3. Primary/secondary raw materials

Most geogenic copper deposits in Switzerland are located in the Pennine and Eastern Alps.[46] There are currently no mining operations for economic reasons; Switzerland does not have an economically usable (scale, enrichment) primary copper deposit. By contrast, Switzerland has large secondary copper reserves: estimated 725 000 t of copper are stored in Swiss landfills alone. In 2013, this corresponded to about 90 kg per capita (Fig. 4), about one-third of the cumulative amount of copper in Switzerland (Fig. 3).[2]

Today, mineable geological copper deposits have an average ore content of 6 ‰ (6 g Cu / kg of rock[6,39]) while electrical waste contains about 50 ‰ (50 g Cu / kg)[50], and building demolition material and slag from waste incineration contain about 5 g Cu / kg of waste[58]. The copper in circulation is contained mainly in the infrastructure and electrical equipment and is consequently concentrated in the urban area (Fig. 3, Fig. 9).

Switzerland is among the countries leading the way in end-of-life copper recycling (43-53 %[51] of copper are recycled globally; in Switzerland: about 50 %[2]). The projected future development shows a further increase of the in-use and landfill-copper stocks (Fig. 4).[2] In 2000, it still looked as if the landfilled amount of copper was growing steadily and would at some point even exceed the amount of cumulative stock (Fig. 4)[2]. Owing to the current efforts being made by government and industry to recover as much copper as possible, the waste disposal (brown curve) is likely to flatten out than shown in Fig. 4. If 100 % of the copper used were recycled, this would cover approximately 75 % of Switzerland's demand for copper.

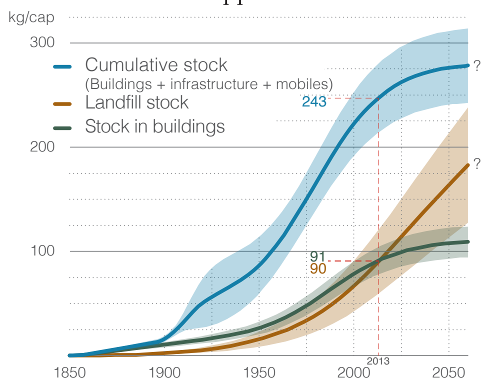
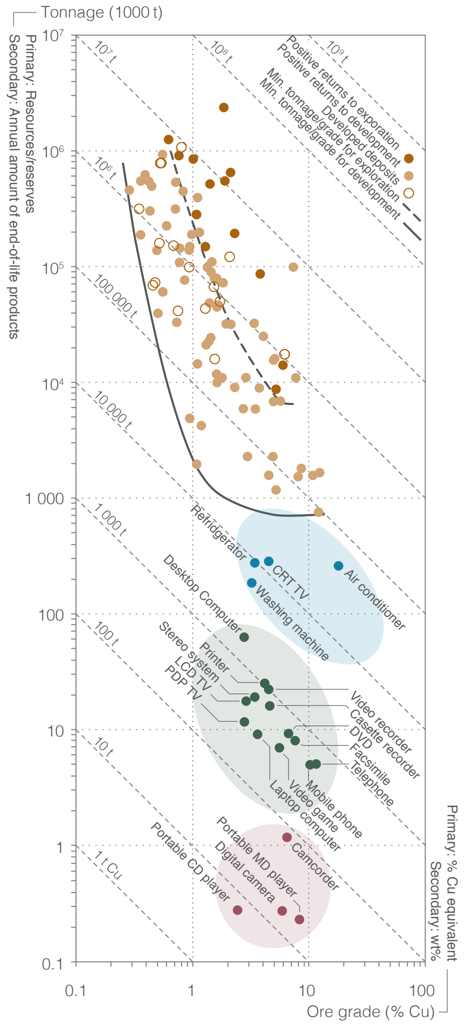


Fig. 4 Development of copper stocks in Switzerland (2). With the planned recovery facility (copper from MSWI slag) the reservoir landfill should grow at a slower rate than is shown here. Shaded: Standard deviation.



▶ Fig. 5 'Tonnage-Ore Grade' diagram for global primary (8) (brown shades) and secondary (36) (blue, green, red) copper resources. Shaded areas indicate a possible classification of secondary resources according to (36). According to this compilation, old air conditioning units amassed in just one year (!) contain more copper than the leanest primary deposits. Note that the meaning of the axes is slightly different for primary and secondary resources.

4. Environment

Copper can be toxic for aquatic ecosystems; it is not very dangerous for higher organisms.[22,31] As a metal, it is deadly for protists, especially bacteria.[31] When copper corrodes, it will inevitably lead to emissions into the environment, mostly into the ground or into the water (Fig. 3).[2] In Switzerland, approximately 100 g of copper per person were flushed into the environment in the year 2 000, a total of 800 t.[2] 70 % of these emissions are due to fertilisers and pesticides, 20 % from the corrosion of buildings; entries from infrastructure and equipment are low.[2]

There are some environmental problems with the primary production of copper: on the one hand, emissions of sulphur dioxide (SO_2) and flue dust into the atmosphere, on the other, arsenic and hydrometallurgical processes can contribute to water pollution.[31]

A life cycle assessment shows that the recycling of copper cables saves on the energy that is otherwise used in the primary production several times over (Fig. 6).[59] In a direct comparison, the recycling of copper slag from municipal solid waste incineration (MSWI) plants needs more energy than the primary production, but when one takes into account the environmental impact recorded by Swiss legislation, it still performs significantly better, mainly because other factors are included in the calculation of EIP (Fig. 6).[59] The polluting emissions of recycled copper are significantly lower than that of the primary production (Fig. 7).

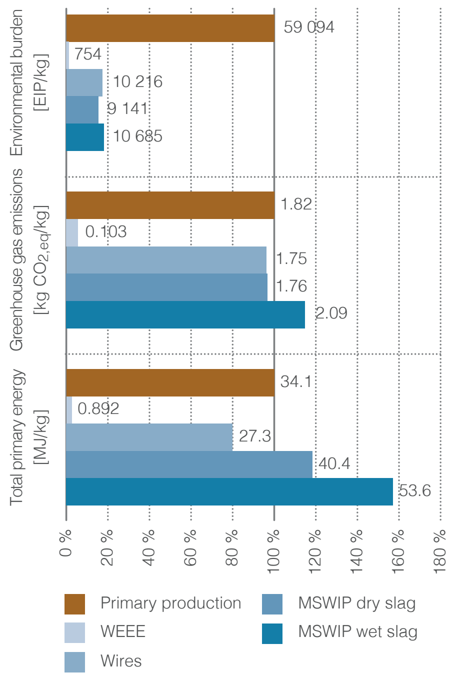


Fig. 6 Life cycle assessment for primary copper (brown), as well as for secondary copper from cable and electrical waste and/or dry and wet discharge from MSWI slag (blue tones). Absolute and percentage values based on the environmental impact of primary production (59). The environmental impact points (EIP) include, in addition to energy consumption and emissions, also land, water use, and landfills; GWP: cumulative effect of various greenhouse gases based on the effects of CO_2; Primary energy total: cumulative energy expenditure (renewable and non-renewable) for the entire delivery chain.

Fig. 7 Mass-related emissions of primary (brown bars) and secondary (blue bars) copper production. SO_2: Sulphur dioxide, PM10: Particles ≤ 10 µm, As: Arsenic (10). Primary production creates significantly higher emissions.

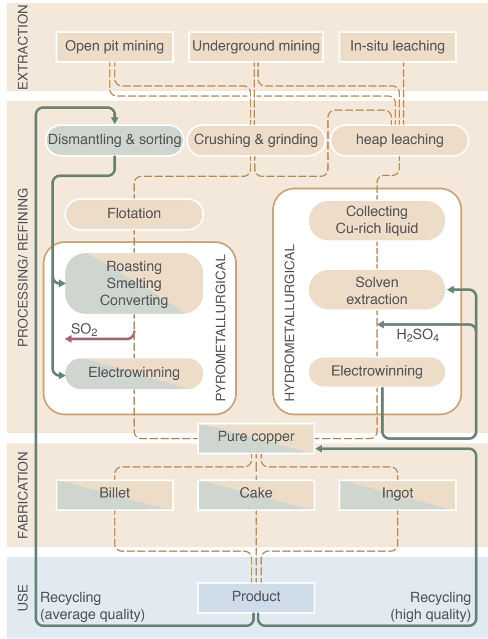
5. Technology

Today, copper is still mostly obtained through open pit mining, more rarely in underground mining or in-situ leaching.[5] The mined ore is mechanically and chemically enriched; pure copper can be produced from the concentrate through pyro- or hydrometallurgical processing (Fig. 8).[5]

Depending on the product, the recovery of copper requires significantly less energy than its primary production, and the recycling performs significantly better in terms of the environmental impact (Fig. 6). Theoretically copper and its alloys can be recycled any number of times without losing their properties.[5,31]

There are different recycling processes. High-quality, easily separable copper waste, found for example in electrical and electronic equipment (Fig. 5), is separated from other materials, remelted and used as high-quality secondary copper without any further processing.[31] The same is also true for high-quality copper alloys. The lower the quality of the secondary copper, the more difficult it is to separate it from other materials, making its secondary processing more costly (Fig. 8).[31] Copper waste of medium quality, for example found in copper cables, is processed via the pyrometallurgical procedure again in order to ensure that it has the necessary purity for electronic applications. Therefore, this additional expenditure justifies the careful separation of end-of-life products and the copper waste contained therein. Waste containing lower quality copper or very little copper, such as MSWI slag is the most expensive to recycle.[31] Similar to the primary production, the source material is shredded / crushed, and the fraction containing copper is mechanically enriched. This is then followed by pyrometallurgic refining. If a wet-chemical extraction step is added to the mechanical processing, it makes more sense to refine the copper using the hydrometallurgical method.

Whether a product containing copper can be economically recycled depends, among other things, on its copper content, the quality and quantity of copper used, its geographical distribution, as well as the amount that is generated every year (Fig. 9).[5,22,31]



◀ Fig. 8 Primary (brown) and secondary production (green) of copper (5,31). Recycling (green) and pollutant flows (red) are highlighted; streams of primary flows are more subtle (dashed lines). Sulphuric acid can be produced (e.g. for the hydrometallurgical process) from the sulphur dioxide, which accumulates in the pyrometallurgical process.

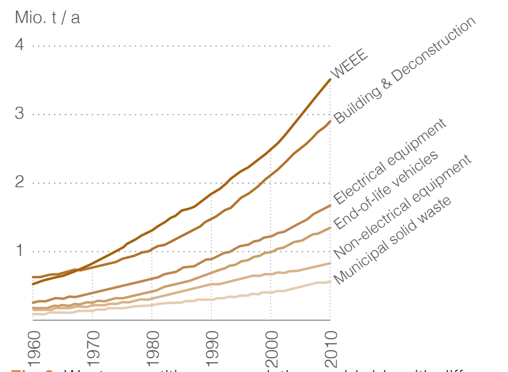


Fig. 9 Waste quantities accumulating worldwide with different content levels of copper (17).

6. Economy

In 2012, over 120 000 t of copper were imported into Switzerland; about 100 000 t were exported (Fig. 10).[14] 'Goods', i.e. semi-finished and finished products, made up the major share.[14] Nevertheless, the import and export trade flows are different: While over 98 % of the imported goods are actually semi-finished products, 86 % of all the exported goods consist of waste and scrap. This is also reflected in the price: while the import of a tonne of copper cost an average of about CHF 9 500 in 2012, the average of an exported tonne was worth CHF 7 200.[14]

In the period 2005-2011, the price of copper increased by about 330 % (Fig. 2, Fig. 11), mainly due to the growing demand of the BRICS countries, but also the formation of oligopolies in the markets. The fact that individual firms control a large share of the market of a natural resource such as copper, involves the risk of targeted price manipulation through fabricated shortages. In addition, speculation increases the volatility of the price (Fig. 11).[15,54]

In order to raise the commercial interests of private operators to exploit secondary raw materials, the cost price must be below the international trade prices. Given the possible speculative price elements, cost prices that are at 70 % of the world market prices are of interest.

In the case of public recycling operators, considerations may be added that elude an economic evaluation, at least partially. In this sense, there could be more of a focus on the independence of the supply, safety planning or reducing the environmental impact. In the case of copper processing from electronic scrap, it seems now possible for private operators to generate profits.

Legal requirements and advance disposal fees play a supportive role here. Whether the recovery of the copper from MSWI slag is financially worthwhile, cannot be conclusively assessed. Based on the plurality of recoverable metals, this can be assumed. The extraction costs can be split between multiple 'payers' (value elements) based on the sale revenues. The percentage of copper is estimated to be about 20 % of the total. It should also be taken into account that waste treatment and disposal costs can be saved.

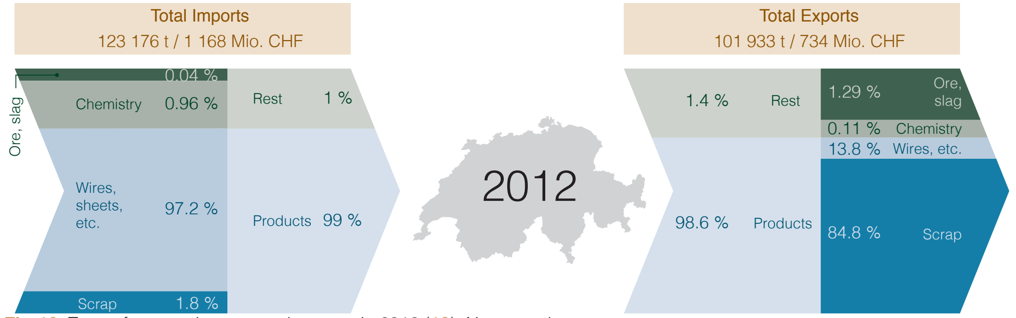


Fig. 10 Type of copper imports and exports in 2012 (10). Not to scale.

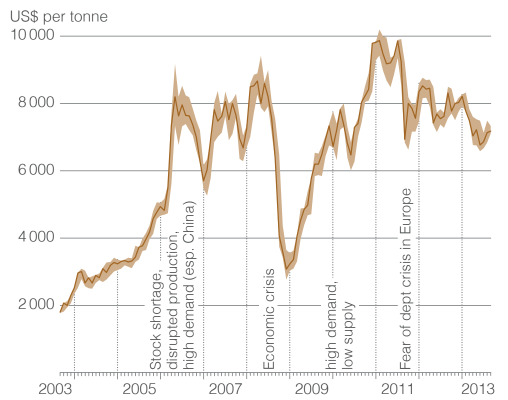


Fig. 11 Monthly copper prices from September 2003 to September 2013 (15, 54). The shaded range represents the difference between maximum and lowest price, the dark brown line the month-end closing prices.

Copper Cu

1. The importance of copper

Copper is a reddish, ductile, malleable transition metal that is a good conductor of heat and electricity and is widely used in the construction and electrical industries (Fig. 1).[12,31,54] As an essential trace element, copper is also important for life because of its catalytic function: too much or too little copper is harmful to many living organisms.[12,31]

In nature, copper rarely occurs in its elemental form; mineable are mostly its sulphides, especially the mineral chalcopyrite ($CuFeS_2$).[5] This is formed by igneous or volcanic activity in porphyries or volcaniclastic exhalative copper deposits; but exogenous sedimentary processes can also accumulate copper.[5] The largest copper reserves are in Chile, followed by Australia, Peru, the U.S.A. and Mexico.[54]

The increasing demand (Fig. 2), mainly from emerging industrial nations (especially the 'BRICS' countries Brasil, Russia, India, China and South Africa), leads to exhaustion of high-grade copper deposits. Thus, the economically recoverable copper ore grades are constantly declining (in the last century from 23 % worldwide to 0.6 %).[39] This leads to higher material and energy costs for the primary extraction. The associated cost increase is, in part, a reason for the rising copper price over the last few decades (Fig. 2).

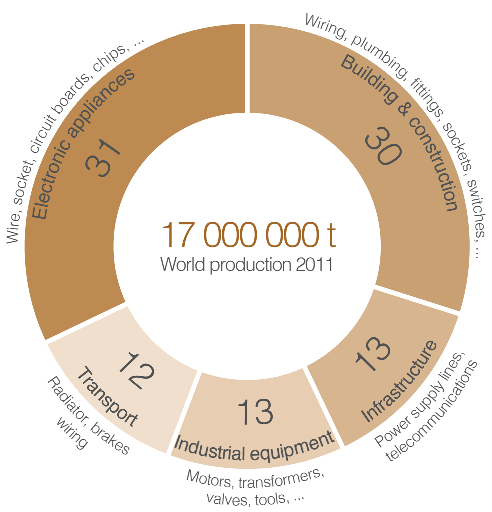


Fig. 1 The use of copper (24, 54) as a percentage.

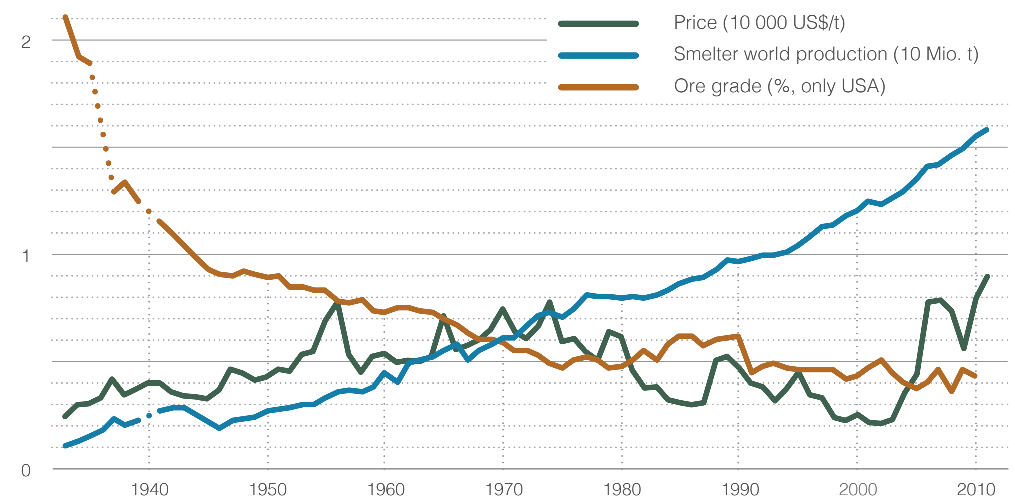


Fig. 2 Price, production and ore content of copper, 1933–2011 (54). Price adjusted to inflation, reference year 2011.

2. Understanding the system

Switzerland's copper demand is entirely met through imports and recycling (Fig. 3).[2] The amount of copper in circulation (in-use stock) has increased steadily with the importation of semi-finished products and goods; in 2000 it amounted to around 220 kg / per capita[2] (global average: 35–55 kg[16]) with a net import (growth) of 5.5 kg / (per capita / year)[2].

In the year 2 000, every Swiss person needed about 8 kg of copper, almost three times more than the global average.[2] At the same time, every Swiss produced 6 kg of copper waste, of which 4.2 kg were recycled and 1.8 kg were disposed of.[2] The amount of copper in landfills will be the fastest growing reservoir in the next 50 years, especially due to the influx of mobiles (Fig. 3, Fig. 4).[2] The recovery of copper from MSWI slag is not taken into account[2]; the forecast is therefore likely to overestimate the amount actually landfilled with today's waste management. The entry of copper into the environment is relatively low, and is discussed with the environmental aspects in section 4.

The increase in stock levels as well as waste quantity flows, coupled with rising costs and prices all justify an increased effort to recover copper. On the one hand, in order to recover some of the copper already disposed in landfills; on the other hand, to reduce the 3 000 tonnes (CHF 20 million) of copper that end up as waste in landfills every year[2].

Although even at the highest recycling rate, the primary copper production cannot be dispensed with because the in-use stock is ever growing, recycling is a good way to minimise the market share and the impact of the primary production.[20]

The largest copper flows only affect Switzerland in a limited way: import-export trade is the most important material flow but has, for instance, comparatively little impact on the Swiss environment (Fig. 3, Fig. 10).[2,14]

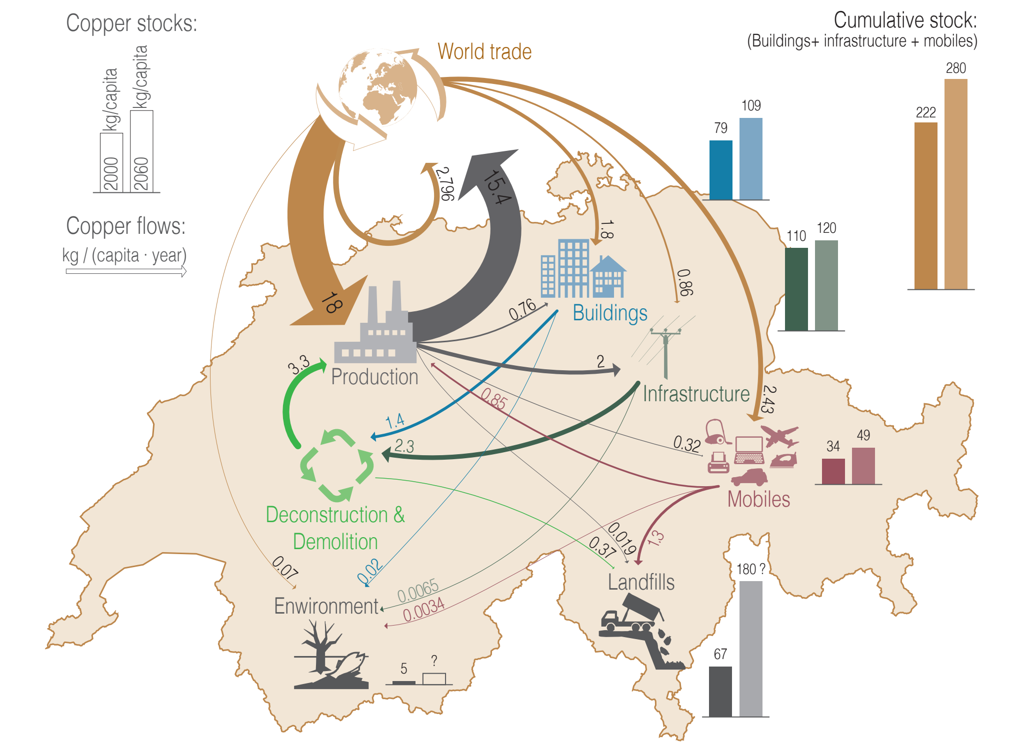


Fig. 3 Copper flows (kg / per capita / year) and stock (kg / per capita) (2); Flows: 2000, stock level: Years 2000 and 2060.

7. Society

In Swiss mechanical and electrical engineering industries (MEM), there are about a thousand companies, which generate over 9 % of the gross domestic product.[42] Copper is an important raw material for about 400 of these companies.

It is estimated that in Switzerland there are about 6 500 people employed in the recycling of metals, including copper,[57] which indicates that the recycling sector is an important employer.

Technical issues are often treated as a priority in the production of raw materials and in recycling, but social and cultural aspects are becoming increasingly important and are, in many cases, even decisive.[40] In the mining sector this is reflected by the 'social licence to mine', which is widely demanded by the local populations and for which certified trade chains can be a criterion.

Tab. 1 Possible social indicators (11).

Effects on people	Example target values
Damage to health	Emissions
Social acceptance	Rate of unemployment
Preservation of aesthetics	Visibility of the plant / activities
Social justice	Households with waste recycling
Quality of life	Impact on the local economy

Various indicators (Tab. 1)[11] can be used to assess the social impact of projects.[4,11]

A comparison between the social impact of the extraction of primary commodities[3,18] or the informal recycling abroad[1] with the social impacts of secondary copper production through recycling in developed countries, shows that the process steps carried out abroad have a significantly lower performance relating to human rights, labour and health conditions.

With regard to the potential of copper recycling, waste electrical and electronic equipment (WEEE) is of great relevance (Fig. 5, Fig. 9).[17] To complete the raw material life cycle, it would make sense to dismantle this waste equipment and to recycle the contained copper in Switzerland, instead of exporting it abroad. This would also create additional jobs in Switzerland.

On the other hand, many people in developing countries make a living disassembling this waste equipment and recycling the metals it contains by the simplest of methods. If we were to keep all the waste equipment, we would be depriving them of their livelihoods.[60]

However, the recycling methods typically used in developing countries are very inefficient[40] and damaging to the environment and people's health. To solve this conflict of objectives, the informal recycling sector in developing countries must be included in formalised trade chains.

If the waste collectors were supplied with the necessary material and know-how, the labour-intensive 'low-tech' processing steps, such as the manual dismantling, could still be done cheaper than it is in Europe. The technically challenging subsequent steps in advanced coutries would be simultaneously more efficient and socially acceptable.

However, the sense of social responsibility of the consumer and the voluntary initiatives of the industrial producers to improve the working conditions are often insufficient and it is necessary for the public sector to implement strategic tools in order to make waste management more sustainable.

8. Resource management: The overall situation at a glance

The public sector feels responsible for advancing the use of the previously untapped potential in MSWI slag in landfills, and in urban stocks. It wants to ensure a high recovery rate. Due to a substantial economic interest in copper, the metal is currently traded at approximately CHF 6 500 / t, the majority of secondary copper is to be recovered by private enterprises.

The recovery of copper from electrical waste is carried out satisfactorily because of the legal requirements (VREG) and the advance disposal contribution. Approximately 3 000 t of secondary copper are recovered per year using this process. The Environment Agency can limit itself to a controlling role for this purpose. At most, technological improvements which could increase the recovery, should be supported.

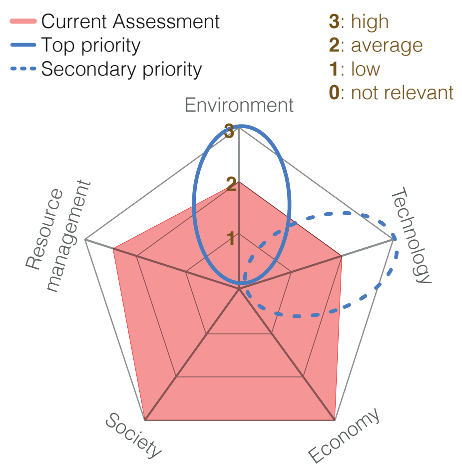
It should be ensured that the secondary raw materials are recovered from exported electronic waste with comparable high environmental and social standards.

The large amounts of copper in landfill waste (3 000 t / yr) justify efforts to recover copper from MSWI slag. This process can also - at least when calculated with all the recyclable metals - be profitable. The Environment Agency could set the wheels in motion for developing the available technologies and can ensure that copper is actually recovered from MSWI slag through appropriate legislation.

▶Fig. 8 Evaluation of the urban mining potential of copper (MSWI slag and electrical waste) based on a qualitative expert assessment.
Criteria: *Environment*: Long-term risk of slag, problems through dissipation (railway roadbed, runoff from roofs and gutters); *Technology*: Recovery from slag and electrical scrap; *Economy*: does not need measures, it runs by itself; *Society*: Mined mainly by mining companies with regulated labour contracts and protection; *Resource management*: No criticality, but it needs a further development of the state of the art.

Open issues

1. How can the dry MSWI slag discharge be universalised in other plants?
2. How can the current figures for the life cycle assessment of the primary extraction of copper be obtained?
3. How can a sustainable recycling chain for electrical scrap be guaranteed abroad?



Literature
Due to limited space, the bibliographic references are summarised in a separate document.
http://daten.sgtk.ch/rohstoff-monitoring/AWEL_Copper_Literature_EN.pdf

This substance dossier was created by Mark Simoni and Benjamin Jost from the Swiss Geotechnical Commission SGTK in collaboration with the GEO Partner AG for the AWEL.

Your feedback is always welcome:
sgtk@erdw.ethz.ch, +41 (0) 44 632 37 28

Swiss Geotechnical Commission
SGTK c/o ETH Zurich
Sonneggstrasse 5
CH-8092 Zürich
www.sgtk.ch

Baudirektion Kanton Zürich
AWEL Amt für Abfall, Wasser, Energie und Luft
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