Economía Agraria y Recursos Naturales. ISSN: 1578-0732. e-ISSN: 2174-7350. Vol. 24,1. (2024). pp. 127-152

Including the change in natural capital stock and environmental degradation in Peruvian mining GDP and NNP

Carlos Enrique Orihuela[a], Víctor Carlos Michel Chumpitaz Añi[b] & José Yasser Dávila García[c]

ABSTRACT: This study adjusts the net national product (NNP) and gross domestic product (GDP) of the Peruvian mining sector by incorporating natural capital depreciation, new discoveries, and environmental degradation during the period 1994–2018. The results suggest that NNP has been overestimated, on average, by 172 % to 210 %, which is attributed to the omission of natural depreciation. When GDP was corrected, the overestimation fluctuated between 64 % and 72 %. This underscores the importance of including natural capital depreciation, especially in countries whose economy is highly dependent on extractive industries, as is the case of Peru.

Incluyendo el cambio en el stock de capital natural y degradación ambiental en el PIB y PNN de la minería peruana

RESUMEN: Este estudio ajusta el producto nacional neto (PNN) y producto interno bruto (PIB) del sector minero peruano, mediante la inclusión de la depreciación del capital natural, nuevos descubrimientos y degradación ambiental durante el período 1994–2018. Los resultados sugieren que PNN ha sido sobre estimado entre 172 % y 210%, debido a la omisión de la depreciación natural. Cuando el PIB fue corregido, la sobre estimación fluctuó entre 64 % y 72 %. Esto resalta la importancia de incluir la depreciación del capital natural, especialmente en países cuya economía es altamente dependiente de las industrias extractivas como es Perú.

KEYWORDS / PALABRAS CLAVE: Mining, GDP, NNP, natural depreciation, degradation, Hotelling rent / minería, PIB, PNN, depreciación natural, renta Hotelling total, costo de degradación.

JEL Classification / Clasificación JEL: E01, Q32, Q52.

DOI: https://doi.org/10.7201/earn.2024.01.06

[a] Facultad de Economía y Planificación. Universidad Nacional Agraria La Molina. Lima, Perú. Círculo de Investigación Economía de los Recursos Naturales y del Ambiente, CIERNA. E-mail: corihuela@lamolina.edu.pe

[b] Universidad Nacional Agraria La Molina. Lima, Perú. E-mail: vmchumpitaz@gmail.com

[c] ESAN Graduate School of Business. Lima, Perú. E-mail: jdavilag@esan.edu.pe

Acknowledgement: This research did not receive specific grant funding from public, commercial, or non-profit sectors.

Cite as: Orihuela, C.E., Chumpitaz, V.C.M. & Dávila, J.Y. (2024). "Including the change in natural capital stock and environmental degradation in Peruvian mining GDP and NNP". *Economía Agraria y Recursos Naturales*, 24(1), 127-152. https://doi.org/10.7201/earn.2024.01.06

Corresponding author: Carlos Enrique Orihuela. *E-mail*: corihuela@lamolina.edu.pe

Received on July 2022. Accepted on March 2024.

1. Introduction

Ever since colonial times, mining activity has played a crucial role in the Peruvian economy (Seminario, 2016). Up until the 1990s, the State managed most of the mining operations; extracting primarily iron, silver, copper, zinc, and lead. In 1991, a rapid privatization process began, accompanied by several reforms aimed at attracting investment to the sector, promoting economic growth and contributing to the country's economic recovery since then (Poveda, 2007).

The global boom in metal prices that occurred during the period 2003-2011 (hereinafter, the boom years) led to a rapid escalation in the extraction levels of gold, silver, copper, iron, zinc, lead, and tin. These minerals accounted for between 55 % and 60 % of the total value of exports during that period (BCRP, 2014). Consequently, the value of mining exports increased from USD 3,205 million to USD 27,381 million between 2001 and 2011 (MINEM, 2012), which in turn contributed to the growth of the gross domestic product (GDP) reaching 9 % and 8.5 % in 2008 and 2010, respectively (BCRP, 2014). As a result, Peru experienced elevated national incomes, fostering a growth dynamic centered around extractive industries, particularly the metal mining sector (McMahon & Moreira, 2014). The mining industry's significance extends beyond the Peruvian economy, as evidenced by Peru's global rankings as the second, third, fourth, and eighth largest producer of copper-silver, zinc, gold, and lead, respectively, at the end of 2020 (MINEM, 2021).

While mineral exports continue to be a driving force in the Peruvian economy, this trend has not only given rise to various environmental issues (Custodio *et al.*, 2020; Salem *et al.*, 2018; Swenson *et al.*, 2011) but has also led to the gradual depletion of corresponding natural capital stocks, diminishing their future availability. It is widely acknowledged that GDP considers all income as flows contributing to its increase, without distinguishing whether income flows from returns on capital investment or the liquidation of capital stocks, such as natural resources (Banerjee *et al.*, 2020). This becomes a pertinent concern for a mineral-rich country like Peru, which relies heavily on the extraction and sale of these resources. Neglecting these aspects in the decision-making process could entail adverse consequences for the country's economic growth.

Typically, the assessment of a country's economic performance, as well as that of its various sectors and industries, relies on conventional income indicators such as GDP and Net National Product (NNP). Both metrics recognize the extraction of natural resources as a source of income but overlook the depletion of capital, as these resources are not treated as assets within the existing National Accounting System (Figueroa & Calfucura, 2004). This omission sparks controversy because, if natural resources were regarded as assets, they would necessitate depreciation calculations. Consequently, the traditional NNP fails to accurately reflect true income, as it neglects, among other factors, the depreciation of natural resources. For a country

endowed with substantial natural capital and an economy exhibiting limited diversification, distortions in this metric could be significant, potentially leading to the implementation of inappropriate policies.

Weitzman (1976) demonstrated that the real NNP, under certain assumptions and appropriate estimation (meaning that it should encompass variations in all forms of capital, including natural capital), is equivalent to the present value of the maximum consumption level that a country can sustain indefinitely. Hartwick (1990) illustrated that NNP reflects the net change in social welfare resulting from small policy changes, including future impacts. In this manner, a country can assess whether its level of welfare is increasing, decreasing, or remaining constant by examining the trend in its NNP. Sustainability (of consumption) requires that this trend is not negative, while long-term economic welfare can only improve if it is positive (Vincent & Ali, 2005).

Weitzman's insight has spurred the development of several economic models (Hamilton, 1994; 1996; 2000; Hamilton & Bolt, 2004; Hartwick, 1990) to formalize the incorporation of natural depreciation, environmental degradation, and even new discoveries into NNP for assessing the sustainability of consumption. The outcome of this process is often referred to as "green NNP" (Asheim, 1997). Despite these models explicitly address adjustments to NNP, they are commonly utilized to modify or correct GDP, giving rise to a concept known as "green GDP". This practice is probably due to the fact that GDP is the most widely used measure of income, which makes it easier to understand and apply in decision-making processes.

Based on these models, numerous studies have calculated green income measures for economies heavily reliant on non-renewable natural resources (Figueroa *et al.*, 2002; Figueroa *et al.*, 2010; Mardones & Del Rio, 2019; Ouoba, 2017; Young & da Motta, 1995). All these studies emphasize the overestimations associated with traditional methods of measuring income, whether at the national or sectoral level, and reveal a reduced rate of income growth when the economic value of natural depreciation is incorporated into the model.

In the Peruvian context, Figueroa *et al.* (2010) adjusted traditional mining GDP by incorporating the costs of natural depreciation, discoveries, and environmental degradation. They observed that the cost of natural depreciation fluctuated between 31 % and 51 % of the sectoral GDP during the 1992-2006 period, varying by year. However, it is crucial to examine the subsequent period, characterized by extraordinarily high prices for key minerals and their export volumes (the boom years). In theory, this phase could result in extreme depletion of these resources, potentially causing significant distortions in traditional sectoral income measures. Additionally, there is evidence suggesting a reduction in the stock of natural capital in Peru during the 1990-2014 period (Managi & Kumar, 2018). This poses concerns for a country whose economic growth is closely tied to the export of mineral resources.

This study aims to derive a more appropriate income measure for decision making by estimating the income of the Peruvian mining sector while accounting for the depletion of natural resources and the environmental degradation resulting from their extraction. In contrast to similar studies, the significance of this research lies in its examination of a longer period (24 years), enabling the differentiation between periods of stable and high prices and facilitating the analysis of implications on the cost of natural depreciation. Furthermore, studies addressing the adjustment of national accounts through the inclusion of the cost of natural depreciation often focus solely on correcting sectorial GDP. This study, however, corrects not only sectorial GDP but also sectorial NNP, which is conceptually the appropriate indicator for measuring green income. These represent the primary contributions of this article to the existing literature.

2. Methodology

2.1. The green net national product model

This study employs the green NNP model proposed by Hamilton (1994; 2000), following the framework outlined by Hartwick (1990). The model is based on the assumption of a small, closed economy that produces a composite good and possesses a stock of non-renewable natural capital. The objective is to maximize social welfare over an infinite time horizon, with the following considerations:

$$\int_0^{+\infty} U(C)\ exp\ (-rt)\ dt \qquad [1]$$

Subject to:

$$\dot{K} = F(K,E) - C - f(E,Z) - g(D,M) - \delta K - a \qquad [2]$$

$$\dot{Z} = -E + D \qquad [3]$$

$$\dot{M} = D \qquad [4]$$

The term r represents the constant discount rate of utility, U, which is dependent on aggregate consumption, C. The stock of manufactured capital, net investment in it, and its depreciation rate are denoted as K, $\dot{K}$, and δ, respectively. The terms Z and E denote the stock of the non-renewable natural resource and its extraction rate, respectively. Further, D and M represent the stock and the flow of new discoveries

(expressions [3] and [4]). Expression [3] indicates that the variation in the stock of non-renewable depends on the balance between extractions and new discoveries. New discoveries are equivalent to the variation in accumulated discoveries [4]. The term $F(K,E)$ represents the production function of the economy's composite good. We assume $\partial F / \partial E > 0$ and $\partial F / \partial K > 0$. On the other hand, $f(E,Z)$ is the total cost of extraction of the non-renewable resource, where $\partial f / \partial E > 0$ and $\partial^2 f / \partial E^2 > 0$. The function $g(D,M)$ describes the cost of exploration for the non-renewable good which depends on current and cumulative discoveries where it is assumed that $\partial g / \partial D > 0$ and $\partial g / \partial M > 0$.

On the other hand, the flow of ecosystem services is denoted as W (expression [5]), which depends on the level of polluting emissions e, which in turn is a function of the extraction level of the non-renewable resource and the cost of reducing that level denoted as a. It is assumed that $\partial e / \partial E > 0$ and $\partial e / \partial a < a$, and there exists a certain level of emissions, h, that can be absorbed by nature. This means that $\dot{W}$ is equivalent to the equation that represents the dynamic of the contamination stock generated by the exploitation of non-renewable resource.

$$\dot{W} = e(E,a) - h\,(W) \qquad [5]$$

The optimal control problem considers K, Z, M and W as state variables, while C, a, E, and D are considered control variables. It follows that the current value Hamiltonian for this problem is given by (expression [6]):

$$H = U(C) + \lambda_1 \dot{K} + \lambda_2 \dot{Z} + \lambda_3 \dot{M} + \lambda_4 \dot{W} \qquad [6]$$

With the following first-order conditions:

$$\frac{\partial H}{\partial C} = 0 \Rightarrow \frac{\partial U}{\partial C} - \lambda_1 = 0 \qquad [7]$$

$$\frac{\partial H}{\partial E} = 0 \Rightarrow \lambda_1 \left(\frac{\partial F}{\partial E} - \frac{\partial f}{\partial E} \right) - \lambda_2 + \lambda_4 \frac{\partial e}{\partial E} = 0 \qquad [8]$$

$$\frac{\partial H}{\partial D} = 0 \Rightarrow -\lambda_1 \frac{\partial g}{\partial D} + \lambda_2 + \lambda_3 = 0 \qquad [9]$$

$$\frac{\partial H}{\partial a} = 0 \Rightarrow -\lambda_1 + \lambda_4 \frac{\partial e}{\partial a} = 0 \qquad [10]$$

After obtaining the optimum value of the shadow prices λ_1, λ_2, λ_3 and λ_4 and substituting them into expression [6]:

$$H = U(C) + \frac{\partial U}{\partial C}\dot{K} + \frac{\partial U}{\partial C}\left[\frac{\partial F}{\partial E} - \frac{\partial f}{\partial E} + \frac{\frac{\partial e}{\partial E}}{\frac{\partial e}{\partial a}}\right]\dot{Z} + \left[\frac{\partial U}{\partial C}\cdot\frac{\partial g}{\partial D} - \frac{\partial U}{\partial C}\left(\frac{\partial F}{\partial E} - \frac{\partial f}{\partial E} + \frac{\frac{\partial e}{\partial E}}{\frac{\partial e}{\partial a}}\right)\right]\dot{M} + \frac{\frac{\partial U}{\partial C}}{\frac{\partial e}{\partial a}}\dot{W} \qquad [11]$$

Rewriting equation [11] in more compact terms, we obtain:

$$H = U(C) + U_C\dot{K} + U_C\left[F_E - f_E + \frac{e_E}{e_a}\right]\dot{Z} + \left[U_C \cdot g_D - U_C\left(F_E - f_E + \frac{e_E}{e_a}\right)\right]\dot{M} + \frac{U_C}{e_a}\dot{W} \qquad [12]$$

Substituting the expressions for $\dot{Z}$, $\dot{M}$, and $\dot{W}$ into the equations, we obtain:

$$H = U(C) + U_C\dot{K} + U_C\left[F_E - f_E + \frac{e_E}{e_a}\right](-E + D) + \left[U_C \cdot g_D - U_C\left(F_E - f_E + \frac{e_E}{e_a}\right)\right]D + \frac{U_C}{e_a}[e(E,a) - h(W)] \qquad [13]$$

The simplification leads to:

$$H = U(C) + U_C\dot{K} - U_C\left[F_E - f_E + \frac{e_E}{e_a}\right]E + U_C \cdot g_D D + \frac{U_C}{e_a}[e(\cdot) - h(\cdot)] \qquad [14]$$

Assuming a lineal utility function $U(C) = U_C C$ (Weitzman, 1976), it is possible to divide equation [14] by U_C to obtain the Hamiltonian value of the NNP in monetary terms. This is because the two first terms on the right-hand side are equivalent to the traditional NNP in a closed economy. It follows that the term on the left-hand side of equation (15) approximates the corrected or green NNP.

$$NNP = C + \dot{K} - \left[F_E - f_E + \frac{e_E}{e_a}\right]E + g_D D + \frac{1}{e_a}[e(\cdot) - h(\cdot)] \qquad [15]$$

The third term, $[F_E - f_E + (e_E / e_a)]$, corresponds to the unitary marginal rent of the non-renewable resource adjusted by an optimal Pigouvian tax, e_E / e_a, which accounts for the negative externality generated by the extraction process of the non-renewable resource (Hamilton, 1994). However, to circumvent the challenge of estimating

the term e_E / e_a, it is assumed to be zero[1]. On the other hand, in equilibrium, F_E is equal to the *in situ* price, P of one unit of E. Thus, $[F_E - f_E]E$ may be rewritten as $[P - f_E]E$. The last term is equivalent to the cost of the non-renewable natural resource's depreciation or total Hotelling rent (Hartwick & Hageman, 1993).

The fourth term, $g_D D$, represents the marginal value of new discoveries. In this model, new discoveries refer to the value of reserves found as a result of exploration activities. This does not imply that future reserves are perfectly anticipated; instead, during each period, new discoveries are valued based on their marginal discovery cost (Mardones & Del Rio, 2019). Due to information constraints, this cost is typically estimated using exploration expenditures (Hamilton, 1994). This study will adhere to this convention.

The fifth term, $[e(\cdot) - h(\cdot)]$, represents environmental degradation, quantified in monetary terms using its marginal social pollution abatement cost, $b \equiv -1/e_a$ (Hamilton, 1996). This calculation corresponds to the expenditure on technology to mitigate polluting emissions that exceed locally regulated limits from mining operations. It is important to emphasize that the impact of excess pollution (beyond established standards or regulations) generated by the mining sector on human well-being is not measured. Instead, the focus is on the cost of mitigating this excess pollution.

2.2. Extending the model to an open economy

The model presented in this work (Hamilton, 1994; 2000) is explicitly designed for a closed economy. However, it is possible to extend it to an open economy by incorporating three additional components: the value of exports, the value of imports, and the interest earned on the stock of external assets (Gómez-Lobo, 2001; Hamilton & Bolt, 2004). Given that the first two components are already accounted for in GDP, it is only necessary to include the third one, referred to as net factor payments (NFP) from abroad. NFP represents the payment of Peruvian factors of production abroad minus the payment of foreign factors of production in Peru. Since the NFP for the mining sector was not available, it had to be calculated.

In the case of the Peruvian mining sector, there were no Peruvian mining companies engaged in activities abroad during the study period. Therefore, the NFP were linked to the activities of foreign mining companies operating in Peru. It was assumed that the payment of external factors of production would be a fraction, represented by J, of the Operating Surplus of Sectoral Exploitation (OSS). It was further assumed that this fraction is proportional to the sales revenue of foreign companies as a part of the sectoral revenue. If T is the tax rate on companies' income, then for a given period t, NFP can be expressed as [16]:

[1] Peruvian regulations do not include Pigouvian taxes.

$$NFP_t = -J_t(1-T)OSS_t \quad [16]$$

T = 30 %, which represents the current tax rate in Peru, was utilized. This tax rate remained constant throughout the entire analysis period. The estimation of J was derived from data sourced from Peru Top Publications (across various years). Given that a significant portion of production in the Peruvian mining sector is undertaken by foreign companies, it is unsurprising that J is relatively high, ranging between 43 % and 89 % depending on the year. Including NFP in mining GDP and subtracting the Consumption of Fixed Capital (CFC) results in the traditional sectoral NNP.

2.3. Measures to correct NNP

To facilitate a comparison of our findings with similar studies (Figueroa *et al.*, 2010; Figueroa *et al.*, 2002; Mardones & Del Rio, 2019), we propose the construction of three measures of green or corrected income at the sector level. The first measure, denoted as [17], involves adjusting traditional NNP by subtracting natural depreciation costs or total Hotelling rent, as indicated in equation [17].

$$NNP1_t = NNP_t - \left[P_t - f_{E,t}\right]E_t \quad [17]$$

The second measure, denoted as [18], is equivalent to adjusting traditional NNP by subtracting not only natural depreciation costs but also the costs resulting from the environmental degradation due to the extraction of non-renewable resource.

$$NNP2_t = NNP_t - \left[P_t - f_{E,t}\right]E_t - b_t\left[e_t - h_t\right] \quad [18]$$

The third additional measure, denoted as [19], adjusts traditional NNP by accounting not only for natural depreciation and environmental degradation costs but also by incorporating new quantified discoveries and adding their marginal discovery cost. It is important to note that the sum of the second and third terms on the right-hand side in equation [19] is equivalent to the net depreciation cost of the natural resource.

$$NNP3_t = NNP_t - \left[P_t - f_{E,t}\right]E_t + (g_D D)_t - b_t\left[e_t - h_t\right] \quad [19]$$

Furthermore, since it has been customary in the literature to derive green income measures by correcting GDP, this study will also incorporate it as a complement to green NNP for comparative purposes. The expressions [20]-[22] for corrected GDP are analogous to [17]-[19], which were established for corrected NNP.

$$GDP1_t = GDP_t - \left[P_t - f_{E,t}\right]E_t \quad [20]$$

$$GDP2_t = GDP_t - \left[P_t - f_{E,t}\right]E_t - b_t[e_t - h_t] \quad [21]$$

$$GDP3_t = GDP_t - \left[P_t - f_{E,t}\right]E_t + (g_D D)_t - b_t[e_t - h_t] \quad [22]$$

It is worth mentioning that it is not possible to estimate each term individually in all the expressions [17]-[22]. This is the reason why these must be calculated as a block. The process is discussed below.

2.4. Cost of natural depreciation

Considering that the Peruvian mining sector extracts various ores, it was necessary to estimate and aggregate the total marginal revenues, $[P_t - f_{E,t}]E_t$, for each of the seven commercial metals (gold, silver, copper, zinc, lead, iron, and tin), which constitute the majority of Peruvian mining exports. Unfortunately, information regarding the marginal extraction cost of these metals is not available. Additionally, many mining companies extract multiple minerals simultaneously, making it challenging to determine the marginal cost for each individual mineral. An alternative approach could involve estimating the total marginal revenue for the entire mining industry using the OSS. However, using this operating surplus is equivalent to a total average profit $[P_t - f_t/E_t]\ E_t$ for the mining industry, rather than its total marginal profit.

Due to the absence of local data, Figueroa & Calfucura (2004), Figueroa *et al.* (2010) and Mardones & Del Rio (2019) adopted $\lambda = 0.7$ as the correction factor to convert average unitary rent into marginal unitary rent. This choice follows the methodology of Davis & Moore (2000), derived this coefficient in a study on the Hotelling valuation principle using information from gold mining in the United States of America. Lacking more precise information, this study will employ the same factor, so that $[P_t - f_{E,t}]E_t = \lambda\ [P_t - f_t/E_t]E_t$.

To calculate the normal return of the mining sector, the aggregate net fixed sectoral assets (*NFA*) in mining were multiplied by a normal return rate for the mining sector, denoted as *r*. This method allowed for the estimation of natural depreciation in the mining sector, depending on the term on the right side of expression [23]. Information regarding *NFA* for the entire study period was sourced from various sources, including Bolsa de Valores de Lima (BVL), Peru Top Publications, and the Superintendencia del Mercado de Valores (SMV). This data encompasses mining

companies engaged in extraction and refining. Information about OSS was obtained from INEI (several years).

$$\lambda[P_t - f_t / E_t]\, E_t = \lambda\, [OSS_t - r_t \cdot NFA_t] \qquad [23]$$

There are no specific studies regarding the term *r* at the local level for the Peruvian mining industry. According to Otto (2002), a rate of return of approximately 14.7 % is suggested for a hypothetical case of a copper mine. Given that a significant portion of Peruvian mining involves copper mining, it is reasonable to consider this rate as representative. Otto's rate is derived from information in the 1990s, a period marked by economic and legal transitions that witnessed the implementation of several sectoral reforms to attract larger investments, generate more production, and increase exports. It is anticipated that the normal rate of return in the 1990s was higher than that of the subsequent period when the country's economy substantially improved. Indeed, since the 2010s, a discount rate of 10 % has been commonly used in projects related to hydrocarbons and mining[2]. Consequently, a rate of *r* equal to 15 % and 10 % will be assumed for the periods 1994-1999 and 2000-2018, respectively.

2.5. Marginal cost of new discoveries

To estimate the term $g_D D$, data from various investments in mining exploration were utilized, information that is available in the statistical reports from the Peruvian Ministry of Energy and Mines (MINEM). Within the SNA framework, expenditures on exploration are already accounted for as investments, so adding them to NNP3 (or GDP3) would result in double counting. However, as Dasgupta *et al.* (1997) demonstrate, if new discoveries stem from accumulated exploration costs, considering these costs within corrected NNP does not imply double counting[3].

2.6. Costs of environmental degradation

Mining activity in Peru generates various air pollutants (CO_2, particulate matter, lead, sulphur), with the most significant being SO_2 emissions, primarily originating from three refineries: Refinería Cajamarquilla, Complejo Metalúrgico de La Oroya (CMLO), and Refinería de Ilo (MINAM, 2014). Component $[e(\cdot) - h(\cdot)]$ would require estimating the excess SO_2 emitted (in comparison to local legislation) for each of the three refineries. This value would then need to be multiplied by the

[2] Peruvian legislation requires an Environmental Impact Study (EIA) for all mining projects. A segment of the EIA includes a Cost-Benefit Analysis, typically applying a discount rate of 10 % for projects associated with extractive industries.

[3] The mining exploration process consists of four stages: prospection (identifying areas with the potential to host mineral deposits), basic exploration (turning a project into a mineralizable deposit if successful), advanced exploration (defining the size and grade quality of the deposit), and economic feasibility (deciding whether to develop and commence production in the mine) (De la Torre, 2001). Therefore, it is anticipated that new discoveries during a specific period will accumulate exploration costs.

respective marginal abatement cost, *b*. Unfortunately, data for both emissions and costs were not available.

In 1997, Doe Run Peru acquired Metaloroya S.A [later renamed Complejo Metalúrgico de La Oroya (CMLO)] for a total of USD 122 million and committed to investing an additional USD 127 million, of which USD 90 million were allocated to the sulfuric acid facility to comply with local environmental quality standards (EQS) of 80 $\mu g/m^3$. Due to various reasons, CMLO was unable to fulfill its investment commitments and ceased operations in 2009 (Mendiola *et al.*, 2018).

In 2015, MINEM stipulated that any company seeking to acquire CMLO assets must adhere to the Corrective Environmental Management Instrument [Instrumento de Gestión Ambiental Correctivo (IGAC)], comprising four projects aimed at mitigating atmospheric pollution and enhancing air quality in accordance with EQS. The IGAC incurs a cost of USD 788.35 million. It is anticipated that this figure would be more accurate than the initially budgeted USD 90 million for EQS compliance. Assuming a similar investment horizon to that of implementing the Environmental Management Adaptation Programme [Programa de Adecuación de Manejo Ambiental (PAMA)], the average annual cost for the 1998-2008 period would be USD 78.83 million. This approximation represents the total abatement costs of CMLO, which were utilized in this study.

Southern Peru Corporation (SPCC), the owner of the refinery in Ilo, has been disclosing its environmental expenditure to improve air quality since 2014 (SPCC, several years). Although this constitutes the total expenditure from its operations in Toquepala, Cuajone, and Ilo, it is reasonable to expect that most of the expenses are incurred in the latter since that is where the refinery is located. Due to the lack of data, the expenditure from 2014 is assumed to be representative for the period between 1996-2018 and is used as a constant. Regarding the refinery at Cajamarquilla, SO_2 emissions did not exceed EQS standards (MINEM, 2004).

The abatement costs for particulate matter and CO_2 were not considered due to companies not disclosing records regarding the expenditure on technologies to mitigate emissions of these two pollutants. Additionally, Peruvian regulations do not mandate the mining industry to minimize CO_2 emissions, so it is reasonable to assume that the marginal abatement cost of this pollutant is zero. Discharges of heavy metals into local waters are also not considered due to a lack of data. Finally, all monetary quantities were converted to 2006 Peruvian soles using the implicit deflator in mining GDP before being converted to 2006 USD using the average exchange rate for that year. Below is a summary of the expressions that will be estimated (Table 1).

TABLE 1

Main variables to be estimated

Term	Significance
NNP_t, GDP_t	Traditional income measures were obtained from INEI (several years)
$\lambda[OSS_t - r_t \cdot NFA_t]$	We assumed $\lambda = 0.7$ (Davis & Moore, 2000), but a sensitivity analysis is proposed. The term r was assumed to be 15 % (Otto, 2002) and 10 % for the periods 1994-1999 and 2000-2018 respectively. NFA_t were obtained by Peru Top Publications (several years) and BVL (several years).
$NFP_t = -J_t (1-T)$ OSS_t	T=30 %, according to Peruvian tax rate. J_t is assumed to represent the sales income of foreign companies as part of the sectoral income. OSS_t is sourced from MINEM (2012; 2021).
$g_D D$	It is estimated as a whole through the sectoral exploration cost (MINEM, 2012; 2021).
$(1/e_a)$ $[e(\cdot) - h(\cdot)]$	Due to limitations, information on disbursements in air quality improvement programs could only be obtained from one of the largest mining companies in the country (SPCC, several years).

Source: Own elaboration.

3. Results and discussion

3.1. Cost of natural depreciation

Table 2 contains information relevant to the calculation process of natural depreciation in the mining sector in Peru during the 1994-2018 period. The second column (*NFA*) illustrates the evolution of the net fixed sectoral assets, representing the stock of manufactured capital accumulated each year. The third column (*OSS*) is equivalent to the gross profits in the mining sector (obtained from the national accounts), from which the normal return to employed capital is subtracted to approximate the cost of natural depreciation or total Hotelling rent in the Peruvian mining industry.

The fourth column, (λ[*OSS* – *r* (*NFA*)]), represents the cost of natural depreciation, fluctuating between 1,468 and 7,194 million USD (in 2006 dollars). Throughout the 1994-2010 period, the trend was upward, but it reversed during the 2011-2015 period, before recovering in 2016 and 2017. The accumulated cost of natural depreciation, accounting for around 45 %, was concentrated during the boom years[4]. During this subperiod, the growth rate in the annual cost in question was 8 %, a higher rate compared to the entire period under study.

[4] Mardones & Del Rio (2019) obtained similar results examining the case of copper in Chile, where the percentage was 58 % although their study period was 1996-2015.

TABLE 2

Main monetary accounts from mining sector (in 2006 USD millions)

Year	Aggregate net fixed assets	Operation surplus	Natural depreciation costs	Exploration expenditures	Environmental degradation costs
	NFA	*OSS*	$\lambda[OSS–r(NFA)]$	$g_D\ D$	$b[e(\cdot)–h(\cdot)]$
1994	3287	2591	1468	NA	388
1995	3764	2724	1511	NA	357
1996	4173	2746	1484	210	377
1997	4463	3165	1747	120	372
1998	5729	3254	1676	115	404
1999	6720	4050	2130	122	445
2000	6904	3913	2256	141	403
2001	9162	4846	2751	223	441
2002	11317	5101	2779	141	433
2003	10438	5882	3387	77	384
2004	8395	6283	3811	86	272
2005	8429	7003	4312	137	243
2006	6352	7896	5083	108	157
2007	6851	9148	6055	126	137
2008	7680	8667	5767	179	158
2009	9597	8810	6010	456	81
2010	7666	9219	6423	526	60
2011	7378	8853	6250	527	42
2012	11482	8538	5820	592	46
2013	21817	9475	5394	638	57
2014	35715	9094	4101	614	68
2015	57761	11138	4083	706	112
2016	58732	13334	5727	475	122
2017	44574	14094	7194	501	92
2018	45073	13621	6379	406	87
$Total_{1994\text{-}2018}$ (A)	403460	189750	103598	7225	5738
$Total_{2003\text{-}2011}$ (B)	72786	74562	47098	2222	1534
(B)/(A) %	18	39	45	31	27
$AAGR_{1994\text{-}2018}$(A)	11.53	7.16	6.31		–6.05
$AAGR_{2003\text{-}2011}$(B)	–4.24	6.41	7.96	27.14	–24.11

NA = not available; AAGR: average annual growth rate.

Source: Own elaboration.

Despite the decline in metal prices starting in 2012, the stock of manufactured capital in the mining industry grew exponentially until 2015. This growth might be attributed to investments that were "left behind" maturing, referring to those that were planned and executed –in large part– during the boom period[5]. The decrease in this stock (in 2016) is associated with investors' expectations during the 2016 presidential elections in Peru and the subsequent political instability, likely leading them to adopt more conservative positions[6].

3.2. Exploration expenditure and environmental degradation costs

Column 5 ($g_D D$) presents the expenditure spent on exploration as a proxy for the marginal costs of discoveries. Due to the implicit use of average cost instead of the marginal cost of exploration, it is expected that the third term on the right of equations [19] and [22] will be underestimated (Figueroa & Calfucura, 2004). Given its small effect, this will not significantly change the results.

The sixth column, $b[e(\cdot)–h(\cdot)]$, reveals the cost of environmental degradation resulting from mining activity, understood as pollution abatement costs from surplus emissions (surplus with respect to the local SO_2 air quality standards). The annual cost of this degradation is significantly lower than those in the other columns, suggesting that the environmental damage from the emissions generated by the mining sector is minimal compared to natural depreciation[7]. Nevertheless, it must be remembered that due to data limitations, only air pollution was considered when coming up with these figures, while soil and water pollution were not.

For the 1994-2018 period, the accumulated values of exploration expenditure, degradation costs and natural depreciation were USD 7225, USD 5738 and USD 103598 million, respectively. It can be seen that the depletion of natural capital is the most significant omission in traditional sectoral income measurements. It should be noted that expenditure on exploration makes up only around 7 % (7225/103598) of the costs of the depletion of natural capital. During the boom period, this percentage

[5] During 2011 alone, 8 operations' expansion projects were registered –totalling USD 9335 million– which were scheduled to begin in 2012. At the time, 11 projects were in their construction stage –for a total of USD 18000 million– which were expected to begin operating during the 2012-2016 period (MINEM, 2012).

[6] As part of the political landscape of the time, investors concentrated their investments to reduce costs and save capital as a way of minimizing risk for their investment assets. In spite of this more cautious attitude, investment in projects that had already begun their development continued (OSINERGMIN, 2016).

[7] The calculation of environmental damage from SO_2 relies on the assumption that locally allowed levels of pollution are exactly set at net-zero. The emissions above this level are apparently not observable directly, so the costs of air quality improvement projects are used as a direct proxy for the monetary value of damage to the environment. There is little reason to believe that these investments by private companies accurately reflect the actual cost of SO_2 damages, since companies have a direct cost-incentive to use any uncertainty for underinvestment. Consequently, environmental damage from SO_2 alone is probably underestimated, perhaps even significantly. However, it is important to highlight that the methodology used only requires the abatement cost from surplus emissions, not full cost of environmental damage generated by the Peruvian mining sector.

was even lower (2222/45139 = 5 %). This is troubling in a country such as Peru, where the largest fraction of foreign exchange comes from the mining industry.

3.3. Traditional and corrected forms of measurement

After estimating the value of natural depreciation, the cost of environmental degradation, and the cost of new discoveries in the mining sector, these components were used to correct traditional measures of income, in this case NNP and GDP. Results are shown in Table 3. Columns 2 and 3 contain the traditional measurements of the Peruvian mining sector constructed using the SNA framework. As expected, traditional GDP exceeded traditional NNP by an average of almost 62 % during the whole study period, with this percentage being mostly attributable to NFP. Columns 4, 5 and 6 show the overestimation of GDP (GDP1, GDP2, and GDP3) considering the components that are missing in traditional estimations. Columns 7, 8 and 9 show the same in the case of NNP. For the 1994-2018 period (lower part of Table 3), 66 % of the average overestimation of traditional GDP corresponded to the inclusion of natural depreciation.

The inclusion of environmental degradation costs raises that percentage to 72 %, but including new discoveries reduces it to 64 %. These percentages are even more marked when the adjusted figure is the NNP (lower part of columns 7, 8, and 9), which varies between 172 % and 210 %. It should be noted that the average annual growth rate (AAGR) of GDP2 and GDP3 (6.16 % and 6.31 %) is larger than for traditional GDP (5.84 %), suggesting more favorable sectoral social welfare perspectives in the long run (compared to traditional GDP). Something similar occurred during the boom period. The AAGR for the period 2003-2011 for GDP2 and GDP3 was 4.94 % and 5.78 %, respectively; figures below and above the respective rate of the traditional measure (5.16 %). This is surprising considering the low level of investment in exploration (compared to the depreciation of natural capital) during this period. However, this implication is not necessarily correct. In the case of NNP, both for the boom period and for the complete period, the growth rates of the corrected measures were lower compared to the respective growth rate of the traditional measure.

Figure 1 shows the evolution of the traditional GDP and NNP and their respective measures corrected for natural depreciation (GDP2 and NNP2). GDP3 and NNP3 were not included since their evolution practically overlaps with GDP2 and NNP2, respectively. This implies that the natural depreciation cost largely explains the difference between the traditional and corrected measures. Note that the variation between the traditional measurements and their corrected measurements had not been uniform throughout the period. The biggest breach between the two (either GDP or NNP) occurred during the boom period. Thus, during the period of high resource prices, the cost of its depletion has been greater: high prices must have induced greater extraction of the resource. In this context, investments in exploration

do not seem to have a relevant effect. In theory, more discoveries should minimize the effect of more extraction, but this has had no impact on the results. Presumably, using (implicitly) the average cost of exploration as a proxy for the marginal cost of discovery may be generating a significant distortion of the results.

For this reason, the average annual growth rate is not necessarily a good indicator of the prospects for future sectoral income (whether traditional or corrected). The need to invest in exploration is highlighted to extend the sector's income horizon, an aspect that is usually limited by political or economic conditions in the country.

TABLE 3

Traditional income measures of the Peruvian mining sector and their corrected measures (in 2006 USD millions)

Year	Traditional		Corrected					
	GDP	NNP	GDP1	GDP2	GDP3	NNP1	NNP2	NNP3
1994	4578	3453	3110	2721	2721	1984	1596	1596
1995	4882	3537	3371	3014	3014	2026	1669	1669
1996	4859	3572	3375	2998	3209	2088	1712	1922
1997	5274	3760	3527	3156	3276	2013	1641	1761
1998	5718	3280	4042	3638	3753	1604	1200	1314
1999	6363	3626	4233	3788	3910	1496	1052	1173
2000	6178	3662	3922	3520	3660	1407	1004	1144
2001	7387	4189	4636	4195	4418	1439	998	1220
2002	7662	4784	4884	4451	4592	2005	1572	1714
2003	8242	4905	4855	4471	4548	1518	1134	1211
2004	8792	4545	4982	4710	4796	734	462	548
2005	9119	4755	4807	4563	4701	443	199	337
2006	9904	5332	4821	4664	4772	249	92	200
2007	11899	6685	5975	5838	5964	760	624	749
2008	12190	7198	6661	6503	6682	1668	1510	1689
2009	12897	8130	7402	7321	7777	2635	2554	3010
2010	12746	8143	6829	6770	7296	2227	2167	2693
2011	12325	7999	6644	6602	7128	2319	2276	2803
2012	12479	8428	7306	7261	7852	3255	3209	3801
2013	13013	8516	7908	7850	8488	3410	3353	3991
2014	12880	8546	9015	8946	9560	4680	4612	5226
2015	16101	10779	12348	12236	12942	7026	6914	7620
2016	18736	12386	13513	13390	13865	7163	7041	7515
2017	19112	12428	12366	12275	12776	5683	5591	6092
2018	17882	11446	11502	11415	11821	5066	4980	5385
GDP/NNP		1.62						
GDP/GDP1			1.66					

TABLE 3 (cont.)

Traditional income measures of the Peruvian mining sector and their corrected measures (in 2006 USD millions)

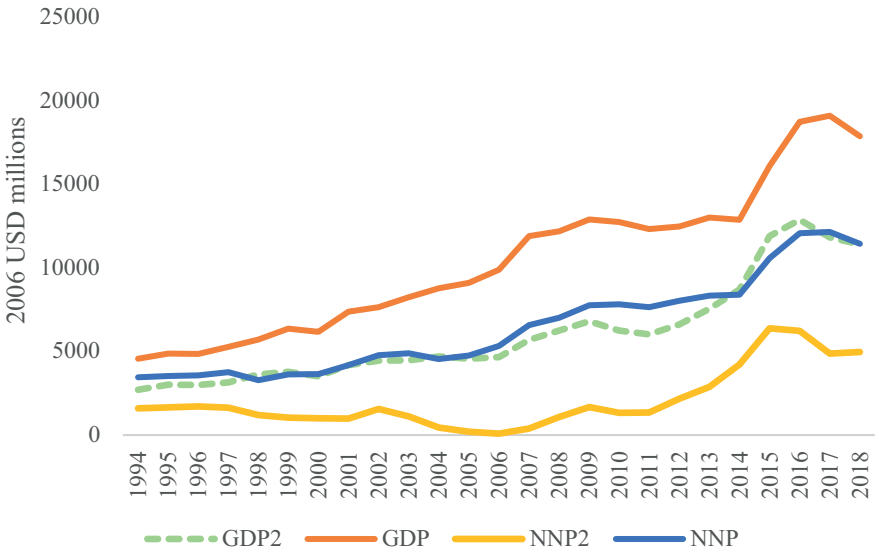
Year	Traditional		Corrected					
	GDP	NNP	GDP1	GDP2	GDP3	NNP1	NNP2	NNP3
GDP/GDP2				1.72				
GDP/GDP3					1.64			
NNP/NNP1						2.79		
NNP/NNP2							3.10	
NNP/NNP3								2.72
$AAGR_{1994-2018}$	5.84	5.12	5.60	6.16	6.31	3.98	4.86	5.20
$AAGR_{2003-2011}$	5.16	6.88	4.00	4.99	5.78	5.44	9.10	11.06

GDP: Gross domestic product; NNP: net national product; AAGR: average annual growth rate; GDP1 = GDP - natural depreciation costs; GDP2 = GDP - natural depreciation costs - environmental degradation costs; GDP3 = GDP - natural depreciation costs - environmental degradation costs + exploration expenditures. NNP1, NNP2 and NNP3 have the same formula but considering NNP.

Source: Own elaboration.

FIGURE 1

Evolution of Traditional GDP and NNP vs GDP and NNP corrected (2006 USD millions)



Source: Own elaboration.

Table 4 illustrates that the value of natural depreciation grows as the factor of correction, λ, increases. It is evident that this growth will result in a larger overestimation of traditional measures of income compared to those adjusted accounting for depreciation, i.e. GDP/GDP1 and NNP/NNP1. An important detail to consider is that for a small increase in the correction factor (λ = 0.75), negative NNP1 levels appear for some years. This is due to the very large difference between traditional GDP and NNP levels.

All this suggests that when an economy has a NFP that is negative and very large (when compared to its OSS), it would be better to only correct the GDP (even if it is not the right measure for this end). This is a recurring issue in countries where most extraction of non-renewable resources is largely in the hands of foreign firms, as is the case for Peruvian mining. Because similar studies mostly evaluate only the correction of GDP (not with a correction factor), it is not possible to corroborate whether this effect on NNP1 is frequent or not. Presumably, this problem could be frequent in cases of underdeveloped countries where the gap between GDP and NNP is usually wide.

It must be highlighted that, in spite that almost half the accumulated cost of depreciation during the 1994-2018 was concentrated during the boom years (Table 2), this did not imply that average annual growth rates of the corrected measures during this period (2003-2011) were higher than those during the 1994-2018 period.

TABLE 4

Overestimation of traditional GDP and NNP using correction factor λ

Λ	GDP/ GDP1	NNP/ NNP1	$AAGR_{1994-2018}$ GDP1	$AAGR_{1994-2018}$ NNP1	NNP1 < 0
0.50	1.40	1.85	5.69	4.48	–
0.60	1.52	2.22	5.65	4.26	–
0.70	1.66	2.79	5.60	3.98	–
0.75	1.74	3.21	5.57	3.81	2006
0.80	1.83	3.76	5.55	3.61	2005-2007
0.90	2.04	5.74	5.48	3.08	2004-2008 y 2010-2011

GDP: gross domestic product; NNP: net national product; AAGR: average annual growth rate; GDP1 = GDP - natural depreciation costs; NNP1 = NNP - natural depreciation costs.

Source: Own elaboration.

3.4. Comparison of the results with other studies

Not many studies have adjusted mining GDP correcting for, at least, natural depreciation, with only five being identified in the literature by the authors of the present study (Table 5). The results of correcting traditional GDP for the Peruvian mining sector during the 1994-2018 period support the findings of four of these studies which found that the cost of natural depreciation accounts for 33 %-85 % of the sector's GDP. The exception to this was the Brazilian case, where this was merely 11 %, which included the extraction of oil, meaning that the mining sector's contribution should be even smaller. This may be explained due to Brazil not being a large producer of either metals or oil during that time (1970-1988 period).

TABLE 5

Overestimation (%) of traditional mining GDP according to each study

Country	Period	Natural depreciation costs	Environmental degradation costs	Total GDP overestimation	Author
Brazil	1970-1988	18[1]	–	18	Young & da Motta (1995)
Chile	1985-1996	33	3[2]	31	Figueroa & Calfucura (2004)
Chile	1995-2015	85	14[3]	98	Mardones & Del Rio (2019)
Peru	1992-2006	56	5[4]	51	Figueroa *et al.* (2010)
Burkina Faso	2007-2013	40	20[5]	60	Ouoba (2017)
Peru	1994-2018	66	6	64	Present study

Note that the 5th column does not necessarily equate to the sum of the 3rd and 4th columns as some studies usually include the discovery cost, which reduces the overestimation.

[1] Result corresponds to the user cost method. Includes oil extraction. Degradation cost was not estimated. Percentage was estimated as 1 - (total user cost during 70-88 / total value added during 70-88)

[2] Only surplus SO_2 abatement costs were included

[3] Abatement cost for excess SO_2. Includes CO_2 and $PM_{2.5}$

[4] Abatement cost for excess SO_2

[5] Cost of illnesses generated by water contamination

Source: Own elaboration.

In terms of the fraction of the cost of environmental degradation as part of sectoral GDP, the result is similar to that obtained by Figueroa *et al.* (2010) and Figueroa & Calfucura (2004) who also used abatement costs to derive the cost of surplus SO_2. Mardones & Del Rio (2019) obtained significantly higher results due to them not only evaluating SO_2, but also $PM_{2.5}$ and even CO_2, where the last two were monetarily quantified using their effects on human wellbeing rather than their abatement costs, leading to broader results.

Similarly, Ouoba (2017) includes not only the costs of air degradation (valued considering its effects on human wellbeing), but also the costs of water pollution, quantifying the latter considering a loss of productivity. Due to using techniques to quantify the effects of pollution on human wellbeing, it is to be expected that Ouoba's results will be higher compared to those using the costs of reducing contamination.

3.5. Limitations

The model used in this study determines the cost of natural depreciation using the net price method, although it is possible to use other techniques to derive it. Evidence from Common & Sanyal (1998) and Santopietro (1998) suggests that the net price method (in this case, total Hotelling rent) produces natural depreciation values that are higher than those obtained using other methods. It follows that if more data were available allowing for the use of other methods (such as net present value or the El Serafy method), the contribution from natural depreciation in traditional measures of income for the mining sector might be lower than that obtained in this study, possibly leading to different AAGRs.

Although it is common practice in several studies, current exploration spending may not be a good approximation of the marginal discovery cost multiplied by discoveries (i.e., $g_D D$). There are no studies that have evaluated this topic. Presumably, such exploration spending would significantly underestimate the term $g_D D$, which could explain, in part, the limited contribution of new discoveries to compensate for the extraction of the non-renewable resource. However, this hypothesis should be corroborated in future studies.

On the other hand, it was not possible to include marginal costs (or total costs) of abatement for heavy metal discharges –over their thresholds– into water bodies, even though this type of pollution is the origin of many problems in Peruvian society (Salem *et al.*, 2018; Swenson *et al.*, 2011). This suggests that the fraction of degradation costs in traditional measures of income for the Peruvian mining sector should be larger than that obtained in this study. Finally, it was shown that results of the corrected measures of income are very sensitive to the factor of correction. This is critical in the case of traditional NNP.

3.6. Challenges for the Peruvian mining sector

For the sustainability of revenues in the mining industry, it is important, among other things, to improve and increase the stock of manufactured capital in the sector, increase mineral reserves to maintain/increase the stock of natural capital in the mining sector, and efficiently reinvest the rents captured by the State. This study presents evidence that the manufactured stock (fixed sectorial net assets) has increased considerably since 2012 (despite the fall in the price of metals), which is a good sign.

A way to increase the natural stock is by looking for new deposits (new discoveries) and/or increasing current reserves through revaluations or extensions. This study's results show that during the period analyzed, expenditure on exploration was very low compared to the costs of depletion and natural depreciation. This is concerning in a country whose extractive sector is the main source of foreign exchange. Although this sector, as is the case for all extractive activities, generates little value-added, its multiplier effect is one of the largest in the Peruvian economy[8]. In this context, not taking into consideration external factors (favorable price conditions of commercial metals and the growth of the global economy), the political and economic stability of the country are important factors in incentivizing investments in mining exploration and other aspects of the mining sector.

4. Conclusions

The results indicate that traditional income measures for the mining sector in Peru were significantly overestimated during the 1994-2018 period due to the exclusion of exploration costs, environmental degradation costs, and natural depreciation costs. The cumulative amounts for these three components during the period were USD 7,225 million, USD 5,738 million, and USD 103,598 million, respectively, with the costs of natural depreciation being the most substantial omission in traditional income measures for the sector. Half of the cumulative natural depreciation costs were concentrated during the boom years. Average corrected annual growth rates during this boom period (2003-2011) were higher than those for the entire 1994-2018 period.

For the 1994-2018 period, the overestimation of traditional sectoral GDP ranged from 62 % to 72 %. However, when using a conceptually appropriate measure (NNP), this overestimation is much larger, ranging from 172 % to 210 %. This underscores the importance of considering the depletion of the natural capital stock and environmental degradation in income measures to accurately assess the economic growth of the sector, especially in countries heavily reliant on extractive industries like Peru.

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[8] According to the input-output table illustrating 2007, the multiplier of mineral exports was 1.68 (Palomino & Pérez, 2011). However, the total effect must be larger, as these linear multipliers only captures the effect for one year.

References

Asheim, G.B. (1997). "Adjusting green NNP to measure sustainability". *Scandinavian Journal of Economics*, 99(3), 355-370. https://doi.org/10.1111/1467-9442.00068

Banerjee, O., Vargas, R. & Cicowiez, M. (2020). *Integrating the value of natural capital in evidence-based policy making. IDB Working Paper Series*, *No. IDB-WP*. Retieved from: Inter-American Development Bank. https://doi.org/10.18235/0002900

BCRP. (2014). *Memoria 2013*. Retrieved from: Banco Central de Reserva del Perú. https://www.bcrp.gob.pe/publicaciones/memoria-anual/memoria-2013.html

BVL. (several years). *Estados Financieros*. Retrieved from: Bolsa de Valores de Lima. https://www.bvl.com.pe/home-general

Common, M. & Sanyal, K. (1998). "Measuring the depreciation of Australia's non-renewable resources: A cautionary tale". *Ecological Economics*, 26(1), 23-30. https://doi.org/10.1016/S0921-8009(97)00111-0

Custodio, M., Cuadrado, W., Peñaloza, R., Montalvo, R., Ochoa, S. & Quispe, J. (2020). "Human risk from exposure to heavy metals and arsenic in water from rivers with mining influence in the Central Andes of Peru". *Water (Switzerland)*, 12(7), 1946. https://doi.org/10.3390/w12071946

Dasgupta, P., Kristrom, B. & Mäler, K.G. (1997). *Beijer discussion paper 104: Should search costs and discoveries be included in the national product?* Retrieved from: Beijer Institute of Ecological Economics. https://beijer.kva.se/publication/should-search-costs-and-new-discoveries-be-included-in-net-national-product/

Davis, G.A. & Moore, D. (2000). "Valuing mineral stocks and depletion in green national income accounts". *Environment and Development Economics*, 5(1), 109-127. https://doi.org/10.1017/S1355770X00000085

De La Torre, J.C. (2001). *Minería peruana 1990-2000: Balance de un década y perspectivas*. Lima, Perú: Instituto de Estudios Energéticos-Mineros (IDEM).

Figueroa, E. & Calfucura, E. (2004). "Growth and green income: Evidence from mining in Chile". *Resources Policy*, 29(3-4), 165-173. https://doi.org/10.1016/j.resourpol.2004.08.003

Figueroa, E., Calfucura, E. & Nuñez, J. (2002). "Green national accounting: The case of Chile's mining sector". *Environment and Development Economics*, 7(2), 215-239. https://doi.org/10.1017/S1355770X02000153

Figueroa, E., Orihuela, C. & Calfucura, E. (2010). "Green accounting and sustainability of the Peruvian metal mining sector". *Resources Policy*, 35(3), 156-167. https://doi.org/10.1016/j.resourpol.2010.02.001

Gómez-Lobo, A. (2001). "Sustainable development and natural resource accounting in a small open economy: a methodological clarification". *Estudios de Economía,* 28(2), 203-216.

Hamilton, K. (1994). "Green adjustments to GDP". *Resources Policy*, 20(3), 155-168. https://doi.org/10.1016/0301-4207(94)90048-5

Hamilton, K. (1996). "Pollution and pollution abatement in the national accounts". *Review of Income and Wealth*, 42(1), 13-33. https://doi.org/10.1111/j.1475-4991.1996.tb00143.x

Hamilton, K. (2000). "Genuine Saving as a sustainability indicator". In OECD: *Frameworks to Measure Sustainable Development: An OECD Expert Workshop* (pp. 65-78). Paris, France: OECD.

Hamilton, K. & Bolt, K. (2004). "Resource price trends and development prospects". *Portuguese Economic Journal*, 3(2), 85-97. https://doi.org/10.1007/s10258-004-0035-x

Hartwick, J.M. (1990). "Natural resources, national accounting and economic depreciation". *Journal of Public Economics*, 43(3), 291-304. https://doi.org/10.1016/0047-2727(90)90002-Y

Hartwick, J.M. & Hageman, A. (1993). "Economic depreciation of mineral stocks and the contribution of El Serafy". In Lutz, E. (Ed.): *Toward improved accounting for the environment: an UNSTAT-World Bank Symposium* (pp. 211-235). Washington, D.C., USA: World Bank.

INEI. (several years). *Cuentas nacionales sector minero peruano por el método del ingreso y gasto*. Retrieved from: Instituto Nacional de Estadística e Informática. https://www.inei.gob.pe/estadisticas/indice-tematico/national-accounts/

Managi, S. & Kumar, P. (Eds.) (2018). *Inclusive Wealth Report 2018: Measuring progress towards sustainability*. London, U.K.: Routledge. https://doi.org/10.4324/9781351002080

Mardones, C. & Del Rio, R. (2019). "Correction of Chilean GDP for natural capital depreciation and environmental degradation caused by copper mining". *Resources Policy*, 60, 143-152. https://doi.org/10.1016/j.resourpol.2018.12.010

McMahon, G. & Moreira, S. (2014). *The contribution of the Mining Sector to socio-economic and human development. Extractive industries for development series, nº 30*. Retrieved from: World Bank. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/713161468184136844/the-contribution-of-the-mining-sector-to-socioeconomic-and-human-development

Mendiola, A., Aguirre, C., Carpio, C.A., Monroy, V. & Paredes, Y. (2018). *Perspectivas de reestructuración del Complejo Metalúrgico de La Oroya mediante un análisis ambiental y económico*. Retrieved from: Universidad ESAN. https://hdl.handle.net/20.500.12640/1220

MINAM. (2014). *Informe nacional de la calidad del aire 2013-2014*. Retrieved from: Ministerio del Ambiente. http://repositoriodigital.minam.gob.pe/xmlui/handle/123456789/802

MINEM. (2004). *Control de emisiones en el subsector minería*. Retrieved from: Ministerio de Energía y Minas. https://www2.congreso.gob.pe/Sicr/Comisiones/2004/Ambiente_2004.nsf/0/0bbb32ee3d0f366405256f3400575524/$FILE/Expo_Julio_Bonelli-MEM.PDF

MINEM. (2012). *Anuario Minero.* Retrieved from: Ministerio de Energía y Minas. http://www.minem.gob.pe/_detallenoticia.php?idSector=1&idTitular=4771

MINEM. (2021). *Anuario Minero.* Retrieved from: Ministerio de Energía y Minas. https://www.minem.gob.pe/minem/archivos/file/Mineria/PUBLICACIONES/ANUARIOS/2021/AM2021.pdf

OSINERGMIN. (2016). *Reporte de análisis económico sectorial. Sector minería. Mercado mundial, nacional, efectos derivados y visión de la minería. Año 5 – N° 6 – Agosto 2016*. Retrieved from: Organismo Supervisor de la Inversión en Energía y Minería. http://www.osinergmin.gob.pe/seccion/centro_documental/Institucional/Estudios_Economicos/RAES/RAES-Mineria-Agosto-2016-GPAE-OS.pdf

Otto, J.M. (2002). *Position of the Peruvian taxation system as compared to mining taxation systems in other nations*. Retrieved from: Ministerio de Economía y Finanzas. https://mef.gob.pe/contenidos/pol_econ/documentos/perufinalreport_280504Otto.pdf

Ouoba, Y. (2017). "Economic sustainability of the gold mining industry in Burkina Faso". *Resources Policy*, 51, 194-203. https://doi.org/10.1016/j.resourpol.2017.01.001

Palomino, V. & Pérez, J. (2011). *Documento de trabajo # 4: Teoría y aplicaciones de la tabla Insumo-Producto a la planeación estratégica.* Retrieved from: Centro Nacional de Planeamiento Estratégico (CEPLAN). https://www.ceplan.gob.pe/documentos_/documento-de-trabajo-4-teoria-y-aplicaciones-de-la-tabla-insumo-producto-a-la-planeacion-estrategica/

PeruTop Publications (several years). *The Top Companies*. Retrieved from: https://www.ptp.pe/top10000/version_impresa.php

Poveda, R.A. (2007). "Mining: The challenge of sustainability". In Giugale, M.M., Fretes-Cibilis, V. & Newman, J.L. (Eds.): *An Opportunity for a Different Peru: Prosperous, Equitable, and Governable* (pp. 435-458). Washington D.C., USA: The World Bank. https://doi.org/10.1596/978-0-8213-6862-6

Salem, J., Amonkar, Y., Maennling, N., Lall, U., Bonnafous, L. & Thakkar, K. (2018). "An analysis of Peru: Is water driving mining conflicts?" *Resources Policy*, 74, 101270. https://doi.org/10.1016/j.resourpol.2018.09.010

Santopietro, G.D. (1998). "Alternative methods for estimating resource rent and depletion cost: the case of Argentina's YPF". *Resources Policy*, 24(1), 39-48. https://doi.org/10.1016/S0301-4207(98)00006-3

Seminario, B. (2016). *El desarrollo de la economía peruana en la era moderna: precios, población, demanda y producción desde 1700*. Retrieved from: Universidad del Pacífico. http://hdl.handle.net/11354/1160

SMV. (several years). *Estados Financieros*. Retrieved from: Superintendencia del Mercado de Valores. https://www.smv.gob.pe/SIMV/Frm_InformacionFinanciera?data=A70181B60967D74090DCD93C4920AA1D769614EC12

SPCC. (several years). *Estados financieros*. Retrieved from: Southern Peru Coppeer Corporation. https://southerncoppercorp.com/reportes-para-la-sec/

Swenson, J.J., Carter, C.E., Domec, J.C. & Delgado, C.I. (2011). "Gold mining in the peruvian amazon: Global prices, deforestation, and mercury imports". *PLoS ONE*, 6(4), e18875. https://doi.org/10.1371/journal.pone.0018875

Vincent, J. & Ali, M. (2005). *Managing natural wealth: Environment and development in Malaysia*. New York, USA: Routledge. https://doi.org/10.4324/9781936331819

Weitzman, M.L. (1976). "On the welfare significance of national product in a dynamic economy". *Quarterly Journal of Economics*, 90(1), 1581-1594. https://doi.org/10.2307/1886092

Young, C.E.F. & da Motta, R.S. (1995). "Measuring sustainable income from mineral extraction in Brazil". *Resources Policy*, 21(2), 113-125. https://doi.org/10.1016/0301-4207(95)00048-U