

Review

A Comparative Study of Mining Control in Latin America

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Abstract: This study analyzes various regulatory framework mechanisms applied to prevent, minimize, and mitigate environmental accidents and disasters, within the extractive mining industry, in seven Latin American countries. The selected countries offer an ample view of the mining industry specter since each one of them is at the different development stages, such as Chile, Bolivia, Mexico, and Brazil. Nevertheless, some of the countries have similar technical characteristics, as is the case of Peru, Colombia, and Ecuador. Controls and regulations employed in each of the countries reveal particularities that should be appreciated and understood. In conclusion, the existence of mining regulations has not diminished the occurrence of environmental accidents in those countries. However, the existing environmental controls allow authorities to quantify with substantial precision the degree of impact coming from Latin America's mining industry. Furthermore, for more than a decade, mining industries have been subjected to several global initiatives to integrate elements of corporate social responsibility into their management systems—mainly in strong cooperation with different governmental formalization programs. The key focus is, cooperation among different scales (industry and small-scale and artisanal mining) which challenged, but also improved the capacities of environmental authorities and the effectiveness of different legal frameworks.

Keywords: mining policy; environmental control; soil pollution; tailings dam



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1. Introduction

Extractive mining in Latin America has a very long history and tradition [1]. Mining activities contribute more than \$18,000 million to various countries in the region [2]. In Mexico, Bolivia, and Colombia, mining corresponds to 10% of their gross domestic product, while in Chile, it corresponds to more than 15% [3]. However, despite all the wealth it generates, even today, the mention of new mining projects causes reluctance from a portion of the Latin American population [4,5] due to different environmental accidents and technological incidents that occurred in the region.

The most important environmental effect of technological accidents, within the mining industry, is surface and groundwater pollution through the presence of toxic solid or liquid wastes. In the global context, recent events have occurred in Myanmar (July 2020), where a heap of mining waste collapsed into a lake, product of a heavy rainstorm that induced a landslide that killed at least 113 people. In May 2020, in the Heilongjiang Province, located in China, tailings from a dam leaked, resulting in the release of supernatant water and tailings that flowed reaching the Yijimi river, threatening the drinking water resource. In April 2019, in India, a failure in a red mud tailings pond occurred, resulting in 35 acres of land cover with toxic mud. In March 2018, in Australia, the tailings dam failed, due to the existence of a low-density foundation layer in the area. Several other cases occurred in China (2017, Tongshan mines, Hubei Province) and the U.S. (2016, mines of New Valley,

Florida). The New Valley event caused groundwater contamination in the Floridian aquifer, a major storage of drinking water, with 200 million gallons of highly acidic wastewater. In Canada, the Mount Polley mine accident drained more than 10 thousand m³ of polluted water into two lakes. In Europe, the pollution from the Sotkamo mines (Finland, 2012) affected surface water, while the events in Hungary (Kolontar, 2010) and (Magadan Russia, 2009) were characterized by the flow of toxic sediments. Two events in Romania in 2000 (Baia Mare and Borsa) carried pollution to the River Tisza, an important tributary of the Danube River [6].

During the last environmental mining accident in Latin America, which occurred in Mexico in May 2020, a dam failure released 6000 m³ of toxic material into the environment. The tailings spilled on a nearby road, covering 8000 m² of soil, reaching and affecting the San Bernabé stream. In July 2019, thousands of liters of sulfuric acid reached the Sea of Cortez, in the California Gulf. Material came from the mining industry [7]. In November 2015, 55 Mm³ of iron ore mineral waste was washed-out in the State of Minas Gerais in Brazil. The main tailing pond presented a breakage, causing an avalanche of mud, contaminating the watershed of the Doce River. This environmental accident occurred along 500 km, eventually reaching the Atlantic Ocean [8]. In August 2014, in the State of Sonora (Mexico), a structural flaw within the main mining tailing storage dam did not withstand the contribution of atypical rains and spill of 40,000 m³ of sulfuric acid into the Sonora River. The tailings produced environmental impact over 420 km of the river [9]. In Potosí, Bolivia, several environmental accidents, such as the spill of more than 3300 m³ of waste in the vicinity of a river, or the collapse of a dam in Potosi, left a popular neighborhood completely waterlogged with toxic waste [10]. In 2011, two toxic spills in Chile were produced in March and April in a 15 day-span, in the regions of Valparaiso and Antofagasta. Arsenic and sulfur dioxide from a refinery and smelting industry operated by CODELCO caused the intoxication of forty-seven people [11]. Nevertheless, the study of the causes of the mining industry's environmental impacts is still limited [12,13].

Mining environmental control arises then as an imperative need that seeks to protect not only the physical environment, the biotic environment, but mainly the well-being of people who have been affected by environmental disasters. The progress made by the Latin American countries differs from those obtained in first world countries. The legal framework and mining environmental control regulations vary across the American continent. This article aims to analyze environmental policies in Latin American related to mining activities, presenting a comparative analysis of the state of the art in which exist regulations in seven Latin American countries—Bolivia, Brazil, Colombia, Chile, Ecuador, Mexico, and Peru. These countries have mining as a percentage of their economic activities.

Extractive mining has been for many years a great contribution of resources for Latin America. However, one of the major problems that have been caused over the years, is the rouse of contamination of resources water, soil, and air spaces where activity occurs. The main focus of small-scale mining has been oriented towards obtaining the resources, without taking into account the affectation on the biota or wildlife species that inhabit the environment. Countries such as Mexico, Chile, Bolivia, Peru, Colombia, and Ecuador have had a long tradition-oriented towards the extraction of mineral resources from the colonial era. In many of these countries during the century, twenty has been the presence of firms from European countries and North America who have had greater mining tradition.

It has been observed that there are spaces of knowledge that have not been published from the point of view of the Academy in the area of research of extractive mining and its environmental impacts. One of these spaces is the environmental analysis of accidents that have occurred in Latin America. To date, it has not been observed the presence of scientific publications related to the synthesis of major technological disasters that caused significant environmental impacts. An analysis of the impact of environmental effects was not found and neither was the effects on improvements in existing regulation of the countries analyzed.

2. Methodology and Analysis

The present study started with the selection of countries to be evaluated. This was done according to the importance of mining activity within their gross domestic product (GDP). Table 1 shows the participation of the GDP of the countries covered within this study. Mining regulations of the countries and mining environmental disasters that occurred were analyzed, despite the existence of environmental guidelines. Then, the state of the art of the selected countries was evaluated.

2.1. Bolivia

In the Bolivian case, the mining industry represents approximately 4.21% of the GDP by 2017 [14]. This South American country has a great mining potential in various metals such as Zn, Sn, as well as precious metals such as Au and Ag. This industry has been specially developed in the high zones of the country, in the region of Potosi [15]. In 1996, one of the greatest environmental disasters occurred in that area when a mudslide discharged 250,000 tons of toxic waste into the Pilcomayo River [16]. In addition, in the city of El Alto, high As measurements have been found on polluted soils and water. Nearby this area, high concentrated W was found, and as well as Pb and Sn close to refineries. High As concentrations were found in the blood of its inhabitants, especially children. Discharges of mining waste contaminants were also found in the area. Values measured in the areas of Rio Grande were as high as 77.9 ppm. Pb, Zn, and Cd were measured in high concentrations in soils in the surrounding areas [17].

Bolivia has a great advantage over the other Latin American countries that are part of this study possess. Non-governmental organizations related to the mining area work closely with governmental officials in areas where extractive mining activity occurs. This is one of the reasons why NGOs operating in Bolivia have had support from the Switzerland Agency for Development and Cooperation. This agency has worked directly with the Bolivian Ministry of Mining and Metallurgy and the Fund for the Environment. In the Oruro and Potosí Departments, municipal governments assumed the role of an environmental authority. There are also programs of cooperative education where environmental problems are treated through the strengthening of cooperatives themselves. This process has undoubtedly been one of the main strengths of the mining industry in the country. The mining law that supported the further elaboration of the mining activities environmental regulations in the country was enacted in March 1997 [15].

2.2. Brazil

National Environment Policy and Institutions of the National Environmental System of Brazil require, within their regulations, the carrying out of environmental impact assessments as an essential tool for the mining sector analysis. Nevertheless, according to Brazilian environmentalists, the country had a structured system of environmental impact assessment rules and provisions that vary within states [18]. To correct the problems of the regulation, the government proceeded to the adoption of resolution CONAMA 237/97 [19], where it was established the specific definitions of the mining activities that needed to be authorized and the steps to follow for the different types of environmental permits that it could be issued depending on the respective prior environmental impact study. Brazilian law No 6938/91 designated every Brazilian State and the Brazilian Government, in its replacement, as competent political bodies to carry out the function of environmental licensing for mining projects. The vast majority of Brazilian municipalities are not prepared for executing this prerogative. In addition, they may only exercise this attribution in the case of existing municipal laws that regulate authorizations in their jurisdiction. Basic environmental authorization procedures shall be established according to the rules of each state in the country, although all its regulations are adopted by federal law [20]. Currently, the Brazilian Institute of the environment and renewable natural resources is responsible for monitoring all processes or activities of mineral extraction on land or sea, besides its transport activities, and possessing environmental licenses [21].

Brazilian regulations seek mining companies to propose measures of mitigation, compensatory or environmental control measures, indicating their application procedure, taking into account the expected environmental impacts. Including also a detailed analysis of the efficiency of the protecting environmental procedures to be deployed, as well as the monitoring of biotic and abiotic resources affected by extractive mining. In Brazil, the mining industry must provide compensatory measures to restore degraded environments. This practice allows them to maintain and preserve ecosystem services. Miners also have to pay a monthly fee, the Financial Compensation for the Exploration of Mineral Resources (CFEM), as part of the environmental cost for the exploitation of nonrenewable natural resources in the country [22].

2.3. Colombia

The Colombian Government on its 1991 Constitution, provides special attention to renewable natural resources. Because of this, in order to carry out any mining activity, the contractor must know the environmental aspects before developing mining activities. Among these aspects are: existing environmental restrictions and the use or exploitation of natural resources according to the activity that will take place. Nevertheless, illegal mining activities cause environmental damages and reduction of biodiversity [23]. Usually, the Colombian Government recommends the use of clean technologies that do not pollute the environment, and simultaneously, the use of renewable and non-renewable natural resources properly and rationally [24]. These technologies apart from complying with cleaner combustion processes, also are required to fulfill the rules and regulations of emissions to air, soil, and water [25]. The Colombian State uses licenses, concessions, and authorizations as legal control mechanisms. This eases the government's load to monitor the use or exploitation of renewable and non-renewable natural resources for the development of any productive activity whenever the case is required. However, in the case of Colombia, more than 83% of the mining units do not have environmental licenses, and it is from those and the ones outside the law that the greatest environmental impacts are generated [26]. Regarding process control, an environmental assessment will evaluate the extractive methodology, depending on the objectives set in the formulation of plans according to the mining project implemented, as set out in the regulations of the country. In addition to the environmental permits and licenses required by Colombian regulation, all mining titleholders are required to contract a mining and environmental insurance policy, which must be in force during the entire duration of a mining project [27].

2.4. Chile

For Chile, mining represents one of the main sources of foreign exchange income. However, it has also caused a strong impact on the environment and this is the main reason for the rejection of the public towards this activity [28]. Chile, within its environmental legislation, has established criteria for the classification of the mining sector. Therefore, its controls on mineral extraction processes depend, not only on the extraction mechanisms but, on the companies' size as well.

Chilean regulations establish a methodology as part of the identification and evaluation of the soil where the mining projects will be developed. Based on this technical premise, the Chilean Ministry of the Environment determines mandatory lines to follow. These processes include gathering information relevant to the mining procedures and surrounding areas, identification, cadaster, and prioritization of vulnerable areas based on its proximity to the population, the development of programs of assessment and management of environmental risks, and finally, the development of management plans of those priority areas.

The Government of Chile also has developed law "Ley 20551", which regulates the closure of mining facilities and operations. This law seeks to safeguard and demand a closure plan of mining operations that includes a set of measures and actions only aimed to mitigate the effects that have caused harm to the environment and society. It also

requires that mining companies can only start operations with a previously approved closure plan [29].

2.5. Ecuador

In 1997, Ecuador proceeded with the approval of a regulation that appointed responsibilities to monitor, evaluate, and penalize industries for the environmental impacts caused by the mining sector. This responsibility corresponded to the Ministry of Energy and Mines. Years later, the Ecuadorian government created the Ministry of Environment and through a ministerial agreement, currently enforced, and established the environmental regulations for mining activities in the country. Currently, the regulations are based on the prevention and control of pollution of air, water, and soil. Ecuadorian legislation has a mining law that establishes phases to obtain mineral benefits. They are established within the Ecuadorian regulation stages: prospecting, exploration, exploitation, marketing, and mine closures, so the analysis of them is a requirement for environmental impact assessments [30].

In Ecuador, government bodies have drafted instructions for mining environmental studies for the control and evaluation phases. The appointed procedures are guidelines for the control and environmental regulation, for instance: a preliminary assessment of environmental impact, environmental impact assessment, and environmental audits.

The presentation, analysis, and approval of studies follow the next process: in-depth evaluation of environmental impacts, provided by article 14 of the Environmental Regulations for Mining Activities in the Republic of Ecuador, the programs, budgets, and annual warranties, according to articles 8 and 9 of the Environmental Regulations for Mining Activities in the Republic of Ecuador, as well as studies and joint plans, provided by article 68 of the General Regulation Substitute for the instruction of the mining law. For the analysis and review of studies, once submitted, the agency responsible must analyze and verify, which may include a technical inspection in the field to finish the evaluation [31].

Various legal reforms in Ecuador are found based on State policy, as well as the interest of non-renewable natural resources. Through the years, a breakthrough has been successfully achieved regarding the mining sector, which has settled the development of the regulations. "The mining legislation, in addition, to obtain permissions and run the same legislation for environmental protection, requirements shall include the implementation an operations evaluation of environmental impacts of the single system of environmental management" [32].

In 2016, the Control and Regulation Mining Agency in Ecuador (ARCOM) developed a digital mining cadaster capable of monitoring the mining activities in the country. This mechanism makes it possible to monitor production and extractive processes existing environmental licenses and accountabilities in the processing plants that currently operate in Ecuador [33].

2.6. Mexico

Environmental problems in Mexico, regarding the mining industry, occurred, according to experts, due to mismanagement of past environmental controls. On certain occasions, this type of control was not demanded. SEMARNAT (Secretariat of the environment and natural resources) whose maximum function is to locate, quantify, and characterize the waste generated by active and abandoned mines, was created in 2004 [34]. One of the potential problems in the Mexican environmental law is not requesting explicitly the elaboration of the baseline in the environmental impact assessment. Although the study must at least contain the description of the environmental system, there are signs of possible environmental problems in the areas studied. Another aspect to consider is that mining projects require a minimum authorization by SEMARNAT, according to the regulations and laws [35].

Mining involves ecosystem alterations. Depending on the impact, the effects will be analyzed to a greater or lesser extent. The methodology to evaluate the impacts is based on

stages of development in the mining process. It is necessary to scan the geology of the area under evaluation. At this stage, the focus is oriented on collecting all information on:

- Possible characteristics, types of deposits, among others. The assessment of future environmental damage will depend on the type of exploitation design as either underground or open pit.
- Development and implementation of the process: analyzes, evaluates, and controls the material removal process, undercutting of the land, the generation of dust, etc., by laboratory tests.
- Operational phase: the study of the different methods and disposal of liquids and solids waste from tailings.

In the case of the Mexican mining areas, the topographic factor is very important to control environmental impacts, due to its predominantly mountainous regions. This fact has occasionally generated design problems, especially for wastes management and tailings dams. It is estimated that nationwide mining waste constitutes 30% of the mass deposit of iron, plaster, and other non-metallic minerals, minerals base 50% and 80% of coal deposits by which Mexico in recent years has been devoted to the evaluation of the tailings operations. At the present time, this problem is being eradicated through dams built according to standards [36]. Tailings deposits often contain a large percentage of residues from processes like cyanidation and flotation. All tailings have alkaline pH, except sandy horizons of a site with 75 years of neglect (Pozuelos) with pH of 5, which indicates that though airy and drained conditions present local acidification. The concentrations of metals in the tailings are medium to high standards of different countries: 37 to 429 mg/kg Cu, 13 to 178 mg/kg Pb, and 36 to 448 mg/kg Zn [36].

Moreover, correcting measures are compelled in case of soil, water, and air pollution related to mining operations. Regarding dust control, Mexico has developed strategies to identify tailings with great potential for environmental risks considering the possibility of particles mobility by the action of the wind.

2.7. Peru

The Ministry of Energy and Mines of Peru also requires the companies to present a plan of management according to the type of exploitation, taking into consideration what you want to monitor and evaluate. Environmental impact studies are kept as a requirement, in which they have developed guidelines to monitor different types of processes. Within procedures established by the Peruvian Government are those of tailings, acid mine drainage management, mining emissions and air quality monitoring, management of wastes from mining activities. Similarly, there are guides for mine closure, treatment of environmental liabilities, etc.

From the point of view of mining environmental control and management, Peru requested that companies take control of: daily monitoring activities, indicating date and time, location in UTM coordinate of the monitored place, also to establish the methodology of monitoring, determine the start time and completion of the activity, indicate the results, following additional observations and the requirements for the next monitoring.

The monitoring activities will allow having a record and control of the environmental components that could be affected by the activities of the mining exploitation program. Depending on the company and the importance of the exploitation in the sector, it is recommended to have a contingency plan to the study of potential hazards that can cause possible relevant emergencies during the mineral extraction procedures [37].

3. The Interface between Corporate Social Responsibility and Environmental Legislation

To better understand the dynamics of the development of Corporate Social Responsibility (CSR) concepts in mining industries in Latin America, it must be taken into consideration that more than 50 importing countries have established restrictions or taxes on the export of raw materials providing mining and implemented programs to monitor supply

risks for essential minerals and have applied import restrictions to ensure responsible and conflict-free production practices.

Even the extractive industries show clearly how far corporate social responsibility is first a risk management strategy to keep existing supply chains. An annual survey 2020 performed with international companies shows that the main risk in this regard for mining in 2020 was obtaining licensees to operate [38,39].

The driving force for the application of CSR and due diligence mechanism is obviously the financial sector. International operating refineries from Canada, South Africa, or Switzerland importing, for example, gold ingots from Peru, Bolivia, Colombia and Ecuador and their main customers (banks and jewelry brands) do have a vital interest in trace-able and clean supply chains and establish alliances with international development cooperation, the United Nations Development Plan (UNDP), and the non-critical pro-mining NGO sector.

In this regard, Swiss refineries in alliance banks and jewelry brands established the “Better Gold Initiative” [40] which implements programs to promote the inter-scale cooperation among industry and small-scale mining about formalization in countries like Colombia, Ecuador, Peru, and Bolivia.

The current programs are public-private in cooperation with the UNDP Planet Gold, the Development Cooperation, and governmental institutions. These programs focus on implementing better technologies for gravimetric mineral enrichment to significantly reduce mercury use of artisanal- and small-scale mining. Furthermore, these programs offer better tailing management and forest management in environmental sensitive areas. The aim is to comply with the prohibition of mercury use in all countries according to their National Mercury Elimination Plans which are in place in all legal frameworks in the Andean countries since 2018 according to the UN Minamata Convention on mercury elimination.

The Better Gold Initiative addresses several other non-environmental topics that qualify mines to deliver clean gold such as occupational health and safety and topics like worst forms of exploitation which can harm the reputation of refineries, and their customers. Non-clean supply chains do not only harm the reputational image, but they are also a legal challenge in importing countries.

One of the emblematic cases that pushed the refiner Metalor to promote and engage in the Better Gold Initiative was in 2014: The Peruvian authorities involved the largest national supplier of the Swiss refinery Metalor Technologies—“Minerales Sur” of Puno—in the dispatch of illegal gold. Metalor’s gold dispatch from Peru between 2002 and 2017 was estimated at 100 tons in total. In March 2017, the Peruvian finance authorities (SUNAT) immobilized 100 kg of gold that was going to be sent to Switzerland in the context of an alleged illegal gold supply scheme from areas of high conflict against Peruvian exporters located in the Madre de Dios and Lima [41].

Apart from the problem of illegal supply activities—with the forms of gold purchase—it is a structural problem of the whole sector based on dispatching gold from local refineries where mining sources are at huge risk coming from illegal environmental sources and environmental sensitive areas.

Due to reports of bad practices and the increased sensitivity to environmental disasters—in the jungle areas of the Amazon (Madre de Dios Perú)—both in producing countries and in purchasing countries—the public pressure from Metalor’s shareholders and the public opinion increased.

Since 2017, Metalor cooperates in the context of the Better Gold Initiative with sustainability certification systems like Fairtrade International which is recognized/benchmarked as a homolog system that enables mines to Metalor suppliers. Between 2019 and 2020 alone, the certification system Fairtrade International in Peru increased the number of certified mines in this context from 2 up to 16. The same applies to other Latin American countries and other certification schemes (such as Responsible Jewellery Council or Fairmined/Alliance for Responsible Mining) [42].

The efforts to improve environmental mining practices can only be achieved through strengthening the environmental authorities and the local legal frameworks. How far this goes concerning the real negative environmental impact and devastation in figures is still an open question and pending to be investigated on the ground (census and available overall impact studies are pending).

4. Discussion

While the countries analyzed have regulations that allow them to take preventive actions aimed to mitigate the occurrence of accidents or technological disasters, these have not prevented the generation of incidents that have been impacting both the civilian population.

The mining activity Latin America level generates resources that have allowed the development of their countries, such as the case of Chile, Mexico, Peru, Colombia, etc. However, it may be necessary to seek to globalize compensatory and mitigation measures to benefit both the industry, workers in the area, mining, as well as the population in general. Latin American countries should be leaning towards learning of mutual experiences. This will allow all countries to move in the direction of more responsible mining procedures that will ensure not only human well-being, but also the environment where the mining activity occurs. Table 1 shows a compendium of programs that are conducted.

Table 1. Compendium of mining policy and major environmental disasters that occurred in Latin America.

	Bolivia	Brazil	Colombia	Chile	Ecuador	Mexico	Peru
Mining GDP 2015 (%) (World Bank)	4.21	1.34	0.62	11.58	0.18	0.63	5.43
Rated by production mining	✓	✓	✓	✓	✓	✓	✓
Mining for Association	State mining, mining private, Mining cooperatives	Not required	Not required	Not required	Not required	Not required	Not required
Cadaster	✓	✓	✓	✓	✓	✓	✓
Evaluation and risk management programs	✓	✓	✓	✓	✓	✓	✓
Activities of daily monitoring required	Not required	Not required	Not required	Not required	Not required	Not required	✓
Consultation with public binding	It is not binding	It is not binding	It is not binding	It is not binding	It is not binding	✓	It is not binding
Management plans	✓	✓	✓	✓	✓	It is not binding	✓
Contingency plans	✓	✓	✓	✓	✓	✓	Recommended
Environmental highlights mining accident	1996 Pilcomayo River Discharge of 250,000 tonnes of waste [43]	2015 Doce River, download 62 million of water and mining waste [8]	2017 Landslides in the Rio Putumayo [44]	2011 Arsenic and sulfur dioxide caused the poisoning, forty-seven people Antofagasta [11]	2017 Presence of silver mines in Zaruma [45]	2014 The structural flaw of mining waste storage dam produced the spill of 40,000 cubic meters of sulfuric acid above the Sonora River. [9]	2000 Choropampa spill 151 kg of metallic mercury [46]
Authority	Ministry of mining and metallurgy Mining administrative judicial authority	Ministry of mines and energy	National Agency for mining	Ministry of mining	Ministry of mining Agency for regulation and Control mining	Ministry of the economy	Mining administrative judicial authority Geological survey, mining and metallurgical

In the case of Chile, mining represents one of its major sources of foreign exchange income. However, it has also caused a strong impact on the environment. Nevertheless, it is necessary to mention, that the main advantage of the Chilean mining industry, over other Latin American countries, has been its orientation towards the generation and adaptation of new technologies. This capacity has enabled Chile to improve its performance and

to minimize the environmental impacts generated as a by-product of extractive mining procedures. Chile also has adopted a policy of continuous revision of its national standard up to international standards for water resources, as well as for soil and air. In the Chilean mining industry, procedures are performed from the point of view of impact characterization. This has allowed the industry to reach two objectives: first, to establish the degree of environmental affectation caused by every mining process. The second objective is to classify the mining tasks that are more likely to generate specific impacts and the risk associated with the potential of each one of the processes used in them.

In the case of Mexico, one of its main advantages is the close economic relationship with Canada. This has granted Canadian investments in Mexico's mining industry. With the aid of Canadian participation, Mexican soils can return to stable, productive, and healthy conditions through practices of landscape architecture and other means of conservation [47].

Peru, Colombia, and Ecuador are in very similar conditions regarding environmental control of extractive processes. However, from the point of view of the organization of monitoring, and control, Colombia tops the list, followed by Peru and finally Ecuador. On the other hand, it cannot be denied, the efforts made by the Ecuadorian Mining Agency for Regulation and Control, which through the use of technology, has made it possible to visualize the mining development in recent years.

The technological accidents presented on Table 1 are of different characteristics. Pilcomayo, Doce River, and Sonora were all events where there were either overspill incidents due to rain episodes overflowing tailings dams, or because there was a fracture on the dam itself. To avoid these types of events, tailings dams' designs should take into account specific hazards associated with geotechnical stability or hydraulic failure, considering advance ecosystems that might be affected in case of a failure, as well as human health and safety. Environmental considerations must also consider emergency readiness, responsive preparation, as well as mitigation measures in case of catastrophic release of tailings or supernatant waters polluted surrounding areas [47]. For these reasons, it is relevant that prior to the initiation of mining ventures, a full baseline assessment is conducted considering direct and indirect impacts areas. Evaluating rain patterns in the region under study, analyzing soil coverage that will facilitate rainfall infiltration and percolation, softening it, evaluating soil types, evaluating seismic behavior, superficial and groundwater patterns are important activities that help to diminish technological mining accidents.

In the Zaruma case (Ecuador), inhabitants in the area, excavated galleries, and sinkholes in different areas of the city, while following gold veins that could be observed on the surface. The different tunnels running underneath Zaruma were constructed using artisanal procedures and were not secure, this caused a sizable sinkhole in the middle of the town. This could have been prevented with regulation oriented to preserve human livelihood within city limits.

The last two cited incidents were a metallic mercury spill that occurred while transporting material, and in the Chilean case, was an arsenic spill in the copper refinery. Environmental impact assessment of mining projects includes contingency plans that must be followed. Most of the time, amid the emergencies, the chain of communication and action are lost. These events worsen the final results of technological incidents and accidents. For this reason, spill drills should be conducted often, and their results evaluated, monitoring response time and mitigation activities.

International organizations like the Fairtrade Standards for Artisanal—and Small-scale Mining Organizations and the Fairmined Standards of the Alliance for Responsible Mining (ARM) established benchmarked standards regarding aspects such as accident prevention, safe tailing management preventing drainage, and securing neglected deposits. Nevertheless, these standards and their certification systems are focused on a group of yet formalized small-scale and artisanal mining.

Despite the massive expansion of formalization programs in Peru, Ecuador, Colombia, and Bolivia, certified mines are still far from being mainstream and preventing environmen-

tal disasters in hot spots like “Madre de Dios in Peru” (Amazon), the “Chocó” in Colombia (Pacific), or in “Zamora” (Ecuador).

When private standards came into being between 2007 and 2010 through their first pilot projects from Fairtrade or ARM (authors accompanied several projects in these countries), there were not more than perhaps 15 in all Andean countries all together.

The counterparts for implementing such projects were the existing mining organizations being yet on the road towards formalization. This critical mass was fruit of the first formalization programs which also addressed securing tailing dams and tailing management. In this regard, Peru was the pioneer country through its revised mining law in 2004 recognizing for the first time artisanal- and small-scale mining.

Currently, all programs together, which were pushed by the corporate responsibility programs do include today around 200 best practices cases in the region—involving some thousand miners where tailing dams and processing neglected deposits of toxic wastewater is as safe as it can be in mining.

At the end, private certification systems focusing on corporate responsibility can never fully technically ensure dam safety, nor technical inspectors of international inspections bodies can do this, as the case of the Mariana dam breach in Brazil in the Fundao retention basin in 2015 showed clearly. The dam was approved by inspectors of an internationally recognized body.

Evaluating what corporate social responsibility contributes to safer tailings, it must be said that only multipartite cooperation among private CSR initiatives, importers, local authorities, and the development cooperation can make remarkable steps forward towards mitigation of the worst environmental impacts of mining.

Nevertheless, an overall impact study with an integrated view on all these programs is still pending. Corporate social responsibility programs must regularly measure their impact due to their accreditation, for example in ISO (International Standard Organization, which refers here to Fairtrade only). But these bodies never evaluate their overall effect since they are in permanent competition for donor resources with others. This NGO character is subject of the main concern on these programs.

During the conduction of the present research, it was observed that there is not enough scientific information regarding technological mining accidents and their descriptions. Scientific information in these cases, is oriented towards the environmental consequences and not to the complete description of the incidents or accidents themselves. Media outlets are the means that describe technological accidents, and they are not considered a scientific source. For this reason, it is difficult to find enough scientific data that would allow researchers to sustain and validate the description of the mining activities or absence of design considerations that might enable the occurrence of mining accidents. It is important the technological mining accidents are reported in scientific outlets, since they are the optimal mean for engineers to learn from past incidents that cost human, environmental, and economic losses to mining enterprises.

5. Conclusions

It is important to note that this study has made a comparison between environmental mining regulations within several Latin American countries and gave a brief outlook on the interface between regulatory frameworks and corporate social responsibility. It has also evaluated the relevance of its existence, which examines the demands carried out to prevent the occurrence of environmental accidents in the mining sector. All countries where environmental mining technological disasters occurred have rules specifically focused on the impacts of each stage of the activity. However, if it is possible to observe that countries such as Peru not only have the regulation but also have specific guidelines for each of the activities related to the process of minerals’ extraction.

In the particular case of Ecuador, regulation and control of the mining industry are fairly recent. The environmental monitoring requirement for mining activities, issued by the Ministry of the Environment, is dated 2014. Environmental regulations that set maximum

permissible levels of wastewater discharges for all industries, as well as mechanisms of environmental auditing, exist only since 2002. On the other hand, Chile, despite possessing one of the first standards for mining environmental control, has had several technological accidents, even affecting the population in general, as well as private assets and natural resources.

In conclusion, while the absence of laws and regulations in South American countries have allowed the discharge of acid drainage mining into bodies of water, and other types of mining waste, affecting water, soil, and other natural resources; the presence of regulations have failed to prevent the occurrence of environmental accidents in these countries. Nevertheless, the existence of the mining control regulations allows quantifying fairly accurately, the degree of environmental damage caused by the mining industry in Latin America.

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