Economic Sustainability Calculations for a Single Mine Site in Potosi, Bolivia

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Abstract
The objective of this work was the development of a framework for assessing just compensation for environmental damage on a single mine site. Previously, the models applied in this work have only been used at the national or regional level. As a result, a sustainable extraction rate was calculated for a single mine site in Potosi, Bolivia for a mixed mine (zinc, lead, and silver). By using an interdisciplinary approach, a dollar value was assessed for environmental damages for a period of years. These were compared to the profitability of the mine with the result being an estimation of the quantity of mining rents that should be reinvested in social and infrastructure capital. This approach assumed that economic development does not exclude environmental protection and may aid in policy decisions at the local level benefiting the longevity of the economy.

Keywords: sustainable development, environmental compliance, analysis of environmental monitoring/remediation

1. Introduction

Figure 1. Department of Potosi, Boliva
This work focuses on sustainability while considering nonrenewable resources. The questions surrounding sustainability are for resource consumption at a single mine site. Previously, calculations have been made for larger geographic areas (Auty, 1998, Green & Blatner, 2015, Etelawi et al., 2017). This paper is an effort to illustrate a potential method for calculating environmental damages needed for economic sustainability during a recent production period (2014 – 2019) on a single mine site located in Potosi, Bolivia (Figure 1). The evaluation of economic sustainability calculations on a single mine site has the advantage of being more relevant from a community standpoint. Calculations on this scale can have an impact on mine production rates in the long run, to ensure mineral sustainability with adequate environmental investment. In a mining operation the question is always is it economically feasible to produce now or should the mining be postponed until the market/new technology makes it more attractive. Either way, when a mining operation comes online it should be able to cover the mining costs in addition to the social/environmental costs and the protection of health in the mining area (resource rent). This situation should hold true for current production rates as well as those anticipated into the future.

2. Background Literature

A mountain of rock must be moved to make a small amount of metal. The target minerals within an ore body makeup but a minor proportion of the rock, and mining commonly requires the removal of tons of unmineralized rock overlying the deposit. Therefore, the mining industry is the largest producer of solid wastes by orders of magnitude. Mudd and Boger (2015) estimated annual global mine waste generation for 2011 finding that the industry produced approximately 7.1 billion tons of tailings – the ground up residue that remains after processing – and 55.9 billion tons of waste rock – rock that is mined but does not contain economic concentrations of ore. That’s the equivalent of more than nine tons of mine waste per human, per year. The water and energy inputs needed for extraction are also linked to the concentration of the target mineral within the rock (known as the ore-grade), as are emissions, such as greenhouse gases, and the consumption of process chemicals, such as cyanide. Everything in mining links to the ore body. (Franks, 2015)

Coupled with the amount of waste that is produced in the mining industry is the international push for “sustainability.” Sustainability gained traction due to the Organization for Economic Co-operation and Development (OECD), and their push for development which stands on three pillars: economic, social, and environmental (OECD 2004). The idea of sustainability was further advanced by the Brundtland Report and their definition “development which meets the needs of current generations without compromising the ability of future generations to meet their own needs” (Emas, 2015:1). Sustainability means different things to different people/professions. Sustainability to an environmentalist can mean ecological sustainability, while for people in business it can mean economic sustainability. In reality, sustainability must incorporate the three pillars of economics, social responsibility and sound environmental practices (Rankin, 2011).

A sustainable rate of mineral extraction was previously defined by Green and Blatner (2015) as an extraction rate that meets the explicit extraction costs as well as external health and environmental costs, in addition to generating revenue that “appropriately” balances current and future economic requirements. In this study we move from a regional model to a single mine model that addresses levels of growth related to the mine’s contribution on a small scale. That is, its contribution to the local and regional economy. We examine sustainability accounting methodology for mineral extraction in conjunction with the sustainability definition from Auty and Mikesell (1998) as noted below.

“The concept of sustainable development requires that the contribution to economic development be maintained, both during periods of temporary reduction in mineral exports and over the long run when mineral producing capacity declines relative to the size of the overall economy. What is required is not the sustainability of the mineral production that initially generates growth, but the maintenance of economic and social conditions for sustaining that growth.” (Auty and Mikesell, 1998:3)

3. Environmental Conditions – Bolivia

The contamination of water resources is one of the complex problems faced due to the high costs and the degree of difficulty involved in the treatment of domestic and industrial wastewater needed to comply with the quality standards established by the Law of the Environment (Cruz, Lopez and Ramirez, 2021). Mining areas are among the most contaminated in Bolivia. In the Department of Oruro, mining pollution in municipalities surrounding the Pukpó Lake basin led to the creation of Supreme Decree 0335 on Environmental Emergency, which defines the strategies for the environmental recovery of the basin Huanuni (Decreto Supremo, 0335, Articulo 1, 2009).

Although, Bolivian environmental Law # 1333 (November 2000), regulates discharges of pollutants into receiving
bodies of water for most industries in country, the law appears to be neither complied with nor enforced. This law was followed by Supreme Decree 25419, (requiring all mining operations to obtain an environmental license), and Supreme Decree 25877, which extended the deadline for compliance. Unfortunately, compliance remains limited (Strosnider et al., 2007).

Deposits of metal ores are normally stable under in-situ conditions, but after being mined and exposed to the elements, acid mine drainage (AMD) occurs. This condition introduces free metal and hydrogen ions into solution, which are often discharged at operating points (adits, seeps) at current and past mine sites (Strosnider et al., 2007:788-9). The presence of water pollution from mining sources is a concern nationwide. With Bolivia currently being the second poorest nation in the Western Hemisphere water pollution is a high price to pay for the country (Slunge and von Walter, 2013). But with Potosi’s economy still having roughly 150 000 residents heavily dependent upon mineral extraction and processing, curtailing of water pollution from mining is a difficult to achieve (Strosnider et al., 2007).

4. Accounting

Mining and associated resources often account for a considerable percentage of GDP in developing countries. The returns are most noticeable in the local/regional area of the mining activity. Unfortunately, the long-range ramifications for the country are not always positive. Many resource abundant countries have suffered from low growth, termed a “resource curse.” This phenomenon has been blamed on production effects, investment within the economy, and the price volatility of international primary goods markets. While others argue it is due to bad political decisions and programs (Sarraf and Jiwanji, 2001).

Another problem to be considered when dealing with a resource extractive industry is the finite limits of the resource. The determination of how to manage a finite resource for the optimal return, or to achieve Auty and Mikesell’s definition of sustainability is challenging at best. Key questions are should the natural resource be used, at what rate, at what price to the local economy, and at what price to the environment?

The Hotelling model specifies a dynamically efficient rate of consumption (depletion) for a non-renewable resource by treating the mineral as an asset. In searching for operational, sustainability-based criterion for mineral extraction, the Hotelling approach provides an important starting place (Green and Blatner, 2015). In terms of treating minerals as an asset, the System of National Accounts (SNA) lists five categories of natural resources, land, mineral and energy reserves, non-cultivated biological resources, water resources, and other natural resources. The System of Environmental Economic Accounting (SEEA) further breaks down the SNA list to Environmental assets that include natural resources (mineral and energy resources, soil resources, water resources, and biological resources), land and associated surface water, and ecosystems. Of this list the SEEA categorizes mineral and energy resources as non-renewable. And finally, the SNA defines depletion of natural resources use as: “Depletion of natural deposits is the reduction in the value of the deposits of subsoil assets as a result of the physical removal and using up of these assets,” (Bain, 2007:5–7).

An approach put forward by Richard Auty in “Patterns of development, resource policy and economic growth, to counter the depletion of minerals” is to set aside an adequate sum of mineral revenues to replace the depleting mineral asset. He continues with, “The amount set aside as the capital component should be that annual sum which, when invested, will yield sufficient income to replace the mining revenue when ore extraction ends” (Auty, 1995:200).

This produces a series of logical questions. How much mineral revenue is being generated by a particular mine site? How much revenue is being used for labor costs? How much revenue goes into capital equipment for the timeline that the mine is producing? How much revenue is being spent on environmental protection? And finally, how much revenue should be set aside in totality for a particular mine site?

When considering accounting methods, payroll, and capital depreciation are relatively straightforward to calculate. But when the environment is considered, this becomes a grey area. This maybe be accomplished using the environmental standards of the International Finance Corporation (IFC), with an emphasis on wastewater and ambient water quality, hazardous materials management, and contaminated land (International Finance Corporation, p. 1, World Bank, 2007)

Environmental regulations have come under fire due to the lack of universal enforcement. While many developing countries have environmental laws in place, the lack of manpower or technical skills in the mining country lead to weak performance by the mining company. This enables a situation where host country governments rely on the mining companies themselves for Environmental Impact Assessments, or other environmental services. Recently, an initiative, “Sustainable Development in Mining Activities” by the United Nations, has increased environmental
compliance pressure on mining companies to perform (United Nations, Department of Economic and Social Affairs – Sustainable Development, 2021). The UN’s expected results in this area are:

a. Create a demand from the public for an environmental-mining process complying with effluent, emission standards and hazardous and toxic management,

b. Pressure mining industries to comply with existing environmental standards,

c. Heighten public awareness on mining industries that pollute,

d. Ensure openness and transparency in the implementation of environmental standards for mining industries,

e. Obtain reliable information on the performance of mining industries. (United Nations, Department of Economic and Social Affairs - Sustainable Development)

The United Nations pressure for mining concerns to comply with environmental standards only adds to the necessity of being able to calculate and include environmental data into an accounting system. This paper concentrates on depletion accounting methods for a single mine. The hope is that this will give us some indication if this mine is operating at a level that will meet international environmental standards, and if it is not, what is the monetary gap needed to meet these standards.

The two basic premises for the single mine site calculations concerns whether monetary values can be used in an accounting system that meaningfully determines the value of the current extraction of a resource versus the long run costs of that extraction. The second is the inclusion of costs necessary for assuring a sustainable society and environment (Green and Blatner, 2015). Different schools of thought will be discussed concerning compensation for the depletion of lead, zinc, and silver, and will be reflected in the methods of calculation. Also, the environmental standards are the baseline for environmental compliance. Accounting and environmental models will be discussed in later sections.

5. Study Area: Bolivia

Bolivia is landlocked country in South America and shares borders with Argentina, Brazil, Chile, Paraguay, and Peru (Figure 1). With an area of 1 099 050 square kilometers square kilometers. Bolivia currently has a high percentage of mestizo and indigenous population (Mestizo 68 percent, Indigenous 20 percent, White 5 percent, Cholo/Chola 2 percent, African descent 1 percent, other 1 percent, unspecified 3 percent) (Index Mundi 2021). Because of this, indigenous values are at the forefront of the environment, and government regulations. The Law of Mother Earth is a prime example of these environmental sentiments.

Potosi is one of nine departments within Bolivia (Figure 1). Each department is further divided into provinces. The Department of Potosi is in the southwestern section of the Plurinational State of Bolivia, between 16 and 23 degrees of southern latitude and between 68- and 69-degrees West Longitude. The Department of Potosi is 118 217 square kilometers in size, and has a population of 828 093 (417 271 women, and 410 822 men). The area of study contains a population of 49 796 and is the center of the mining activity. The study mine is located roughly 35 kilometers southeast of the city of Potosi in the Kari-Kari and Andacaba mountain ranges.

The HDI (Human Development Index) is a measure for assessing long-term progress in three basic dimensions of human development: a long and healthy life, access to knowledge and a decent standard of living. Bolivia’s HDI value for 2021 was 0.692. This places Bolivia in the medium human development category, positioning it at 118 out of 191 countries and territories (UNDP 2021). Between 1990 and 2021, Bolivia’s HDI value increased from 0.550 to 0.692, an increase of 25.8 percent (UNDP 2021). Similarly, between 1990 and 2021, Bolivian life expectancy at birth increased by 7.2 years, mean years of schooling increased by 3.8 years and expected years of schooling increased by 3.4 years. Bolivia GNI per capita increased by about 86.4 percent between 1990 and 2021 (UNDP 2021).

6. Environmental Concerns with a Lead-Zinc Mine

Costs associated with the remediation of modern mine sites were not well documented in the public record for several reasons including:

- Remedial measures may be designed and implemented in response to compliance and enforcement actions.

- Some actions may involve limited, short-term actions (i.e., cleaning up minor spills); however, others may require more complex, long-term solutions that are often completed in multiple phases.
• Costs are often considered proprietary by the mine operator (U.S. EPA – Cost of Remediation at Mine Sites 1997).

For this study, environmental problems associated with the single mine site to be accounted for in a lead-zinc mine operation are:

• Acid Rock Drainage for Waste Rock Piles. The primary waste generated by mineral extraction in underground mines, which is typically used in onsite construction for road or other purposes. Of concern is that the runoff and leachate from waste rock piles may include heavy metals. Also, these piles may also generate acid drainage if sulfide minerals, oxygen, and moisture are present in sufficient concentrations without adequate neutralization or other controls. Waste rock piles and tailings impoundments are of particular concern, since these are the areas in which toxic contaminants are most commonly found.

• Acid Rock Drainage for Tailings. Tailings are the discarded material resulting from the concentration of ore through various beneficiation operations. This material has minimal value at present but is produced in extremely large quantities. Tailings are characterized by fine particle sizes and varying mineralogical and chemical compositions. Tailings typically take the form of a slurry. The waste slurries from milling, gravity concentration, and flotation contain approximately 65 percent water and 35 percent solids. In general, most wastes from beneficiation of lead-zinc ores are disposed of in tailings impoundments from which water is likely to be reclaimed during the mine's life. (Carter, 1991a in U.S. EPA, Technical Resource Document, 1994, p 1-29).

Initially, the ore is milled (crushing and grinding) and then concentrated through a flotation process. “Flotation is a technique by which particles of one mineral or group of minerals are made to adhere preferentially to air bubbles in the presence of a chemical reagent. This is achieved by using chemical reagents that preferentially react with the desired mineral. Flotation is the most used method to concentrate lead-zinc minerals” (U.S. EPA – Technical Resource Document, 1994).

• Treatment Acid Rock Drainage (flotation). After the removal of values in the flotation process, the flotation system discharges tailings composed of liquids and solids. Between 1/4 and 1/2 of the tailings generated are made up of solids, mostly gangue material and small quantities of unrecovered lead-zinc minerals. The liquid component of the flotation waste is usually water and dissolved solids, along with any remaining reagents not consumed in the flotation process. These reagents may include cyanide, which is used as a sphalerite depressant during galena flotation. Most operations send tailings to impoundments where solids settle out of the suspension.

Spending on environmental projects at the mine site took place over a period of years. Initially, work was done during the mine preparation including construction of the water treatment plant to comply with discharge requirements. Several civil facilities to minimize the water inflow to the landfill in the rainy season were completed costing approximately 300,000 USD. Monthly costs around 5,000 USD are spent in water treatment. These and other operational expenditures accounted for on the company’s balance sheets were used in the final calculations.

7. Models

Mineral reserves for Bolivia are not calculated for regional and localized areas. In addition, calculating economic sustainability for a single mine site required some decisions on how to allocate GDP for the mine site. The World Bank Method and the Net Price Approach (Repetto) for this analysis produced the same results since no additional reserves were accounted for by the United States Geological Survey (USGS), Bolivian Government, or private company.

7.1 World Bank Method

The World Bank Method does not consider new discoveries that are added to national/regional reserves. In addition to the resource depletion value calculated, the World Bank Method assigns an environmental damage for CO2 which has been updated using the World Bank’s CO2 Emissions for Bolivia, the single mine site records for number of employees, and an U.S. EPA Technical Resource Document, dealing with Lead-Zinc mining operations (Neumayer 2000).

\[ P = \text{resource price} \]  \hspace{1cm} (1)

\[ AC = \text{average cost} \]  \hspace{1cm} (2)

\[ R = \text{depletion (P-AC)} \]  \hspace{1cm} (3)
7.2. **Net Price Approach (Repetto)**

Repetto’s *Net Price Approach* is similar to the Hotelling rule which states, “The mineral rights price, which is the difference between the mineral price and the sum of extraction and finding cost, rises at the rate of interest (Lesser et al. 1997: 476 - 477).” The main difference is that resource rent or net price is defined as the current market price minus average extraction costs, including a normal profit on the capital investment. Resource depletion is the net reduction in the stock of the natural resource times the net price (Neumayer 2000). Given no new additional reserves at the single mine site level, the *World Bank Method* and the *Net Price Approach (Repetto)* models produce identical results.

\[(P - AC)(R-D)\]  
\[D = \text{resource discoveries} \]

(4)  
(5)

### 7.3 World Bank plus CO₂

In addition, the *World Bank Method* assigns an environmental damage value for CO₂ which was updated based on the World Bank’s CO₂ Emissions for Bolivia, the single mine site record for number of employees, and an U.S. EPA Technical Resource Document, dealing with Lead-Zinc mining operations (Neumayer, 2000).

### 7.4 User Cost (El Serafy – United Nations) Method

This United Nations approved method provides lower estimates due to less importance given to GDP in the calculations. It also agrees with the conventional definition of sustainable income (Auty and Mikesell 1998) that requires the natural capital asset be replaced only to the extent needed to maintain the income stream indefinitely.

\[(P-AC) \cdot (1/(1+r)^n+1)\]
\[P = \text{resource price} \]
\[AC = \text{average cost} \]
\[R = \text{depletion} \]
\[r = \text{discount rate} \]
\[n = \text{is the number of remaining years of the resource stock if production was the same in the future as in the base year (Neumayer 2000).} \]

(6)  
(7)  
(8)  
(9)  
(10)  
(11)

Use of U.S. Environmental Protection Agency’s *Cost of Remediation at Mine Sites*, and their Technical Resource Document, *Extraction and Beneficiation of Ores and Minerals, Volume 1, Lead-Zinc, 1994*, provided the technical information to place a price on environmental concerns from the single mine site. These documents, along with company provided information, regarding concentrations, processing, treatment and quantities of product allowed for calculation of a total dollar amount for the two scenarios of low and high-cost treatment for acid rock drainage for waste rock piles, acid rock drainage for tailings, and treatment of acid rock drainage. In addition, the CO₂ calculations were updated through use of the World Bank’s CO₂ Emissions for Bolivia, the single mine site record for number of employees. The breakdown of the two scenarios are as follows:

**Scenario #1**

Estimated Costs of Engineered Solutions for Acid Rock Drainage for Waste Rock Piles (2015 USD/Tons of Waste)

- Low Cost with Composite Soil Cover
- Low Cost with Composite Soil Cover
  - Cost to Treat Acid Rock Drainage (2015 USD/Gallon/Minute/Flow)
- Low Cost with Lime Precipitation

**Scenario #2**

Estimated Costs of Engineered Solutions for Acid Rock Drainage for Waste Rock Piles (2015 USD/Tons of Waste)

- High Cost with Composite Soil Cover
• Estimated Costs of Engineered Solutions for Acid Rock Drainage for Tailings (2015 USD/hectares of Tailings Footprint).
• High Cost with Composite Soil Cover
• Cost to Treat Acid Rock Drainage (2015 USD/Liters/Minute/Flow)
• High Cost with Lime Precipitation (U.S. EPA 1997)

We used the categories of Wastewater and Ambient Water Quality, Hazardous Material Management, and Contaminated Land from the International Finance Corporations’ (IFC) environmental standards in our economic sustainability calculations. These categories coupled with company records and U.S. Environmental Protection Agency’s classification for Zinc-Lead mines and its corresponding remediations figures allowed us to use EDP2 (environmental domestic product 2) in our calculations.

8. Data and Methods

For this analysis, an effort at redefining economic sustainability in a smaller/more precise setting, the calculations were based on the formula presented in Auty and Mikesell (1997), *Sustainable Development in Mineral Economics*. The single mine site as compared to a regional analysis, required further adjustments to GDP. For the calculation of the single mine site’s contribution to the Gross Domestic Product we used mining’s contribution to this category and data from the Department of Potosi. Mining GDP was calculated by using the percentage of population of the Province of Jose Maria Linares and by comparing the mine’s output as a percentage of Jose Maria Linares mining GDP. The single mine site production and its contribution to the area was used as the basis for calculating economic sustainability. The acronyms used in the following discussion are summarized in Tables 1 and 2 instead of scattering them throughout the text to improve readability of the manuscript.

Table 1. Terms and Definitions of Economic Sustainability Related to the Mining Industry

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Meaning</th>
<th>Derivation, definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFA</td>
<td>consumption of fixed assets produced in the economy</td>
<td>the depreciation of fixed assets</td>
</tr>
<tr>
<td>NDP</td>
<td>net domestic product</td>
<td>(= \text{GDP} - \text{CFA} + \text{minor adjustments})</td>
</tr>
<tr>
<td>CE</td>
<td>Current Extraction</td>
<td>Mineral extracted in year (t)</td>
</tr>
<tr>
<td>RD</td>
<td>natural resource depletion</td>
<td>Resource depletion is the value by which the mineral asset has been reduced or depleted (per year)</td>
</tr>
<tr>
<td>DQR</td>
<td>the deterioration to the quality of natural resources</td>
<td>(\text{CO}_2) – World Bank \nSet to zero for other methods</td>
</tr>
<tr>
<td>PR</td>
<td>expenditures for protecting or restoring natural resources from damage by human activity</td>
<td>Includes PR1 and PR2</td>
</tr>
<tr>
<td>PR1</td>
<td>Environmental damage</td>
<td>(high value – 100 percent perceived or real environmental remediation)</td>
</tr>
<tr>
<td>PR2</td>
<td>Environmental damage</td>
<td>(low value - the minimum environmental expenditures to safeguard human health)</td>
</tr>
<tr>
<td>EDP</td>
<td>environmental domestic product, general category for estimate of sustainable income</td>
<td>Includes EDP1 and EDP2</td>
</tr>
<tr>
<td>EDP1</td>
<td>environmental domestic product, or estimate of sustainable income using limited/no data from DQR and PR due to lack of data in those categories</td>
<td>(= \text{GDP} - \text{CFA} - \text{RD} - \text{minor adjustments})</td>
</tr>
<tr>
<td>EDP2</td>
<td>environmental domestic product, or estimate of sustainable income using greater data from DQR and PR</td>
<td>(= \text{GDP} - \text{CFA} - \text{RD} - \text{DQR} - \text{PR} - \text{minor adjustments})</td>
</tr>
</tbody>
</table>

From Auty and Mikesell
### Table 2. Data Sources for the Variables Defined in Table 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>National Institute of Statistics (INE) - Bolivia</td>
</tr>
<tr>
<td>CFA</td>
<td>Single Mine Site Records – Memoria Descriptiva</td>
</tr>
<tr>
<td>NDP</td>
<td>Calculations based on GDP (INE) and Single Mine Site – Memoria Descriptiva</td>
</tr>
<tr>
<td>RD</td>
<td>USGS and Single Mine Site – Memoria Descriptiva</td>
</tr>
<tr>
<td>PR1</td>
<td>U. S. EPA Cost of Remediation at Mine Sites – 1997</td>
</tr>
<tr>
<td></td>
<td>Tech Support Doc. US Govt. Social Cost for Carbon #12866</td>
</tr>
<tr>
<td>PR2</td>
<td>U. S. EPA Cost of Remediation at Mine Sites – 1997</td>
</tr>
<tr>
<td>EDP</td>
<td>Environmental Domestic Product – includes EDP1 and EDP2</td>
</tr>
<tr>
<td>EDP1</td>
<td>– Calculations based upon available information</td>
</tr>
<tr>
<td>EDP2</td>
<td>– Calculations based upon available information</td>
</tr>
</tbody>
</table>


Having production data, processing information related to quantity mined, quantity treated, and quantity of zinc, lead and silver produced allowed us to view environmental aspects from a more defined approach. As stated previously we used the categories of Wastewater and Ambient Water Quality, Hazardous Material Management, and Contaminated Land from the International Finance Corporations’ (IFC) environmental standards in our economic sustainability calculations. These categories, coupled with company records, and U.S. Environmental Protection Agency’s classification for Zinc-Lead mines and its corresponding remediations figures allowed us to use EDP2 (environmental domestic product 2) in our calculations. In Tables 3 - 6, high and low values for the studied years environmental domestic product 2 (EDP2) are presented in 2015 USD.

Bolivia has known reserves of 1 600 thousand metric tons of lead (Pb), 5 200 thousand metric tons of zinc (Zn), and 22 000 metric tons of Silver (Ag) (listed as Reserves in the Mineral Commodity Summaries, (U.S. Geological Survey, Reston, Virginia: 2021). No estimates of reserves exist at the Departmental level as corroborated by the Bolivian National Institute of Statistics (INE). Consequently, the reserves listed for the single mine site were used. The single mine site listed their reserves as 600 000 metric tons with a mean concentration of 4 percent Zn, 2 percent Pb and 200 grams/dry metric to ton (DMT) Ag (average production – 400 DMT/day) and is classified as an underground polymetallic Zn-PB-Ag mine with thin veins (Memoria Descriptiva).

For this exercise in calculating economic sustainability of a single mine site certain conditions were assumed. The basic protection of human health is addressed at two levels minimum and maximum. The minimum level of health was viewed as non-negotiable and listed as the lowest acceptable dollar amount (2015 USD) to achieve this level of protection. The maximum level of estimated remediation is listed as the greatest dollar amount (2015 USD), but is limited due to the lack of widely variable information for remediation data for Lead-Zinc mines. The categories used are those relevant to a Lead-Zinc mine and are covered in the International Finance Corporation’s environmental categories of Wastewater and Ambient Water Quality, Hazardous Materials Management, and Contaminated Land. The dollar amounts were addressed via U.S. EPA documents concerned with Lead-Zinc mines, and the cost of remediation at mine sites.

The negative externalities of environmental damage were accounted for through the single mine site’s resources spent on environmental projects/water treatment, and daily operations. This is shown in the company’s balance sheets. These costs are calculated into the EDP2 calculations as 2015 USD, which reduces the amount of the dollar value for Low and High estimates. It was assumed that the single mine site would have to either make direct payments or provide another avenue to insert income into the local economy to reach an acceptable level of
sustainable income. This will be discussed in the conclusions and will relate to PR1 (High Value) and PR2 (Low Value), and the amount of profit generated by the company possessing the single mine site.

Table 3. World Bank Total Calculations in 2015 US Dollars – Single Mine Site

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Single Mine Site Contribution to GDP in 2015 USD</td>
<td>3 550 572</td>
<td>6 139 834</td>
<td>9 381 379</td>
<td>11 415 353</td>
<td>15 583 430</td>
<td>7 767 333</td>
</tr>
<tr>
<td>CFA Single Mine Site In 2015 USD</td>
<td>714 171</td>
<td>610 635</td>
<td>603 125</td>
<td>218 374</td>
<td>*596 149</td>
<td>*397 433</td>
</tr>
<tr>
<td>RD World Bank Depletion - Single Mine Site in 2015 USD</td>
<td>1 584 268</td>
<td>2 260 764</td>
<td>4 687 704</td>
<td>7 245 315</td>
<td>10 532 541</td>
<td>4 782 558</td>
</tr>
<tr>
<td>PR2 - Low Value for Total Environmental Damage</td>
<td>393 470</td>
<td>423 014</td>
<td>950 551</td>
<td>1 136 738</td>
<td>1 547 519</td>
<td>884 477</td>
</tr>
<tr>
<td>PR1 - High Value for Total Environmental Damage</td>
<td>6 707 458</td>
<td>10 033 806</td>
<td>18 258 448</td>
<td>21 983 182</td>
<td>28 170 115</td>
<td>16 206 868</td>
</tr>
<tr>
<td>EDP (using EDP2) Low Value (CFA+RD+PR2) Single Mine Site Estimate of Sustainable Income</td>
<td>2 691 909</td>
<td>3 294 413</td>
<td>6 241 380</td>
<td>8 600 427</td>
<td>12 676 209</td>
<td>6 064 468</td>
</tr>
<tr>
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<td>12 905 205</td>
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<td>-1 108 545</td>
<td>-1 041 775</td>
<td>-1 578 034</td>
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<td>-2 302 710</td>
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<td>-18 885 931</td>
<td>-22 293 635</td>
<td>-28 925 306</td>
<td>-16 652 096</td>
</tr>
</tbody>
</table>

The estimates of sustainable income EDP incorporate more detailed information (EDP2) provided by the company of the single mine site. This along with reserves data provided by the company and departmental and provincial data obtained from the Bolivian Institute of Statistics form the basis for analysis of sustainable income by the three methods (World Bank, Net Price (Repetto), and User Cost (El Serafy)). Although, in the case of the World Bank, an additional calculation was added to include CO2. The two calculations for each method of PR1 (High Value) and PR2 (Low Value) comprise a segment of the conclusion as to the available capital to be invested into the local economy.

9 Results and Discussion

9.1 World Bank Method and the Net Price Approach (Repetto) Methods

We combined the World Bank Method and the Net Price Approach (Repetto) due to them both having the same results (Tables 3, 4). In both methods the World Bank Method and the Net Price Approach (Repetto) there exists a shortfall at the Low Value of Environmental Domestic Product when using EDP2, which was enabled by using more specific information from the single mine site. Whereas, the single mine site profits cover the lower level of Total Environmental Damage (DQR), the shortfall exists in the inability of being able to cover sustainable income (EDP), which suggests that at least in these methods that the mine site is actually a negative influence on provincial sustainability in the long run. Based on this analysis no other way was identified to meet the desired sustainable income level due to lack of economic rent.
Table 4. Repetto (Net Price) in Millions of 2015 USD (Same as World Bank due to no new reserves)

<table>
<thead>
<tr>
<th></th>
<th>2014 (10 mo)</th>
<th>2015</th>
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<td>Single Mine Site Contribution to GDP in 2015 USD</td>
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<td>603 125</td>
<td>218 374</td>
<td>*596 149</td>
<td>*397 433</td>
</tr>
<tr>
<td>RD Repetto (Net Price) Depletion - Single Mine Site in 2015 USD</td>
<td>1 584 268</td>
<td>2 260 764</td>
<td>4 687 704</td>
<td>7 245 315</td>
<td>10 532 541</td>
<td>4 782 558</td>
</tr>
<tr>
<td>PR2 - Low Value for Total Environmental Damage</td>
<td>393 470</td>
<td>423 014</td>
<td>950 551</td>
<td>1 136 738</td>
<td>1 547 519</td>
<td>884 477</td>
</tr>
<tr>
<td>PR1 - High Value for Total Environmental Damage</td>
<td>6 707 458</td>
<td>10 033 806</td>
<td>18 258 448</td>
<td>21 983 182</td>
<td>28 170 115</td>
<td>16 206 868</td>
</tr>
<tr>
<td>EDP (using EDP2) Low Value (CFA+RD+PR2) Single Mine Site Estimate of Sustainable Income</td>
<td>2 691 909</td>
<td>3 294 413</td>
<td>6 241 380</td>
<td>8 600 427</td>
<td>12 676 209</td>
<td>6 064 468</td>
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</tr>
</tbody>
</table>

9.2 World Bank plus CO2

Table 5. World Bank Plus CO2 in Millions of 2015 USD

<table>
<thead>
<tr>
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<th>2014 (10 mo)</th>
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</tr>
<tr>
<td>RD World Bank Depletion CO2 Single Mine Site in 2015 USD</td>
<td>1 609 505</td>
<td>2 291 047</td>
<td>4 719 581</td>
<td>7 277 192</td>
<td>10 564 418</td>
<td>4 802 848</td>
</tr>
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<td>PR2 - Low Value for Total Environmental Damage</td>
<td>393 470</td>
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<td>EDP (using EDP2) Low Value (CFA+RD+PR2) Single Mine Site Estimate of Sustainable Income</td>
<td>2 717 145</td>
<td>3 324 696</td>
<td>6 273 257</td>
<td>8 632 304</td>
<td>12 708 086</td>
<td>6 084 758</td>
</tr>
<tr>
<td>EDP (using EDP2) High Value (CFA+RD+PR1) Single Mine Site Estimate of Sustainable Income</td>
<td>9 031 133</td>
<td>12 935 488</td>
<td>23 581 154</td>
<td>29 478 748</td>
<td>39 330 682</td>
<td>21 407 149</td>
</tr>
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<td>Estimate of Sustainable Income - Low Value - Shortfall of Funds</td>
<td>-1 133 781</td>
<td>-1 072 058</td>
<td>-1 609 911</td>
<td>-1 479 068</td>
<td>-2 334 587</td>
<td>-1 349 995</td>
</tr>
<tr>
<td>Estimate of Sustainable Income - High Value - Shortfall of Funds</td>
<td>-7 447 769</td>
<td>-10 682 850</td>
<td>-18 917 808</td>
<td>-22 325 512</td>
<td>-28 957 183</td>
<td>-16 672 386</td>
</tr>
</tbody>
</table>
Using the World Bank’s Bolivia CO₂ emissions in conjunction with a U.S. Technical Support Document on the Social Cost of Carbon, we were able to make the World Bank plus CO₂ calculation. Using the World Bank plus CO₂ as an indicator for pollutants, provides a measure of the deterioration of environmental quality (DQR) and therefore must be considered a more realistic assessment of the environment in the study area. Although, the final dollar amounts rose using EDP2 for both Low and High values, the results mirror those of the World Bank Method and the Net Price Approach (Repetto) methods (Table 5).

9.3 User Cost (El Serafy)

Unfortunately, the User Cost (El Serafy) indicates that economic sustainability is not being met. We see that there is a shortfall of funds to even meet the Low Value EDP (using EDP2) for the period (2014-2019). The High Value EDP (using EDP2) is further out of reach. This scenario shows the greatest shortfall of funding for economic sustainability, and this model does not include CO₂ calculations which would only increase the funding shortfall. Because of the study area being more focused the ambiguities of expenses for environmental remediation/reclamation are reduced in the equation so negotiated future payments start on a more solid basis. Also, through using EDP2 the deterioration of environmental quality is somewhat addressed (Table 6).

Table 6. El Serafy (User Cost) in Millions of 2015 USD

<table>
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<td>*397 433</td>
</tr>
<tr>
<td>RD El Serafy (User Cost) Depletion - Single Mine Site</td>
<td>1 720 473</td>
<td>1 692 946</td>
<td>4 545 719</td>
<td>8 193 708</td>
<td>11 872 662</td>
<td>4 391 901</td>
</tr>
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<td>EDP (using EDP2) Low Value (CFA+RD+PR2) Single Mine Site Estimate of Sustainable Income</td>
<td>2 828 114</td>
<td>2 726 595</td>
<td>6 099 395</td>
<td>9 548 820</td>
<td>14 016 330</td>
<td>5 673 811</td>
</tr>
<tr>
<td>EDP (using EDP2) High Value (CFA+RD+PR1) Single Mine Site Estimate of Sustainable Income</td>
<td>9 142 102</td>
<td>12 337 387</td>
<td>23 407 292</td>
<td>30 395 264</td>
<td>40 638 926</td>
<td>20 996 202</td>
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<tr>
<td>Estimate of Sustainable Income - Low Value - Shortfall of Funds</td>
<td>-1 244 750</td>
<td>-473 957</td>
<td>-1 436 049</td>
<td>-2 395 584</td>
<td>-3 642 831</td>
<td>-939 048</td>
</tr>
<tr>
<td>Estimate of Sustainable Income - High Value - Shortfall of Funds</td>
<td>-7 558 738</td>
<td>-10 084 749</td>
<td>-18 743 946</td>
<td>-23 242 028</td>
<td>-30 265 427</td>
<td>-16 261 439</td>
</tr>
</tbody>
</table>

10. Conclusions

The findings show the approach is a realistic starting point. The inclusion of environmental costs on a per unit basis, while not ideal, provides a framework from which to start. The single largest improvement is that of additional information at a reduced geographic scale (i.e., amounts of reserves for the metals and the area being studied). Mixed mines have a greater degree of uncertainty when it comes to the calculations of environmental damage (past/current/future), but more data and more accurate data is becoming available allowing for greater accuracy in dollar predictions for the protection of human health and reclamation/remediation.

In recent years, economists have differentiated between weak and strong sustainability. While this study falls into the category of weak sustainability (natural capital can be substituted by manufactured capital or human capital), at
the present time we see this as the logical approach. Strong sustainability “whereby natural capital is no longer considered replaceable, so the stock of natural capital should be maintained to satisfy conditions for sustainability,” is a worthwhile goal but as of now is not possible (UNDP – Managing mining for sustainable development, 2018). This analysis continued the development of a methodology to evaluate economic sustainability for a smaller/single mine site, compared to the previous regional analysis. Whereas discussions over the impact of a single mine site are telling, its’ ramifications would have to be addressed on a larger scale (regional, national,) through policy and environmental regulations/enforcement. The possibilities of future negotiations between governmental entities and mining/businesses concerning cash flow back into the economy could exist, but other issues up for discussion should include where environmental enforcement efforts should be focused to get the best return on remediation dollars, and the need for greater information concerning the availability of mineral reserves.

Finally, we believe this study:

- Shows the cost of environmental deterioration/degradation in dollar values using unit costs.
- Is a realistic method to discuss sustainable development related to mining at a single mine site.
- Advances the discussion of economic sustainability in mining.
- Points out areas where further research is needed.
- Provides a framework to protect human health.
- Will advance the conversation of “weak sustainability” vs “strong sustainability.”

References


Convert Cubic Meter Per Year to Gallons (us fluid) Per Minute. Retrieved May 31, 2020 from https://www.unitjuggler.com/convert/cubic-meters/to/acre-feet


and New York.


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Authors contributions

Not applicable

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Competing interests

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Informed consent

Obtained.
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The journal’s policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).

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Data sharing statement
No additional data are available.

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