Industry 4.0 in Developing Countries: The Mine of the Future and the Role of Women

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Abstract

Industry 4.0 technologies are seen to offer an opportunity to break gender-bias in employment, primarily by reducing previous technical barriers to female entry into the workforce. This study unpacks whether increased technological intensity of processes impacts female employment share, specifically analyzing the incorporation of digital technologies in an historically male dominated industry. Specifically, it delves into whether employment patterns in the large-scale mining sector in Chile – a leading mining country - have changed with the adoption of new digital technologies. These technologies have removed major barriers for women in the sector – mining employment is no longer driven by physical strength and endurance conducted in remote locations. Indeed, it is becoming increasingly common for these operations to be carried out from a distance; mining, to some extent is becoming a downtown, knowledge-intensive office job. How has this translated to female employment?

The findings of this exploratory research indicate that high tech is changing the gender equation, but progress is slow. A higher share of women is concentrated in those activities which have adopted new technologies, but female participation is still very low. Importantly, the new technologies have removed technical barriers to female inclusion, but other non-technical ones have gained importance. The Chilean experience offers key lessons for policy makers in resource rich countries seeking to use technology to overcome the gender gap in these sectors.

1. Introduction

New digital technologies or 'Industry 4.0' have come to dominate global discussions of trade competitiveness in recent years, and there is growing interest in their impact on employment and gender issues. However, little attention has yet been paid to their role in natural resources industries, arguably the most important economic sector for a significant share of countries around the world. Global value chain (GVC) participation in a large number of developing countries, particularly those in Africa and Latin America, is indeed driven by their upstream role in mining and oil and gas (UNCTAD, 2018). Approximately half of the world's population – and women – live in resource-rich countries where these industries play a dominant role in trade and investment (World Bank, 2018a). Yet, extractive sectors are notorious for very low levels of female participation (Macdonald, 2017).

Industry 4.0 technologies are seen to offer an opportunity to break gender-bias in employment (WEF, 2017a), primarily by reducing previous technical barriers to female entry into the workforce. In the case of capital-intensive extractives, these technologies not only improve safety and environmental conditions and reduce physical requirements, but also move jobs from the field to urban centers. By removing these major constraints, this should have important implications for reducing the gender deficit in extractive sectors. While theoretically sound, to date, there is little empirical evidence to support these claims, potentially due to the relatively incipient nature of the technology.

This research brief aims to contribute to this knowledge gap by examining how the uptake of these new technologies is and will impact female participation in one of these sectors – large scale mining in Chile. Driven by well-financed, global firms, the Chilean mining sector is well positioned to adopt these technologies and its experience should offer important insights regarding the potential impact on gender. Furthermore, the research brief employs a GVC approach, breaking the industry down into segments and roles to better understand where specific opportunities for using the technology to bring women into this male dominated sector can be found.

Chile is a world leader in the mining industry, and the sector is the most important driver of economic growth, accounting for 50% of exports, 10% of GDP and the most significant share of domestic value-added in its GVC participation (OECD, 2018). It is a pioneer amongst developing countries in incorporating new technologies into the sector and it is clear that this is shifting the nature of mining jobs from manual to remote operated and automated. This has been particularly profound in the extractive and processing stages of the value chain stage, where 39% and 63% of job profiles are already remote operated and automated respectively (Mining Skills Council, 2018).

The findings of this exploratory research indicate that, while female participation in value chains positions is one of the lowest amongst major mining countries (3.8%), the changing nature of jobs has created new opportunities for women. A higher share of women is concentrated in GVC segments which have already adopted remote operated and automated technology when compared to overall employment (Share of females compared to share of total employment: extraction, 38% compared to 25%; processing, 23% compared to 14%). Fewer women participate in segments with low levels of adoption (maintenance: 39% compared to 61%). New technologies have removed technical barriers to their participation, but other non-technical barriers have gained importance, and female employment remains low. These barriers include a relatively uneven adoption of new technologies as a result of a slowdown in investment and legacy systems, gender differentiated participation in relevant education degrees, entrenched recruiting practices that require industry experience, and strong gender stereotypes at both the industry and societal level that reinforce perceptions that mining is a man’s job.

The Chilean experience to date offers key lessons for policy makers in resource rich countries seeking to use technology to overcome the gender gap in these sectors. Perhaps most importantly, is that while there is growing awareness of the gender deficit, the prevailing approach has been to address this as a minority inclusion issue, rather than understanding the important role women should have as a strategic asset for competitiveness of extractive sectors of the future. This requires an important shift in mindset, political will and a commitment from industry leadership. Key implications for policymakers include:

(1) The gender dimension is generally absent from the discussion on human capital development for the future of extractives. Initiating multi-stakeholder dialogue on this issue is an essential first step.

(2) Digital technologies demand new and advanced capabilities in which women excel. Increasing labor market awareness of the changing nature of extractive sector jobs and the strong potential for female employment in these roles is required.

(3) Women are already underrepresented in courses for the qualifications necessary for the future. It is necessary to strengthen female participation in STEM courses at all levels, especially early education.

(4) Extractive industries historically have been male dominated and there are few women in the sector. Incentivizing mining firms to create opportunities for qualified women with no sectoral experience is required to tap into new talent pools to make full use of the new technology available.

(5) Mining is the worst performing industry in the world in terms of inclusion of women in C-suite and board positions, closely followed by oil and gas. Efforts must be made to foster the promotion of women into senior leadership positions.

(6) Like other GVCs, in extractive industries there is a high degree of fragmentation of activities; suppliers account for a large share of the workforce and these firms have poor gender parity. Lead firms can be pressured to influence their suppliers to develop gender policies.

2. Women in Mining

The large-scale mining sector has traditionally been male-dominated, with some of the worst global gender parity indicators. The share of female workers in mining, comprising just 5-10% of the global workforce, is one of the lowest amongst all economic sectors (Ledwaba, 2017; Macdonald, 2017; WIM (UK) and PwC, 2013).[2,3] Low female participation is pervasive across all value chain segments (e.g. exploration, extraction, processing, maintenance), geographic locations, and organizational levels, from the mine to the board room (Connell & Claughton, 2018). Just 5% of board seats are held by females in the top 500 mining companies (WIM (UK) and PwC, 2013).

Reasons for this poor gender performance have varied over the past fifty years. Prior to the 1990s, most countries participating in large-scale mining prohibited the employment of women in particular roles, including underground work (MINCOSA, 2017).[4] After regulatory restrictions were removed, practical limitations and cultural norms became key drivers of

[2] In Australia and Chile, the share of female workers in the mining industry is 15% and 8%, respectively (Stefanovic & Alvayay, 2016; WGEA, 2014).

[3] In Australia, women comprise only 4.5% of technicians, 11% of machinery operators and drivers, and 13% of laborers. In higher positions, women's participation improves: 15% and 16% of key management personnel and general management personnel is female, respectively (Connell & Claughton, 2018).

[4] These legislations ratified the 54/1935 convention by the International Labor Organization (ILO), which prohibited the employment of women in underground mining. Countries denounced this convention in the last three decades of 1990s, including: Australia (1988), Canada (1978), Chile (1997) and South Africa (1996) (MINCOSA, 2017).

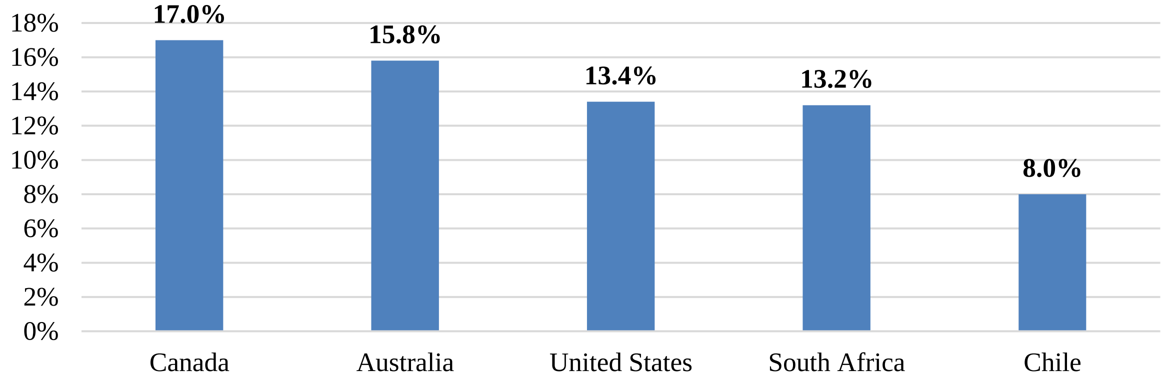
female underrepresentation in the sector. These can be categorized as five inter-related barriers: (1) hazardous conditions and security risks; (2) infrastructure complications; (3) physical requirements; (4) remote workplace locations; and (5) discrimination.

1. **Hazardous conditions and safety risks.** The occupational dangers associated with these jobs – chemical, physical, ergonomic and biological - have made it culturally unacceptable for women to participate in the mining workforce in most regions around the world (Abrahamsson et al., 2014; Stefanovic & Alvayay, 2016). Nonetheless, objective hazards in the industry have declined significantly as the mining sector has made tremendous strides in improving safety and environmental problems (AMMA, 2018; Kohler, 2014).
2. **Infrastructure complications.** Mining sites were not always set up to be accessible for women, lacking the right equipment, hygienic and sanitary facilities, or childcare areas (Abrahamsson et al., 2014; IWiM, 2017; Ledwaba, 2017). This issue began to lose relevance in the late-1990s; the entry of female workers into the mining industry obliged organizations to upgrade and improve their infrastructure to effectively integrate women in the workplace (Ledwaba, 2017).
3. **Physical requirements:** One of the biggest hurdles for women to perform production mining jobs is rooted in the notion that women are less suitable than men for activities that require extreme physical strength and endurance (Jenkins, 2014; Stefanovic & Alvayay, 2016). This constraint has become less pronounced with major technological advances, such as the introduction of hydraulic steering, which have reduced the strength requirements to operate heavy machinery.
4. **Remote workplace locations**: Mine sites are typically located in remote locations, at notable distance from urban centers (MiRH, 2016; Peetz et al., 2014). This makes it more challenging for women to manage work-life issues. Since traditional gender roles assign a greater degree of responsibility on child, family and household care to women than to men, females continue to be challenged by the difficulty to meet these demands while working in the mining industry. This constraint is likely to become more important as mines become increasingly remote as more accessible resources are depleted (Bamber et al., 2016).
5. **Gender Stereotypes and Norms**: In the past, women's roles as wives and mothers, along with their generally smaller stature and physical strength discouraged their recruitment in the mining industry (Abrahamsson et al., 2014; Lahiri-Dutt, 2012). Over

time, this evolved towards women avoiding the sector due to fear of social judgment for potentially abandoning their traditional gender roles (Peetz et al., 2014; Stefanovic & Alvayay, 2016). Today, more subtle influences, such as micro-inequities or unconscious biases, continue to influence recruitment and selection strategies, as well as impacting educational choices of women (MiRH, 2016; Stefanovic & Alvayay, 2016). With fewer women than men opting to pursue relevant degrees, the gendered division of labor in the mines is reinforced as mines have a more difficult time to identify potential female recruits.

Growing awareness of the importance of women in the workplace (Credit Suisse, 2016; Macdonald, 2017), together with pervasive human capital shortages in the industry (Field Research, 2018) have encouraged both public and private efforts to reduce the impact of these barriers. In Canada and Australia, public funds were allocated to develop research, improves work conditions of women in mining, and increase the number of people taking up STEM occupations (GSA, 2015; MiHR, 2018). A small number of global lead firms have launched gender inclusion programs. The Australian mining giant BHP, for example, has become a global pioneer in the sector; in 2016, the company announced its Global 50:50 Program whereby the company aims to achieve gender equity by 2025 (Treanor & Davies, 2016). While these efforts have had a degree of success, female participation remains very low. In 2016, the most advanced mining country in terms of gender equity was Canada with a 17% female share of the workforce (Figure 1). Key areas where female participation is higher is in office and administrative jobs and in professional, service and sales positions. In Australia, value chain positions are still very male dominated; only 13% of machine drivers and operators (which account for approximately one quarter of all jobs) are female (Macdonald, 2017).

Figure 1. Share of Women in Mining Sector Employment, by Country, 2016



Source: Albornoz (2016).

3. New Technologies and the Changing Nature of Work in Mining

The nature of work in the mining industry, as in many other sectors, is beginning to change as new digital technologies are developed and implemented. These technologies include enhanced digital monitoring and control, automation, machine learning, and advanced analytics amongst others (Durrant-Whyte et al., 2015). While research on this issue is still relatively scarce (Karakaya & Nuur, 2018),[5] there is general agreement at the industry level that their increased use will shift the composition of the mining workforce to one of highly skilled workers operating sophisticated automated systems from centralized locations (Durrant-Whyte et al., 2015; Oshokoya & Tetteh, 2018). Over half of the major international industry events between 2017 and the first semester of 2019 were focused specifically on Industry 4.0 and digital innovation.[6]

While the sector is considered to be a slow adopter of these technologies (McKinsey Global Institute, 2017), important advances are already underway, particularly in developed countries such as Australia, Canada and Sweden. Increased connectivity and sensor sophistication has allowed for mining equipment to be controlled at a distance (Porter et al., 2014); large scale autonomous haulage trucks (AHT), for example, have been in operation since 2008 (Komatsu, 2010). Leading mines around the world have established integrated operations centers (IOC) where employees can monitor and control multiple aspects of operations simultaneously, including automated vehicles and machinery, 3-D mapping using drones, and continuous drilling (AMMA, 2018; WEF, 2017b). Increasingly, IOCs are based away from the mine sites, in major metropolitan 'service hubs' led by senior technicians operating unmanned machinery on-site, or instructing manual technicians on the ground, thousands of kilometers away (BHP, 2013; Oshokoya & Tetteh, 2018).[7]

Remotely operated and automated equipment is particularly attractive to the mining industry as it lowers operating costs, while enhancing safety and environmental sustainability; their incorporation into mining operations leads to multi-million dollar savings (Deloitte, 2017; Turner, 2018). Analysis of the operational data streamed from a miner's equipment fleet can

[5] Karakaya and Nuur (2018) carry out a systematic review of the literature on extractive industries to identify key themes in social science research between 2008-2018. They find very few studies directly addressing the issue of digital technology, industrial internet of things, or even automation. However, many of the studies reviewed indicated these were key areas for future research for the industry.

[6] 7/15 events held in Australia, Canada, Chile and South Africa, including International Mining and Resources and Future of Mining in Australia, Mines and Technology Toronto in Canada, INDABA South Africa, and Expomin Chile.

[7] Both Rio Tinto and BHP Billiton have opened Remote Integrated Operations Center in Perth; the former in 2007 and the latter in 2013. Together, these centers have 700 workers managing automated trucks and other tasks across more than 20 iron ore mines in the Pilbara, Australia.

also lead to the identification of key bottlenecks in production and processing, allowing the firm to optimize systems and improve overall mine efficiency (Porter et al., 2014). Data analytics from mining equipment also allows firms to roll out preventative and predictive maintenance plans to avoid downtime, as well as to improve inventory management of spare parts and increase the efficiency of their supply chains (Grubic & Peppard, 2016; Kasper, 2018).

Further advances continue to be made which will increase automation; for example, Rio Tinto is seeking to create human-robot teams for underground mining, where the robotic assistant contributes its physical strength and precision, while the human is in charge of cognitive work and decision making (Baggaley, 2017). While this will reduce the need for human capital in potentially dangerous work, it will increase the demand for specialized knowledge and tech-savvy personnel.

As a result of the uptake of these technologies, the skills requirements of the industry are predicted to change considerably over the next decade. As illustrated in Table 1, by 2016, developed countries such as Australia and Canada had already implemented many of these, reducing physical and manual requirements to just 43% of the workforce. By 2030, the demand for these skills along with basic cognitive skills are expected to decrease to 34% and 9% respectively, while demand for skills in social and emotional, and technological categories are expected to grow. Technological skills in high demand will be advanced programming, metallurgy, bioinformatics, Big Data and data analytics, and robotics, among others. Blue collar occupations such as heavy vehicle drivers, driller operators, on-site maintenance workers will continue to decline, giving way to growing demand for sophisticated technicians and professionals (e.g. software developers, electrical engineers, and computer systems analysts) (Bughin et al., 2018). These new jobs are centered on Science, Technology, Engineering and Mathematics (STEM) qualifications (Bughin et al., 2018).

What do these skills changes mean for opportunities for women in the industry? First, these new technologies go a long way in overcoming many of the barriers that have driven gender segregation in the extractive sector in the past. Digital equipment controls fully removes physical strength considerations from operations job profiles; automated and remote controlled equipment operated at a distance removes an important share of the workers from the field site – out of harm's way, resolving needs for gender-sensitive infrastructure and equipment, and converting operations jobs into office-based positions in urban areas. They also create opportunities for skill sets in which women are known to excel – decision-making in times of stress, multi-tasking, etc. (Mather & Lighthall, 2012; Sroet et al., 2013).[8] Yet, at the same time, the job profiles for the mine and rigs of the future are built on STEM requirements. Women are still underrepresented in STEM education, both globally and in mining countries. On average, globally women account for just 14% of STEM graduates; all large-scale mining countries fall below this average: Australia: 9.67% (2015); Canada: 11.63% (2016); Chile: 6.48% (2016); South Africa: 12.68% (2016) and United States: 10.42% (2016) (UIS.Stat, 2018).

The following section explores the case of Chile examining whether these changes are taking place and how this may be impacting women's opportunities.

Table 1. Evolution in Skill Categories Deployed in the Mining Industry, by % of Total Workers' Time

Skill Categories	**% of Total Workers Time**		**Change in hours of 25 Skills (%)**
	2016	**2030**	
Physical and manual skills	43%	34%	• General equipment repair & mechanical skills • Gross motor skills & strength • General equipment operation & navigation • Craft and technician skills • Fine motor skills • Inspecting & monitoring
Basic cognitive skills	11%	9%	• Basic literacy, numeracy and communication • Basic data input & processing
Higher cognitive skills	20%	21%	• Quantitative & statistical skills • Advanced literacy and writing • Critical thinking & decision making • Project management • Complex information processing & interpretation • Creativity
Social and emotional skills	14%	17%	• Teaching and training others • Adaptability & continuous learning • Advanced communication & negotiation skills • Interpersonal skills & empathy • Leadership & managing others • Entrepreneurship & initiative taking
Technological skills	14%	19%	• Advanced data analysis & mathematical skills • Scientific research & development

[8] The first Chief of Analytics at leading mining equipment supplier Caterpillar is 35 year-old Morgan Vawter, a young female leader in the analytics world (Fortune, 2016).

			• Basic digital skills • Advanced IT skills & programming • Metallurgy skills • Bioinformatics skills • Big data and data analytics skills • Robotics skills

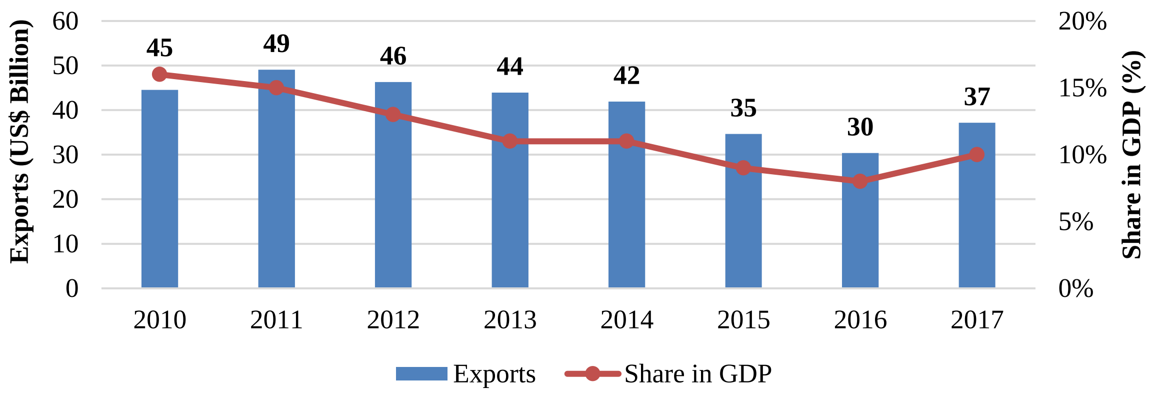
References: **Decrease** **Increase**

Source: Authors based on Bughin et al. (2018); Simich (2017).

4. Chilean Mining, New Technologies and the Role of Women

Mining is a major industry in Chile; in 2017, the sector accounted for approximately 50% of the country's exports and contributed more than 10% to its GDP (Mining Council, 2018). Chile is the world's largest copper exporter, with a 28% global market share and more than US$37B in exports in 2017 (UN Comtrade, 2018). The industry is led by large world-class miners; these include Chilean companies CODELCO (state owned) and Antofagasta Minerals (AMSA), as well as global mining companies, Anglo American, Barrick Gold, BHP, Freeport-McMoRan, Glencore, Rio Tinto, Southern Copper, Teck Resources and Vale. The sector also accounts for a significant share of Chile's foreign direct investment (FDI); between 2012 and 2017, mining attracted on average 36% of total FDI (Mining Council, 2018).

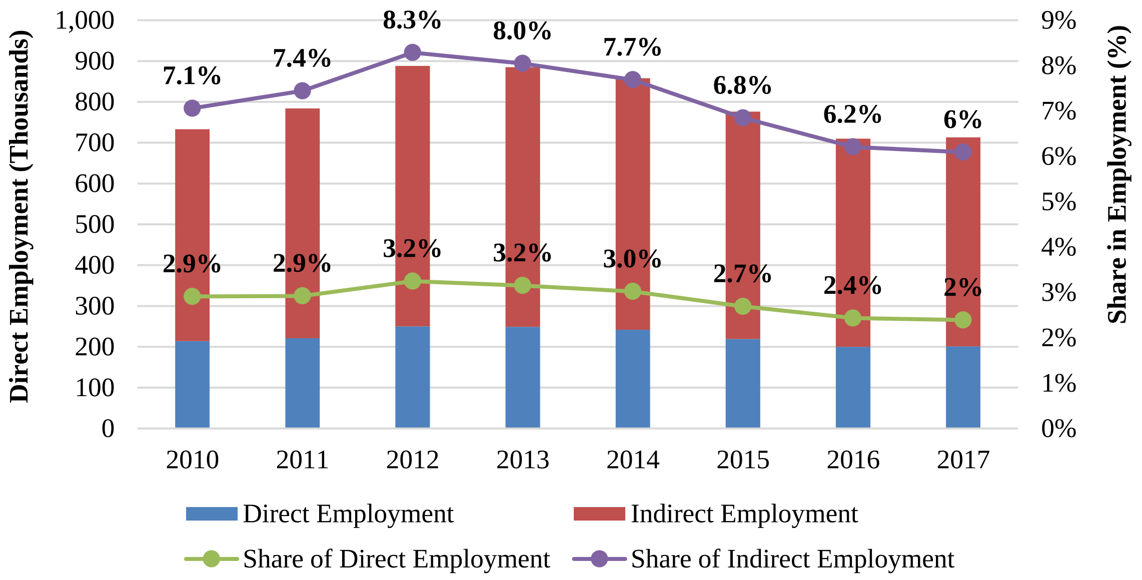
Figure 2. Chile's Mining Exports and Mining Contribution to GDP, 2010 – 2018



Source: Authors based on Mining Council (2018).

As a highly capital-intensive segment of the extractives industry, sectoral employment in large-scale mining is small, but it is well qualified and compensated despite a high degree of sub-contracting. Although, mining is the most important economic contributor to the country, employment accounted for just 2% of the national labor force in 2017 (200,000 workers; see Figure 3). This is expected to grow by 10-15% by 2023 as the commodities markets recover (Mining Skills Council, 2017). Approximately 25% of employment is in the extraction stage of the GVC, 14% in processing segments and 61% is in maintenance jobs (Mining Skills Council, 2017). Work is concentrated in one region, Antofagasta in the north of the country. A minimal level of high school education is required in the industry, and an important share of the workforce has additional technical training or university education. It is the highest paid economic activity in the country; wages are double the average national salary (Mining Council, 2018) and the six highest paying jobs for young professionals (4 years post graduation) are all related to the mining industry (Ministerio de Educación, 2018). Sub-contracting is high, with over half of the workforce employed by contractors (Mining Skills Council, 2017).

Figure 3. Mining Employment and Contribution to National Employment, 2010 – 2017



Source: Authors based on Mining Council (2018).

4.1. Adoption of New Industry 4.0 Technologies in Chilean Mining and Impact on Employment

All major mining companies in Chile have introduced digital technologies, although the extent of this varies by firm and GVC stage. In the extraction segment, around 39% of the job profiles are already remote-operated and automated; in the processing stage of the chain the figure increases to 63%, while in the maintenance segment, just 17% of jobs are off-site/automated (See Figure 4). Approximately 60% of job profiles still require manual skills compared to 43% in developed countries; at the same time, some 40% of the world's AHT mining fleet operate in Chile, yet each truck is remote operated by the same drivers as before from control centers located within the mine (Field Research, 2018). This uneven adoption of technology is to a large degree the result of the cycles of investment in the mining industry. Major technological investments are typically only introduced in greenfield projects or major brownfield expansions. Investments in expansion and in new projects have been delayed since the end of the commodity super-cycle in 2012.

As commodity prices have recovered, miners have once again focused on new investments, both in new operations and expansions of existing mines and this is predicted to have a major impact on the adoption of new technology in coming years. There are 44 projects valued at US$66B in the pipeline for the next ten years (Cambero, 2018). These investments are increasingly focused on underground mining (Bonomelli, 2017) where new digital technologies are essential to driving mine feasibility. Several major existing mines are also moving from open-pit to underground mining; Chuquicamata, the world's largest open-pit mine, is one of the most important ones to make this transition. At the same time, new mines will be located closer to key agricultural and urban centers, and in more complex geological areas; these require an underground mining approach, further driving demand for new remote technologies (Field Research, 2018). The implementation of these new projects are expected to increase remote-operated and automated job profiles to 71% in extraction, 90% in processing and 58% in maintenance in the next five years (Mining Skills Council, 2018). This will completely alter the world of work for the mining industry, significantly reducing the importance of physical and manual skills (see Table 1).

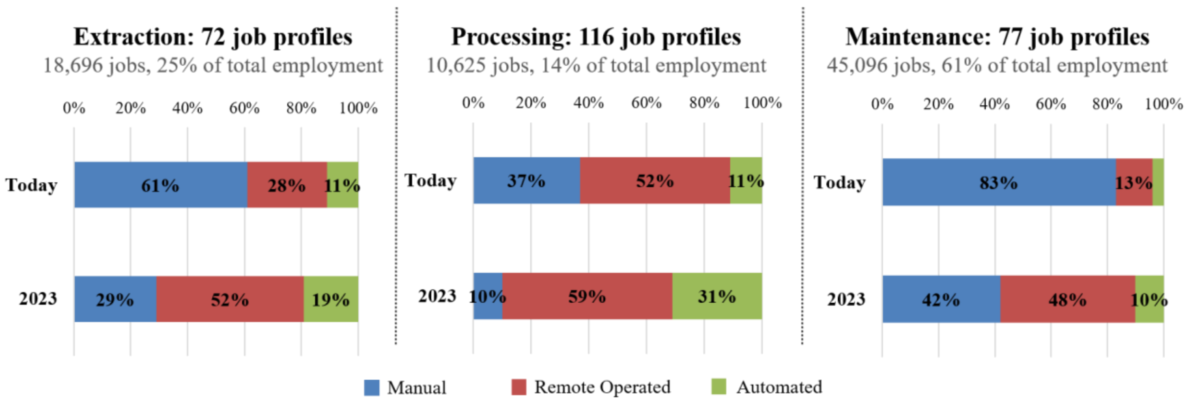
Codelco has been the leading company to adopt digital technologies in Chile. It was the first company in the world to adopt AHTs in 2008 and to fully automate one of its mine haulage fleets as early as 2011. It was also the leader to implement IOCs, to commit to including these across its mining divisions and is the only miner to have relocated some of these to urban centers to date (CODELCO, 2018c).[9] El Teniente, Chile's oldest and most developed underground mine, was at the forefront of the incorporation of IOCs, establishing its control center in the city of Rancagua in 2015, 50 km from the mine (CODELCO, 2018c; El Rancagüino, 2018). While many mines in the country have fully automated processing plants, these are still managed from the mine site. Codelco Division Ministro Hales is the only mine

[9] In 2018, BHP began building IOCs for two of its major mining operations in Santiago.

to establish their IOC in Chile's capital city, Santiago, over 1,000km from the mine and in the heart of the financial district (Bonomelli, 2017; CODELCO, 2017; MCH, 2018a).

This has gradually impacted the characteristics of jobs in the industry. As seen in Figure 4, by 2018, 28% and 52% of jobs in the extraction and processing segments of the GVC respectively in Chile were remotely operated, while over 11% of jobs in extraction, processing and maintenance were automated (Mining Skills Council, 2018). The uptake of technology in these job profiles has led to relative redistribution of employment; maintenance accounts for the highest share of value chain employment in the industry (61%), with correspondingly high degree of manual labor (83%). The most significant change has been the relocation of the job from the mine face to an office job, although the operations continue to be performed by the same personnel and increased levels of complexity have not yet been incorporated. Diagnostics by the industry stakeholders indicate that over the next five years as more of the available cutting-edge technologies are adopted in new investments, the number of jobs in extraction (25% of total) that will be remote operated will almost double, while the level of automation will triple in processing (14% of total employment) and increase by a factor of ten in maintenance roles (Alta Ley, 2018; Mining Skills Council, 2018).[10]

Figure 4. Job Profile Changes in Chile's Mining GVC, 2017 vs. 2023



Source: Authors based on Mining Skills Council (2018) .

Key stakeholders understand that these new roles need new skills. The mining industry association, Consejo Minero, together with technology driver Fundación Chile[11] are

[10] This is based on the assessment of Chilean operations adopting the cutting-edge digital technologies that have already been launched globally.
[11] Fundación Chile is non-profit, quasi-public organization, focused on fostering Chilean business and industry growth through technological innovation and implementation.

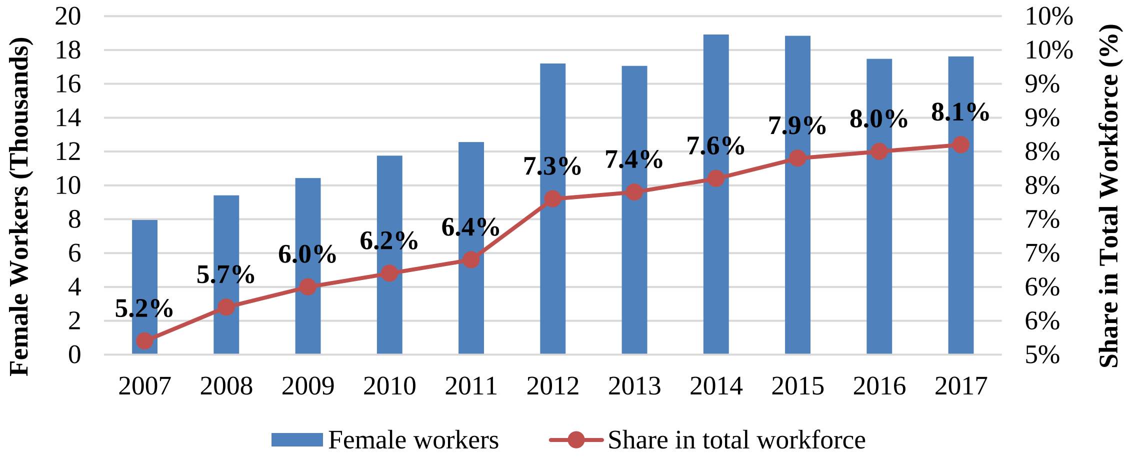
developing the specific competencies required for each of these near-future jobs, while Alta Ley, a public-private initiative to support innovation in the sector is focused on improving institutional linkages between the sector and educational and research institutions to help increase the use of new cutting edge technology to drive productivity (Alta Ley, 2018).

These near-future roles require major shifts in the approach to human capital development for the industry. Specifically, these require more and better skills, raising the minimum educational level for the industry from a high school diploma to a four-year technical degree (Field Research, 2018). Workers need to have stronger analytical skills in order to make more and faster decisions, while simultaneously requiring systems thinking skills as operations become more integrated (Mining Skills Council, 2018). Achieving these changes requires a paradigm shift for training and education in the sector, both internally and with educations institutions, as these remain overly focused on training for traditional mining roles. Currently, educational programs are focused on qualifications such as geologists and extraction engineering specialists, with much less emphasis on developing those profiles required for the mine of the future (RTM, 2016a).

4.2. Role of Women in the Chilean Mining Industry and the Impact of Digital Technologies on Female Employment

Female participation in Chile's mining workforce is extremely low, and it is the lowest among leading mining countries (see Figure 1). Female share of workers reached just 8.1% accounting for less than 18,000 workers in 2017 (Figure 5); these figures are very low compared to economy-wide statistics in which female share of the labor force is 41% (World Bank, 2018b), despite the economic importance of the sector to the country. Traditional barriers to female participation in mining in Chile have been similar to those seen in the global industry, including (1) hazardous conditions and security risks; (2) infrastructure complications; (3) physical requirements; (4) remote workplace locations; and (5) discrimination. Prior to 1986, women were legally prohibited from working in mining operations (Dirección del Trabajo, 2018), strong cultural superstitions precluded their presence on site in any capacity; the remote location of the majority of Chile's mines at high-altitude added to the physical and extreme environmental and work-life balance demands of the job that complicated female participation (Field Research, 2018). Mining has thus typically been considered as a man's job (Delgado et al., 2009).

Figure 5. Number and Share of Female Workers in Chile's Mining Industry, 2007 – 2017



Source: Authors based on Mining Council (2018).

These barriers to female participation, however, have evolved in the past 20 years creating an opening for women in the mining world (see Table 2). These changes have been facilitated by the adoption of new technology and increased safety and environmental protocols, as exports grew and productivity requirements intensified. The introduction of mechanized and hydraulic powered equipment in the 1990s, in particular, removed physical strength as a key job requirement. In the 2000s, equipment modification, such as on-board/portable bathrooms and modifications for operator size, helped reduce infrastructure concerns for women on the mine site. The latest innovations in the 2010s, including IOCs and remote-controlled equipment have relocated jobs away from the mine face, significantly reducing exposure to hazardous conditions and safety risks. Continuous improvements to safety and environmental protocols have also mitigated concerns regarding the work environment. These changes boosted female participation in mining to 6.2% by 2010 and 8.1% by 2017. Women entered the mine sites in value chain specific jobs including as truck drivers and machine operators.

Table 2. Evolution of Incorporation of Women in the Chilean Mining Sector

Time	Before 1986	1990s	2000s	2010s	Future
Mining Exports (US$, B; mid-decade)	1,760	6,392	15,815	34,642	
Female participation	None	Very low	Begins to grow	Growth rate higher than male	See Box 1
Female intensity (%)	0%	n.a.	Less than 6% 2008: 4.2%	More than 6%	
Adoption of Frontier Technologies	Manual	Mechanized	Mechanized with hydraulic power	Remote -operated	Automated
Barriers for female participation	Not legally allowed to participate in the industry	• Physical requirement • Hazardous conditions and safety risks • Infrastructure complications • Remote work location • Gender stereotypes and norms	• Hazardous conditions and safety risks • Infrastructure complications • Remote work location • Gender stereotypes and norms	• Mining Experience • Remote work location • Gender stereotypes and norms	• Gender stereotypes and norms
Job Site	Mine	Mine	Mine	Mine. Very few urban IOCs	Off-site. Urban centers

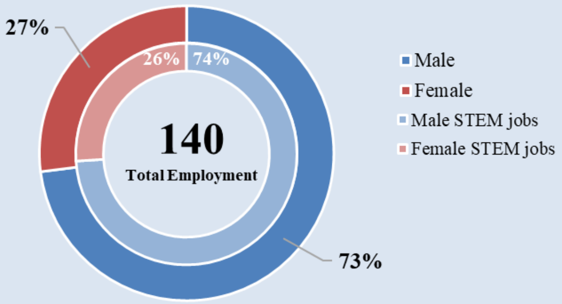
Source: Authors based on Meller (2003); Mining Council (2018).

As the sector adopts more automated technologies and moves operating centers toward urban areas in the near future, further reduction of these barriers occurs. Jobs are based on digital technologies requiring more STEM knowledge and much less sector-relevant experience, and urban jobs relieve shift inflexibility and facilitate improved work-life balance. Recent industry experiences, such as Codelco Tech (Box 1) indicate that this could lead to further improvements in female participation.

Box 1. Codelco Tech: Gender Perspective

Codelco Tech, a subsidiary focused on introducing cutting-edge technological innovations into the mining industry, was founded in 2017. The objective is to become the global pioneer in accelerating the integration of mining experience and know-how with new technological capabilities. Its organizational model is based on open innovation platforms that incorporate and promote collaboration amongst miners, suppliers, research centers, universities and technology start-ups.

Figure 6. Female Participation in Codelco Tech and STEM Jobs (%), 2018



Source: (Albornoz, 2016).

With an almost exclusively STEM workforce (only 17 employees in the company are in non-STEM roles), the company has the highest levels of female employment in the industry at 27% (Figure 6). Furthermore, these female workers are not in administrative roles; 86% of women (compared to 89% of men) in the company are in STEM jobs (Albornoz, 2016).

The last decade (2010s) has also been characterized by increased awareness of gender issues in the sector. Public and private inclusiveness programs were launched to attract women to mining, helping to drive the hiring rate for women higher than men in several companies (Mining Skills Council, 2017). The earliest public gender program for the industry was launched in 2007 with Programa Iguala by the government which raised the issue of equal participation between men and women for the first time. These initiatives later evolved into a national certification norm (3262) in 2012 focused on gender equity and work-life balance (Albornoz, 2016; CODELCO, 2018a; SERNAM, 2013). In the private sector, two companies, in particular, have led on gender, Codelco and BHP; other companies include gender under a broader banner of diversity and inclusiveness.

As with the incorporation of new technologies, Codelco has been at the forefront of gender initiatives. It is the only miner to have certified its divisions under the 3262 norm, and aims to have all divisions certified by 2020 (CODELCO, 2007). It was also the first company to establish a gender diversity strategy in 2015, including increasing awareness of gender issues amongst its male workforce and establishing professional development plans specifically for female workers (Albornoz, 2016). By 2016, women accounted for 15-20% of its hires, including across senior leadership positions, raising overall female share to 9.5% by 2017 – higher than the industry 8.1% average (MCH, 2018b). It also launched a program called *Graduados*, a leadership program oriented towards the leading university graduates from the country; approximately 40% of these are women (Field Research, 2018). Codelco's Technology Contract and Alliance Director is also female (MCH, 2018c).

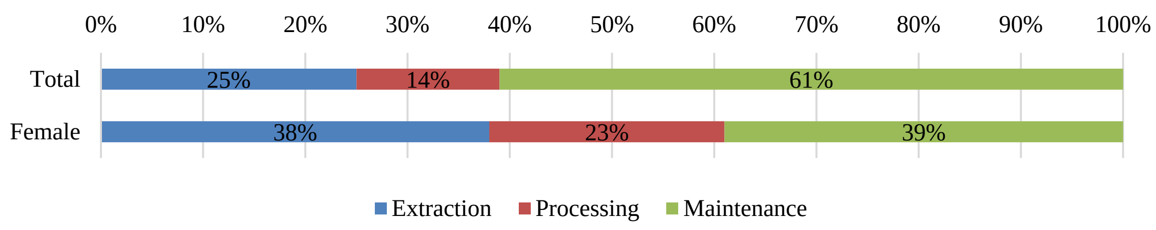
The most successful mine in Codelco driving female participation is Gabriela Mistral Mine (Gaby), commissioned in 2008. By design, Gaby is the industry showcase for social innovation. The goal is to have the highest level of female participation in the industry, the mine reduced experience requirements to allow women with no previous mining knowledge into the sector, targeted recruitment and training programs towards women in local communities, and included over 60 gender-sensitive policies at the company to help women balance their work-life commitments/ responsibilities. For example, women in their last trimester of pregnancy prior to pre-natal leave are offered the opportunity to take online training programs instead of working in operations (Field Research, 2018). By 2018, these efforts were paying off; 23% of Gaby's workforce was female. As a recent investment, Gaby was also commissioned with state of the art technology; including an automated fleet (CODELCO, 2018b). The introduction of AHTs and automated processing equipment relocated several jobs away from the frontline towards centralized operating posts in the mine.

Similarly, BHP began implementing its global strategy towards gender parity in its Chilean operations. Central to its initiatives are increasing shift flexibility and moving towards eight hour shifts instead of 12 hour ones, actively recruiting women with strong educational backgrounds but no relevant industry experience, and promoting women into senior leadership positions (BHP, 2018). For example, they have hired females into the top positions at Spence (General Manager) and Escondida (Production Manager), two of Chile's largest mines (Pérez-Cueto, 2018). Escondida alone accounts for 18% of Chile's fine copper exports. Placing women in senior leadership has been found to drive increased participation in higher levels of the organization (WIM (UK) and PwC, 2013). By 2017, BHP had increased female share to 15% (BHP, 2016; UTA, 2017).

Gender initiatives among other lead firms are generally embedded in broader diversity programs (Field Research, 2018), however, they are making strides to place women in senior leadership positions. AMSA, which has a 10% female share, joined a Gender Parity Initiative program sponsored by the government. The company has added new female board members to six of its divisions (RTM, 2016b). Anglo American and Glencore have followed similar approaches (MCH, 2018c).

These initiatives boosted overall participation to 8.1%. However, analysis of roles directly in the value chain (i.e. extraction, processing, maintenance roles) shows that female participation is just 3.8% and has only increased 0.4% over the past five years -- that is, just over 8,000 female employees. The distribution of this female mining employment by value chain stage differs considerably from that of the national average. Women are more concentrated in the extraction and processing segments; notably these are the two segments with the highest share of remote operation and automation (Figure 7).

Figure 7. Distribution of GVC Employment by Segment, Total and Female (2017, %)



Source: Authors based on (Mining Skills Council, 2017)

Table 3 illustrates female participation in major job profiles in three GVC segments (+85% of industry employment, based on available data). Notably, the segment with the highest female intensity is extraction, especially in geology with 20% and extraction engineering specialists with 11%. In the processing stages, the highest female intensity is in engineering (specialist in processing (17%)). The lowest female intensity is in more labor-intensive maintenance activities with a mere 2% of representation in mechanical maintenance. The higher increases of female participation in mining job profiles, are seen in the areas of mobile equipment operator and engineer positions in different segments on the mining GVC. These are generally highly paid positions.

Table 3. Female Intensity in Different Mining Job Profiles

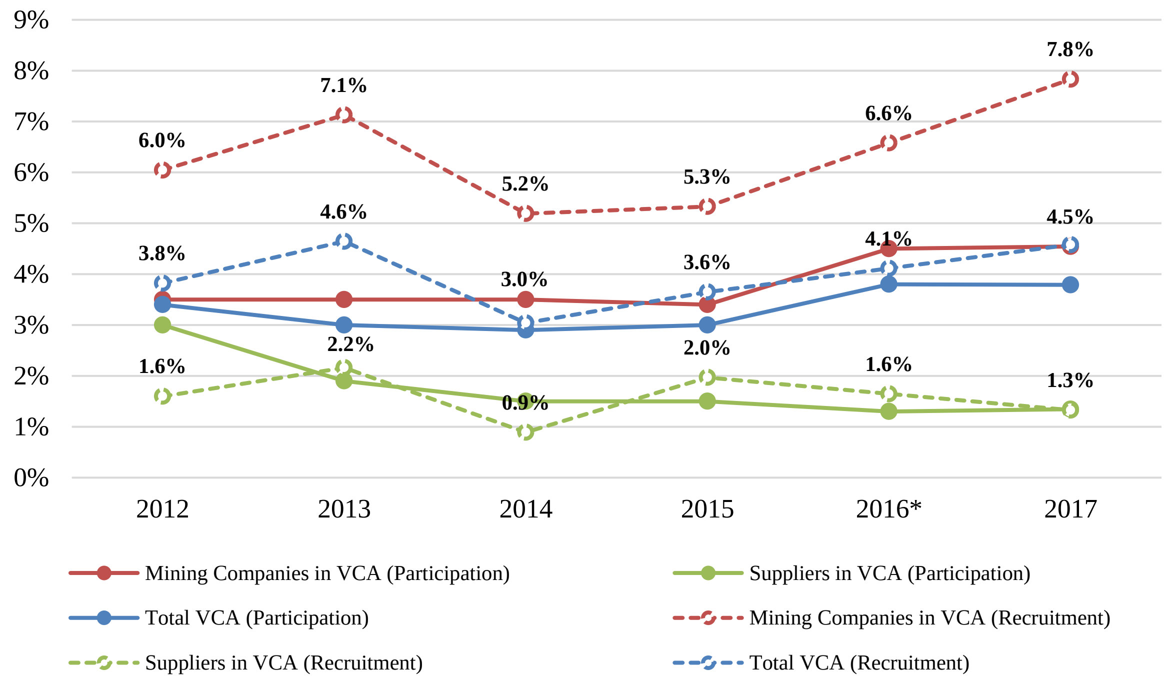
Profile/Years	**2012**	**2013**	**2014**	**2015**	**2017**
Extraction					
Geologist	17%	20%	19%	21%	20%
Mine extraction professional	6%	7%	6%	7%	5%
Engineer, specialist in extraction	9%	8%	8%	9%	11%
Extraction supervisor	3%	2%	2%	3%	4%
Other occupational profiles	4%	4%	5%	6%	6%
Mobile equipment operator	3%	3%	3%	6%	7%
Processing					
Processing professional	10%	11%	10%	12%	10%
Engineer, specialist in processing	13%	15%	15%	15%	17%

Processing supervisor	4%	4%	5%	8%	9%
Fixed equipment operator	2%	2%	3%	4%	6%
Maintenance					
Maintenance professional	5%	6%	4%	7%	4%
Engineer, specialist in maintenance	6%	6%	6%	6%	8%
Maintenance supervisor	2%	1%	1%	2%	3%
Mechanical maintainer	5%	5%	2%	2%	2%
Electric maintainer	3%	4%	2%	3%	3%

Source: Mining Skills Council (2018)

While there have been important increases in the extraction and processing segments, this continued low participation is partly a result of chain fragmentation; overall participation combines two sets of companies, mining firms and mining suppliers, with respective female shares of 4.5% and 1.3%. Suppliers account for an estimated 62% of total employment (Mining Skills Council, 2017). Mining companies efforts to attract more women in the value chain have increased recruitment from 6 % to 7.8%; however, on the other hand, suppliers female recruitment have decreased from 1.6% to 1.3%. This is critical as suppliers account for over half of employment in the industry.

Figure 8. Female Participation and Recruitment by Activity (%), 2012 - 2017



Source: Authors based on Mining Skills Council (2017). **Notes**: (*) In 2016, figures of participation are equal to 2017, but data for this year was not collected; labels with VCA include all companies participating in Value Chain Activities.

In brief, as gender diversity awareness has grown in the industry, there has been an increased demand for women and a slight increase in female intensity. Gender programs address traditional problems of women in the workplace; this is a necessary but insufficient step to address the gender gap. The value chain data shows that this has not translated to substantial opportunities for women in operational activities; however, there is initial evidence that female employment is increasing in segments where there is a higher incorporation of new digital technologies. Yet, the issue of gender is absent from discussions of how Chile will develop competencies for the digital mine of the future and gender initiatives overall have not yet recognized the importance of digital technologies as a future driver of female inclusion in the industry.

4.3. Constraints to Female Participation in the Mine of the Future

The key technical barriers to female participation in mining of physical requirements, safety concerns, and infrastructure constraints have been eliminated as new technologies have been introduced; yet female roles in mining remain limited. The findings of this exploratory research indicate that while digital technologies have created new opportunities for women by removing technical obstacles, other non-technical ones have gained importance. As industry stakeholders around the world work to define the competencies of future digital mining jobs, there is an opportunity to understand these emerging constraints for female participation and to put policies and practices in place to mitigate them.

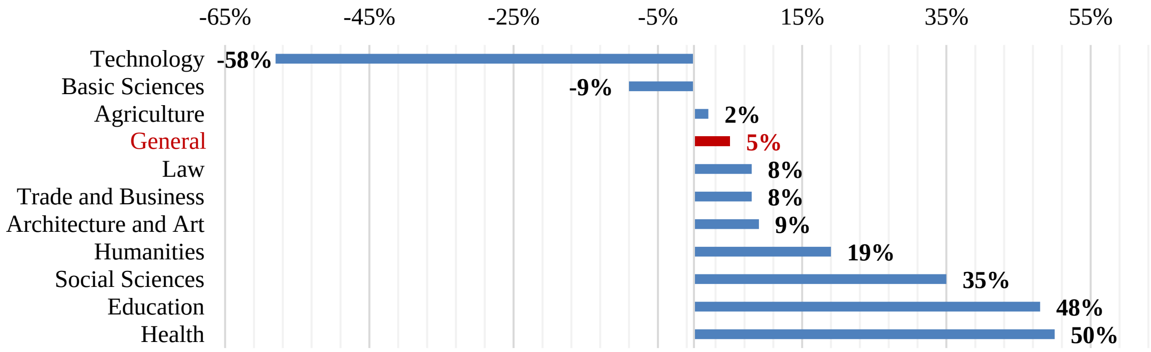
These constraints can be grouped into four areas:

First, location remains a problem for female inclusion. Mines have been slow to relocate remote controlled and monitoring operations away from the mine. This is partly technical and partly the result of inertia due to legacy operations. Slow roll out of advanced communications technology means that in many cases, it has not been feasible to move all remote controlled and monitoring operations away from the mine (Field Research, 2018; Guzmán, 2017). The bandwidth required to transmit the extremely high levels of data is significant, and much of the cutting-edge equipment will require 5G technologies that are only recently being implemented. In the majority of cases, mines have not yet been willing to invest to move their operations centers, and have been reluctant to make revolutionary changes in the recent context of low commodity prices.

As a result, while jobs are no longer on the frontline, they unnecessarily remain located at the mines. This requires employees to live on site and operate in multi-day shifts. Thus, this continues to be a major drawback for the inclusion of women; 70-80% of female applicants are not willing or able to commit to this schedule (Field Research, 2018; Vantaz, 2018). At the same time, this represents a major burden for female retention; 69% of female employees say that distance and family separation are the most important negative factor of working in the industry (Vantaz, 2018).

Second, there are few qualified female candidates for the industry. This is a result of imbalance in education and career development opportunities, and will continue to deepen in the future as women are underrepresented in the emerging STEM degrees required by the industry. As seen in Figure 9, the gender gap for enrolment in technology careers, that is, female participation minus male participation, is 58%, the highest across all areas of participation. This is notable since women account for a 5% higher share of tertiary enrolment as a whole. At the same time, high levels of education have failed to translate into career advancement, discouraging qualified women from pursuing mining careers. 81% of women in the industry have a university degree while one third of these also have completed graduate degrees. However, there is overall a low level of female participation in high level jobs (Albornoz, 2016). Lack of professional development is one of the most frequently cited reasons for women leaving the sector (Vantaz, 2018).

Figure 9. Enrolment in Tertiary Education (Undergraduate and Graduate Degrees), Gender Gap by Degree Type



Source: Authors based on Albornoz (2016). **Note:** Gender gap is measured by female participation minus male participation in the industry.

Third, the industry maintains experience requirements for many positions, which limits additional female participation. Given historical barriers to female entry, there are relatively few women with mining experience in the labor force. This experience requirement has been extended to jobs related to these new technologies. In particular, in remote-operated jobs, it has been common practice to retain existing operators and train them for the remote-located position (Field Research, 2018). For example, Chuquicamata trained its existing workers at El Teniente as they prepared to make the transition to automated and remote controlled underground mining (Field Research, 2018). This creates an important obstacle for new human capital –male and female alike - to enter the industry, particularly recent graduates who are more likely to have the technology skills required for these new jobs.

The experience requirement has also had an important impact on rotation rates of women already in the industry. As more mines seek to implement gender strategies, the demand for experienced female mining workers has grown and poaching has increased notably in the industry (Field Research, 2018).

This experience barrier is also one of the contributing factors to poor female representation amongst suppliers. Miners require their suppliers to provide experienced human capital for jobs. Suppliers therefore have a much lower female share, and of these only 20% of their female employees work in operational positions in the value chain (Jenny, 2018).

Finally, gender stereotypes remain strong and mining is still considered to be male work. Industry marketing and communications is highly masculinized, and common perceptions remain that it requires strength and stamina. Industry networks continue to be dominated by men, making it difficult for women to access work groups, limiting opportunities, visibility and job satisfaction. Furthermore, Chilean society stigmatizes women in mining, favoring female workers for more traditional roles such as education, healthcare, retail and domestic staff (Comunidad Mujer, 2018).

5. Conclusions and Implications for Policy Development

Digital technologies are removing the principal technical barriers to female participation in extractive sectors. However, as a first mover among developing countries, the Chilean experience illustrates that the introduction of these new technologies is not sufficient to drive gender parity in the industry. This is an essential lesson for the many developing countries that are dependent on natural resources. The case demonstrates that non-technical constraints continue to limit gender parity. Company strategic planning maintains job locations in the mines, gender bias is embedded in the education system, entrenched labor practices regarding experience make it difficult to bring the new talent required for the coming high-tech jobs into the industry. At the same time, gender stereotyping and norms remain pervasive. Unless the gender debate shifts from one of overcoming difficulties of minority inclusion to one that is focused on how women can contribute to competitiveness of the industry, the sector will continuously have to introduce reactive gender measures. Women need to be viewed as a strategic asset in the context of the changing industry.

Public policy and company strategy must be aligned to break this cycle. Ensuring that these 21st century technologies can indeed help reduce the gender gap requires a commitment of leadership in the industry to proactively mainstream gender into the development for the new jobs of the future and in all industrial policy strategies for the developing of mining in the country.

Policies for Mainstreaming Gender for Extractives 4.0

The initiatives below focus on shaping both the demand for women in the workplace and generating an adequate supply of women to meet that demand.

- **Initiate dialogue of gender for the future of extractive industries amongst stakeholders.** This includes incorporating actors from industry, the public sector, educational institutions and civil society organizations. In particular, emphasis should be placed on bringing together working groups on gender issues with those focused on resolving the human capital requirements for the future. These new technologies offer a clean slate for addressing the sector's female deficit.
- **Increase labor market awareness of the changing nature of the work in the extractives sector and the subsequent strong potential employment opportunity for women.** Shift the focus from traditional jobs in the extractives sector to those of the future. Women that were not able to previously participate in the industry will have an opportunity to enter the sector with very different skill qualifications. Roles such as equipment maintenance and management have already begun to adopt new technologies, which require increased cognitive work, decision-making and data analytics. Support organizations focused on increasing female participation to help disseminate these messages.
- **Strengthen female participation in STEM education**. Gender equity in specific degrees is more important for the sector that general gender equity in education. The industry's new

skills will be based on STEM jobs yet women are underrepresented in these degrees. This replicates past tendencies in which female share of traditional mining qualifications were low. This needs to be addressed from early education to avoid the need for future catch-up in gender parity. Gender inclusion initiatives in education continue to be focused on those qualifications that will soon be obsolete. In 2015, BHP launched Choose Match, a US$15 million five-year partnership with the Australian Mathematical Science Institute to increase the representation of women in the field of mathematics and to reduce a decline in girls studying math and entering STEM related careers (BHP, 2015)

- **Incentivize mining and oil and gas firms and suppliers to create opportunities for qualified women with no sectoral experience**. Global human capital shortages in extractives will intensify quickly as new large-scale investments are undertaken; these will increasingly require the use of digital technologies. Drawing more women into the sector will also reduce high levels of rotation of female workers amongst firms, while increasing the share of workers with the skill sets in which women are known to excel – such as decision-making under pressure and multi-tasking can boost initial mine productivity. CODELCO Chile is using its leadership program *Graduados*, which is oriented towards the leading university graduates from the country to bring women into the sector; approximately 40% of participants are women (Field Research, 2018).
- **Encourage/incentivize promotion of women into senior leadership positions.** Specifically, this should be encouraged in divisions with an emphasis on technology to help create role models for women who are frustrated with lack of career advancement as well as to create a cascading effect to promote women into all levels of the organization. Increased transparency of promotion and selection processes for these senior role is important, while a quota approach may also work. In 2002, the South African Mining Charter introduced a 10% quota for female employees; female employment grew from 2% in 2000 to 13.2% in 2016 (WRS, 2014).
- **Put pressure on lead firms to influence their suppliers to develop gender policies.** Suppliers can account for a large share of the mining workforce. Suppliers have some of the lowest participation of women in the industry. Gender participation norms can be mainstreamed as a key requirement for suppliers, using the same mechanisms that mining companies have used to enforce safety and environmental standards through their supply chains. This can include publishing of gender disaggregated data on numbers and roles of employees.

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