Semana Economica. (2017). Obtenido de Resemin y el Boom de la Innovación bajo Tierra: https://www.youtube.com/watch?v=ShidyVyc2QA.

Sleight, C. (2015). The Yellow Table: Equipment Top 50. *International Construction*.

Smith, K. (2005). Measuring Innovation. In J. Fageberg, D. Mowery, and R. Nelson, *The Oxford Handbook of Innovation* (pp. 148–177). New York: Oxford University. doi:10.1093/oxfordhb/9780199286805.003.0006.

Stracon-GyM. (2018). Cobre Panamá: Case Study - First Quantum Minerals. Retrieved from https://www.slideshare.net/HenryVizcarraValenci1/cobre-panama-project-fqm-stracon.

Stubrin, L. (2017). Innovation, Learning and Competence Building in the Mining Industry. The Case of Knowledge Intensive Mining Suppliers (KIMS) in Chile. *Resources Policy*, 54, 167–175.

Sumitomo. (2019). About Us. Tokyo, Japan: Sumitomo Metal Mining Co, Ltd. Retrieved from http://www.smm.co.jp/E/.

Teck. (2018). Ideas at Work: Improving the Future Through Innovation and Technology. Retrieved from https://www.teck.com/media/Tecks-Approach-to-Innovation-and-Technology.pdf.

The University of Sydney. (n.d.). Australian Centre for Field Robotics. Sydney, Australia: The University of Sydney. Retrieved from https://sydney.edu.au/engineering/our-research/robotics-and-intelligent-systems/australian-centre-for-field-robotics.html.

Thornton, A. (2019). China is winning the electric vehicle race. Cologny, Switzerland: World Economic Forum. Retrieved from https://www.weforum.org/agenda/2019/02/china-is-winning-the-electric-vehicle-race/.

Tras100d. (2017). Vinculación del Presupuesto Público con la Estrategia Sectorial de Minería al 2030.

UN Comtrade. (2019). Imports/Exports Copper Ore & Concentrate (260300), Anodes (7402) and Refined Copper (7403). All Importers/All Exporters. Geneva. New York, NY: United States Statistic Division.

UNESCO. (2019a). Peru. Paris: United Nations Educational, Scientific and Cultural Organization. Retrieved from http://uis.unesco.org/en/country/pe?theme=science-technology-and-innovation.

UNESCO. (2019b). Welcome to UIS.Stat. Paris: UNESCO. Retrieved from http://data.uis.unesco.org/.

Universidad del Pacífico. (2019). Centro de Estudios sobre Minería y Sostenibilidad (CEMS). Retrieved from https://www.up.edu.pe/investigacion-centros/centros-up/centro-de-estudios-sobre-mineria-y-sostenibilidad-cems/Paginas/default.aspx.

Upstill, G., and Hall, P. (2006). Innovation in the Minerals Industry: Australia in a Global Context. *Resources Policy*, 31(3), 137–145. doi:doi.org/10.1016/J.RESOURPOL.2006.12.002.

Urzua, O. (2013). The Emergence and Development of Knowledge Intensive Mining Service Suppliers in the Late 20th Century. Brighton, UK: University of Sussex. Retrieved from https://www.researchgate.net/publication/280776976_The_emergence_and_development_of_knowledge_intensive_mining_service_suppliers_in_the_late_20th_century.

USGS. (2019a). Mineral Commodity Summaries 2019. Reston, Virginia: United States Geological Survey.

USGS. (2019b). National Minerals Information Center: Copper Statistics and Information. Reston, Virginia: USGS. Retrieved from https://www.usgs.gov/centers/nmic/copper-statistics-and-information

World Bank. (2019a). Research and Development Expenditure (% of GDP). Washington, DC: World Bank. Retrieved from https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?name_desc=false.

World Bank. (2019b). World Bank Open Data. Washington, DC: World Bank. Retrieved from https://data.worldbank.org/?

Yamada, G., and Oviedo, N. (2016). Educación Superior y Subempleo Profesional : ¿una Creciente Burbuja Mundial? Lima: Universidad del Pacífico.

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