ZINC, LEAD, SILVER & INDIUM

Linking the Bolivian minerals to the European industry

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Wall painting of metallurgy in the city of Oruro

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Introduction

Although Indium might be a rare metal, it is not rare at all in your daily life. No smartphone can be produced without its use. Flatscreens, touchscreens, LED lights, photovoltaic panels and even the high efficiency glass of the windows in your house can contain this element.

Indium is a metal that has grown in importance since the 21st century. Lots of new technologies are based on its use, as it has the particular property of being transparent in thin coatings and still acting as an excellent conductor.

The source of this raw material is not always easy to track. The indium market is very opaque. The present document is part of a fact-finding mission by the European Union project 'Make ICT Fair'. It tries to reveal a considerable part of the supply chain of indium by starting its research in the very beginning of the chain: a few mining cooperatives on the Bolivian highlands extracting silver-lead-zinc polymetallic ore; and it traces the supply chain beyond, feeding the European industry.

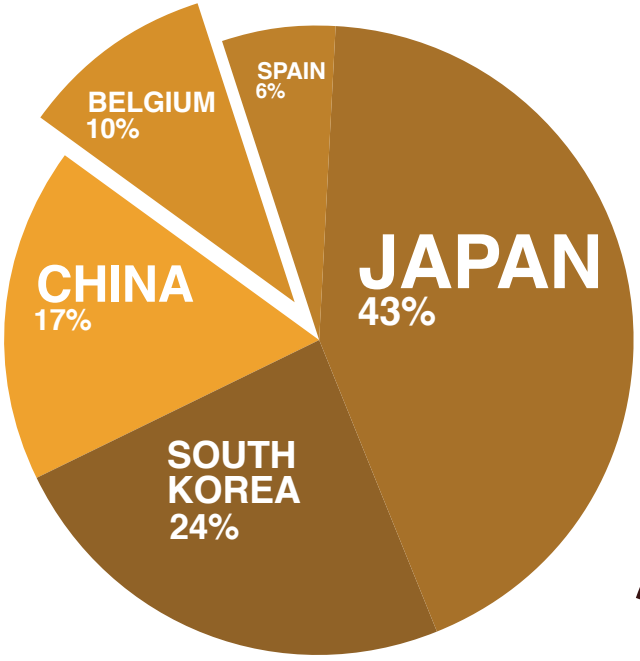
It is remarkable that official Bolivian data registers the export of indium as zero (MMM, 2019). This implies that neither the Bolivian miners nor the Bolivian state is paid for the extraction of this metal, indispensable for the technology of the 21th century

Neither the Bolivian miners nor the Bolivian state is paid for the extraction of this metal.

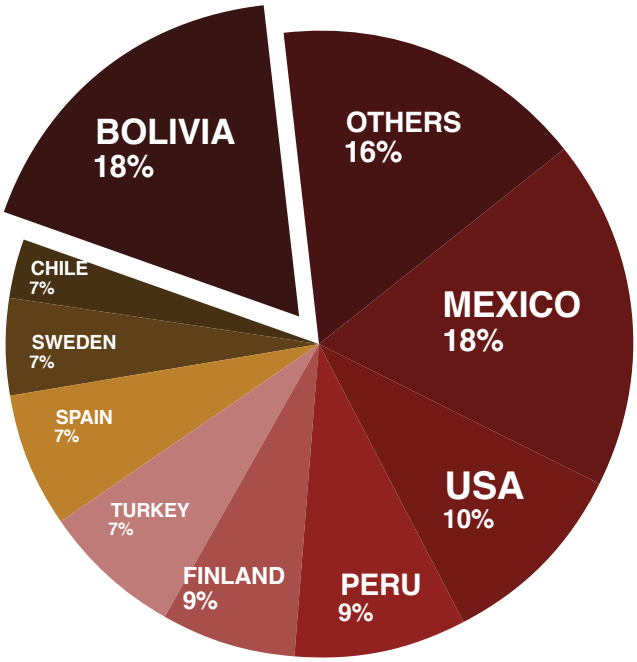
Miners are today only paid for the sale of concentrates rich in zinc-silver and lead-silver. Therefore, their wages depend on the market price of those three metals solely. In reality, the minerals being extracted by those miners are rich in many other metals at lower or higher concentrations, but are supposed not to be economically interesting for the buyer. In the cases studied, **officially no company is buying the indium content of their minerals**, so no miner gets paid for that existing concentration.

Bolivian mining law (law n° 535 of 2014) requires a 5% royalty for the export of indium ore, which has to be paid in case the minerals have a "commercial value". Considering the critical caracter of this rare metal, the relatively high indium content of the Bolivian zinc ores (Schwarz-Schmpera and Herzig, 2002) and Bolivia estimated as the 5th largest extractor of indium worldwide (Zapata, 2018), this seems a very unfair practise on behalf of the corporations from the world's wealthiest nations.

This fact-finding mission tracks the material flow from the mining activities in the Bolivian Department of Oruro. Although the Bolivian zinc ores are exported to Japan, South Korea, China, Belgium and Spain (MMM, 2019 – see Figure 1a), this research **limits its tracking to those exported to Belgium.** In 2019, 22 % of the zinc ores and concentrates imported to Belgium came from Bolivia (Eurostat, 2020 – see Figure 1b), corresponding with 88% of all total Belgian imports from Bolivia (NNB, 2019), making clear the significance of this commercial relation, which has been increasingly crucial during the last 15 years.



Bolivian Export



Belgian import

The extraction of zinc ore in Bolivia

The mineral ores studied are polymetallic vein deposits primarily extracted for their silver-lead-zinc content. The abundant mineral is sphalerite, the main zinc ore and, at the same time the principal source for indium (Pat Shanks III et al., 2017). For example, the indium concentrations in the Bolivar mine[1] are about 584 ppm[2] (Ishihara et al. 2011), **being amongst the richest indium ores of the world** (Schwarz-Schampera and Herzig, 2002).

Although those concentrations are very low, all indium in the market is recovered as a by-product, mainly from zinc ores, and to a lesser extent from copper, tin and silver ores. The production of indium through End-of-Life recycling is still very marginal in terms of overall Indium production (UNEP, 2013; European Commision, 2020). As this metal is produced as a by-product, indium production is limited by the amount of zinc production. Therefore, its production does not depend on market demand.

The amount of zinc concentrates by artisanal and small-scale mining (ASM) has increased substancially since the rise of zinc price in 2006. The amount of zinc exported from Bolivia to Belgium has a similar volume and follows the same trend as the ASM production of zinc concentrates inside Bolivia. However, the Bolivian export of these concentrates to Belgium does not come only from ASM sites.

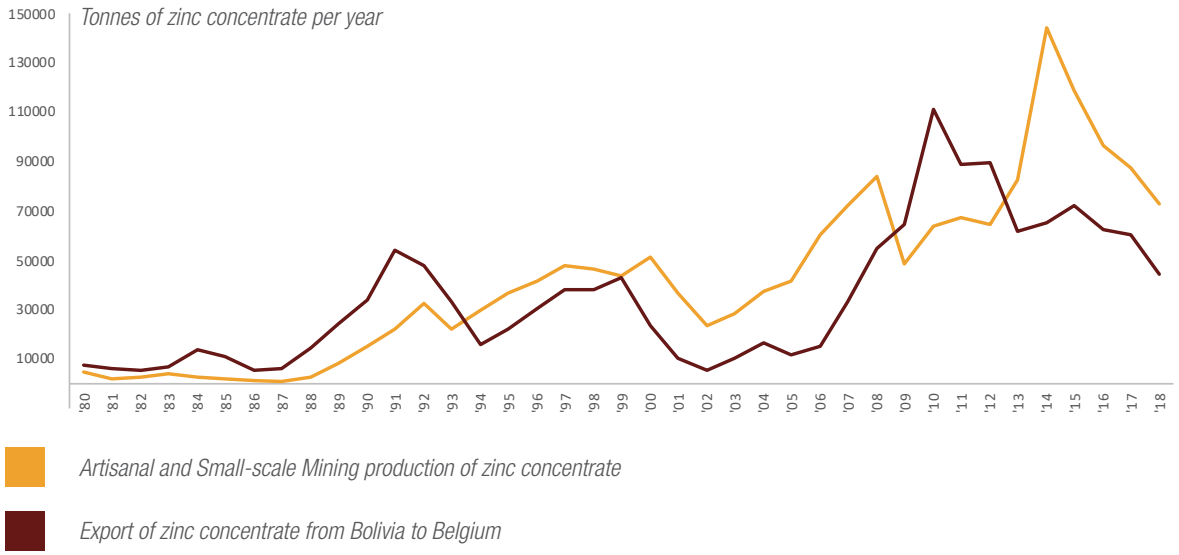


Figure 2: Annual export of zinc from Bolivia (MMM, 2019; own elaboration, data from 1980 to 2018).

[1] *Located in Antequera, Oruro, owned by COMIBOL, Bolivan state company, and operated by Illapa S.A., a subsidiary of Glencore.*
[2] *Parts per million (e.g.: 1 gram in 1 tonne).*

The Supply Chain of Indium: from Bolivia to Europe and beyond

The mining of polymetallic silver-lead-zinc ore by mining cooperatives

In the Department of Oruro, Bolivia, polymetallic silver-lead-zinc ores are mined in the underground Bolivar mine[3] on the one hand, and by tens of mining cooperatives and local small-scale companies on the other hand. **These silver-lead-zinc ores also contain recoverable concentrations of indium**. In the report of the first stage of this fact-finding mission, a more detailed case study on the mining cooperatives was performed (CATAPA, 2019).

Mining cooperatives might consist out of twenty up to a few hundred miners gathered as a legal socio-economic entity. The Bolivian mining law provides a legal structure for small scale and artisanal mining, which creates an income for around 2% of the entire population, approximately 200.000 people (CATAPA, 2019).

Read the full report on mining cooperatives in Bolivia here:
https://www.ed.ac.uk/sustainability/what-we-do/supply-chains/initiatives/make-ict-fair-project/towards-a-fairer-ict-supply-chain

The cooperative miners then work in small groups of 2 to 6 associates. They extract veins rich in valuable metals with pneumatic drills and dynamite.

High income insecurity was observed because their production is unpredictable as they cannot know the grade of the ore they will be extracting next month. The income insecurity is compounded by the volatile and

[3] *Located in Antequera, Oruro, owned by COMIBOL, Bolivan state company, and operated by Illapa S.A., a subsidiary of Glencore.*

Figure 3: Both tin and polymetallic silver-lead-zinc ore is extracted at the mining cooperative Morococalla, Santa Fe mining district, Oruro.

fluctuating metal prices that they can sell their ore's for, which is of daily concern for the miners (each year the zinc price can double or be halved).

Miners work amongst harmful dust and extremely hazardous conditions. During periods of low prices, their income is not high enough to cover their basic needs, investing in occupational health and safety measures is not their primary concern. As a consequence, health problems and fatal accidents are frequent. Not to mention the impact produced on children's health in mining areas and on downstream agricultural villages. To compound this mass migration is reinforced by issues of soil and water pollution and problems in local water management (CATAPA, 2019).

Concentration of the ore minerals by mining cooperatives or local traders

A first concentration of the zinc ore from the remaining rock is in some cases done by the mining cooperatives themselves or, if the cooperatives do not have the necessary equipment, it might be done by local traders.

The concentration process is done by grinding the rock and using gravitary or flotation processes to artisanally separate the mineral from the waste rock. By concentrating the zinc ore, the indium concentrations are also increased.

Although most cooperatives do have some equipment, it is frequently outdated or no longer efficient due to a lack of maintenance or renewal.

Local trading and mineral preparation

On an individual level or collectively with all members of the cooperative, the minerals are sold to local traders. Based on the analysis carried out on behalf of the local trader at the moment of sale, the miners are paid for their material.

Due to low zinc pricing, high treatment charge (TC)[4] and unfair tactics of some local traders, miners get an unfair payment for their work. As officially there is no indium sold, then **no indium is analysed in Bolivia for commercial or taxation purposes nor do the miners get any payment for the indium content.**

[4] *Treatment charge (TC) is a fee defined by smelters and commodity traders, paid by the miner to a smelter for the refining of the concentrate or ore to a refined product.*

Figure 4: San Jose Jallpa has limited mechanical equipment to carry out the ore concentration process.

Figure 5: Miners sell their mineral individually or collectively with the entire cooperative, depending on their own rules

Thanks to collaborations with local universities, some miners are aware of the indium content of their mineral, but ignore whether the indium is being extracted in a later phase.

According to Zapata (2018), the mining actors would have missed out 18.150.000 euro for the value of the indium content exported in 2011. And for the state, the value of royalties not collected for the indium content exported would amount up to 6.050.000 euro[5].

International commodity traders

The local traders then further supply some of the largest commodity traders in the world. The minerals from different suppliers can be mixed to provide the concentrations required by the **international traders who manage the purchase contracts and set up the conditions of sale**. Based on daily transport data, it is estimated that in 2019 roughly 9/10th of the zinc concentrates exported at the Port of Arica was sold to Trafigura (Singapore-Switzerland), current owner of Nyrstar[6], and the remainder to the Korea Zinc group (South Korea).

Bolivian actors have no control over the treatment charges (TC) applied, which are set by a small international oligopoly of zinc refiners and commodity traders. No smelting of zinc ore takes place in Bolivia itself despite the completion of a metallurgical plant for refining these concentrates in 2013[7]. All zinc ore continues to be exported as concentrates without any further processing or added value.

Mineral preparation in the port terminal of departure

After almost 500 kilometers of transport by truck, the freight arrives at Chilean ports (e.g., Arica and Iquique). The metal content of the minerals is checked twice along its way, first at the Bolivian-Chilean border and second at the arrival in the port terminal. Every day about thirty trucks can unload in the port of Arica or about 300 tonnes per day.

The concentrates are prepared for transport, again by mixing and reconditioning the cargo, before leaving the continent.

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[5] *Zapata assumes that all the concentrates are exported and sold to companies refining the indium content.*
[6] *Zinc refiner, also discussed further in this report.*
[7] *The Karachipampa metallurgical plant in Potosí was built by the Bolivian State in the 1980s and has never been fully operational. It was renewed and inaugurated in 2013, but shut down several times due to technical issues. It has been refining lead and now aims to also produce lead-silver ingots.*

Figure 6: Zinc concentrate is transported in bulk to the port of Arica and a lesser extent in containers to the port of Iquique, both located in Chile.

Oversea shipping by cargo lines, customs and freight forwarders

13.000 kilometers by sea transport brings part of the exported concentrates to the port of Antwerp, Belgium. A trip from Arica to Antwerp takes about one month and can carry about ten thousand tonnes of dry cargo (Vessel tracker).

On arrival in the port, the customs office must be informed about the type of goods and the value of the cargo being imported. Freight forwarders are companies in charge of the logistical organisation of the transport and the administration with customs.

Figure 7: The general cargo vessel Jan Van Gent transporting Bolivian minerals to the Port of Antwerp, Belgium.

Figure 8: The quay of the Antwerp Bulk Terminal of Sea-Invest receives and prepares the mineral for transport to the different metallurgical plants.August 2020.

Mineral preparation in the port terminal of destination and inland shipping or rail transport

On average every year 150.000 tonnes of Bolivian zinc ore arrives at the Port of Antwerp (Eurostat, 2013-2019).

The Antwerp Bulk Terminal (ABT) of Sea-Invest has space for the storage of max. 445.000 tonnes of ore and concentrate. **An annual transhipment of 1.250.000 tonnes of zinc and lead ores is expected** by the company according to its environmental license (2011).

The arriving ores and concentrates are automatically weighed and analysed in order to determine their metal concentrations. Depending on their concentrations, zinc concentrates are further loaded for inland transport (by truck or freight train) or again on smaller cargo vessels for inland shipping.

The port terminal is well prepared to perform mineral manipulation with minimization of dust creation in the environment. However, such closed warehouses, indoor loading of trucks and railcars and closed grippers for the loading of cargo vessels, cannot avoid the pollution of water and air with heavy metals.

Metallurgical processing with the production of metallic indium

The zinc concentrates arriving in Belgium, for the year 2018, are further divided into 36% transformed inside Belgium, 39% exported to the Netherlands and 20% exported to France (Eurostat, 2020). **As the only zinc refiner present in those three countries is Nyrstar, the main proportion of these concentrates must feed their metallurgical complexes**, which are located in Balen (Belgium), Budel (The Netherlands) and Auby (France).

The Bolivian zinc ores rich in indium are very likely processed in Auby, where also indium is being refined. Before implementing the process to recover indium, Nyrstar's Technology Management communication stated: "They already have the raw material, and with a limited additional cost, the valuable indium can be produced" (Constant, 2012).

The Auby smelter bases its extraction process on the calcination (roasting) of zinc ore to consecutively extract zinc by leaching and electrolysis. In 2007, the processes in this smelting plant were adapted for the

Figure 9: The metallurgical plant of Nyrstar Balen (Belgium), above, does not have the process to recover indium, while the Auby plant has.

production of 'indium cement', which is an intermediate product for further refining to obtain refined indium metal.

It was reported in a company presentation that "Nystar could expect to make a high margin on indium metal" from converting its indium into metal (Constant, 2012). The project for an indium metal facility was initiated in 2011 and since 2012 metallic indium (99,998%) is being produced in France and commercialized by Nyrstar[8].

The indium ingots are sold in units of 1 or 5 kg. The annual production is about 50 tonnes per year (USGS, 2020), with a maximum capacity of 72 tonnes per year (Nyrstar, 2017).

The resulting 'leach product'[9], rich in lead and silver – amongst other lower concentrations of metals – is further processed by the Nyrstar fumer in Høyanger (Norway), transforming the 'leach product' into 'matte', 'slag' or high value 'fumes'. All those by-products can be further processed by other metallurgical plants.

Secondary raw materials processing of metallic indium

Umicore refines rare metals in Belgium at its Hoboken and Olen metallurgical plants (both in Belgium – the company also operates in other countries).

Umicore bases its production processes on secondary sourcing, which consist of recycling or slag from other refiners, such as Nyrstar. It means that the waste from primary materials[10] processed by other smelters are further processed at Umicore's installations.

The Hoboken based copper smelter, lead blast furnace and lead refinery perform the extraction of metals such as indium, selenium and tellurium. Also the Bolivian silver and lead can be further refined by the Hoboken complex.

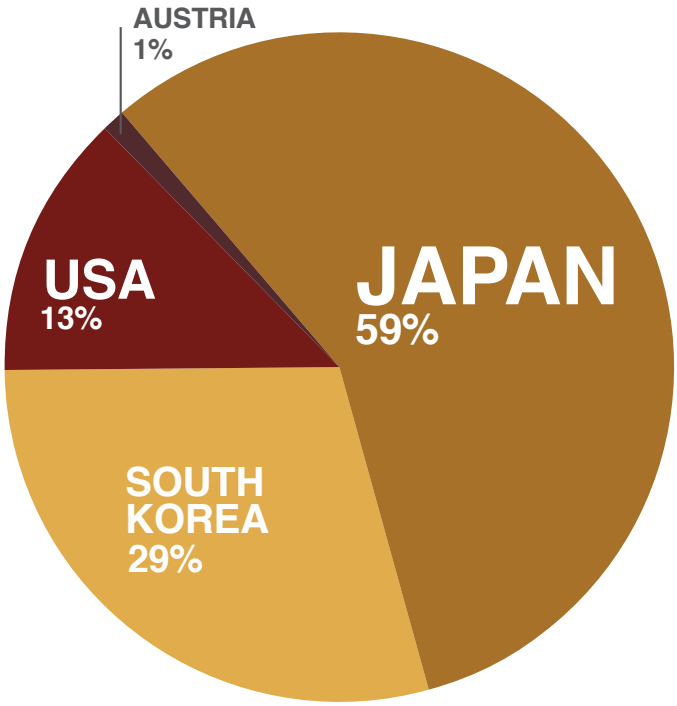
Currently Umicore produces crude indium(III) hydroxide – $In(OH)_3$ – with 80-90% indium content, due to the low efficiency of its former refining process for metallic indium (Deferm, 2018). The annual production of the articles containing indium is about 20 tonnes per year (USGS, 2020).

[8] *Due to a fire at the smelting facility, no metallic indium was produced in 2016.*
[9] *It is a waste product from the zinc refining process, but still rich in lead and many valuable metals.*
[10] *Ores and concentrates directly from mining activities.*

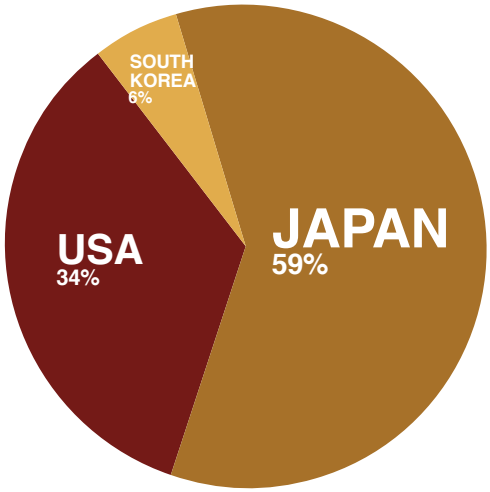
Figure 10: The Lorca inland cargo vessel brings indium rich concentrates from the Port of Antwerp to Nyrstar's metallurgical plant in Auby.

Export of indium from the European Union

In 2018, the metallic indium and indium powders produced in France (Auby, Nyrstar) and Belgium (Hoboken, Umicore) were **mainly exported to the United States of America, Japan and South Korea** (Eurostat, 2020 – see Figure 11). Both countries represent 85% of the European Union export. The articles of indium produced in Germany (where Umicore also has production facilities) are mainly exported to China.



a) Indium export France



b) Indium export Belgium

Figure 11: a) French export of unwrought indium and indium powder of 30 tonnes per year counts for 46 % of the total EU export; b) Belgian export of unwrought indium and indium powder of 16 tonnes per year counts for 24% of the total EU export (Eurostat, 2020; own elaboration, data of 2018).

Production of end products for the ICT industry

The majority of metallic indium is used for the production of **Indium Tin Oxide (ITO)** and Indium Germanium Zinc Oxide (IGZO). ITO coated glass is also known as “conductive glass” (a transparent and electric conductor) and **it is essential for the production of any flatscreen and touchscreen.**

To produce flat-panel displays, ITO ‘sputtering targets’ are produced. Those are discs of high purity ITO to be used in sputtering. The added value of this production is very high as the quality of the targets needs to fit the particular quality standards. Small imperfection in the discs can cause malfunctioning in the end-product displays.

ITO is sputtered in a homogenous thin layer or coating on a base of glass or plastic. This process wastes a lot of ITO in its execution, which is then recycled to be re-used again in the same process. This recycling of ITO accounts for 2/3 of world production.

The conductive glasses are further assembled in the display of electronics and then mounted in the end-consumer products. It is still very challenging to recover the indium from the recycling of the end products. It is estimated that only 1% of indium is recycled worldwide from end of product waste (UNEP, 2013) and **inside the EU the rate for End-of-life Recycling was recently reported at 0% (EC, 2020).**

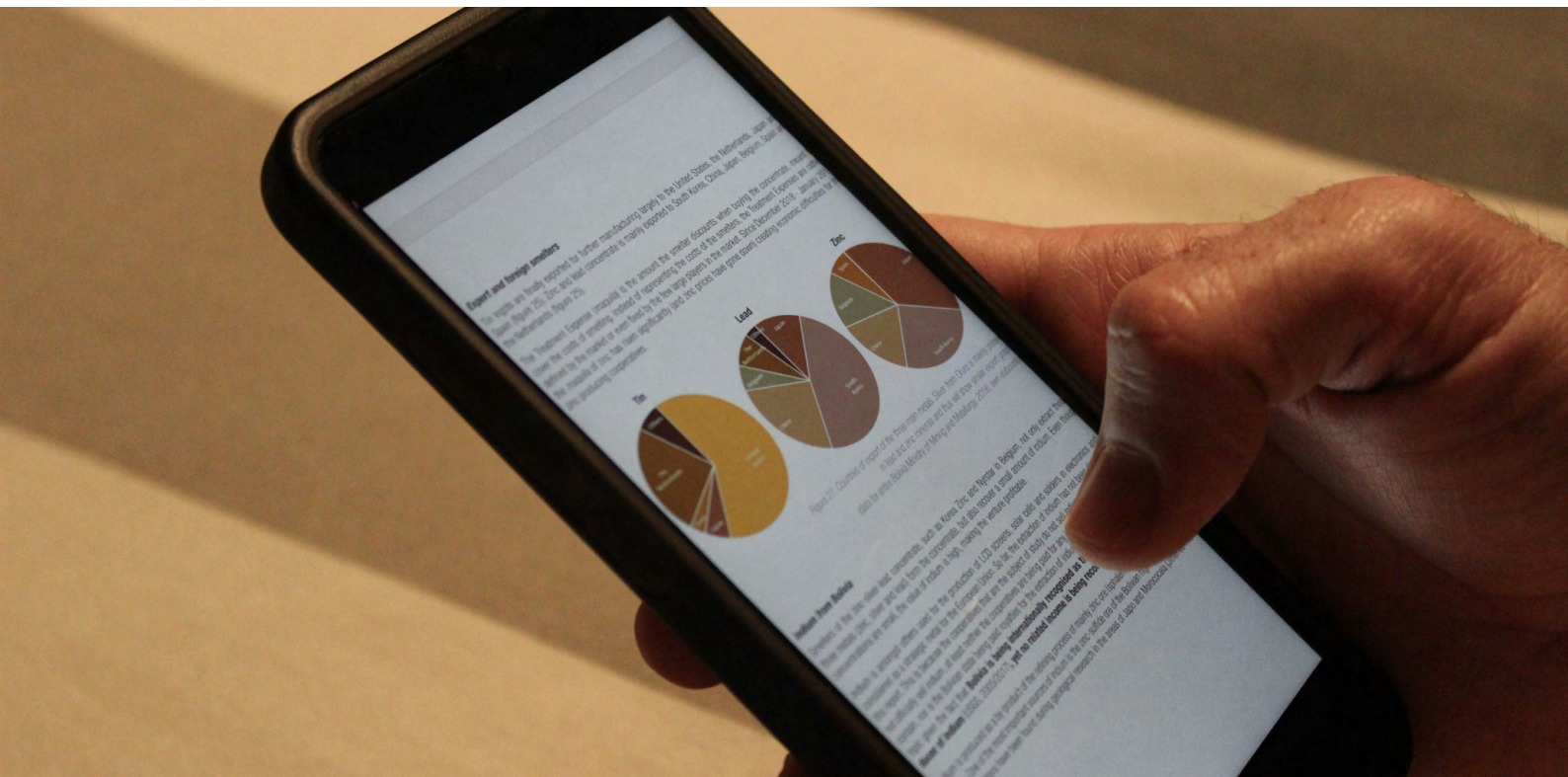
Most producers of ITO targets, conductive glass and flat-panel screens are situated in Japan, South Korea, China and the USA, which matches the export data shown in figure 11.

The production of indium in Belgium for the year 2018 was estimated at 22 tonnes (USGS, 2020). The export data of unwrought indium and indium powder equals 16 tonnes for 2018 (Eurostat, 2020).

Umicore has the option to either sell the metallic indium produced in Hoboken (Belgium) to other companies, or to process it itself further up the value chain in its own factories. For example, **Umicore has an ITO producing plant in Providence, USA** (Umicore, 2009).

It is also of note that while France exported 30 tons of Indium in 2018 according to Eurostat (2020), it was registered that this country produced 40 tonnes that year (USGS, 2020). These remaining 10 tonnes might have been exported under a different category or used for local consumption or been stockpiled. Since France has made no announcement regarding stockpiles of indium, and data of other exports is negligible, it is assumed that this indium is being consumed locally in industrial activities.

Figure 12: Touchscreens contain a thin Indium tin oxide (ITO) coating.



Since Nyrstar was taken over by Trafigura Group, a prominent international commodity trader, is it challenging to track exactly where the flow of indium from the Auby smelter (in France) goes to. **Two companies in France produce intermediary products of indium:** The first company InPACT, makes Indium phosphide substrate (InP), a semiconductor used in the communications and optical industry; and the second company Soitec, makes semiconductors based on nitrate of Indium-Galium (InGaN), as well as Indium phosphide (BRGM, 2007).

Other applications of indium

Flat-panel displays are by far the most frequent application for indium making up for 60% of the end-use of indium. Other applications are its use as a solder, in photovoltaic cells, thermal interface material, batteries, alloys/compounds and semiconductors and LEDs (Figure 13).

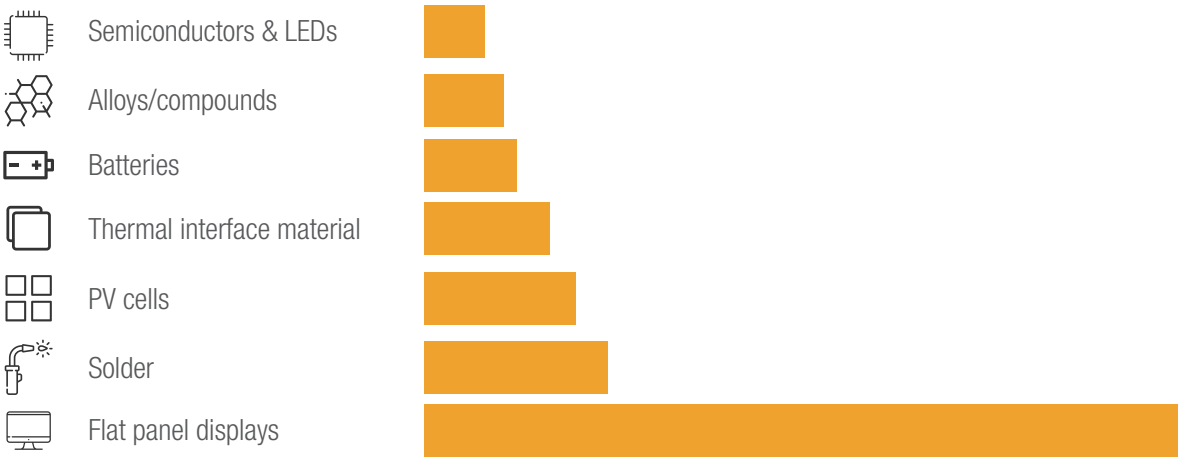


Figure 13: Applications of indum (European Commission, 2020; based on NACE2 sectors assignement; own elaboration).

Conclusions of the supply chain of indium

At this point we can better understand the supply chain of one of the many metals used in a smartphone or a laptop (figure 14).

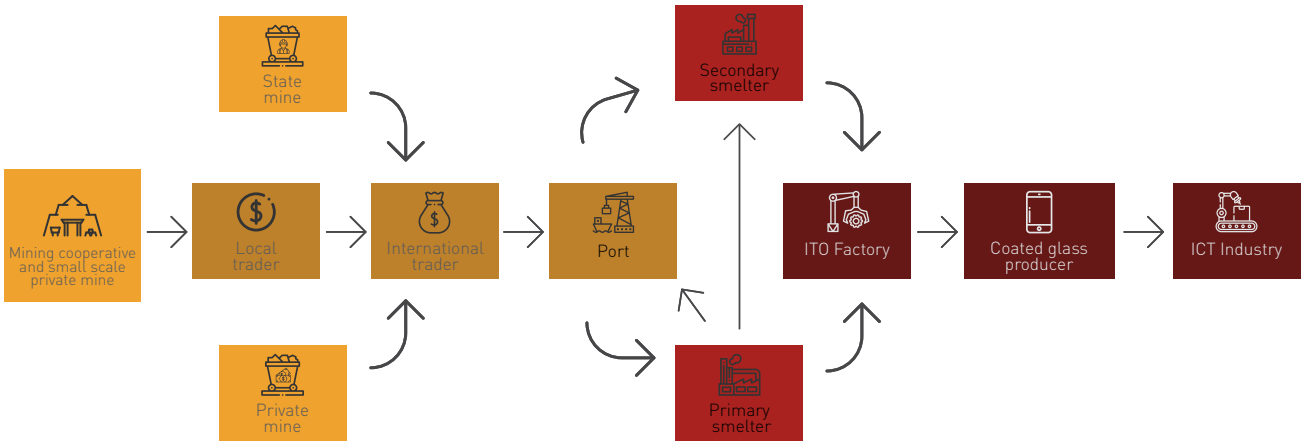


Figure 14: Summary of the supply chain of Bolivian indium bearing ore to the ICT industry.

This supply chain map is limited to the indium bearing concentrates extracted in Bolivia and refined in Europe. **Nyrstar and Umicore are not the only producers of indium in the world, and they are far from being amongst the biggest ones.** There are indium producing plants in China, South Korea, Japan, Canada, Russia and Peru, using raw material sources coming from different parts of the world (USGS, 2020).

All these chains converge on a tiny amount of commodity traders and smelters. It is an oligopoly of a few players in the indium market. These players establish an annual treatment charge for zinc ores/concentrates. The "charge" is a cost paid by the mining party and is meant to cover the processing cost for the refining party. **In reality the "charge" is independent of the cost of the refining process** and is actually being set by the major players in the zinc market, its price decided based on the price of zinc.

The Bolivian miner, for whom it is a daily uncertainty whether she/he would be able to extract enough valuable zinc ore out of the ground to bring bread to the table, has nothing to do in determining this price – nor does the Bolivian State. For example, due to the high refining charge of 2019, it was not possible for Cooperativa Minera Santa Fe (mining cooperative located in the department of Oruro, Bolivia) to cover the fixed costs for the maintenance of their technical installations, **which are necessary to work safely and prevent the discharge of acid water to the river.** In total, hardly any income was generated that year for the cooperative.

The current practice could be undermining the reason for the existence of the treatment charge and might represent a harmful distortion of the free market, being dangerous to business competition and acting against efficiency improvements in the refining sector – the latter being especially relevant today as it is necessary to increase recycling rates (e.g. of indium) of electronics.

In this case study, **the unbalanced relationship between the indium producing country and the indium consuming countries is illustrated.** Indium-rich minerals extracted by mining cooperatives are transported and further processed as a by-product from zinc refining in several countries but leaves no added financial value in Bolivia, both for locals or their state.

The EU's Due Diligence framework is not working and will not work because it lacks four key components, that are necessary in order to avoid the ongoing human rights violations and environmental damage:

1. **It is not comprehensive;** the EU's Due Diligence framework lacks detailed information that can allow a standardised or homogenous way for its implementation (e.g., What is the list of requirements to decide if the case studied is in a CHARAs?).

2. **There is no transparency;** there is no mandatory, defined structure for the companies to collect the data and make it accessible to the public so anyone can check its veracity.

3. **There is no accountability towards workers and communities,** there is no way for other involved local actors to add more information about the local mining or metallurgical site besides the company itself.

4. **There is no governing body;** no institutions have the mandate to take decisions on Due Diligence, nobody is able to monitor its implementation, no one can enforce or request anything about it.

Minor metals like indium, which are increasingly needed in the ICT industry, are extracted mainly as a by-product of the processing of ores rich in base metals such as zinc, lead and copper. In order to understand and track the supply chain of these scarce metals, **it is necessary to start working from the extraction sites.**

Taking into account the complexity and opacity in the industrial sectors, the existing approach based on the tracking of supply chains from the the consumer end-products cannot reach the original sources of the raw materials being used. Therefore, it is neglecting the problems occurring in the first stages of the supply chain.

Recommendations

This article is part of the European Commission funded project "Make ICT Fair - Reforming Manufacture & Minerals Supply Chains through Policy, Finance & Public Procurement". CATAPA is one of its 11 co-applicants, which also include the University of Edinburgh (UK), Electronics Watch, Südwind (Austria), People and Planet (UK), SETEM Catalunya (Spain) and Swedwatch (Sweden), among others. The project aims to mobilise EU citizens, decision makers & ICT purchasers/procurers working in the EU Public Sector **to improve the conditions of workers & communities along the ICT sector.**

There are nowadays **few smelters and refining facilities in the world** that have the technical know-how and metallurgical capacity to recover these metals. Therefore, a fairer and responsible supply chain would be today already possible if sufficient effort were being made in the **setting up of obligatory monitoring frameworks between the competent public institutions (at national and supranational levels) and the very few refiners and commodity traders dominating the market.** The establishment of monitored supply chains is necessary if end-product consumers – whether from the public sector or the private – want to stop human rights violations, and prevent increasing environmental damage in the early stages of metal supply chains.

The Bolivian State needs international transparency and supportive tracking systems in order to enforce its own legislation to tax minerals rich in indium – and other valuable rare metals it may be exporting – that currently leave Bolivian borders without any financial contribution. Without royalties for their minerals, the Bolivian Administration will hardly be able to independently afford the costs of the social and environmental services that mining activities cause in the short and long terms. This socio-environmental debt shouldn't be left in the Bolivian hands alone, but corporations profiting from these minerals have to contribute to the mitigation and remediation of the ongoing human rights violations and environmental pollution included in the minerals they purchase, process and sell.

In summary, these are the authors key recommendations:

- The creation of a fair supply chain is urgent and needs the collaboration between public bodies that can legislate and enforce the law, international monitoring institutions that can report on the supply chains and community-based organisations that can give local information to contrast the data provided by the companies.
- Traders that cannot guarantee transparency on how the production of metals meet human rights and environmental standards, should not be able to sell in the international market, especially not EU companies. But first we need a legal structure to collect, access and monitor that information.
- Tax contribution by the companies exporting indium-rich minerals should be reported to and requested by the Bolivian state.
- The refining process of zinc and indium should be taking place in Bolivia to generate the added value locally and to cover the costs of remediating the environmental damage of the mining activities. It would also avoid the negative effects of the global transport of heavy mineral concentrates.
- Bolivia should implement the mitigation of its historical tailings at sites rented to cooperatives and enforce the treatment of wastewater from acid drainage. The Government has to ensure access to water as a fundamental right; water for domestic and agricultural use should always be prioritised over extractive and industrial activities.

The current situation also gives the large companies involved the ability to make a real difference through their sourcing process, by taking responsibility along their supply chain and by being transparent with their customers. ICT products are the result of many actors throughout a long and complex mix of supply chains in several countries. Therefore, governments need to implement an appropriate global framework that can track this complexity and stop environmental damage and human rights violations wherever they occur. However, industrial efforts still need to be made to drive the necessary change towards fair and responsible metals production.

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