Social metabolism of mining: Zacatecas (1980-2018)

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Abstract

This article analyzes mining in the Mexican state of Zacatecas from an ecological, economic and social metabolism theoretical perspective, using a mixed methodology. The qualitative analysis estimated the environmental surplus of the main metals at the national and state levels, while the qualitative analysis used four local case studies to examine the social and cultural dimensions. Findings suggest that researchers need a clearer understanding of the various problems arising from mining extractivism and point to the need for more comprehensive accounting in production which includes factors absent from the macroeconomic data, such as ecological damage, forced displacement, disruptions to the local economy, human rights violations, and social conflict. The article concludes that mining policy should be redesigned with due consideration given to these factors.

Keywords: mining; natural resources; ecological rucksack; sociometabolic fractures; socio-environmental conflicts.

1. INTRODUCTION

In recent years, Mexican mining has undergone important technological and productive changes, which have led to a transition to large-scale mining, focused on the international stage and characterized as mining extractivism (Gudynas, 2015).

The transformation of the mining sector favors corporations and governments alike. These actors emphasize that the growth of certain macroeconomic indicators such as Foreign Direct Investment (FDI), mining production and exports, along with the creation of jobs, constitutes an engine of development. It should be noted that in the period 2003-2017, Mexico ranked third in the capture of FDI flows for mining (15%) in Latin America, behind only Chile (40%) and Brazil (24%) (Bárcena, 2018). The production volume of the main metallic minerals grew considerably between 1980-2018, with gold being the one to register the greatest growth, with its extraction volume increasing 26-fold (National Institute of Statistics and Geography [INEGI][1] , 1984; Mexican Geological Survey [SGM][2] , 2019). Meanwhile, the value of metallic and non-metallic mineral exports increased 20.5 times between 2000-2018, going from US$881 million to US$18.124 billion (SGM, 2001, 2019). Meanwhile employment in the mining sector increased 118% in the period 1980-2018 (SGM, 1983, 2019).

The Latin American critical approach assumes that this take on development has its foundation in conventional economics, as it is based on “economic growth as an indispensable attribute of development” (Gudynas, 2020, p. 1). This approach is promoted by businessmen, academics and politicians, who argue that the economic benefits outweigh the social, cultural and environmental disadvantages which large-scale mining activity entails (Gudynas, 2019).

This point of view is limited as mineral commercialization prioritizes the economic side and “ignores the costs of replacing the ecological heritage damaged” (Gudynas, 2019, p. 31). This view does not take into account the quantity of materials disturbed by the interaction between the economic process of mineral extraction and the impact it has on the natural environment, known as social metabolism. This interaction tends to create problems linked to the socio-cultural reconfiguration of the space and its connection to socio-environmental conflicts (Machado, 2014).

There is research in Latin America that takes on the problems of developmental strategy based on the appropriation and mass export of minerals based on the theory of social metabolism (Machado and Rossi, 2017; Garcia, 2017; Carrasco, 2019); there are also some contributions which stand out at the national level (Delgado, 2012, 2013).

The objective of this article is to analyze Mexican mining using local case studies in the state of Zacatecas, with a mixed methodological approach based on ecological economics and the theory of social metabolism. In this regard, an estimate was made of the ecological rucksack for the main metallic minerals at the national and state level; meanwhile, at the local level, four specific cases in the state are singled out to demonstrate some qualitative indicators linked to social conflict and socio-cultural changes caused by mining.

The questions that guided this research were the following: what has been the evolution of mining extractivism’s social metabolism in Mexico and in Zacatecas between the years of 1980-2018? How has the increase in social metabolism stemming from large-scale mining activities impacted local spaces?

This work is divided into eight sections. After the introduction, the theoretical approach is outlined and then the materials and methods used are presented. The fourth section analyzes the political-economic conditions which made the expansion of mining extractivism in Mexico possible. The fifth, sixth and seventh sections take on the analysis of mining's social metabolism at the national, state and local levels respectively, while the final section concludes with some final thoughts.

2. THEORETICAL APPROACH

This research uses the theoretical approaches of ecological economics (Martínez Alier, 2007) and the theory of social metabolism (Foster, 2013), based on Latin American contributions in these fields and their relationship with mining extractivism.

Conventional economics do not include nature in economic accounts. Neither business accounting nor macroeconomic accounting make deductions due to "the environmental liabilities to which they are oblivious"[3] (Martínez Alier, 2007, p. 149). In order to fill in these gaps, the World Bank promoted Adjusted Net Savings, an economic theory founded on sustainable development which includes environmental deterioration in its accounting.

This theory incorporates the damages caused by pollution and the value of environmental assets extracted or depleted "based on estimates of resource profits calculated as the difference between the global price and the average cost per unit extracted" (Arias, 2006, p. 206). Due to the difficulty in locating specific local information, estimates were limited to the inclusion of global damage caused by carbon dioxide emissions (Arias, 2006).

If one moves forward by incorporating other elements, including not only purelyeconomic growth but also environmental damage, the use of quantitative indicators continues to prevail, leaving out important qualitative aspects. Therefore, I turned to ecological economics which, unlike conventional economics and the theory of Adjusted Net Savings, allows for a more holistic study by incorporating into the economic analysis ecological, social and cultural elements (Martínez Alier, 2007).

This interdisciplinary theoretical field takes upon itself the study of material flows between the economy and the environment, with the aim of explaining the conflict between the two, putting into question whether such conflict can be resolved using sustainable development and other alternatives such as eco-efficiency or ecological modernization (Martínez Alier, 2007).

Viewed from the stance of the relationship between development and mining extractivism, conventional economics puts first economic growth as an indispensable characteristic of development, achieved by increasing the capture of FDIs, mineral exports and production. According to the actors who promote this idea, growth will generate spillover effects on the local population's well-being by creating jobs and consumption (Gudynas, 2012; Azamar and Ponce, 2015).

However, far from benefiting local economies and improving finances, mining leaves important social and environmental problems in its wake, in spite of the great economic surplus it creates (Azamar and Ponce, 2014). These problems stem from the fact that extractivism consists of a group of productive relationships centered on the exploitation and commercialization of nature, which "promotes links of unequal trade which weaken the country from which it is extracted due to dependence, given that it focuses on international trade and not on strengthening local value chains" (Azamar, 2020, p. 139).

A tool for power operates (Martínez Alier, 2007) which works by "externalizing environmental costs due to the massive destruction of land, toxic pollution and high levels of energy and water consumption" in local spaces (Tetreault, 2013, p. 223).

As such, mining extractivism implies an unequal economic and ecological exchange with the latter focusing on the asymmetric flows of biophysical resources (labor, land, energy, and materials) which mineral extraction requires and can be thought of as costs poorly paid or surplus value (Hornborg, 2019). A multifaceted perspective originating in political ecology states that "the presence of surpluses always includes components that are the result of environmental losses, which are difficult to recover [...] or irrecoverable (the case of mineral depletion is one example)" (Gudynas, 2019, p. 43).

As such, the interaction between the economic process of mineral extraction and the natural environment entails altering nature to some degree, which manifests itself in the creation of material flows between the natural system and the economic subsystem (Delgado, 2012), defined by the Marxist tradition as social metabolism (Foster, 2013).

According to Toledo (2013), the theory of social metabolism studies the interactions between society and the environment; in other words, the way in which human beings organize themselves within society defines the way in which they affect, transform and appropriate nature, which itself determines the way in which societies are configured.

These studies analyze human communities at different levels, both in their relationship with "local natural resources and with the market sectors with which they have transactions (mercantile exchanges), demonstrating in an integrated manner the articulations that exist between ecological exchanges and concrete economic exchanges" (Toledo, 2013, p. 47).

According to this point of view, the proposed theoretical inputs allow us to take on not only quantitative aspects of mining extractivism's social metabolism, but also qualitative elements which, together, make for a more complete accounting of mineral extraction in Mexico.

For the quantitative analysis we turn to the concept of the ecological rucksack, understood to be "the sum of all materials necessary to obtain a good throughout its entire lifecycle" (Gudynas, 1998, p. 50). The concept of environmental surplus was used to interpret the ecological rucksack

As was previously noted, using a multifaceted approach, the surplus refers not only to the economic value generated by the commercialization of minerals, but also integrates the loss of natural heritage brought about by economic activities (Gudynas, 2019). As such, this approach understands environmental surpluses to be the volume of material disturbed by mineral extraction.

In terms of the qualitative analysis, the concept of sociometabolic fractures was used, with which one can explain not only physical changes, but also the social and cultural changes caused by mining extractivism. This notion allows one to "give an account of a profound alteration of productive practices, territorial configurations and socio-cultural frameworks" (Machado and Rossi, 2017, p. 282).

According to Tetreault (2013, p. 220) "underground mining and open-pit mining leave behind heaps of rubble which release heavy metals and other toxic substances into the environment." This, in addition to aesthetic considerations, implies a loss of habitat for wildlife. Likewise, when mining ventures occupy a space, this "implies that it will be impossible to use the area for another purpose, such as agriculture" (Gudynas, 2019, p. 42), bringing distortions to the local economy (Tetreault, 2013) due to the cultural change in these populations' way of life. These impacts generate socio-environmental conflicts between the affected population and mining companies, which are normally backed by the government (Uribe and Tuscano, 2020).

Thus, the idea of mining extractivism's social metabolism proposed herein consists of the volume of material consumed in the extraction of minerals, presented as an environmental surplus; but also in the socio-cultural reconfigurations in local spaces brought about by this economic activity.

3. METHODS AND MATERIALS

A mixed methodology was used, with one part being quantitative in order to estimate the environmental surplus of mining extractivism and the social metabolic growth rates at the national, state and local levels. This was complemented with a qualitative element to integrate indices linked to social conflict and sociocultural changes.

First, statistical information was collected on the production of the main metallic minerals in Mexico (gold, silver, lead, copper and zinc) for the period between 1980-2018 for the three levels analyzed. The data was obtained from the INEGI and SGM and organized in Excel, setting tons[4] as the unit of measurement. Then, the environmental surplus was calculated using the ecological rucksack factor (Schmidt-Bleek *et al*., 1999), which offers an index of the total quantity of materials disturbed by the extraction of the minerals analyzed (see table 1).

Table 1. Ecological rucksack factor

Copper	(1:500)
Lead	(1:16)
Zinc	(1:27)
Gold	(1:540000)
Silver	(1:7500)

Source: created by the author based on Schmidt-Bleek *et al*. (1999) and Delgado (2012, 2013).

To obtain the environmental surplus, the volume of the annual production of each mineral was multiplied by the corresponding ecological rucksack factor:

$$\begin{aligned}\textit{Environmental Surplus} = {} & \textit{(Annual production of mineral n)} \times \\ & \textit{(Ecological Rucksack Factor for mineral n)}\end{aligned} \quad (1)$$

The results were also organized in tables according to each level of the study. Subsequently, the annual total and the total of the analysis period were calculated. Temporary cuts were made to estimate the periods in which the volume of disturbed materials was greater. The growth rate of the social metabolism of mining extractivism at all three levels was considered. To do this, the following formula was used (López, 2019):

$$\textit{Growth rate} = (\textit{period } n \, / \, \textit{base period} - 1) \times 100 \quad (2)$$

The period of 1980-2018 was used as a reference with the year 1980 as the base. Thus, the total environmental surplus of 2018 was divided by the total environmental surplus of the base period and one was subtracted from the result, which was then multiplied by a hundred.

These calculations demonstrate an estimation of the ecological impacts generated by the extraction of the main minerals per year and the variation between two moments in time. This made it possible to study the behavior of social metabolism and compare the data obtained with environmental impact evaluation methods, mitigation measures and, in general, Mexico's mining policy.

With the data of the environmental surplus, the volume of materials consumed, which is not normally taken into account, was incorporated into the accounting of mining production. At the national level, a calculation of total production resulting from adding the production volume and the environmental surplus was proposed.[5] The results were calculated using the following formula and integrated into Table 2:

Table 2. Environmental surplus of the main minerals' production in Mexico 1980-2018 (tons and percentages)

Mineral	Production	Environmental surplus	Total production	Percentage of environmental surplus
Gold	1624.80	877391395.0	877393020.0	9.42
Silver	122515.83	918868695.8	918991211.7	9.87
Copper	13909748.10	6954874055.0	6968783803	74.7
Lead	6863557.36	109816917.8	116680475.1	1.18
Zinc	16628737.90	448975923.8	465604661.8	4.82
Total	37526184.00	9309926987.0	9347453171.0	100.00

Source: created by the author with data from INEGI 1983, 1987, 1992, 1994, 1998, 2002, 2007, 2013 and SGM 2015, 2016, 2017, 2019.

$$\textit{Total mining production: Mining production + Environmental Surplus} \qquad (3)$$

Nevertheless, in order to arrive at a more complete accounting of mining production, it is necessary to incorporate qualitative indicators which complement, from a social and cultural perspective, that which is behind the economic data present in conventional accounting. To achieve this, four local cases from Zacatecas were analyzed: *Real de Ángeles, Peñasquito, La Colorada* and *Salaverna.* The empirical information for this section was obtained by means of documentary research of academic texts and articles as well as articles published in the press. Satellite images taken from *Google Earth* were also used to show the changes which the landscape underwent in the territories where the *Real de Ángeles* and *Peñasquito* projects operate.

Some of the limitations of this work were that the environmental surplus focuses on general calculations which do not specify what the disturbed materials are nor their economic costs. Furthermore, esimates of the national and state levels do not include details on the type of mining (whether underground and open-pit) due to the complexity in locating this data (for a more detailed case see Delgado (2013)).

4. THE POLITICAL-ECONOMIC CONTEXT OF THE MINING TRANSFORMATION IN MEXICO

The conditions which made the Mexican mining transformation possible were the liberalizing and opening up of the economy in accordance with neoliberal thinking, within the framework of the Washington Consensus, promoted in order to foster free trade and market-led development (Harvey, 2007).

The growth of the world economy and the industrialization and urbanization processes of primary and emerging countries (Pengue, 2017) caused an increase in the transfer of natural resources from Latin America. The scale of material extraction doubled between 1990-2009, reaching more than 8 billion metric tons in the last year with a significant portion made up of minerals, representing 25% of total material flows in the region (Martinez-Alier and Walter, 2016).

This growth dynamic intensified within the framework of the *commodities consensus* (2003-2012), a scenario characterized by "the expansion of projects tending towards the control, extraction and export of natural goods, without much added value" (Svampa, 2012, p. 1).

External factors were those which pushed for the deregulation of the Mexican mining sector: in 1992 Constitutional article 27 was amended, thereby allowing the commercialization of public social property which had until then been inalienable; that same year saw the enactment of the current Mining Law, which in article 6o defines this activity as a public utility with preference over other land uses; in 1993, the Foreign Investment Law[6] was issued, which "authorized up to 100% foreign ownership of national assets and the unconditional repatriation of profits" (Téllez and Sánchez, 2018, p. 5); and, in 1994, the North American Free Trade Agreement (NAFTA), now USMCA, came into effect.

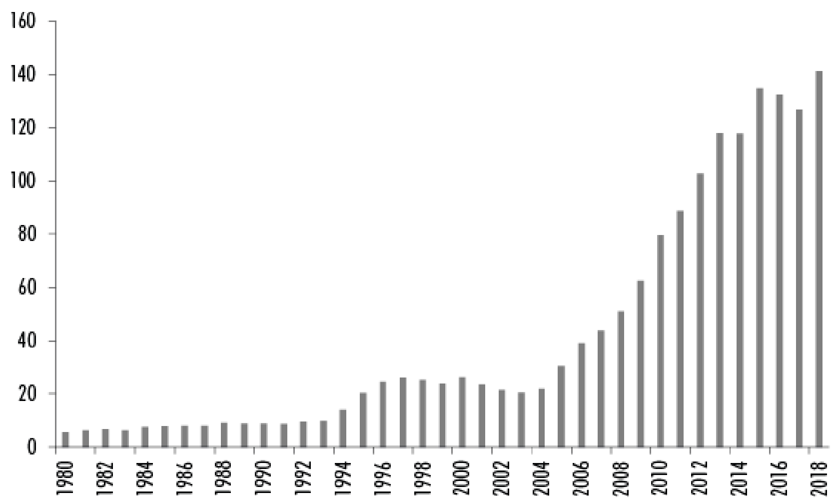
By 1980, private mining led the sector with sales totaling MXN$25.698.9 billion, or 48% of the total. Small and medium-scale mining accounted for 17.5%, while state-owned mining accounted for 34.5% (INEGI, 1983). In the late 1980s, state-owned mining companies underwent an important privatization process and a great Mexicanized mining capital was consolidated at the same time that a large number of foreign companies, mainly of Canadian origin, arrived on the scene (Sariego, 2009).

The transformation process of Mexican mining was characterized by legislative changes, methods for appropriation and mineral production volumes, as well as by the volume of environmental surplus generated by the extractive process.

5. SOCIAL METABOLISM OF MINING EXTRACTIVISM IN MEXICO AT A NATIONAL SCALE

Gold production in Mexico between 1980-2018 was 8.9 times greater than all the gold mined in 300 years of Spanish colonization, with the amount extracted going from 5.4 tons to 141.1 tons. Figure 1 shows that 2006 was the turning point, corresponding with the supercycle of commodity prices, achieving a sustained growth, with its best year being 2018.

Figure 1. Gold production in Mexico 1980-2018 (tons)



Source: created by the author with data from INEGI 1983, 1987, 1992, 1994, 1998, 2002, 2007, 2013 and SGM 2015, 2016, 2017, 2019.

Currently, more than 90% of the Mexican mining infrastructure for the main metallic minerals corresponds to large-scale mining: gold (97.33%), silver (95.21%), lead (93.47%), zinc (96.41%) and copper (98.02%) (SGM, 2019). Furthermore, prior to 1982, 81,717 hectares had been conceded in the form of 1,506. A broader analysis shows that from 1900 to 2015, 33,306 titles equaling 35,890,967 hectares were granted (Téllez and Sánchez, 2018). This indicates that with the implementation of neoliberal reforms the number of hectares ceded by the government between 1982 to 2015 was 35,809,250, thus raising the concentration of land for mining by more than 438 fold in just 33 years.

Land concentration was raised in a period which favored open-pit mining specializing in the operation of low grade ore, an activity characterized by its "employment of a reduced labor force and requiring large volumes of water and chemicals such as sodium cyanide or sulfuric acid, as well as the occupation of large quantities of land" (Téllez and Sánchez, 2018, p. 6).

Exports have historically gone to the United States, with it being the main destination country. However, China began to occupy an important role in Mexico's mining exports starting in 2007, to the point that it surpassed the United States in 2011. Nevertheless, this accounting does not take into account the material flows disturbed by the extractive process.

According to the analysis, the production of the five main minerals in Mexico created an environmental surplus of more than 9.309 billion tons: 74.70% corresponds to copper, with it producing the largest environmental surplus, followed by silver (9.87%), gold (9.42%), zinc (4.82%) and lead (1.18%) (see table 2).

Table 2 shows that the environmental surplus caused by the extraction of the main metallic minerals in Mexico in the period analyzed exceeds 248 times the production volume. If one takes this aspect into account and integrates it into conventional accounting, the commercialized total would be 37,526,000 tons of minerals plus its environmental surplus, which together would add up to 9.347 billion tons.

Mining extractivism's social metabolic growth rate for these minerals was 333.39% between 1980-2018. In just the last 10 years of the period studied (2008-2018), the environmental surplus represented 43.16% of the total, equaling 4.018 billion tons. Taking these elements into account puts into question the measures implemented in Mexico meant to regulate and compensate for the environmental damage caused by mining activity.

Along these lines are the Environmental Impact Analyses and the Mining Fund.[7, 8] Regarding the former, one of their limitations is that they restrict themselves to assigning economic values to problems and prioritize technical solutions. As for the latter, an evaluation of the resources from 2014-2015 identified that most of the works carried out were more of a palliative for the impacts had by mining activity when compared to economic, social and environmental alternatives which would be sustainable in the long term for the affected populations (FUNDAR, 2017). Along these lines, it was mentioned that “76% of the 22 municipalities where gold production is concentrated have poverty levels higher than the national average, and more than half surpassed the average level of extreme poverty” (FUNDAR, 2017, p. 233).

Although these measures in some way make up for part of the material consumed with infrastructure and compensations, it is not comparable to the loss of natural heritage nor does it guarantee a better quality of life for local citizens. Therefore, public policies which regulate mining activity in Mexico need to be readjusted. There is a need for a legal framework which takes into consideration the magnitude of the environmental, cultural and social impacts had by damages which can be irreversible, such as water depletion, changes in the rural way of life, forced displacement of communities and the articulation of socio-environmental conflicts.

6. THE ENVIRONMENTAL SURPLUS OF MINING EXTRACTIVISM IN ZACATECAS

The state of Zacatecas is second in terms of mineral production value in Mexico, accounting for 21.61%, equivalent to MXN$71.398 billion (SGM, 2019). According to INEGI (2016, p. 15), between 2003-2014, the mining sector had “an average annual growth at the state level of 11.5%, greater than that registered at the national level (-0.8%).” In 2016, mining contributed 28.9% of the state’s Gross Domestic Product (GDP), positioning it as the main sector in the Zacatecan economy (INEGI, 2016).

From 1980-2018, Zacatecas was responsible for 13.91% of total gold production, 6.70% of copper, 36.91% of lead, 35.77% of zinc and 40.36% of silver, making it the main producer of the latter in Mexico. However, Zacatecan mining only generates 15,876 jobs, which is equal to only 2.4% of all jobs in the state (STPS, 2020).

According to Uribe and Tuscano (2020, p. 30) this demonstrates that:

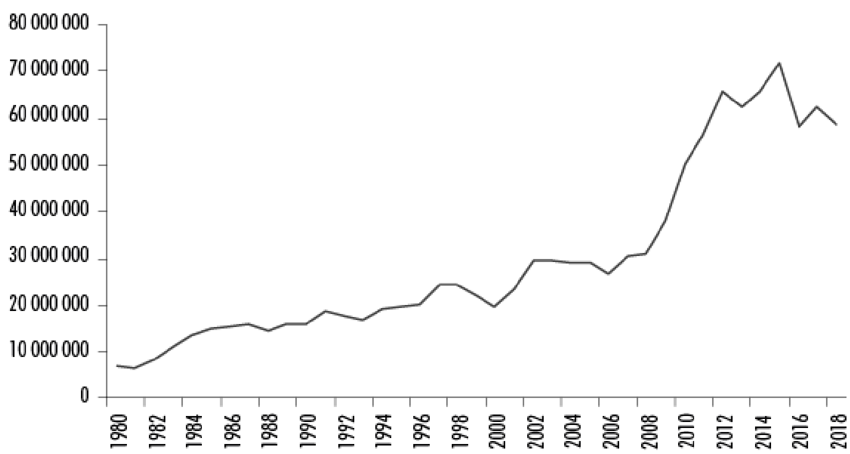
> [...] contrasts between what mining companies get and what is experienced in the local host spaces: the benefits of mining do not achieve a spillover effect even at the local level, where instead they experience poverty, marginalization, social deprivation and multiple conflicts.

The state government and the mining companies that operate in the state promote the sector as an engine of development (Gobierno del Estado de Zacatecas, 2017), highlighting FDIs, production, job creation, the impact on local economies and the percentage of the state’s GDP which the sector represents. Nevertheless, such attributes do not take into consideration the environmental surplus or socio-cultural changes. As such, these actors extol mining based on what can only be considered an incomplete accounting.

According to the analysis, the estimated environmental surplus generated by the extraction of the main metallic minerals in Zacatecas was 1.160 billion tons, representing 12.46% of the national total. Meanwhile, mining extractivism’s social metabolism growth rate was 760.64%, more than double than that recorded at the national level.

Along these lines, mining’s social metabolism remained relatively stable in the period of 1980-1998 and did not surpass 30 million tons of environmental surplus. Starting in 2003, one can see an increase, but it is in 2009 that the growth takes off, registering 65 million tons in 2012 and 71 million tons in 2015, even with the decline of subsequent years, it continues to present between 55 and 60 million tons of environmental surplus (see figure 2).

Figure 2. Evolution of the environmental surplus due to the extraction of the main metallic minerals in Zacatecas 1980-2018 (tons)



Source: created by the author based on data from INEGI 1983, 1987, 1992, 1994, 1998, 2002, 2007, 2013 and SGM 2015, 2016, 2017, 2019.

The increase of the main metals' social metabolism in Zacatecas is linked to the commodity price boom period and continues until 2015. Copper generated 40% of the total environmental surplus, followed by silver (31.95%), zinc (13.83%), gold (10.52%) and lead (3.49%). The extraction of gold alone between 2009 and 2018 is equivalent to 9.40% of the total environmental surplus registered in the state.

Lead and zinc extracted in Zacatecas represent 37 and 36% of all disturbed materials nationwide, which lines up with the importance Zacatecas has as a deposit and supplier of these minerals. Thus, the data analyzed shows an estimate of the pressure that mining extractivism exerts on both nature and territories. In this regard, contrary to the official discourse that promotes mining, "for local populations, where mineral extraction is carried out and where the effects are felt the most, mining represents another reality" (Uribe and Tuscano, 2020, p. 42).

In addition to labor disputes over poor working conditions, the harmful effects produced by large-scale mining have triggered various socio-environmental conflicts, as while this activity responds to the needs of the international market, the costs are high for communities neighboring the mines, "although the mining companies currently speak of social responsibility, it does not seem to be enough for the host communities as conflicts increase from the moment the exploration phase begins" (Uribe and Tuscano, 2020, p. 42).

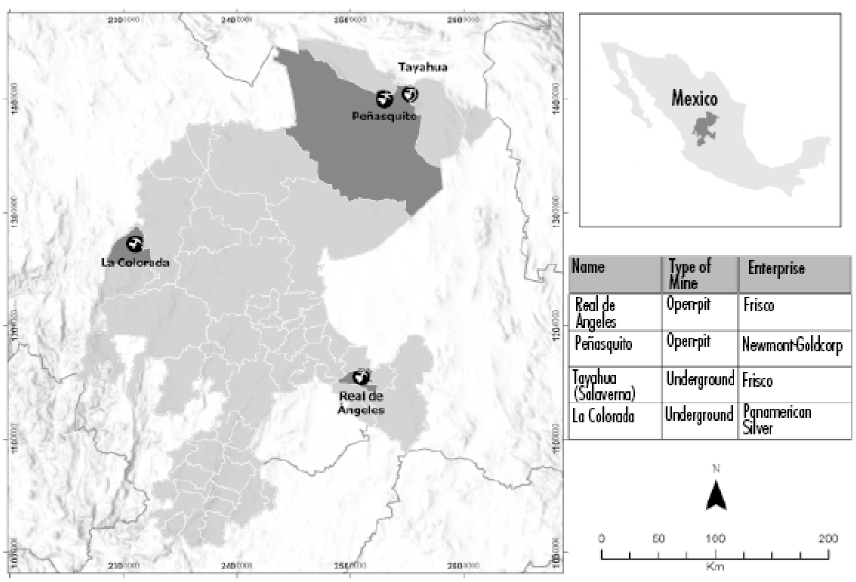
7. SOCIO-ENVIRONMENTAL CONFLICTS AND SOCIAL METABOLIC FRACTURES IN LIGHT OF FOUR LOCAL CASES IN ZACATECAS

In Mexico, socio-environmental conflicts surrounding mining have proliferated since the late nineties as a result of neoliberal reforms that give private companies the power to plunder the country's mining resources (Tetreault, 2013). These types of conflicts are defined as:

> [...] those where dynamics of opposition over territorial control and access to and use of mineral resources, land and water, are expressed with local population groups and their allies on one side and the mining companies and different levels of government on the other (Uribe *et al.*, 2020, p. 6).

Zacatecas is second nationally when it comes to mining conflicts with 16 cases recorded – only behind Sonora (17) – of which at least 13 are due to socio-environmental issues and three due to labor issues (Uribe and Tuscano, 2020). For the purpose of this study, four local cases were selected as they demonstrate the relationship between the increase in mining extractivism's social metabolism and social conflict to reveal the main socio-ecological transformations within these environments (see Figure 3).

Figure 3. Map indicating the locations of the case studies.



Source: created by the author with the technical support of Damián Xotlanihua Flores.

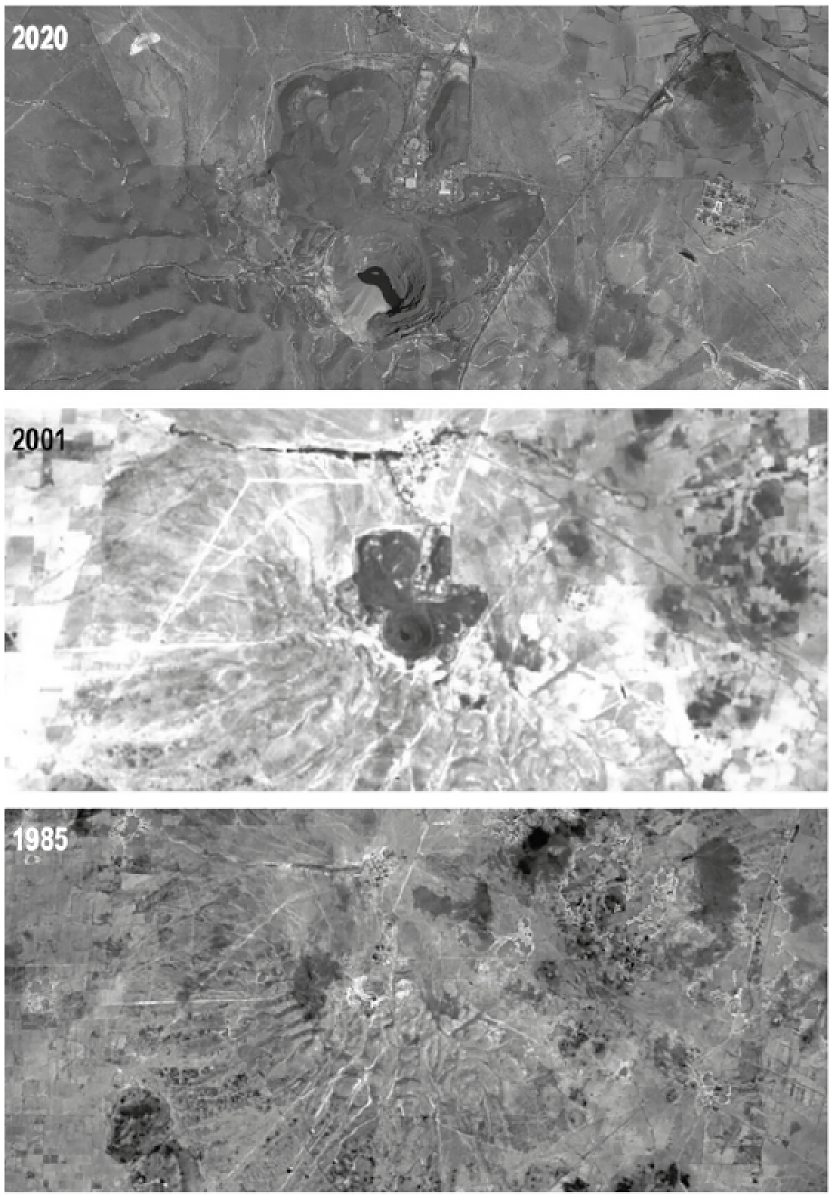
The first case corresponds to the *Real de Ángeles* mine, located in the municipality of Noria de Ángeles. It was the first undertaking in Zacatecas to implement open-pit mining. During its time of operation (1982-1999) it was considered the most important silver mine worldwide (Burnes, 2010). The project was owned by Grupo Frisco, which in turn was owned by Carlos Slim, one of the richest men in the world.

Installation of the mining complex required the relocation of the original population along with the colonial church, which was carried out stone by stone with the authorization of the National Institute of Anthropology and History (INAH)[9] (Burnes, 2010). 4,343 tons of silver were extracted from this mine during its 17 years of operation, equivalent to 10.94% of total national silver production and 29.82% of the state's production for the same period.

While it was in operation it was considered the economic pride of the state. Nevertheless, today it is a desolate expanse contaminated by mining waste, due to the negative environmental impact and contamination by lead, arsenic and other toxic chemicals dispersed through both the soil and air (Valadez, 2005). The estimated environmental surplus generated by this mine in its 17 years of extracting silver, lead and zinc, was 56.9 million tons, with a social metabolic growth rate at the municipal level of 199.81%.

The main impacts reach an area two kilometers to the northwest of the tailings dam and three kilometers towards the farmlands (Valadez, 2005), which one can assume to imply various social and cultural transformations in the local environment. This case exemplifies the developmental problems derived from mining extractivism in Mexico as seen from a concrete experience, not only in quantitative terms regarding the volume of environmental surplus generated, but also qualitatively in terms of the forced displacement and probable distortions to the local economy caused by the contamination (see Figure 4).

Figure 4. Transformation of the landscape in the municipality of Noria de Ángeles



Source: Google Earth.

The second case corresponds to the Peñasquito mine, located in the municipality of Mazapil, a currently active open-pit project consisting of two sites: Peñasco which is 1,820 meters in diameter and Chile Colorado, where 90 to 110 thousand tons of material containing gold, silver, lead and zinc are extracted daily. These are minerals which benefit from flotation and leaching methods.

This project was owned by the Canadian company Goldcorp, which in 2006 invested US$1.5 billion to start it up (Valadez, 2009). By 2019, the mine had created 5,336 jobs, 2,962 directly and 2,374 indirectly (Serrano, 2020). Since the Peñasquito project was announced, state authorities praised the positive aspects of this investment and the potential jobs, quickly making the endeavor the new economic pride of the state. In 2015 it was the main gold mine in Mexico with a production of 860.3 thousand ounces (Mexican Mining Chamber [CAMIMEX],[10] 2016).[11]

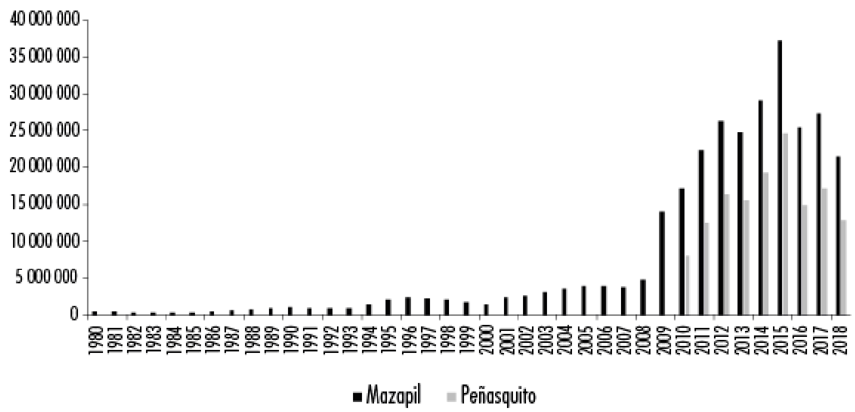
Paradoxically, one of the most important mines in the country is located in Mazapil, the fourth poorest municipality in Zacatecas, which in 2015 registered 12.9% of its population as suffering from extreme poverty, according to the National Council for the Evaluation of Social Development Policy (CONEVAL).[12] ,[13]

This municipality shows the contradictions of mining extractivism in Mexico, where on the one hand it is one of the most important in terms of production and contribution to the state and national mining GDP; on the other hand, it exemplifies the traits of an antiquated structural framework for an activity primarily focused on exports. Mining extractivism has strong socio-environmental impacts and little economic growth, given that it functions as an enclave and does not create productive chains that invigorate the local economy.

Of the mine's 938 suppliers, only 38 are from Zacatecas and of the jobs directly created by it, only 685 are occupied by locals from Mazapil (Serrano, 2020). This case exemplifies the uneven relationships of economic exchange. For every thousand dollars in sales the company keeps US$999.12, while the communities only receive US88¢ (Garibay *et al*., 2014). A more complex analysis shows that the Goldcorp company paid farmers just "MXN$0.50 per square meter of land, which were the best lands in a rain-fed microbasin producing beans and corn, fodder for animals, palm, agave and nopal" (Burnes, 2010, p. 202).

Figure 5 shows that there has also been an uneven ecological exchange in the form of the unreplenished volume of exported ores. As they are non-renewable resources, this international trade scheme means the loss of natural heritage in the local environment. This turns the area into a sacrifice offered up in order to maintain resource exchange flows which economically favor the entrepreneurs and countries which buy these minerals.

Figure 5. Comparison of mining extractivism's environmental surplus in the municipality of Mazapil for 1980-2018 and the contribution of Peñasquito 2010-2018 (tons)



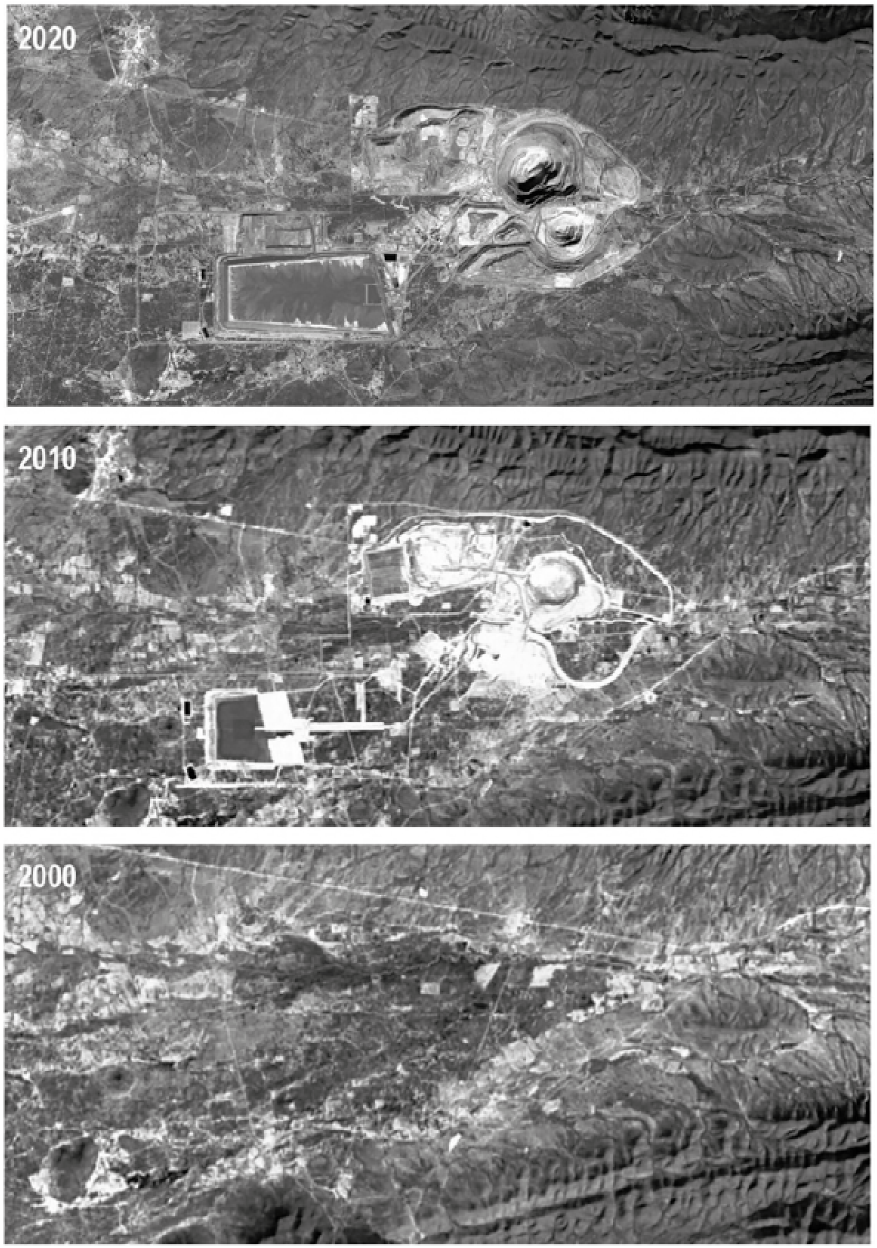
Source: created by the author with data from INEGI 1983, 1987, 1992, 1994, 1998, 2002, 2007, 2013; SGM 2015, 2016, 2017, 2019 and CAMIMEX 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019.

On the other hand, the rural communities surrounding the mining project bear the social, cultural and ecological costs. This in turn has triggered various socio-environmental conflicts. With the arrival of Peñasquito, the town of the same name that was located on top of the deposit was relocated, creating a change in way of life and in the productive practices of farmers which were typical of these communities' residents (Castro *et al*., 2015).

The open-pit mining of today is very different from that of days of old as it now demands a greater consumption of resources and materials which, according to Panico (2018, p. 8) explains why "the metabolism of the valley has undergone a dramatic growth in terms of the use and transformation of available energy," as well as how, the "land, water and, territory in general, face a situation of permanent stress, which is leading to the forced disappearance of previous socio-productive and environmental relations."

The social metabolic growth rate between 1980 and 2018 in the municipality of Mazapil was 5,064.39%, accruing a total of 296,363,275 tons. A comparative analysis between the municipality and the Peñasquito mine showed that between 2010-2018, this site contributed 47.74% of the total municipal environmental surplus[14] with 61.19% generated in the same period (see Figure 5). This shows that the opening of Peñasquito was a decisive factor in altering Mazapil's sociometabolic relationships (see Figure 6).

Figure 6. Transformation of the landscape by the Peñasquito mine



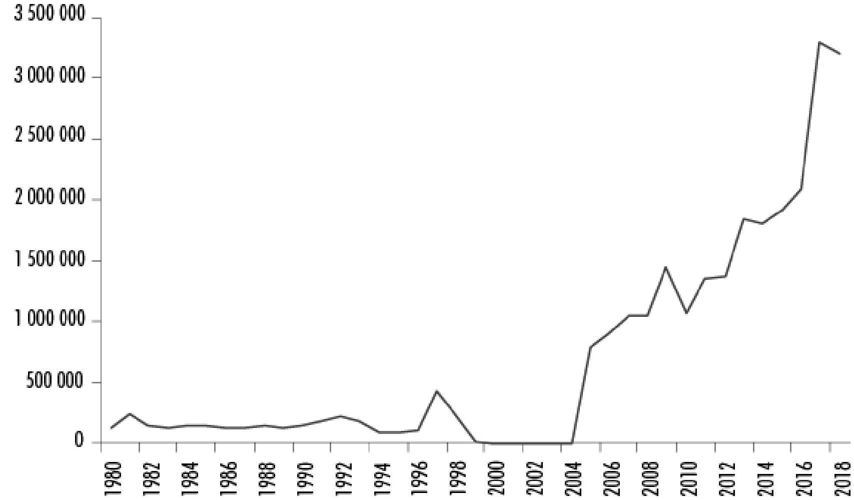
Source: Google Earth.

The third case corresponds to the *La Colorada* mine, located in the municipality of Chalchihuites. In 1998, the Canadian company Pan American Silver acquired the underground silver deposit. Its arrival marked a transition towards large-scale mining which caused changes in the lives of the local population.

Total silver production at the municipal level between 1980-2018 was 2,666 tons; 90.96% of this coming from just the period of 2005-2018, a period that coincides with the start of large-scale operations at the La Colorada mine. The environmental surplus produced by mining extractivism in Chalchihuites during the analyzed period reached 26.3 million tons, with the most representative mineral being silver, accounting for 75%.

The year 2005 marked a breaking point, and from then on until 2018, the environmental surplus accounted for 87.80% of the municipal total (see figure 7).

Figure 7. Mining extractivism's environmental surplus in the municipality of Chalchihuites 1980-2018 (tons)



Source: created by the author with data from INEGI 1983, 1987, 1992, 1994, 1998, 2002, 2007, 2013 and SGM 2015, 2016, 2017, 2019.

The increase in the extraction volume meant a significant loss of the natural heritage for the town of La Colorada, and for the municipality as a whole, as there was an increase in the social metabolic rate of 2,216.82%. The effects of these sociometabolic changes are also expressed in its connection to conflicts, forced displacement and changes in their way of life.

Along these lines, the construction of a new Pan American Silver ore processing plant involved the relocation of the town to a colony built by the company (Valadez, 2017), disrupting their way of life and farming productive practices which had already been modified with the implementation of large-scale mining, as many residents signed up as laborers. With the expansion project, local workers were let go (Uribe, 2019) and in 2017 the population was forcibly evicted by the mining company with the aid of private security guards equipped with firearms (Valadez, 2017). Currently, there is a socio-environmental conflict between local residents and Pan American Silver.

Finally, the fourth case deals with *Salaverna*, a rural town located in the municipality of Mazapil. Since 2010, the Mexican company Frisco sought to change the Tayahua underground mine to an open-pit mine in order to exploit a gigantic copper deposit. The problem is that the mineral deposit was under a human settlement, so in order to achieve its objective, Frisco needed to relocate this population (Uribe, 2019).

In Salaverna, in addition to the increase in the environmental surplus which prevails in the municipality of Mazapil, there are sociometabolic fractures associated with Grupo Frisco’s intent to expand their extractive activities. Just like in La Colorada, the scale of extraction was modified and local mining workers were laid off. A large part of the population was displaced and their homes destroyed, which triggered various socio-environmental conflicts (Uribe *et al*., 2020). In 2016, government officials and state police led a forced eviction which resulted in the destruction of their school and church (see table 3) (Uribe *et al*., 2020).

Table 3. Conflicts and indicators of socio-cultural changes

Conflict	*Municipality*	*Reasons for the conflict*	*Indicators of socio-cultural changes*
Real de Ángeles	Noria de Ángeles	The opening of the mine involved the forced displacement of the original village. In 1999 Frisco stopped operations, thereby causing great contamination which damaged the farmland.	Forced displacement. Distortions to the local economy. Change in the rural way of life.
Peñasquito	Mazapil	To start operations in 2006, Goldcorp displaced the town of Peñasquito. Starting in 2010, changes in access to and the quality of water, the landscape and local production became evident.	Forced displacement. Distortions to the local economy. Change in the rural way of life.
La Colorada	Chalchihuites	Construction of a new processing plant meant the forced displacement of the settlement of La Colorada. In 2017 the inhabitants were forcibly evicted by security guards carrying firearms.	Forced displacement. Change to the rural way of life. Eviction. Violence.
Salaverna	Mazapil	The expansion project of the Tayahua mine meant the displacement of the local population as the copper deposit they wish to exploit was located under the human settlement. In 2016 state police and government officials led an eviction in which the school and church were destroyed.	Forced displacement. Change in the rural way of life. Violation of human rights.

Source: created by the author.

8. FINAL THOUGHTS

The analysis presented here offers contributions on the social, environmental and cultural problems created in Mexico by the development strategy for large-scale mineral extraction and export. From this perspective, a holistic view of mining accounting is proposed, one which considers not only economic elements, but also integrates the environmental surplus as a fundamental aspect to quantify the material consumed by the extraction process, as well as the sociocultural changes caused by mining.

As such, using ecological economics and the theory of social metabolism, mining production can be seen and analyzed in a way that takes into consideration economic, environmental, social and cultural indicators, using an approach that encompasses everything that is behind the macroeconomic figure: ecological damage due to depletion and pollution of resources such as water and soil, social conflict, forced displacement, distortions in the local economy and violations of human rights. These impacts can result in processes of rural depopulation and run the risk of growing in step as the social metabolism analyzed herein grows.

Another important factor is that growth rates for mining extractivism's social metabolism at the state and municipal level, except that of Noria de Ángeles, suddenly find themselves higher than the national average. This shows that the analysis becomes more complex as it becomes more concrete, since the local case studies together show the relationship between the environmental surplus volume and socio-cultural changes.

Along these lines, it is important to note that the extractive activities of both foreign and domestic companies involved the forced displacement of communities in the four local case studies and in at least one, Salaverna, human rights were violated due to the participation of government officials and state police in the eviction of the town. This is not regulated as neither the Mexican Environmental Impact Assessments nor its current Mining Law itself take these elements into account. Although measures seek to make up for part of the socio-environmental damage caused by means compensations and infrastructure works, it is neither comparable nor does it guarantee a good quality of life.

Finally, quantitative and qualitative data on the social metabolism of mining extractivism at different levels in Mexico show that there needs to be a change in public policies on mining, so that these take ecological, social and cultural elements into account, and not only those of an economic nature. This not only requires "the existence of actors in the legislative and public sector willing to understand these demands and the ability to turn them into politically viable policies and laws" (Bebbington *et al*., 2019, p. 6), but also civil society to have a stronger organization and participation.

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[1] TL note: from the original Spanish name *Instituto Nacional de Estadística y Geografía*.

[2] TL note: from the original Spanish name *Servicio Geológico Mexicano*.

[3] TL note: all quotes have been translated from the original Spanish text.

[4] TL note: ton in this article refers to a metric ton, i.e. 1,000kg.

[5] For each individual mineral analyzed or for all of them as a group.

[6] TL note: translated from the original *articulo 27 constitucional*, *Ley Minera*, and *Ley de Inversión Extranjera* respectively.

[7] This fund is created from companies giving 7.5% of their profits to the federal government, which are then distributed to the states and municipalities for social infrastructure works and to repair damages to the environment (FUNDAR, 2017). In 2019 the final destination of these funds was modified when 85% of them were earmarked for use by the Ministry of Public Educaiton (*Secretaría de Educación Pública*) for building and repairing schools.

[8] TL note: *Manifestaciones de Impacto Ambiental*, which are in a standardized format, and the *Fondo Minero* in the original Spanish respectively.

[9] TL note: from the original Spanish *Instituto Nacional de Antropología e Historia*.

[10] TL note: from the original Spanish *Cámara Minera de México*.

[11] In 2018 the venture was acquired by the American giant Newmont.

[12] TL note: from the original Spanish *Consejo Nacional de Evaluación de la Política de Desarrollo Social*.

[13] https://www.coneval.org.mx/coordinacion/entidades/Zacatecas/Paginas/pobreza_municipal2015.aspx

[14] Equaling 141,504,227 tons.

[15] TL note: *Dinámicas extractivas de minería a cielo abierto y procesos de despoblamiento rural. Los casos de la comuna de Putaendo (Valparaíso, Chile) y Salaverna (Zacatecas, México)*

[16] TL note: *Pontifica Universidad Católica de Valparaíso*