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Original Article

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Innovation and competitiveness in the copper-mining GVC: developing local suppliers in Peru

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Abstract

Although Peru is one of the main producers of copper worldwide, the domestic industry has not yet fully taken advantage of the potential that the exploitation of this commodity offers. This paper explores the opportunities and challenges that Peruvian suppliers face in their insertion into the mining global value chain. Our analysis is based on a mixed-methods approach, combining both quantitative and qualitative primary and secondary sources, including semi-structured interviews with key actors in the Peruvian mining sector. Our findings suggest that the weak presence of Peruvian suppliers in a sector dominated by few foreign firms is due to global industry dynamics as well as the underdeveloped capabilities of local firms operating in a fragile local institutional setting. However, their opportunities for their insertion are primarily in areas where new solutions are required, which places a demand on the supplier's innovative capacity.

JEL classification: O13, O32

1. Introduction

Peru is the world's second-largest copper producer and exporter, and the sector largely drives the country's economy. The strength of Peru's copper-mining sector is based on large reserves with low-cost extraction compared to the other global locations. Over the past 15 years, this has raised the country's relevance to the global industry, and copper's importance to the local economy. By 2017, copper represented 50% of mining exports and 5% of the 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 the electrification of national energy supply and rapid urbanization in the developing world. However, historically, the increase in demand or any price boost in commodities has not translated into substantial gains for resource-rich economies. It has been difficult for these countries—such as Peru— to capture the value of exploiting these commodities to drive growth and development. Much of the industry is operated by foreign firms in relative isolation from the rest of the economy. This separation has prevented the development of relationships between natural resource industries and "enabling sectors" that supply novel efficiency-enhancing products, essential partnerships that have been central in the economic development of countries such as Australia and Norway (Ville and Wicken, 2013). Thus, as functional upgrading into processing activities is no longer an

attractive path, given that it offers only marginal value gains, host countries have sought alternative pathways to capture value from the sector. A key strategy to accomplish this is the fostering of backward linkages. Today, numerous host economies are promoting the development of local suppliers that can offer products and services to the mining sector (Bamber and Fernandez-Stark, 2022).

This study aims to explore how the country can leverage its strong position in the copper-mining value chain to foster innovative activities and develop local suppliers, thus allowing the national industry to obtain benefits from participating in the global production. We base our analysis on the global value chain (GVC) framework. Several data sources were used for the analysis. Quantitative primary sources were complemented with research from secondary sources; these included a review of the existing academic, trade, and policy literature as well as firm 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.

Our findings suggest that, as it is 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. These are concentrated in services, consumable products, metal structures, niche capital equipment segments, and supply of sophisticated heavy machinery. Local supply has a comparative advantage in these segments, benefiting from proximity, high volume-to-value shipping costs, and the knowledge of specific geological conditions. Many local firms with the potential to supply other areas lack the organizational capabilities, scale, and scope to participate in the industry. Moreover, the integration of more and higher value-added Peruvian suppliers in the copper-mining industry is undermined by its still weak national innovation system and a Peruvian copper-mining policy that has focused heavily on regulation, with little emphasis on the need to innovate and upgrade.

Our findings are relevant for several reasons, as they could be extended to lower-middle-income countries or countries with limited innovation capacity that do not use their geological resources to their full capacity. First, our findings provide a rigorous understanding of the external and internal challenges that limit the access of Peruvian suppliers to the copper-mining GVCs. Second, this paper presents a clear pathway for suppliers with the potential opportunities to develop backward linkages, e.g. supporting the development of industry-specific organizational skills for mining suppliers, as well as the growth of innovation capabilities of local firms. The paper also contributes by presenting a set of policy recommendations for Peruvian suppliers to gain access to the copper GVC, focused on the institutionalization of the sector, increasing the participation of suppliers, and incentivizing upgrading and innovation.

The paper proceeds as follows: in Section 2, we describe the global dynamics of the copper-mining industry. This includes mapping the copper GVC, analysis of the chain geography, the governance structures in the industry, and how these influence the procurement patterns of mining companies. Next, in Section 3, the focus shifts to Peru's evolving sector, identifying where and how local firms are successfully participating and innovating in the industry. Finally, a set of policy recommendations are provided in Section 4, focused on fostering increased participation and innovation by Peruvian suppliers.

2. The copper-mining GVC

This section presents the global trends of the copper-mining industry, from the GVC perspective, including a discussion of how the governance structure of the lead firms shapes the procurement patterns of mining companies around the world.

Copper has become a key input for manufacturing and construction. Today, it is the third most consumed industrial metal after iron and aluminum (USGS, 2019a). This is especially relevant for Latin America, as it is one of the regions with the largest reserves of the red metal. In the particular case of Chile and Peru, the mining industry is a significant contributor to their GDP, accounting for 10% and 5% of GDP, respectively (Banco Central de Chile, 2019; MINEM, 2019). The region leads global copper production and exports, as Chile and Peru alone account for close to 44% of the world's output.

In recent decades, the price of copper has presented a significant fluctuation. However, demand has steadily increased, and there are strong expectations for growth in the coming years. Major structural changes in demand include a growing use of electric vehicles—which use up to four times as much copper as internal combustion engine cars—and a shift into green energy, which is more copper-intensive than coal-generated power (Copper Development Association, 2018). In addition to this, an expected boost in construction due to a sharp increase in global urbanization is also likely to increase the demand for copper (Schipper *et al.*, 2018; Drzik, 2019). These trends suggest that copper is entering a new upward cycle, which is a major opportunity for producer countries such as Peru to develop a more robust sector that would allow the insertion of local firms into the GVC.

Although the copper GVC feeds a large variety of downstream industries, from automotive to construction and energy to health care and manufacturing, the sector upstream is relatively concentrated. Production in the upstream stages is highly concentrated because of the location and economic viability of reserves, as 50% of the world's reserves are located in just five countries. The Latin America region (led by Chile and Peru) dominates these upstream stages (USGS, 2019b).

Peru could be considered as one of the most important actors among countries focused only on copper extraction, rather than processing and refining. In these countries that primarily produce unprocessed copper ores and concentrates, over 75% of export revenues are generated from unrefined copper. These trends of growing demand could offer extracting countries such as Peru a major opportunity to develop their mining sector, in order to obtain greater gains from the industry.

2.1 What is the role of major mining companies in the copper GVC?

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% of production worldwide, with a very strong presence in Latin America, especially Chile, and Peru. Most of the major miners are engaged in all upstream and midstream stages of the value chain, from exploration to refining. In each of these stages, these firms depend on a large number of input providers; outsourcing is as high as 60% in some countries.

2.2 How are the mining companies supplied?

Procurement in the mining sector, of both products and services, is carried out by two key actors—miners and engineering firms. Despite the capital intensity of the industry, services account for approximately half of the operational spending in the copper-mining sector. In the case of Chile, for example, services are dominated by high-value activities; engineering services are the most important category of inputs, accounting for approximately one-fifth of industry spending.

Sourcing practices by these firms 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. Miners are typically very conservative in hiring new suppliers due to the high costs of operational failure on cash flow and profitability, even when other more innovative solutions may be available (Deloitte, 2018).

As a result of the global trends within the industry, with miners primarily sourcing from their established global supply base—and making little effort to connect with local suppliers (Fessehaie and Morris, 2013; Katz and Pietrobelli, 2018)—host countries have placed a strong emphasis on promoting the incorporation of local suppliers into the value chain as backward linkages. Supplying inputs and services to mining companies located in the country, local firms would move to higher-value activities in the GVC, which is key to increasing the benefits from participating in global production.

Local suppliers typically face multiple challenges to 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. Local suppliers in developing countries, on the other hand, tend to be considerably smaller in size, technically specialized, and with lower access to finance and organizational capabilities than their global peers (Katz and Pietrobelli, 2018). Furthermore, as new entrants to the industry, they lack the trust to gain access to mines to pilot their technologies/services (Pietrobelli *et al.*, 2018). Even if the firms are capable of delivering the required product/service, they often are unable to comply with many of the guarantees and prerequisites to become preferred suppliers (Banchile Inversiones, 2016).

With the purpose of creating value-adding opportunities for local firms within the chain and reversing the trends that show that most mining inventions come from a few countries (Fernandez, 2021), some mining countries have adopted a new approach focused on enhancing a more collaborative relationship between miners and local suppliers. Such strategies aim for the adoption of new technologies and innovation that would lead to the development of backward linkages. However, the mining innovation literature highlights factors that hamper the ability of local suppliers to develop innovative solutions, such as a shortage of local skilled labor force, high level of risk aversion among mining companies, limited communication between them and suppliers (Bravo-Ortega and Muñoz, 2021; Calzada, 2022), the phase of the mineral price cycle (Atienza and Modrego, 2019; Calzada and Iisuka, 2020; Fernandez, 2022), and financial and regulatory obstacles (Fernandez, 2020).

Numerous policies and programs have been implemented around the world 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 (Korinek and Ramdoo, 2017). However, these policies have been met with varying degrees of success. The next section explores the opportunities and challenges that the Peruvian copper sector faces in the insertion of local providers into the mining sector.

3. Opportunities for Peruvian suppliers in the copper-mining GVC

Peru is the world's second most important copper producer (World Bank, 2021), 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, this is dominated by foreign suppliers, and there is very low participation of Peruvian suppliers in value-added inputs. The relatively weak presence of local suppliers in the industry is reflective of global industry dynamics combined with the generally undeveloped capabilities of local firms. The prospects for their insertion are mostly in areas where new solutions are needed, which puts a heavy burden on the potential for innovation 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 increase, as the development of new mines would provide a significant boost in demand, for a range of services from feasibility to engineering and construction services, so as for products used as inputs for processing plants. This represents a significant potential opportunity for the country; however, neither the current local supply base nor the national institutions are prepared to take advantage of this.

3.1 Methodology

This research paper follows the GVC methodology. 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 the Peruvian mining sector. Additionally, multiple academic, trade, and gray literature sources were analyzed to cover private-sector engagement in the industry. This included reviews of the annual reports of 12 leading copper-mining companies (multiple years), reviews of both miner and supplier websites, sustainability reports, and private-sector databases (e.g. Orbis), as well as a review of relevant industry publications, including the World Copper Fact Book, Mining.com, Mining Global, and Global Mining Review among others.

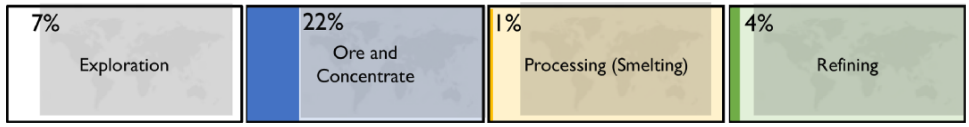

Figure 1. Peru's position in the copper global value chain (GVC). *Source*: Authors based on UN Comtrade (2019).

In order to identify procurement patterns in the Peruvian mining sector, as well as the challenges and opportunities that Peruvian suppliers face in their insertion into copper GVCs, more than 20 semi-structured, 1-hour interviews were carried out between March and May 2019 with (I) mining companies in Peru, (II) Peruvian mining suppliers, (III) mining industry experts in Peru and Chile, (IV) government officials (current and former), and (V) 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-mechanic sector. Both interviews were carried out in 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 both 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 a "snowball" technique, having interviewees identify suppliers or peers.[1]

3.2 Peru in the copper-mining GVC

As the world's second-largest exporter of copper ore and concentrate (UN Comtrade, 2019), Peru is a major actor in the upstream stages of the copper GVC. The strength of Peru's copper-mining sector is based on large reserves with very low cash costs. With 81 million MT, Peru has the third largest copper reserves in the world after Chile and Australia (USGS, 2019a). These reserves are relatively cheap to extract; at the country level, Peru's cash costs are the lowest in the world.[2] As a cheap destination with ample supply, the global growth in copper demand has thus spurred the development of the industry in Peru (Figure 1).

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 country's importance resides in the upstream stages, as it accounts for 22% of the global copper concentrate exports in 2017 (Figure 2).[3]

Production is concentrated in a small number of large- (>200kilotons (KT) and medium-sized mining companies ($45KT < X < 200KT$). The top 10 mines account for 96% of all copper produced. The three largest mines are world class mines,[4] owned by consortia of primarily foreign majors and operated by local mine-specific companies: Cerro Verde (US–Japanese–Peruvian), Las Bambas (Chinese), and Antamina (Australian–Swiss–Canadian–Japanese). Southern Peru Copper (Mexican–US) is the largest single-firm mine operator in the country. Only one Peruvian firm has a significant position in Peru's copper-mining sector, Buenaventura, which owns 20% of Cerro Verde and operates the medium sized, El Brocal, which accounts for 2% of national copper output. Seventy percent of copper-mining production is located in Southern Peru (MINEM, 2019) (Table 1).

Large reserves have attracted considerably exploration activities. In 2017, Peru captured 7% 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.

[1] 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.

[2] It costs approximately US$1.10/lb in Peru compared to US$1.48/lb in Chile, Australia, and Canada and US$1.42 on average globally (BBVA Research, 2019).

[3] This concentrate is destined primarily to Asia, which accounted for 82% of copper exports in 2018. Chinese smelters absorb the majority (64%), followed by Japan (9%) and South Korea (6%) (UN Comtrade, 2019).

[4] Global top 10.

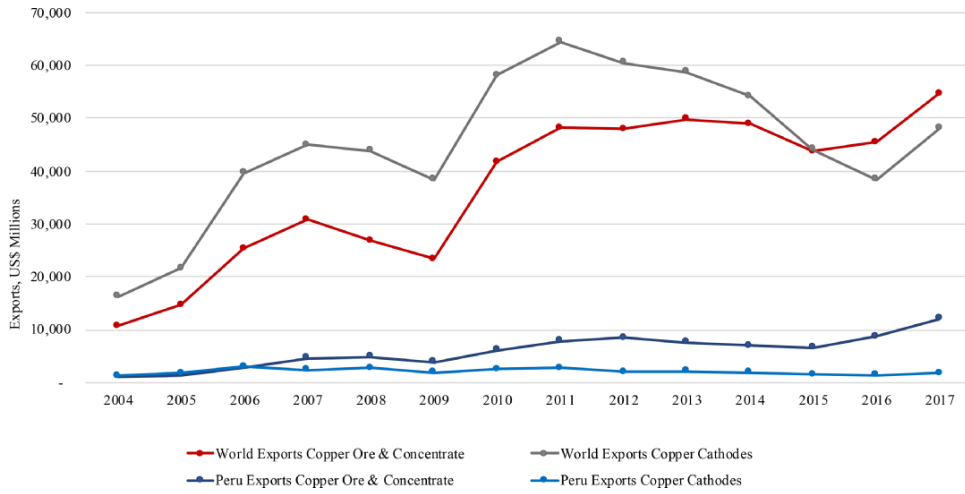

Figure 2. Peru in the copper global value chain (GVC), exports by value (US$M), 2004–2017. *Source*: (UN Comtrade, 2019).*Notes*: HS02 260300 (copper ore and concentrate), 7402 (unrefined copper and copper anodes for electrolysis), and 740311 (copper cathodes). Peru/All exporters. Downloaded May 23, 2019.

Table 1. Peru's leading copper mines

Mines	Ownership	Processes	Output (MT)	
			2017	%
Cerro Verde	Freeport-McMoran, Sumitomo, Buenaventura	Solvent Extraction-Electrowinning (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, and SE-TW	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).

Feasibility and mine development are led primarily by foreign firms; of the 23 projects in the copper portfolio, only 3 are owned by Peruvian firms: Trapiche, Río Seco (Buenaventura), and Quechua (Compañia Minera Quechua). The remaining projects are owned primarily by major mining firms. Consistent with a poor global pipeline within the next years, only two projects are currently under construction. Quellaveco, jointly owned by Anglo-American and Mitsubishi, is the largest new project nearing commissioning and the expansion of Toromocho (Chinalco Perú).

New investment projects include a new 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 its production permit. There are also new projects that will produce Solvent Extraction-Electrowinning (SE-EW) cathodes, including Tia Maria, which would produce 120,000 tons of copper cathode (Figure 3).

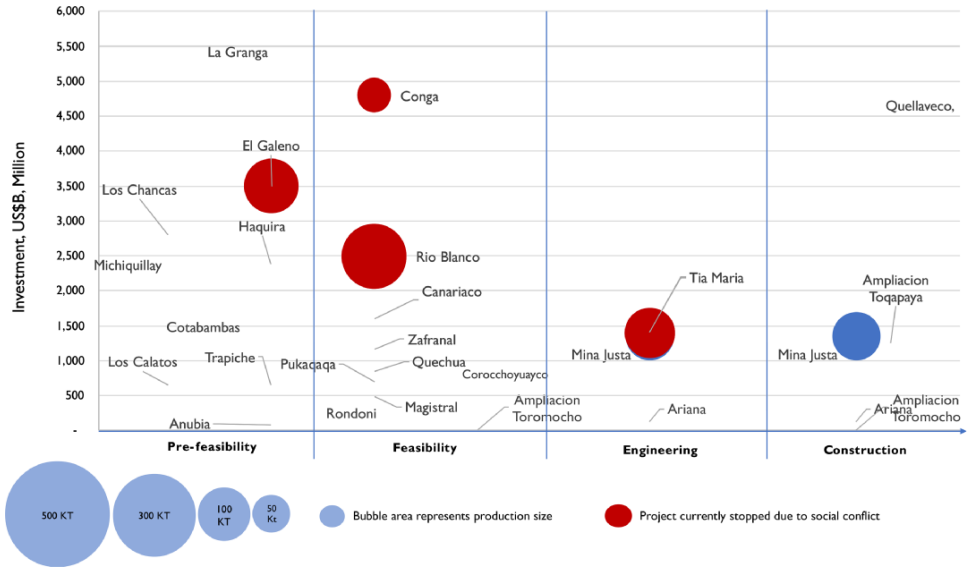

Figure 3. Key investments in the copper-mining sector in Peru, by stage of mine development. *Source*: Authors based on MINEM (2019).

3.3 Copper-mining procurement in Peru

As a leading producer of various minerals including copper, expenditure in the Peruvian mining industry is considerably high. In 2017, for the sector as a whole, this reached US$9 billion in goods and services.[5] Goods spending was concentrated on fuels and utilities, followed by chemicals and explosives and capital equipment, which collectively account for 80% of spending. On the other hand, services spending is focused on transportation and logistics, professional and technical services, and labor contracting (82%).[6] Excluding categories characterized by oligopolistic supply (e.g. fuel and utilities), the approximate annual market size in Peruvian mining is US$2.3 billion for goods and US$4.4 billion for services. Copper is estimated to account for approximately half of this expenditure,[7] representing a considerable market for suppliers. See Figures 4 and 5 for the expenditure of the Peruvian mining sector, and Table A1 for details on the products and services purchased by mines in Peru.

Procurement, of course, varies by value chain stage driven primarily by variations in capital expenditure (CAPEX). CAPEX is most significant during mine development and/or expansion (46% of the total procurement costs), with the building of mine infrastructure and mineral processing plants collectively accounting for 37% of CAPEX in 2018 (INEI, 2017). As the mine prepares for extraction, a further 10% is spent on the acquisition of mobile mining equipment such as drills, shovels, and haulage trucks. For example, the expansion of Cerro Verde, which doubled its production, included US$4.6 billion in procurement (MINEM, 2019); Las Bambas mine development investment totaled US$10 billion[8]; and Southern Peru Copper invested US$1.2 billion in a major expansion underway at Toquepala (Gestión, 2017). Mining investment for new project development/expansion is projected to be US$21 billion between 2018 and 2021 and, by 2028, US$58.5 billion (Millan Lombrana and Quigley, 2018). This expansion offers potential for more procurement although new mine investment itself is dependent on a sustained copper

[5] This includes all expenditures for mining registered in the national current accounts, excluding that noted as gross fixed capital formation. This is comparable to spending in both Chile (US$12.2 billion, 2016) and Australia (US$20 billion, 2016) although expenditure as a share of output is much larger in Australia than in Chile and Peru.

[6] Source: INEI (2017).

[7] This is based on the following assumption: copper mining accounts for approximately half of the output of the country and is carried out by capital-intensive global miners.

[8] Direct imports by Cerro Verde of capital goods and construction materials—excluding those acquired from foreign subsidiaries in Peru—accounted for approximately 25% of that expenditure (Aduanas—SUNAT, 2017).

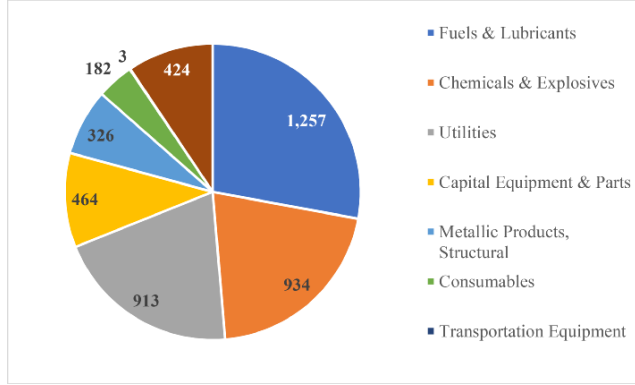

Figure 4. Expenditure of Peruvian mining sector in products, 2017. *Source*: Authors, based on 2017 Peruvian Supply Use Matrix INEI (2017).

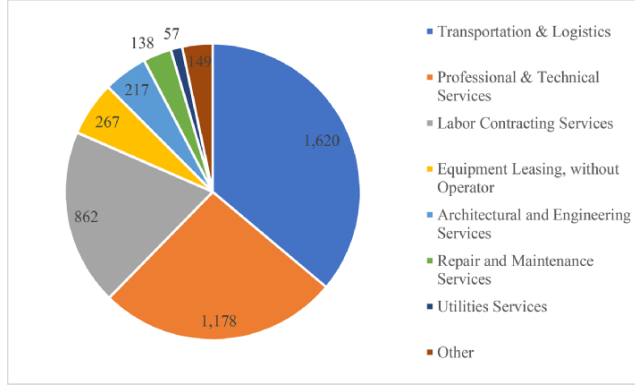

Figure 5. Expenditure of Peruvian mining sector in services, 2017. *Source*: Authors, based on 2017 Peruvian Supply Use Matrix INEI (2017).

price. Figure 6 illustrates mine procurement expenditures in 2018 by value chain stage, including the top mine spenders.

3.4 Mining supply chain in Peru[9]

While Peru's copper-mining sector was initially supplied by foreign firms from global or Chilean headquarters, today, there is a growing local supply chain (Field Research, 2019). In 2017, the leading 10 copper miners directly imported just US$446 million (Aduanas—SUNAT, 2017).[10] Several of these copper miners report procuring as much as 90% of their inputs locally (Field Research, 2019).[11] The local supply chain consists of three main sets of suppliers: (I) subsidiaries of global mining suppliers, (II) subsidiaries of Chilean mining suppliers, and (III) Peruvian suppliers. Foreign suppliers with operations in Peru include a strong presence of mining equipment

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

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

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

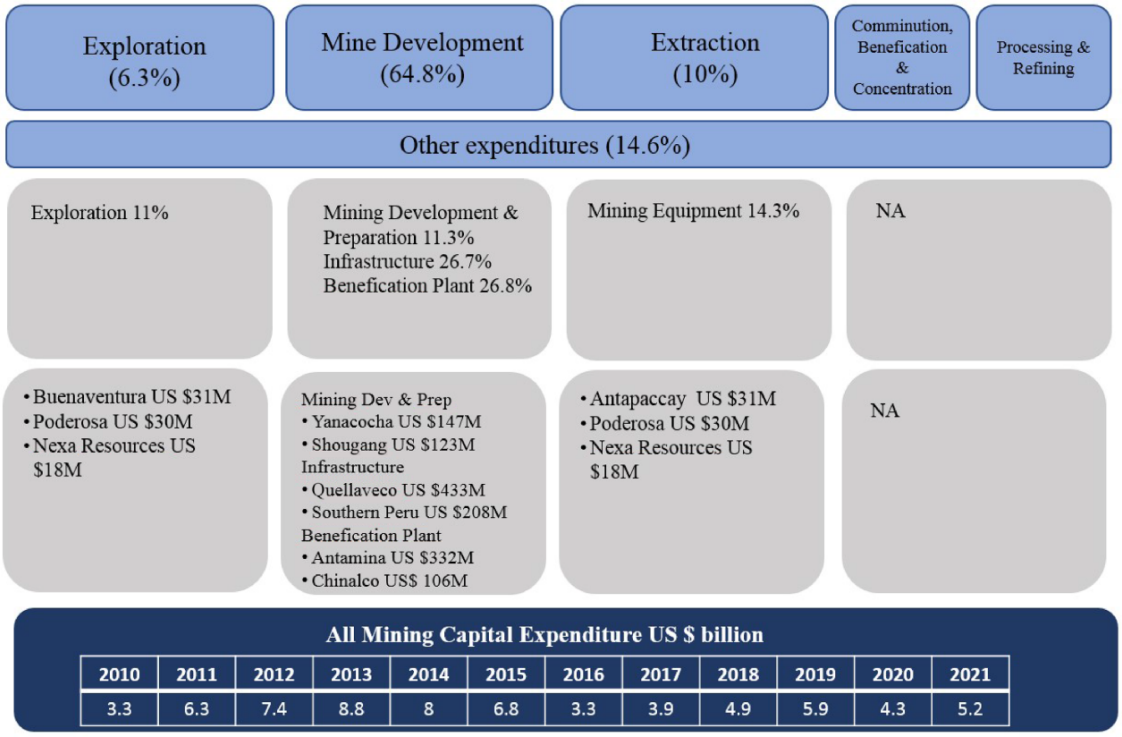

Figure 6. Mining capital expenditure by value chain segment, 2021. *Source*: Authors based on Anuario Minería Peruana 2010–2021 (MINEM, 2022).

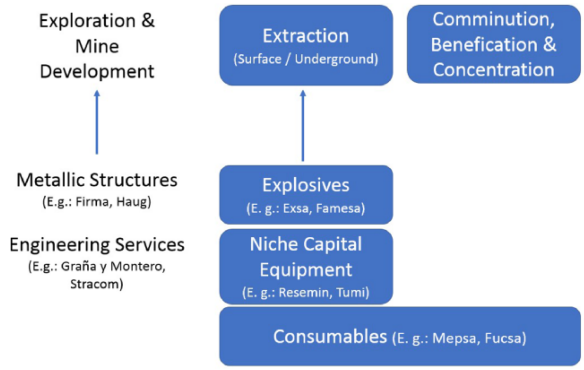

Figure 7. Select Peruvian suppliers in the copper global value chain (GVC). *Source*: Authors. *Note*: Fuel/transportation/accommodation services are not disaggregated as they tend to be non-tradable.

suppliers and engineering firms. However, after more than two decades in the copper-mining industry, there is a growing number of Peruvian suppliers.

Peruvian suppliers are present in 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 (Figure 7). 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 *et al.*, 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 into the mining GVC due to their lack of scale and scope, access to finance, and relatively weak organizational structure playing against them. In addition to this, reputation and past experiences are also key factors in the mining industries, resulting in a big disadvantage for emerging suppliers against more experienced firms (Molina, 2018). Moreover, in some cases, suppliers do not have formal channels through which they can offer their products. Therefore, they use indirect linkages to engage with the mining sector[12] (Aron and Molina, 2020).

Most local suppliers are producing standardized products and services, with a 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 of 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, 2017; Aron and Molina, 2020).

3.4.1 Services

In terms of value-added activities, local firms provide a range of services for the pre-feasibility and feasibility activities within the exploration and mine development stage of the chain, particularly with respect to environmental, social, and geotechnical areas where local expertise is an asset. These include Proesmin, MinConsulting, and SRK Consulting, among others. These firms have tended to expand their service offerings over time, for example, licensing and customizing foreign software. SRK Consulting went from providing environmental services to providing due diligence in site exploration.

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 were suppliers that 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 to reduce new tire consumption by 18% in Antamina (Antamina, 2017). NDT Innovation, on the other hand, introduced a new-to-market innovation with noninvasive digital technologies to offer preventative maintenance services. 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 to further their understanding of how to tailor their services for specific contexts and gain reputation in the local market.

A second group of service suppliers are also emerging following the global trend of "servicification" of the mining industry. These product manufacturers are adopting an equipment-as-a-service (XaaS) business model. These include firms in a range of different activities. For example, Exsa, a leading Peruvian explosive 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 for monitoring 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 a new product Quantex in 2015, which

[12] Examples of this include the following:

- The entrance of an investment partner that had several clients within the mining sector was a determinant for the insertion of the supplier into the sector.
- Professional networks of their co-founders were determinants for the establishment of business relationships with mining firms.
- In another case, a business relationship was established, thanks to the fact that both firms share the same owner.

helps reduce mine blasting costs by up to 20%. Qaira developed an autonomous charging station (Field Research, 2019).

3.4.2 Products

The presence of Peruvian suppliers in product supply is concentrated in metallic structures, consumables, and niche capital equipment. Suppliers include Fabertek, Fima, Haug, Andes Peru, and Mimco among others. These firms also serve multiple other sectors including construction, infrastructure, and oil and gas, as well as acting as suppliers for Original Equipment Manufacturers (Bamber *et al.*, 2016). As standard products for existing equipment, innovation among this group of suppliers is limited. Upgrading in these products has consisted primarily of improving product quality, 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).

3.5 Peruvian supplier capability development[13]

Peruvian mining providers utilize different strategies to develop their capabilities to offer products and services to the mining sector. These approaches can be grouped into two general categories: (I) fostering internal capability development through the recruitment and cutivation of skilled human capital, and/or establishing in-house research and development (R&D) departments and (II) tapping into external expertise and knowledge, at local/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 later.

3.5.1 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 engineering, master's, and doctoral degrees in technical fields. While this is particularly notable in services firms—Proesmin primarily employs engineers with masters—this also extends to manufacturing companies; approximately 15–20% of Resemin's staff are engineers. Employees are mostly Peruvian 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 skill sets. For example, SRK Consulting places new employees in operations in Australia or the United States for up to 2 years. These employees may also undertake graduate degrees during this time, with financial support from the company. Exsa, likewise, invests in foreign training for its employees.

Several of the larger Peruvian mining products suppliers have created strong R&D centers, and usually, these are the well-known firms in the sector such as Exsa, Resemin, and Tumi. These are the companies that concentrate on patents in Peru. Exsa invests around US$2.2 million annually in its R&D department that employs nine highly qualified workers; it holds at least three patents. Famesa Explosivos spends 0.75% of its revenue on R&D; yet the company holds the highest number of patents awarded in Peru (CARMAR, 2018). Resemin designs its equipment with an in-house team. Likewise, Tumi created sophisticated underground mining equipment with its workers in its Peruvian workshop.

Some of the service providers also invest 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; in the last 2 years, the firm spent more than US$2 million on innovation. Green Mining places a heavy emphasis on internal R&D capabilities and has patented much of its work, albeit outside of Peru. Overall, services firms noted that they have concentrated protection efforts in constantly innovating in their services rather than in

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

patenting them. So, the number of patents does not show a strong correlation with the level of innovation of local mining suppliers.

3.5.2 External capability development strategies

Universities are important sources of knowledge for innovation in processes and products, as the knowledge and ideas emanating from universities and research institutions increase both the quality and quantity of innovations (Arundel and Geuna, 2004; Demircioglu *et al.*, 2019). Thus, 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. Some innovative firms (e.g. NDT and Qaira) have close links to universities, including Pontificia Universidad Catolica del Peru and Universidad de Ingenieria y Tecnologia (UTEC). It is more common for these firms to partner with foreign universities, particularly those in Australia (e.g. University of Queensland) and the United States (e.g. Massachusetts Institute of Technology (MIT) and University of Houston). Partnering with universities is one model firms use to access national and international funding for innovation; Qaira, for example, won a seed capital innovation award from MIT to help develop the company.

Relationships with foreign suppliers are considered critical by firms to gain market access—in Peru and abroad—as well as to develop 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 the adaptation of foreign technology for the local market. MinConsulting, for example, became an authorized software provider for two key foreign suppliers, which had previously only been available from foreign locations. In addition, international exchange between foreigners and Peruvian staff helped to increase the service quality in Peru and improve their position in the local market.

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. Due to ongoing provision, services firms tend to have a higher degree of interaction in the development of their solutions; Minconsulting, for example, noted that it holds weekly meetings with buyers. Nonetheless, product suppliers also emphasize that their experience working in the mine regularly is a major contributor to their base knowledge and mine needs for new solutions. New products and/or service testing or piloting is more limited although both miners and suppliers concur that there is some (limited) space for providing testing innovations where there is a trusted relationship (e.g. Exsa) or there is non-intrusive testing (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, which focused on supporting the capability development of local suppliers, but rather than providing technical know-how, this mostly focused on indicating areas in which new solutions would be welcome and providing testing facilities (Field Research, 2019) See Figure 8 for the summary of key capability development mechanisms.

3.6 National innovation system in Peru

The relatively weak innovative activities by firms in the sector are, 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 in most global innovation indicators. While stakeholders agree that significant progress has been made over the past 5 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.[14]

[14] Between 2015 and 2017, the country experienced a rise of just 0.004% in R&D expenditure as a share of GDP. Peru also performs poorly compared to both its regional peers, and the global average. In 2017, Peru spent 0.12%/GDP compared to 0.36% in Chile, 0.76% in Latin America, and 2.2% (global) (World Bank, 2019).

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 those existing actors to maximize upon their contributions (Concytec, 2017; BBVA Research, 2019; Field Research, 2019). However, recent efforts have been made to establish new innovation research centers, with the establishment of Centros de Innovación y Tecnología (CITEs). These, however, 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). Policies to support and coordinate innovation activities are crucial, as country-level macro and institutional characteristics are important determinants of firm-level innovation in developing countries (Paus *et al.*, 2022).

Importantly, as the innovation ecosystem has slowly emerged in public, private, and academic areas, these have operated in silos, with weak coordination across actors undermining the potential for synergies and applied research. Among research centers, only 26% have linkages with the private sector and only 37% have any connection to local, regional, and/or national government (Belapatiño and Perea, 2018). Peru is ranked 98th of 129 economies (2018) for private-sector–university collaboration 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% 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.

Within this context, the innovation ecosystem supporting the mining sector in Peru is relatively new and fragmented, emerging in parallel to 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

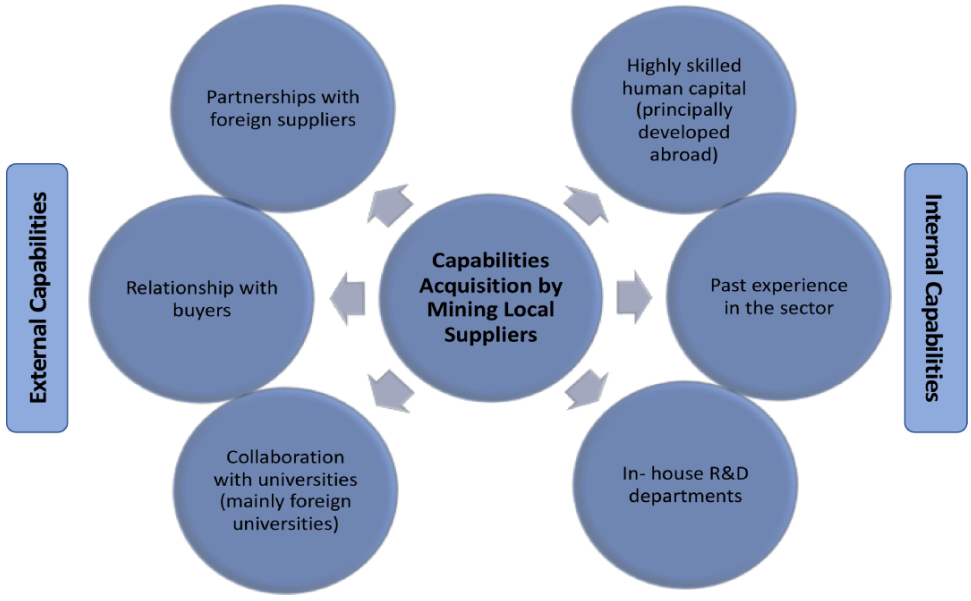

Figure 8. Summary table of key capability development mechanisms. *Source*: Authors.

regulating the sector, particularly concerning environmental and social concerns,[15] rather than 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. These include a working group at the Ministry of Economics and Finance (MEF) 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, among others. 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 to 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 (see Table A2 for a detailed list of policies and programs), but these have had a low impact on the industry. The most relevant programs for the development of innovative mining suppliers include (I) Innovate Peru, (II) the 2015 R&D Fiscal Credit, and (III) Accelerated Patent Development Programs. However, very few Peruvian mining suppliers have taken advantage of these initiatives to date. Only 51% of innovative firms in Peru serving natural resources industries even know about the public programs (INEI, 2017), and the ones that are familiar with these instruments are reluctant to apply due to 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 little impact to date with low awareness (Gestión, 2018). Only 49 projects were approved across the entire economy—not just the mining sector in the 3 years of operation. By comparison, in Chile where a similar R&D credit was introduced in 2012, in 2018, the mining sector alone received the same R&D credits as the entire economy in Peru (US$10 million) (Gestión, 2018).

There are emerging research centers focused on mining although these nascent initiatives are limited. Most of these are driven by private universities; of the 47 public–private research institutes established under the CITE program by 2018, only one is focused on mining, with initiatives generally coalescing around environmental issues related to mine closure and was established together with the private sector (Instituto Tecnológico de la Producción, 2019; Universidad del Pacífico, 2019). Leading private universities, including Universidad Católica de Peru, Universidad del Pacífico, Universidad Nacional de San Agustín, and UTEC, have research efforts underway 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 via the mining canon[16]; in 2018, these universities received US$48 million destined for scientific research in 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 ones, not local institutions.

3.7 Findings and discussion

3.7.1 Challenges and opportunities of Peruvian suppliers

In this section, we will present the main findings obtained from the GVC framework used to study the trends that affect the Peruvian copper-mining industry and its current and potential suppliers. As it was stated at the beginning of Section 3, only there is a small number of Peruvian suppliers inserted into copper-mining GVC. The GVC analysis suggests that procurement patterns locally reflect those of the global industry, as the Peruvian copper-mining industry is dominated by large

[15] Since 2007, the Agency for Environmental Assessment and Enforcement and the Ministry of Labor joined the Ministry of Energy and Mines in the oversight of the mining sector activities, which turned into excessive bureaucracy and high degrees of redundancy (Vivoda, 2008). As a result, there is an overregulation of the mining industry, as the number of regulations increased more than 10-fold, from 24 to 242. One of the consequences of overregulation can be seen in the time that takes an Environmental Impact Statement to be granted. While in Canada and Chile it could take around 2 weeks and 3 months, respectively, in Peru, the waiting time ranges between 18 and 24 months (Revista ProActivo, 2021).

[16] This is based on the government' income from mining. In 2018, the majority of these funds (70%) must be destined to research, development, and innovation.

multinational corporations. Purchasing by miners is led by the principals 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. The 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 1–2 years; 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. 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 among others. However, in order to obtain these social licenses, mining firms should focus on community responsibility, environmental responsibility, and stakeholder engagement (Saenz, 2021). In particular, as water has become one of the main causes of social conflicts in the mining sector, mining firms must improve their decisions in terms of water-related factors in order to earn social licenses (Saenz, 2022).

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, new innovations are not encouraged (Field Research, 2019). The cost of disrupting operations to introduce a new process is 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. However, by leaving the contractors and suppliers with the responsibility to update technologically, their role in the process of innovation is only to inform the potential suppliers of their needs rather than to provide them with adequate tools to achieve the solutions required (Molina *et al.*, 2016). In addition to this, miners are typically reluctant to publicly disclose where they have challenges in their operations, leading to information asymmetries (Field Research, 2019).

Table 2 summarizes the strengths and weaknesses of these local firms in supplying the copper GVC. These firms have a comparative advantage based on their strong local knowledge, proximity to clients, and their willingness to be flexible to specific client needs, as 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

Table 2. SWOT analysis of Peruvian mining suppliers

Strengths	Weaknesses
• Strong local knowledge (geological, cultural, and 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 and social) • Increase in centralized global sourcing • Social conflict • Uncertain global trade environment

Source: Authors.

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.

3.7.2 Capability development and innovation in Peruvian suppliers

The GVC framework suggests that, in order to obtain the benefits from participating in the international copper industry, Peruvian suppliers should insert into the copper GVC through the development of backward linkages. In order to provide higher-value inputs to mining companies, in Section 3.5, we observe that Peruvian suppliers use different approaches to develop capabilities.

However, the analysis suggests that there is virtually no capability development as a result of interaction among domestic suppliers. Suppliers typically operate in silos and have no industry representation beyond one focused exclusively on metal-mechanic firms[17] and a brand-new Department for Suppliers at Sociedad Nacional de Minería, Petróleo y Energía (SNMPE) although this organization primarily represents miners' interests rather than the industry as a whole.

As it was mentioned in Section 3.6, research efforts focused on the Peruvian mining are undermined by a lack of sufficient funding and their limited application. The analysis based on the data collected from the interviews suggests that underlying these issues lies a shortage of human capital available to support research initiatives for innovation in the copper-mining sector. This shortage is observed across university programs, independent research centers, and even within firms themselves. University programs have typically produced engineers with basic sets of skills, rather than those oriented specifically toward the mining industry. There have been efforts to address this shortage; however, these remain limited and still focused on meeting the operational rather than innovative needs of the industry.

The lack of qualified human capital combined with poor access to finance undermines research among private-sector actors, amplified by the uncertainty of whether local suppliers will have market access to 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 required, 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.[18]

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 the 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 (see Table 3).

The following section offers a set of policy recommendations focused on fostering increased participation and innovation by Peruvian suppliers.

[17] Asociacion de Empresas Privadas Metalmecanicas del Peru was established in 2013 and currently has 25 members (AEPME, 2019).

[18] While technically, most firms are eligible for the R&D fiscal credit, in order to actually benefit from the R&D fiscal credit, companies must first be paying income tax. The fiscal credit, in effect, reduces the total tax owed. It thus only becomes an incentive to carry out R&D if the firm is generating sufficient profit for the R&D credit to offset income taxes owed.

Table 3. 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 the 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 the government • High levels of bureaucracy in using instruments • Lack of policymakers with experience in innovation instruments • Relatively weak Intellectual Property Protection (IPP) • No coordination among industry stakeholders

Source: Authors.

4. Policy recommendations

In order to develop strong and innovative local mining suppliers, the country needs to focus first on creating strong institutions to support the development of the sector; second, it needs to assist and facilitate the entry of the local providers to the mining GVC; and third, it is imperative to incentive innovation and upgrading of the local providers. These recommendations are discussed later.

4.1. Institutionalization

First, 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, and little focus has yet been placed on how to upgrade within the copper-mining GVC or how this sector can be effectively utilized 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 the ministry has staff qualified to manage innovation initiatives. Currently, there are multiple, redundant initiatives underway in the country, with a varying array of actors participating. A single multi-stakeholder council led by the policy champion 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 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. At the same time, the formation of an industry association to represent mining suppliers should be supported. A collective entity would facilitate miners' efforts to interact with local suppliers, create a platform for potential collaboration to help suppliers in achieving scalability, and help the direction of internationalization endeavors.

4.2. Participation—entry

Policies need to be implemented to both improve the organizational and technical capabilities of local suppliers and 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 do exist for technically capable firms. First, firms would benefit from training on 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.

A second 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.[19] The current requirements, however, are vague and lack enforceability, and the institutional complexity in Peru undermines the analysis and transmission of this information to relevant stakeholders, rendering it largely ineffective. The mining sector is neither required nor incentivized to run private local supplier development programs. 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 of local supplier capabilities, and to create opportunities to directly link these two. Examples include public online procurement platforms and/or supplier matchmaking days among others. Suppliers' databases can be organized by ethnic groups, gender, and geographic locations, among others, to help miners to meet relevant public obligations and internal corporate social responsibility commitments.

4.3. Innovation and upgrading

Promoting innovative local suppliers in the industry requires significantly more support. First, as miners do not typically 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. Link Miners is seeking to address this gap; this model could form the basis for a national-level program as has happened in Chile.

Developing innovation capabilities requires initiatives in areas of human capital availability, research and development infrastructure, and commercialization of innovation. 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 Science, Technology, Engineering and Mathematics capabilities as well as offer opportunities to work in applied research centers. However, in the long run, the policy should aim to improve engineering, technical, and related programs in Peruvian universities as well.

Second, the 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-long term, training of R&D personnel at foreign universities can help to shift the culture toward one of the greater applications.[20] In the short-to-mid-term, this can be addressed with a dual approach—by the creation of a new public–private R&D center in one of the key mining regions such as Arequipa[21] to be staffed by a combination of experienced foreign and younger local researchers and by incentivizing firms to engage in R&D activities with foreign universities. Mining3 is an industry-focused research organization in Australia, with the mission to develop solutions to provide both incremental and major increases in productivity and overcome key global mining challenges. The organization partners with members from the industry (8-year terms), universities, suppliers, and service providers to develop these solutions. The research program is directly linked to mining challenges identified by the miner members, and a technology transfer plan ensures that 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 generally are 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 has Chile under the Alta Ley project. The Mining Technology Testing Center (M2TC)

[19] It was put in place in 2003 for the first time.

[20] In addition, "research facilitators" can be introduced to help local SMEs 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 (Koutsogeorgopoulou and Park, 2017).

[21] The South of Peru concentrates 70% of copper production and 50% of all future mining projects.

Table 4. Select policy recommendations

Institutionalization	Participation: GVC entry	Innovation and upgrading
• Develop a long-term national strategy for the copper-mining sector • Identify 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 the development of an online portal to link suppliers and buyers • Suppliers' matchmaking forums	• Establish/strengthen mechanisms to support demand-driven innovation (e.g. portals, events, and studies) • Improve the availability of human capital in key areas using scholarships abroad • Support a short-term strategy of local suppliers to work with foreign universities on R&D until the local universities establish know-how • Create an R&D center exclusively focused on applied research for copper mining • Support the 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 raining programs on financing innovation, protecting intellectual property, and managing innovation programs

Source: Authors.
GVC, global value chain.

is co-financed by CORFO, four leading Chilean universities, and Minnovex, the industry association for mining suppliers. The center allows suppliers to test technologies at the same scale as the mining sector, access expert advice for scaling up the solutions, and apply global mining standards.

Third, local suppliers would benefit from capability development specifically with respect to the commercialization of innovation. This has several facets including options for R&D financing, protecting intellectual property (IP), and managing innovation projects. R&D financing includes, but is not limited to, R&D fiscal incentives and the mining canon. While there needs to be increased awareness of these incentives and perhaps a restructuring of the way in which canon financing is distributed,[22] a focus should be placed on educating private and public actors about the range of other opportunities from accelerators such as UP Emprende to angel and venture funds, as well as raising the profile of mining suppliers among these risk capital actors (Expande Minería, 2019). Likewise, there is a need for training regarding protection and ownership of IP 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 these, and firms may not be well positioned to defend against patent infringement. In Table 4 select policy recommendation can be found.

[22] In this regard, in 2020 and 2021, CONCYTEC presented two bills (Proyectos de Ley 7594/2021-PE and 07339/2020-CR) for the creation of a National Fund for Science, Technology and Innovation. This fund would be financed, among other sources, with 3% of the resources coming from the canon, overcanon, and mining royalties. However, both bills were shelved.

5. Concluding remarks

In this paper, the GVC framework was used to analyze how the governance structures of the lead miners worldwide shape the acquisition patterns of mining companies in Peru, in spite of the privileged position of the country in the upstream stages of the copper value chains. The findings suggest that these global trends have an impact on the domestic industry, as local suppliers struggle to insert in higher-value stages of the copper-mining GVCs. In this context, opportunities for domestic suppliers arise mainly in new mine developments. However, an underdeveloped local industry, in combination with an environment that discourages innovation, hinders the ability of suppliers to provide high-value inputs to miners.

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 policy from the government is little focused 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.

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References

Aduanas - SUNAT (2017), 'Data Aduanas (exportaciones e importaciones)'. Superintendencia Nacional de Aduanas y de Administración Tributaria: Lima.

AEPME (2019), 'Asociados,' https://aepme.pe/no-sidebar-full-width-2-2-2/.

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

Aron, A. S. and O. Molina (2020), 'Green innovation in natural resource industries: The case of local suppliers in the Peruvian mining industry,' *The Extractive Industries and Society*, **7**(2), 353–365.

Arundel, A. and A. Geuna (2004), 'Proximity and the use of public science by innovative European firms,' *Economics of Innovation and New Technology*, **13**(6), 559–580.

Atienza, M. and F. Modrego (2019), 'The spatially asymmetric evolution of mining services suppliers during the expansion and contraction phases of the copper super-cycle in Chile,' *Resources Policy*, **61**, 77–87.

Bamber, P. and K. Fernandez-Stark (2022), 'Agregar valor en las cadenas globales de recursos naturales: el caso chileno,' *Revista Integración Y Comercio*, **48**(26), 17.

Bamber, P., K. Fernandez-Stark and G. Gereffi (2016), 'Peru in the Mining Equipment Global Value Chain: Opportunities for Upgrading,' Washington D.C. 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: Chile.

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

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

Belapatiño, V. and H. Perea (2018), 'Perú: innovación una agenda pendiente,' BBVA Research: Lima.

Bravo-Ortega, C. and L. Muñoz (2021), 'Mining services suppliers in Chile: a regional approach (or lack of it) for their development,' *Resources Policy*, **70**, 101210.

Calzada, B. (2022), 'Innovation in mining: what are the challenges and opportunities along the value chain for Latin American suppliers?,' *Mineral Economics*, **35**(1), 35–51.

Calzada, B. and M. Iisuka (2020), 'How does innovation take place in the mining industry? Understanding the logic behind innovation in a changing context,' *Working Paper No. 2020-019*. UNU-MERIT, Maastricht University. www.merit.unu.edu/publications/working-papers/abstract/?id=8511.

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

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

Copper Development Association (2018),' Copper is Among the Best Conductors of Electricity and Heat,' https://copperalliance.org.uk/aboutcopper/applications/energy-and-renewables/.

Cornell University, INSEAD, and WIPO (2018), *The Global Innovation Index 2018: Energizing the World with Innovation*. Ithaca, Fontainebleau and Geneva: Cornell University, INSEAD, and WIPO.
Deloitte (2018), 'Tracking the Trends 2018,' https://www2.deloitte.com/content/dam/Deloitte/us/Documents/energy-resources/us-er-ttt-report-2018.pdf.
Demircioglu, M. A., D. Audretsch and T. Slaper (2019), 'Sources of innovation and innovation type: firm-level evidence from the United States,' *Industrial and Corporate Change*, **28**(6), 1365–1379.
Drzik, J. (2019), 'Infrastructure around the World Is Failing,' https://www.weforum.org/agenda/2019/01/infrastructure-around-the-world-failing-heres-how-to-make-it-more-resilient/.
Expande Minería (2019), 'Open Innovation in Mining,' https://expandemineria.cl/wp-content/uploads/2019/02/OpenInnovation-OK-1-1.pdf.
Fernandez, V. (2020), 'Innovation in the global mining sector and the case of Chile,' *Resources Policy*, **68**, 101690.
Fernandez, V. (2021), 'Cross-country concentration and specialization of mining inventions,' *Scientometrics*, **126**(8), 6715–6759.
Fernandez, V. (2022), 'Innovative intensity in the mining industry: evidence from patent families,' *Resources Policy*, **78**, 102805.
Fessehaie, J. and M. Morris (2013), 'Value Chain Dynamics of Chinese Copper Mining in Zambia: Enclave or Linkage Development?,' https://link.springer.com/article/10.1057/ejdr.2013.21.
Field Research (2019), 'Peru field research copper mining industry,' Lima.
Gestión (2017), 'Southern Copper Planea Invertir Cerca de US$ 1,200 Millones en el 2017,' 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,' 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,' https://gestion.pe/economia/bid-plantea-brinde-credito-fiscal-empresas-impulsar-innovacion-258156-noticia/?ref=gesr.
Hudbay (2017), Positioned for growth, 2017 annual and CSR report. Hudbay: Toronto.
IDB (2018), 'Directorio proveedores mineros peruanos,' IDB: Lima.
INEI (2017), 'Cuadro Oferta Utilización – Año 2017'. INEI: Lima.
Instituto Tecnológico de la Producción (2019), 'Bienvenidos al CITE,' https://www.itp.gob.pe/nuestros-cite/.
Katz, J. and C. Pietrobelli (2018), 'Natural resource based growth, global value chains and domestic capabilities in the mining industry,' *Resources Policy*, **58**, 11–20.
Korinek, K. and I. Ramdoo (2017), 'Local content policies in minerals-exporting countries,' OECD.
Koutsogeorgopoulou, V. and T. Park (2017), Boosting R&D Outcomes in Australia', OECD Economics Department Working Papers, No. 1391. OECD Publishing: Paris.
Lampadia (2017), 'Revisión de la Situación Actual de la Red de Centros de Innovación Tecnológicos (CITE) en Perú,' https://www.lampadia.com/assets/uploads_documentos/0b63c-resumen-ejecutivo-informe-onudi-.pdf.
Millan Lombrana, L. and J. Quigley (2018), 'Peru's Mining Investment Boom Leaves Political Woes Behind,' https://www.bloomberg.com/news/articles/2018-10-01/peru-s-mining-investment-boom-leaves-political-turmoil-behind.
MINEM (2019), '2019 Anuario Minero Peru,' Ministerio de Energía y Minas: Lima.
MINEM (2022), '2022 Anuario Minero Peru,' Lima.
Mining3 (2019), 'Mining3,' https://www.mining3.com.
Molina, O. (2018), 'Innovation in an unfavourable context: local mining suppliers in Peru,' *Resources Policy*, **58**, 34–48.
Molina, O., J. Olivari and C. Piertrobelli (2016), 'Global Value Chains in the Peruvian Mining Sector,' Inter-American Development Bank: Washington, DC.
Paus, E., M. Robinson and F. Tregenna (2022), 'Firm innovation in Africa and Latin America: heterogeneity and country context,' *Industrial and Corporate Change*, **31**(2), 338–357.
Pietrobelli, C., A. Marin and J. Olivari (2018), 'Innovation in mining value chains: new evidence from Latin America,' *Resources Policy*, **58**, 1–10.
Revista ProActivo (2021), 'Obtenido de La Sobrerregulación Pone en Riesgo la Futura Producción Minera,' https://proactivo.com.pe/la-sobrerregulacion-pone-en-riesgo-la-futura-produccion-minera/.
Saenz, C. (2021), 'The relationship between corporate social responsibility and the social licence to operate: a case study in Peru,' *Resources Policy*, **74**, 102399.
Saenz, C. (2022), 'Keeping up with the flow: using multiple water strategies to earn social license to operate in the Peruvian mining industry,' *Resources Policy*, **77**, 102687.

Schipper, B., H. Lin, M. Meloni, K. Wansleeben, R. Heijungs and E. der Voet (2018), 'Estimating global copper demand until 2100 with regression and stock dynamics,' *Resources, Conservation and Recycling*, **132**, 28–36.
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.
S&P Global Market Intelligence (2018), 'World Exploration Trends,' https://mineralsmakelife.org/wp-content/uploads/2018/03/World-Exploration-Trends-Report-2018.pdf.
UN Comtrade (2019), 'Imports/Exports Copper Ore & Concentrate (260300), Anodes (7402) and Refined Copper (7403),' All Importers/All Exporters. United Nations: Geneva.
Universidad del Pacífico (2019), 'Centro de Estudios sobre Minería y Sostenibilidad (CEMS),' https://www.up.edu.pe/investigacion-centros/centros-up/centro-de-estudios-sobre-mineria-y-sostenibilidad-cems/Paginas/default.aspx.
USGS (2019a), *Mineral Commodity Summaries 2019*. USGS: Reston, Virginia.
USGS (2019b), 'National Minerals Information Center: Copper Statistics and Information,' https://www.usgs.gov/centers/nmic/copper-statistics-and-information.
Vivoda, V. (2008), 'The Return of the Obsolescing Bargain and the Decline of Big Oil,' *VDM Verlag Dr. Mueller e.K.*
Ville, S. and O. Wicken (2013), 'The dynamics of resource-based economic development: evidence from Australia and Norway,' *Industrial and Corporate Change*, **22**(5), 1341–1371.
World Bank (2019), 'Research and Development Expenditure (% of GDP),' https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?name_desc=false.
World Bank (2021), 'Mining Sector Diagnostic Peru,' https://documents1.worldbank.org/curated/en/448141632473923087/pdf/Peru-Mining-Sector-Diagnostic.pdf.

Appendix

Interviews' details

Second round of interviews	First round of interviews
• Between March and May 2019. • Interviewees: ° Mining companies located in Peru ° Peruvian suppliers to the mining sector ° Industry experts from Chile and Peru ° Government officials (including former) ° Universities and research centers.	• Between 2015 and 2018. • Interviewees: a similar group of actors, including organizations from the metal-mechanic sector.

Databases utilized

- London Metals Exchange: evolution of the price of copper cathode.

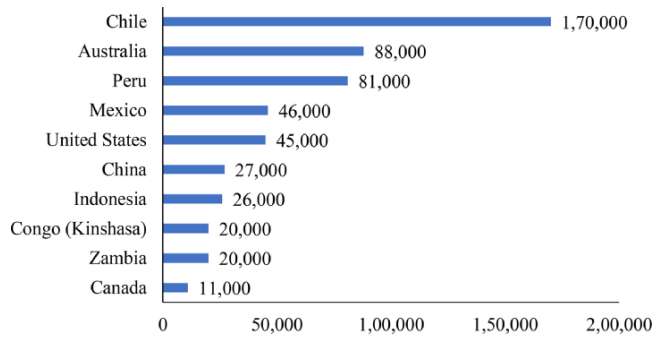

Figure A1. Copper reserves per country, 2018 (MT, million) *Source*: USGS (2019b).

- United Nations Statistics Division Comtrade Database: international trade statistics was used to identify country positions in the copper global value chain. HS codes were analyzed: HS-2002, 260 300, copper ore and concentrate; HS-2002, 7402, unrefined copper and copper anodes for electrolysis; and HS-2002, 7403, refined copper.
- Copper Alliance World Copper Fact Book 2018: indicators on the production capacity by country, leading mines, leading smelters, and leading refineries.
- US Geological Survey 2018: indicators included global copper reserves, extraction, and refining.
- National Supply Use Tables to identify the total annual operational procurement and categorize goods and services supplied to the industry from:
  - Australia (2016)
  - United States (2012)
  - Chile (2013 and 2016)
  - Peru (2017)
- Anuario Minero Peru for detailed statistics on the Peruvian mining industry (years covered, 2010–2018): indicators included production, exports, and investment by value chain stage.
- SUNAT—Customs Data (2012 and 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.

Table A1. Expenditure of Peruvian mining sector, 2017

	US$ (million)	Share of total (%)	Share of products (%)
Total procurement	8991	100	
Total goods	4504	50	100
Utilities	913	10	20
Chemicals and explosives	934	10	21
Capital equipment and parts	464	5	10
Fuels and lubricants	1257	14	28
Consumables	182	2	4
Metallic products, structural	326	4	7
Others	424	5	9
Transportation equipment	3	0	0
Total services	4487	50	Share of services
Architectural and engineering services	217	2	5
Professional and technical services	1178	13	26
Transportation and logistics	1620	18	36
Utility services	57	1	1
Repair and maintenance services	138	2	3
Labor contracting services	862	10	19
Equipment leasing, without operator	267	3	6
Others	149	2	3

Source: Authors, based on 2017 Peruvian Supply Use Matrix INEI (2017).

Table A2. Government and private-sector policies and programs

Program/policy	Description	Responsible institution	Mechanism	Effectiveness
Entrepreneurship (support for the creation of new firms/start-ups)				
Start-Up Peru: Dynamic Entrepreneurs	Co-financing up to an amount of approximately US$41K (S./140 000) for new firms with innovative technological solutions in the commercialization phase.	Innovate Peru (Ministry of Production)	To be eligible, firms must have sales above US$36K (S./120K). Firms receive support with respect to software improvement, intellectual property registration, marketing strategies, and product upgrading.	NA
Start-Up Peru: Innovative Entrepreneurs	Co-financing up to an amount of approximately US$15 000 (S./50 000) for teams of two to four people with innovative products/services/business models.	Innovate Peru (Ministry of Production)	Financing includes market studies and focus groups to validate business model feasibility, prototype development and enhancement, and networking events, among others.	NA
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 nationwide 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 (MIPYME).	As of 2018, the program had co-financed more than 3000 R&D and entrepreneurship projects.
National Science, Technology, and Innovation Plan for Competitiveness and Human Development (Law N°28 303)	A 15-year (2006–2021) cooperation agreement between regional governments, governmental institutions, private schools, and firms. Its main goal is to facilitate the development of innovative products and processes.	CONCYTEC	The plan focuses on different strategies that include the promotion of highly innovative processes, securing foreign financing, the diffusion of innovative practices, direct assistance toward firms in matters regarding innovation, and facilitating the cooperation between private agents, among others.	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-sized enterprises (SMEs).	CONCYTEC	100% tax deduction of Research, Development and Innovation (RD&I) 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 3 years of the program, 49 projects received this credit, for a total of US$30 million (S/108 M). Surveys indicate that only 30% of companies were aware of this benefit by 2019.

(continued)

Table A2. (Continued)

Program/policy	Description	Responsible institution	Mechanism	Effectiveness
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 an Annual Consolidated Declaration (DAC for its name in Spanish) on these commitments to MINEM. Local content requirements are part of mining firms' Environment Impact Assessment plans. In addition, the local content clauses of Decree 042-2003-EM were also 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	PROMPERU offers a specialized assessment for micro and small exporters firms in order to introduce them to the global market and connect them with potential clients.	PROMPERU—Ministry of External Commerce and Tourism	The assessment consists of several steps that include virtual training programs, nationwide seminars, and international conventions, among others.	NA
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, namely to improve the productivity of the mining firm and 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. The firm offered capable suppliers the opportunity to co-design these 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.