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Colombian mineral resources: An analysis from a Thermodynamic Second Law perspective

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ABSTRACT

Natural non-renewable resources, such as minerals, are becoming increasingly depleted against a backdrop of intense industrialisation. Through the exergy analysis and thermoeconomic tools it is possible to assign a figure to the degree of depletion. This is because the exergy replacement cost represents the effort needed by humankind to return minerals to their original conditions from the "commercially dead state", Thanatia. The authors undertake an evaluation of the ten most significantly produced minerals in Colombia, since 1990. Via the 2011 mineral balance, this paper shows that the highest exergetic losses are in the extraction for export and not national consumption rates. The loss in mineral wealth, quantified in exergy terms for 2011 is 119.2 Mtoe (4.99×10^9 GJ) and has, since 1990, accumulated to 1,543.4 Mtoe (6.46×10^{10} GJ). In converting these losses into economic terms, it becomes clear that the nation must re-think its mineral export strategy, if it is develop sustainably.

Introduction

This paper's principal idea is to provide a quantitative assessment with which to ascertain the gain or loss of annual GDP, should those mineral resources extracted be evaluated with exergy and not through global market prices. The results divulged are the first of their kind for an emerging country and represent an improvement and national advance in mineral management and accountability. It should be noted that exergy is one way to physically assess mineral resources but it is not the only one. In addition, while exergy is able to measure physical facts, related to the composition, concentration or cohesion of minerals, it is incapable of quantifying social or certain environmental aspects that are also crucial in the mining industry.

The physical costs of mineral resources, as well as their scarcity, are natural outcomes of the Second Law of Thermodynamics. This paper, through the lens of exergy, a unit used in thermoeconomics, looks at mineral wealth and extraction in Colombia in the late 20th and early 21st centuries. Specifically it looks at those elements considered, since 2000, to be drivers for the Colombian economy into 2020. It then goes on to describe how exergy replacement costs can be used to evaluate the nation's mineral wealth and its depletion. Using the exergy balance, the authors determine the role Colombia plays in terms of mineral dependence or provision.

Methodology

This paper contextualises both a "descriptive" and "deductive" methodological process by obtaining the secondary data previously provided by other authors and institutions (such as those associated with the provision of a reference environment and the non-fuel and fuel mineral national statistics of Colombia). This data is then used to support the analysis published here. It is also hoped to lead to a thorough understanding of the problem of mineral scarcity and depletion. Such data are beneficial in helping the authors and subsequently the government of the Republic of Colombia arrive at potential solutions, by making use of the most important variables. At the same time, such data are used to develop the theoretical knowledge that aids the practical application of the tools readily used in Exergoecology (Valero, 1998) and more specifically Physical Geonomics (Valero and Valero, 2010).

The evaluation predominantly involved the consultation of secondary data produced by research institutions in the form of special reports or academic articles or that published by the Colombian Government, in the form of official statistics for the extractive sector and the national geological department. The data of particular interest

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included measured and indicated reserves, production, import, export and recycling figures for gold, silver, platinum, nickel (ferronickel), copper, iron, limestone, coal, oil and gas. The selected minerals are those which are considered priority minerals by the Colombian National Government, due to their contribution to GDP and the growth of the economy. The principal sources consulted were those stemming from the Ministry of Mines and Energy of Colombia (Infogeominas), the Mining System of Information of Colombia (SIMCO), the U.S Environmental Protection Agency (US EPA) and British Petroleum (BP). It is worth calling attention to the lack of information regarding non-fuel mineral reserves, given the 2013 admission by the Mining and Energy Ministry that only nickel (which incidentally has the same figure as the 1987 record) and coal reserve data have been updated (MME – Ministerio de Minas y Energía, 2013). The production data used for all other non-fuel minerals have been consolidated since 1990, whilst exports and imports figures have been compiled since 2003 by SIMCO – Sistema de Información Minero Colombiano (2013).

The evaluation of Colombia's fuel and non-fuel mineral production is based on a standard process defined as an exergy analysis, which involves the following steps:

- The provision of a description of the system to be analysed and its reference baseline, along with the mining and energy consuming processes involved. Specifically, for this paper, the reference baseline corresponds to Thanatia (Valero et al., 2010, 2011).
- A definition of the idealisations and the necessary assumptions made in order to develop a manageable model, which considers the complexities involved in using the reference baseline and developing an understanding of the mining and energy process involved.
- The calculation of mass and energy through a First Law analysis and the exergy replacement cost of each mineral.
- Perform an analysis regarding mineral resource loss between 1990 and 2011, in terms of percentage extracted during this timeframe.
- Elaborate an exergy flow diagram and evaluate the localisation and magnitude of the principal exergy losses. *Note: For this analysis the authors use 2011 production data*.

For the balance the following statement will be used:

$$\text{Extraction} + \text{Imports} + \text{Recycling} = \text{Exports} + \text{Consumption} \quad (1)$$

Note: *Recycling comes as a derivation of consumption*, *while the remaining consumption refers to the mineral which is stored or used for humankind*, *or disposed of. Mineral storage from previous extractions were not considered.*

- Approximation of the exergy replacement cost of both fuels and non-fuels to the monetary value (average global prices) of the mineral studied for 2011.
- Evaluate recycling's ability to reduce the loss of mineral capital, according to technical innovation and national/regional waste management tendencies.

Colombia in context

Colombia holds significant quantities of minerals due to the geological confluence of the Andean system and that of Guyana which generate good conditions for mineral extraction. The country is the number one producer of emeralds in the world, the number one producer of nickel and coal in South America and the tenth largest producer of gold in the world (Peace Brigade International, 2011).

The national territory of Colombia is 114 million hectares of which some 8.7 million, were as of 2011, licensed for non-fuel mineral deposit exploration. A further 37 million has been assigned to crude oil (González, 2011). In total, 40% of the land has either been licensed or solicited for mining concessions (Sanchez-Garzoli, 2012). This boom is a relatively recent phenomenon and has led to an extensive mineral and hydrocarbon large scale mining sector with the biggest names in the mining industry having set-up there due to export opportunities.

The $3.2 billion (USD) paid in royalties in 2010 jumped to $4.3 billion (USD) in 2011 (Rudas, 2012a). That said, money from royalties does not reach the people it should with many of the municipalities with natural resources also being among the poorest (Rudas, 2012b). This may mean that even should coal export double and mining production triple as the government aims by 2019, a weak tax regime and a lack of transparency could cost Colombians more in terms of social, environmental and human right violations than mining generates. Hence the significance of the candidacy status within the international standard, the Extractive Industries Transparency Index (EITI) to address some of those issues relating to transparency and accountability or at least provide a platform for the initiation of dialogue. This paper uses exergy to see the physical cost of extraction. Exergy could in the future be used as an indicator to bring about progressive and sustainable policies and decision-making.

Exergy and resource scarcity

According to Valero, modern society is based on an inefficient use of energy and materials (Valero, 2008). This inefficiency has created a natural resource scarcity, something which is crystallising into some of the most complex and urgent issues facing the world in the 21st century (WFF – World Foresight Forum, 2011). Kooroshy et al., for example, highlight the fact that global mineral production multiplied fivefold from 1950 to 2000 (Kooroshy et al., 2009). This has obvious effects on the environment, geopolitics and socioeconomics. It is thus important to carefully measure the extent of the shadow cast by mineral extraction and depletion on society.

Exergy, once a reference environment has been provided, can be used measure all resources with a single unit. It is thus a quantitative expression of how much useful energy is needed to replace the mineral wealth that has been dispersed and irreversibly lost through extractive activities. This because any quantity of matter with a given composition, a concentration and a mass relative to that of the Planet Earth (i.e. scarcity or abundance) has an exergy replacement cost that can be calculated by simply evaluating the effort needed to obtain it either with reversible processes (in which case one speaks of exergy) or with the best available technology. The latter, measured in energy terms, is a good candidate for the assessment of regional, national or global mineral wealth. This is because as with any good indicator, it is as absolute as possible, universal and relatively easy to operate. Furthermore it provides a sense of objectivity to mineral wealth calculations, a role traditionally given over to money – which is itself intrinsically flawed by the relativity of price and thus does not reflect the physical cost "paid" by Nature to form and concentrate mineral deposits.

In terms of materials, the Earth can be considered as a closed system containing a finite number of substances, except for the very occasional contribution of meteorites. The intense extraction and use of minerals by society is transforming it into what the authors call Thanatia, a theoretical planet modelled on the present Earth but having had all its mineral deposits mined and all fossil fuels burned. It is thus a commercially dead planet and represents the reference baseline used in this paper. Exergy costs can subsequently be used to