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Byproduct production of minor metals: Threat or opportunity for the development of clean technologies? The PV sector as an illustration

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ABSTRACT

Today, the fight against global warming and the coming hydrocarbon exhaustion involve a drastic increase of clean energies. These technologies resort to many minor metals which are byproduct of major metals. We will take the definition of Hagelüken and Mesker (2010, Complex Life Cycles of Precious and Special Metals. In: Edition Thomas E. Graedel, Ester van der Voet (Eds.), Strüngmann Forum Report, Linkages of Sustainability, MIT Press) to show precisely what minor metals are: "[they are] metals that have relatively low production or usage, which occur in low ore concentrations, are regarded as rare, or are not traded at major public exchanges". We will analyze the byproduct status affecting almost each minor metal in order to determine if the link with the metal main product can involve a threat for clean technology development. This paper will also deal with the theory and implications of the relationship between the byproduct and the main-product and then check it with empirical data. Until now, byproduct metal production and its variations seem relatively independent from major metal production thanks to the non-saturation of potential supply. By 2050, photovoltaic solar development should not lead to the saturation of potential supply.

Introduction

Today, the development of clean energies in order to fight global warming and the coming hydrocarbon exhaustion lead to the use of wide range of metals. The consumption of an extended range of metals can be a good way to decrease the risk of supply disruption thanks to the diversification of raw material needs. However, it is interesting to note the huge amount of ferrous metals, base metals and minor metals (JRC et al., 2011; Andersson, 2000; Andersson and Rade, 2001) required by clean energies (wind power, photovoltaic, Carbon Capture and Sequestration). There is no formal definition of minor metals but the definition of Hagelüken and Mesker (2010) provides a precise idea of what minor metals are: "[they are] metals that have relatively low production or usage, which occur in low ore concentrations, are regarded as rare, or are not traded at major public exchanges".[1] Minor metals are characterized by low level productions ranging from several tons to a few ten thousand of tons a year. In comparison, the global production of copper and nickel is about several million tons a year while global iron production exceeds one billion tons. These low productions accumulate other drawbacks like a very limited end-of-life product recycling (UNEP, 2011) but also a production more concentrated than base metals productions (Table 1). Moreover, China holds a high part in minor metal production. Actually, it is a significant point because this country used trade practices prohibited by WTO (export quotas) in the past, especially for indium and rare earth elements. A strong attention should be devoted to analyzing the behavior and interests of the most populated nation in the world (20% of global population) which generates a tenth of global GDP. Even more striking, the Chinese relative part in the growth demand of base metals varies from 70% to nearly 100% (Humphrey, 2010). But the more important fact which allows separating minor metals from major metals or precious metals (gold, silver) is their byproduct position. Indeed, low concentrations of minor metals associated to their current valuation make unprofitable their extraction in main product as is done for gold and copper. The natural occurrence of minor metals in the crust is low as it is underlined by Taylor and McLennan (1985). As for indium, the average concentration in the crust does not exceed

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[1] The following list includes most minor metals: Lithium, Beryllium, Bore, Vanadium, Gallium, Germanium, Arsenic, Selenium, Strontium, Zirconium, Niobium, Molybdenum, Cobalt, Cadmium, Indium, Antimony, Tellurium, Barium, Tantalum, Tungsten, Rhenium, Mercury, Bismuth, and the Rare Earth Elements (REEs).

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Table 1
Minor metals, a production concentrated geographically.

Metal	Part of the top 5 producing countries (%)	Chinese part (%)
Aluminum[a]	66	41
Gallium[b]	85	32
Zinc[a]	68	29
Indium[a]	90	52
Germanium[a]	(+)75	66
Copper[a]	61	7
Tellurium[c]	82	19

[a] USGS, commodities summaries 2011.
[b] Production capacities in 2008 provided by http://www.environment-agency.gov.uk/static/documents/Business/EPOW-recovering-critical-raw-materials-Annex-T5v2.pdf.
[c] Naumov (2010).

0.05 ppm[2] which is nearly the silver crust concentration. Tellurium also gets an average concentration which is very close to gold (0.001 ppm). In contrast, gallium is more abundant in the geological sense (17 ppm). Although minor metals are not really abundant, their prices do not allow them to be classify in precious metals. For example, in 2012, tellurium price amounted to 150 $ per kg, more expensive than selenium and molybdenum, respectively being 130 and 30 $ per kg. Gallium and indium, more expensive, are traded for 500 $ per kg while germanium is sold for 1300 $ per kg, largely below the valuation of gold and platinum (50,000 $ per kg).[3]

We can distinguish two kind of production for this category of metals:

– The extraction of several minor metals in joint production in order to cover all the joint cost and the specific cost of each after the split point. These metals are named co-products and the valuation of each ensures the profitability of the project. It is the case with the rare earth elements (REEs) industry extraction and that the co-production of cobalt with copper and nickel metals.
– The extraction of one or several minor metals in parallel with major metals (the main product) ensures the project profitability. The minor metal is then called byproduct of the main product and it provides only an extra value to the mining project.

While the co-product valuation partly determines the optimal quantity to produce, the byproduct valuation does not influence the optimal ore quantity produced. Accordingly, if the demands of the by product and the main product do not change in the same way or in the same order of magnitude then the byproduct will be rationed or overproduced.

Until now, the relationship between a byproduct and its primary product in the mining industries has not been studied much (Pindyck, 1982; Campbell, 1985; Verhoef et al., 2004; Naumov and Grinberg, 2009; Brooks, 1965). It can be explained both by the margin position of minor metals in our economies during the twentieth century and the lack of reliable price and production data. Major developments in clean technologies but also information and communication technologies which imply a surge in minor metal consumption radically change this outcome. Recently, several reports have pointed out the lack of knowledge about minor metals (JRC et al., 2011; European Commission, Enterprise and Industry, 2010) and have express a lot of concern about the critical positions of minor metals in key technologies (DOE, 2010, 2011). In fact, minor metals are used almost everywhere: in wind power (REEs), photovoltaic (indium, tellurium, selenium, …), Carbon Capture and Sequestration (vanadium, niobium, cobalt, …), in the oil sector (tungsten, beryllium, tantalum, REEs), in supercritical power plants (cobalt, molybdenum, rhenium, tungsten, niobium, hafnium), in transports (lithium, cobalt, REEs), in energy efficient lighting (gallium), smart-grid (germanium), etc. We need to determine whether this byproduct relationship involves a real constraint for minor metal availability and thus a threat for clean technology development or whether we can consider this specific status as an opportunity to save costs and environmental pollution.

In the second part, we will present how the theory can highlight the mining byproduct relationship to its primary product. We will see that the byproduct status depends on both metal economic valuation and its concentration in deposits. Mining producers vary the optimal joint production by following the ratio between the price and the concentration of byproduct and primary product. Next, we will assess in a third part the presence of the empirical link between different byproducts and their primary products by performing various statistical tests. A strong link would involve that the byproduct constraint is saturated and thus the minor metal availability could be endangered if its demand was to increase too quickly. On the contrary, if the byproduct production evolves with no obvious relationship with the primary production, it could indicate the presence of a production margin. Finally, we will estimate in a fourth part this potential production margin and verify if the development of thin photovoltaic panel could take up this supplementary margin and come up against the byproduct constraint. Then, we will draw our conclusions in the fifth and last part.

Assessment of the theoretical relationship between mining byproduct and its primary product

A link between mining byproduct and its primary product implies that the byproduct production evolves depending on the needs of primary product demand. As illustrated in Fig. 1(1.1), the first graph represents the equilibrium between the supply and the demand in the primary metal market (a) while the second graph below shows the equilibrium between the inelastic byproduct supply and its demand on the byproduct metal market (s). As we suppose the producer does not consider the price of the byproduct because it does not cover the profitability of mining; thus, the price elasticity of the byproduct supply (Os) is null. Why do not producers extract more byproduct in the case of rising prices? The answer is proposed by Hagelüken (2011, p. 363): “Since the byproduct (“minor metal”) is only a very small fraction of the carrier metal, here the usual market mechanisms do not work. An increasing demand will certainly lead to an increasing price of the by-product metal, but as long as the demand of the major metal does not rise correspondingly, mining companies will not produce more, because this would erode the major metal's price. In this respect, the supply of byproduct metals is price-inelastic, even a “tenfold increase” in its price could usually not compensate the negative impact on total revenues when there is oversupply of the major metal”. Q_a* and Q_s*, the equilibrium quantities, vary together and their ratio is approximately the average ratio of their concentrations in the deposit. Like two roller coaster cars secured to each other, the second car (the byproduct) must reproduce the falls and the rises performed by the first car (the primary product). The hook linling the two cars represents the constraint between the byproduct production and the primary production. The rises and the falls are variations so we can test if they are coordinated. The strong dependency of the byproduct production to the

[2] Parts Per Million.
[3] See theses websites: http://www.minormetals.com/?tab=1&site=4&lang=EN and metal pages: https://www.metal-pages.com/