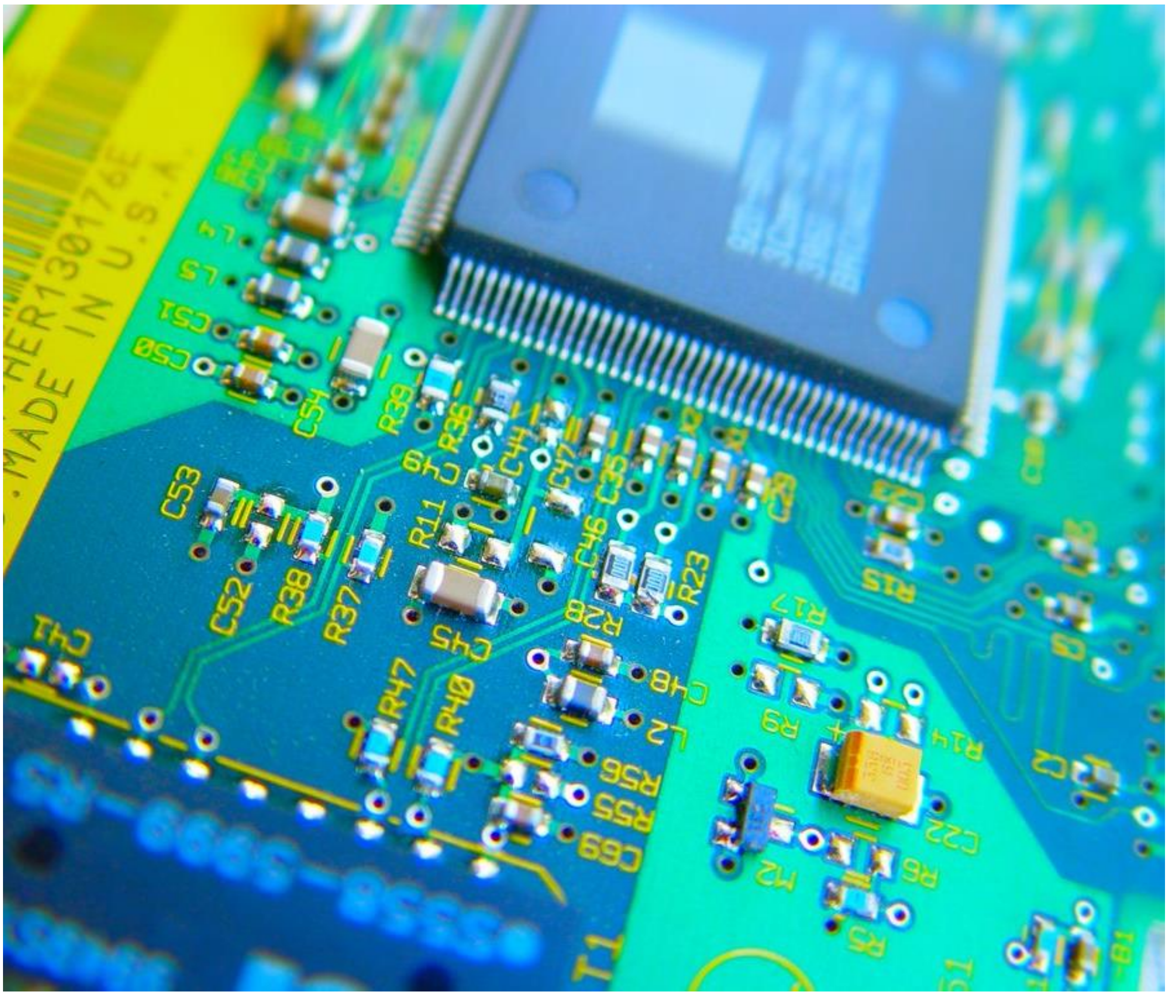
Anthesis

Study on tin solder recycling in China

Fairphone and Alpha Assembly Solutions

10th January 2020



Executive Summary

Worldwide demand for tin is set to rise and the technology manufacturing sector in China is the biggest consumer. Tin is considered to be a commodity of concern from a sustainability perspective, and recycling and waste management practices are currently not well understood. Using a combination of interviews and desk-based research, this study investigates the potential to improve the waste management and recycling of tin in China.

Our findings show that a lot of waste is generated during mining and at product end of life, with potential for significant improvements in the amount of materials recycled at both these stages of tin's lifecycle. While less waste is generated during smelting, conversion and assembly, the study highlights that waste management practices in these supply chain stages can also be improved too.

Tin waste and waste electronics are often collected by informal actors, who do not take appropriate health, safety and environmental precautions when handling waste materials. Scale is a challenge to the economically viable collection of more tin scrap along the supply chain, through adequate treatment routes, and scrap PCBs represent a considerable foregone recycling opportunity. Given the scale of material involved, the use and storage of mining tailings are areas of focus and conditions in artisanal and small-scale mining operations are also priorities.

Several potential interventions are suggested, to improve recycling and waste management along the tin supply chain, these include:

- Improving the economics of tin recovery by supporting aggregators of scrap.
- Developing end of life separation technologies to enable greater recovery.
- Reaching out to ongoing projects around the world in order to learn from best practice on how to improve the resource efficiency of tin.

Further potential interventions include developing reliable sources of recycled tin through take back programs, education in new markets and certification schemes; as well as improving dialogue with recycling organizations, to enable the greater recovery of components and base metals via better design e.g. standardizing solder alloys.

In order to improve recycling and waste management along the supply chain, this report recommends that there should be greater engagement between mining projects and new separation technologies, to discuss scalability and partnership. Another next step would be to discuss the potential for aggregation, investment and cross supply chain dialogue between OEM's, recyclers/collectors, and brands. Overall, this report aims to stimulate discussion among stakeholders on how to effectively improve recycling and waste management along China's tin solder supply chain.

1. Background

Worldwide demand for tin is set to rise and the technology manufacturing sector in China is the biggest consumer. The tin supply chain has long been subject to scrutiny, to prevent extraction and processing from financing conflict, and to counter other social pressures like forced labour. The fate and sustainability impacts of end-of-life tin, both in the supply chain in end-of-life products, is less well understood.

As responsible businesses and the policy community strive towards a more circular economy, fully understanding all impacts of the commodities that we use is crucial. Given the growing importance of tin, this report presents research into the sustainability impacts of end-of-life tin throughout the supply chain with a focus on China. The evolving policy environment around sustainability in China is a further compelling argument for better understanding of the wider impacts of tin.

The research is then used for the basis of a structured evaluation of priority areas for intervention at end-of-life for tin, based on likely impact and risk, before recommendations are made on next steps.

1.1 Tin Use

Tin, especially solder, is essential in the manufacture of electronics and is considered a commodity of concern for a number of reasons:

- Worldwide demand for tin is rising, with potential growth into new markets like energy storage.
- It has been estimated that economically available reserves of tin will cover the next 20-30 years of forecast consumption.[1]
- The Dodd Frank act classifies tin as a conflict material.
- Lastly, despite the global drive for a more circular economy, the recycled input rates of tin have plateaued at around 30%.[2]

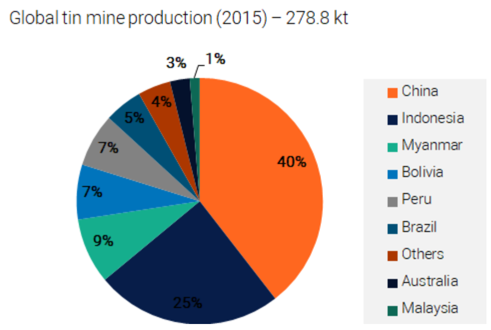
1.2 Tin in China[1,3]

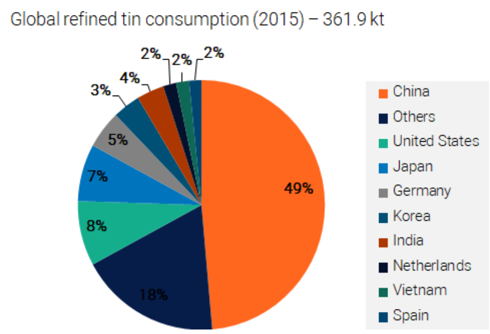
Tin production and consumption in China accounts for almost half of global use. However, practices around tin recycling and waste management for the material are unclear. 61% (2017) of Chinese tin consumption is used in the production of solder (49% globally).

[1] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

[2] Global Tin Use., 2017 – ITA Report

[3] Yang et al., 2017 - https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.7b02903





1.3 Chinese Waste Policy

Chinese waste management policy is evolving quickly, changing the recycling and environmental landscapes that the users of tin solder are operating in. There are several policies that will significantly affect the tin supply chain:

- China's current Five Year Plan encourages industrial parks to adopt more circular operational flows.[4]
- Since 2018 China's Environmental Protection Tax Law has introduced charges on solid wastes with a $2.26/tonne charge being placed on tailings and $3.77/tonne charge on slags.[5]
- Furthermore, the Chinese E-waste Disposal Fund Scheme, in effect since 2012, plans to increase the collection and disassembly of electronics with the aim to squeeze out informal waste collectors.[4]

Among all this regulation, the China Nonferrous Metals Association has developed guidelines for recycling and disposal of Copper, Aluminum, Zinc and Lead, but there are still none for tin.[6,7]

2. Methodology

A multidisciplinary research team of Anthesis Group experts from China, USA and the United Kingdom, in partnership with Fairphone and Alpha Assembly Solutions, worked together to produce a holistic picture of recycling in the tin supply chain.

The research team carried out 13 stakeholder interviews at specific stages of the tin supply chain, as well as qualified experts with an overview of the industry and policy. The findings from these

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[4] Anthesis report on Chinese waste policy landscape for a leading retail company in the circular economy

[5] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

[6] Interview with an organisation representing interests at several stages of the tin supply chain

[7] China Nonferrous Metals Industry., 2019 - http://www.cmra.cn/en/china-recycling-nonferrous-metal-industry-development-report-2018-for-sale.html

interviews were developed further, with both published and draft or internal reports from industry, process charts, environmental management systems, scholarly articles as well as publications from NGOs and companies.

The research centered on tin in the electronics industry in China. The supply chain for tin was broken down into to following stages, with our results for each step presented individually:

Mining

Smelting

Converting
3 interviews

Assembling
2 interviews

Collecting and recycling
4 interviews

2.1 Limitations

There are limitations to the methodology. For certain topics there was a lack of relevant local information available and in such cases, reference points from other geographies were used (we have highlighted where this is the case in the results). We also found that some interviews yielded conflicting information. The table below outlines the quality of the evidence for different aspects of the study, from Uncertain to High confidence.

	Mining	Smelting	Converting	Assembling	Recycling/Disposal
Production processes					
Types of waste generated					
Recycling processes					
Waste and recycling volumes					
Waste disposal practices					

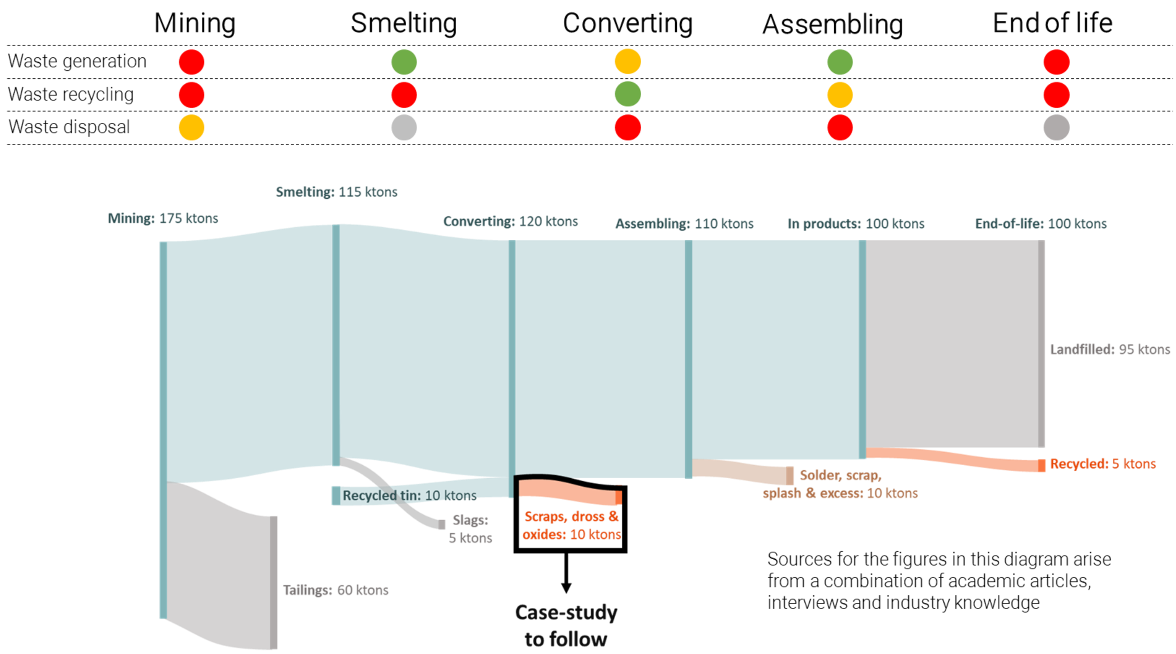
Evidence scale
Consistent evidence from both interviews and desk-based research or Consistent evidence across several peer-reviewed articles
Evidence from either: - Interviews - Peer-reviewed articles - Other desk-based research
Evidence on regions other than China or Evidence from sources with limited reliability
Conflicting or sparse evidence
Data deficient

3. Results

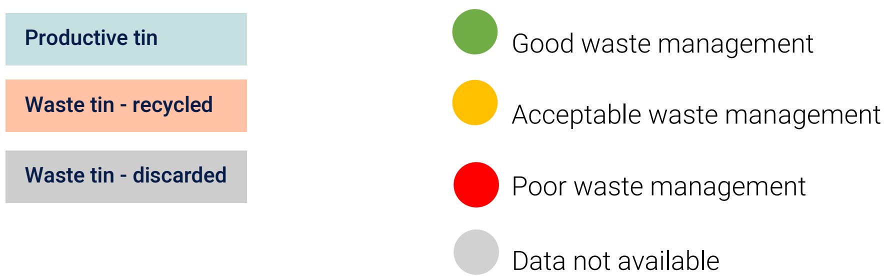
Our results from the interviews and desk based research are presented in the following sections. Firstly, a high level view of material flows is presented for tin in China. Following on, for each stage in the supply chain, an explanation of practice and sustainability performance at end-of-life are presented.

3.1 Waste and recycling in the tin supply chain

At a high level, the material flow of tin through its supply chain can be characterised by the following Sankey diagram:



Key for the Sankey diagram:



As can be seen in the above diagram in the 175,000 tonnes of tin that is mined an estimated 65% of the tin is recovered from the ore and 35% of the tin is discarded as tin tailings. The remaining 115,000 tonnes of tin plus an estimated 10,000 tonnes of recycled tin from the converting stage of the supply chain undergo the process of smelting where approximately 5% of the tin is discarded in the form of slags. Of the remaining 120,000 tonnes of tin, the process of converting the tin into several different solder products generates around 10% of waste of solder scrap which is then recycled back into the smelting stage. The process of assembling the remaining 100,000 tonnes of solder into circuit boards produces results in 10% of the tin being discarded but this is captured and recycled. At the end of life of the circuit board, approximately 95% of the tin ends up in landfill and 5% of the tin is recycled through formal waste management systems.

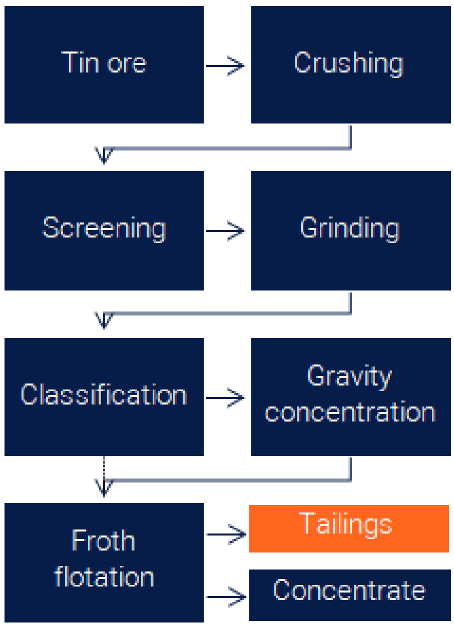
Further to the material flows, we have plotted a generalised view of waste management practices which are elaborated on in the following sections which are specific to the different supply chain stages.

3.2 Mining

The results on mining are presented in the following section, with information drawn from desk based sources only.

3.2.1 Processes[8,9]

Tin is often mined from Cassiterite and there are several methods for mining it. Underground mining involves sinking vertical or inclined shafts with horizontal tunnels to intersect the mineral veins where ore can be exposed. Another method is dredging, which involves mining alluvial deposits with large floating processing plants. Gravel pumping involves washing tin-bearing sand from the face of surface mines using high-powered jet of water. Lastly, open cast mining is when ore is removed using mechanical shovels or manual labour. The general processes for mining tin can be characterised by the following diagram:



Adopted from 2017 ACS article[10]

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[8] Interview with an organisation representing interests at several stages of the tin supply chain

[9] ITA website

[10] Yang et al., 2017 - https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.7b02903

3.2.2 Waste generation[11,12]

During mining, 67% of the tin is recovered from the ore. Yields can be lower for non-cassiterite tin sources and for artisanal and small-scale mining operations. At least 30% of the tin mined is discarded in tailings which has a tin content of around 0.2%. All these processes could be improved with new technologies. With new and innovative gravity and flotation technology, an increase in tin recovery rates could be expected, reaching up to 80%.

3.2.3 Waste recycling

Mining waste is rarely recycled, despite research showing tin tailings have beneficial properties when blended with construction materials.[13,14] For example, a study conducted on Nigerian tin mining waste found bricks which include a proportion of tin tailings have similar refractory properties to bricks used to line furnaces such as firing, shrinking and cold crushing strength. Therefore, bricks which have a proportion of recycled tin tailing included can used to line furnaces.

3.2.4 Waste disposal

Tin tailings present a risk to human health, so waste is often sealed to prevent toxic discharges.[15] Abandoned tin operations leave vast areas of land rendered useless due to the pollution and the lack of carbon, nitrogen, phosphorus and low cation exchange capacity in the soil, thwarting new growth. Another adverse impact of tin production is the relatively common history of tin tailing dams collapsing, leading to loss of life and further environmental impacts.

3.3 Smelting

The following section presents an overview of the smelting process, with data gathered from desk based research only.

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[11] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

[12] German Federal Institute of Geosciences - https://www.bgr.bund.de/EN/Themen/Min_rohstoffe/Downloads/studie_efficiency_Rwanda_ASM_Sector.pdf?__blob=publicationFile&v=3

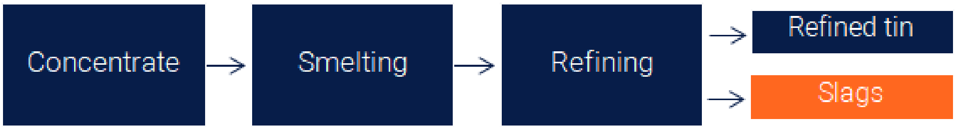
[13] Aigbodion et al., 2010 - https://file.scirp.org/pdf/JMMCE20100200004_39349959.pdf

[14] Rustandi et al., 2018 - http://iopscience.iop.org/article/10.1088/1757-899X/299/1/012046/pdf

[15] Aznar-Sanchez et al., 2018 - https://www.mdpi.com/2075-163X/8/7/284/pdf

3.3.1 Processes

Tin smelting is a very efficient process, with recovery rates of up to 98% of the content from tin concentrate.[16] The general processes can characterised by the following diagram:



Adopted from 2017 ACS article[17]

3.3.2 Waste generation

Tin smelting is very efficient, so waste generation low, although there the processes do release a number of emissions. The small amounts of waste that are created are likely to be landfilled, though there is little information available on this.

3.3.3 Waste recycling

Some dross is created when tin slags are gravity separated and processed in smelters.[18] In China, sometimes fuming processes are used which produce lower levels of slag. Unlike metals like copper and zinc, tin slags have few valuable secondary uses[16,19] so they are rarely reused or sold onwards.

3.4 Converting

The followings section presents our findings on conversion, which are drawn from interviews with stakeholders in China and other countries, as well as desk-based research.

3.4.1 Processes[20]

Tin is converted into solder, often as an alloy with metals such as lead, silver, copper, antimony, bismuth and nickel. There are a number of different solder products, some examples include:

- Solder wire, which is convenient for manual soldering, for topping up wave baths and for repairs.
- Solder bar, which is suitable for wave soldering and some dip soldering. According to our interviews this results in the highest percentage of solder scrap (as dross).

[16] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

[17] Yang et al., 2017 - https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.7b02903

[18] Interview with an organisation representing interests at several stages of the tin supply chain

[19] Permana et al., 2016 - http://iopscience.iop.org/article/10.1088/1757-899X/131/1/012006/pdf

[20] Summary of desk-based research and several interviews with solder manufacturers

- Solder paste, which is used in surface mount soldering. According to our interviews, this process results in the lowest levels of scrap.

3.4.2 Waste generation[21,22]

There was mixed evidence on the amount of waste generated in this stage of the supply chain. Solder manufacturing generates many different types of waste – scraps, oxides, dross – and the total scrap rate was estimated to be 5% by a European manufacturer, and as much as 20% by a Chinese manufacturer (this variation will account for different technologies and markets). This is likely further complicated by use of recirculation techniques and solder supplier takeback of excess.

3.4.3 Waste recycling[23]

Most solder scrap is likely to be recycled, although the methods vary and the recyclers may sometimes not be licensed (see case study later in report). Generally, manufacturers that had more in-house technologies for recycling dross and scrap were more successful in recovering tin waste. Converters that sold waste to recyclers had little visibility of the offtake markets and recycling practices in place, which can be linked to problematic emissions and hazardous waste.

3.4.4 Waste disposal[23]

Most solder manufacturers used hazardous waste disposal companies for their residual waste. One disposed theirs via landfill. The waste disposal companies and converters interviewed in China were not making sure that the waste was disposed safely. The Chinese government are embarking on an enforcement program in this area, which could change practice around all waste management more generally. It was reported that many recyclers were not accepting lead-bearing waste, despite the recycling process being almost identical, just with more EHS concerns, which would reduce options for safe disposal of lead based solders further.

3.4.5 Case study of Tin waste in the converting stage

One of the converters in China provided us with the following case study of their operations, which is best articulated in the following Sankey diagram (quantities are indicative):

[21] Three interviews with solder manufacturers, two in China and one in Europe

[22] Interview with an organisation representing interests at several stages of the tin supply chain

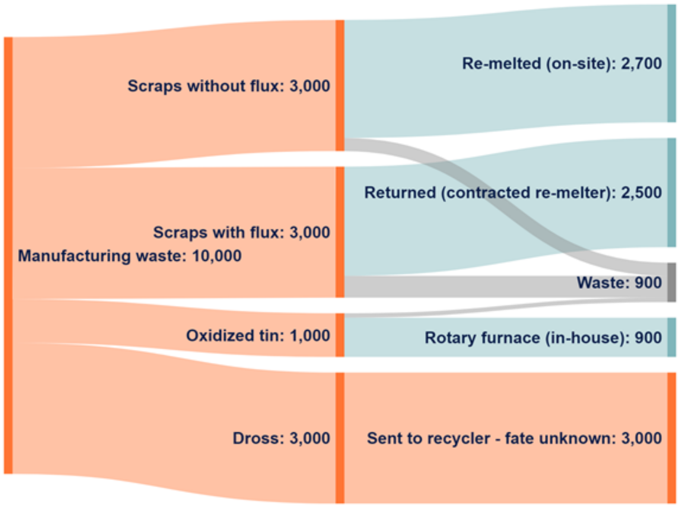
[23] Several calls to waste disposal companies and contracted recyclers to validate and complement findings

Scraps without flux – from solder bar, paste and wire. These have a high percentage of tin and a high recycling value. They are therefore re-melted on site, with about 5% scrap rates.

Scraps with flux – from solder paste and some kinds of wire. This is sent to a contracted re-melter, which returns a percentage of the recycled alloy. The flux is generally wasted.

Oxidized tin – from re-melting solder scrap. This is recycled using a rotary furnace.

Dross – from smelt furnace slag. This has a low percentage of tin and a low recycling value. It was sent to a recycler whose certification status was unknown, they were not audited and did not disclose what they did with the waste



The results from evaluating the different waste streams from manufacturing solder demonstrate that recovery rates are good, overall. However, the diversity of waste types and recovery methods signal that a mix of technologies are needed for proper processing, and recycling takes place both in-house and externally. This gives the solder manufacturer limited visibility of recycling practices and the eventual processing used to treat wastes. The limited visibility risks uncertified waste management practices, inadequate health, safety and environment safeguards, and illegal disposal of residual wastes.

3.5 Results: Assembling

The following section presents findings from the product assembly stage of the tin supply chain, which includes specific information from assembles in China as well as a more general and desk based view.

3.5.1 Processes[24]

Several soldering techniques can be used when assembling circuit boards (not exclusively and often in combination):

- Wave soldering involves the circuit board being passed over a pan of molten solder, in which upwellings are produced using a pump. This generates some oxidised tin wastes.

[24] Summary of desk-based research and several interviews with PCB assemblers and cellphone suppliers

- Dip soldering is when the PCB with mounted components is dipped and the solder wets to the exposed metallic areas of the board (those not protected with solder mask), creating a reliable mechanical and electrical connection. The dip tank easily oxidises, creating more waste.
- Surface Mount (SMT)/reflow soldering is when solder paste is applied to the circuit boards solder pads, pick-and-place machines then mount components and the PCB is heated. This produces very little tin waste and is mainly used for repair.
- Manual soldering is soldering by hand with a soldering iron, which generates some solder slag.

3.5.2 Waste generation

Interviews yielded conflicting information on the levels of waste generated at this stage of the supply chain. Some assemblers claimed that almost no waste was generated at this stage[25], whereas stakeholders from other stages of the supply chain thought the opposite.[26] The conflicting viewpoint could be complicated by scrap takeback by solder companies, or the use or recirculation techniques. Most solder wastes were either dross or solder-contaminated containers.

3.5.3 Waste recycling

One assembler had on-site equipment for the preliminary smelting of metal scraps, which were then sent to a recycler for further refining. Another company returned their scrap to the solder wire vendor in exchange for new wire, but what happened to the scraps was unknown. A third sent theirs in the general waste to a disposal company for incineration. In cases where scraps were recycled, recovery rates were high, but environmental standards and transparency were poor.

3.6 Common themes across conversion and assembly

From our interviews with assemblers and converters, a few common themes about waste management and recycling emerged. First, contracted recyclers are rarely audited. Solder and PCB manufacturers are unaware of how their materials are recycled, under what conditions and with which certifications.

Secondly, environmental non-compliance appears to be relatively common. Several waste disposal companies lacked the necessary licenses and re-smelters did not have necessary air treatment technology, even in a case where a solder manufacturer had the equipment in-house. For a contracted recycler to an assembling company, the operations had to be moved away from the advanced Shanghai area because of the pollution it generated. The Chinese government is currently acting on this and therefore the situation could change quickly.

Scale is also an issue. Relatively small amounts of recycled tin being generated results in converters and assembler having to rely on several recyclers to gather the necessary amount of recycled tin for their operations. Lack of supply creates barriers to the amount of recycled tin being used in

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[25] Two interviews with assemblers in China

[26] A solder manufacturer and an organisation representing interests at several stages of the tin supply chain

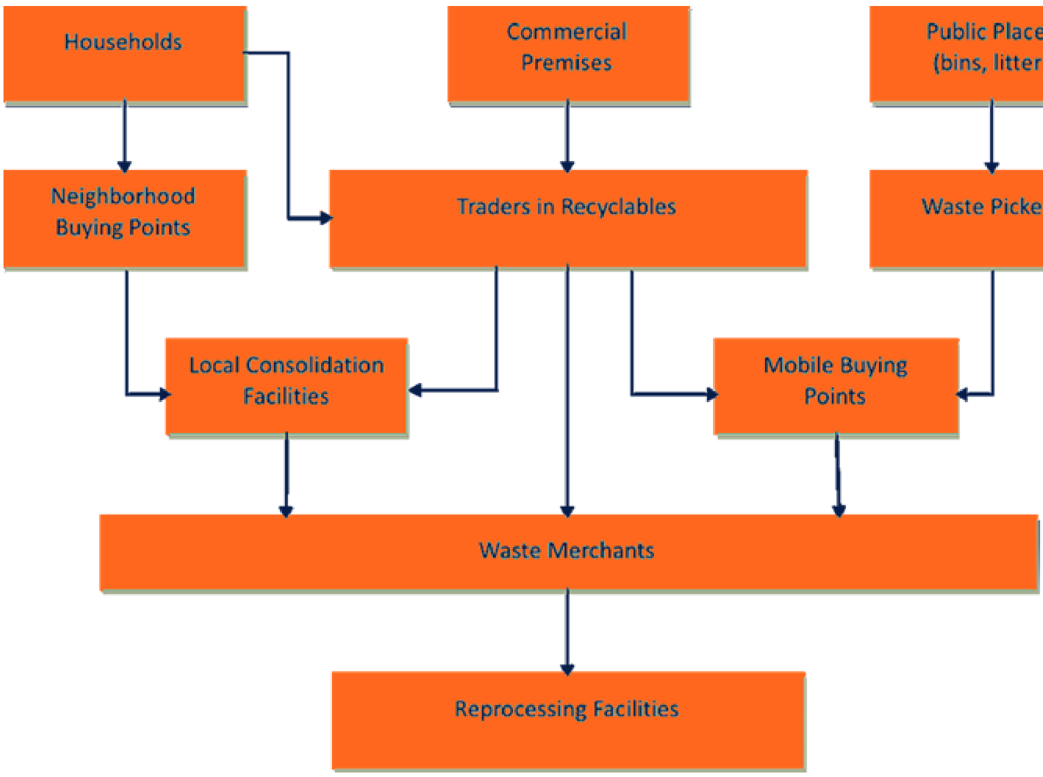
converting and assembling operations. Furthermore, small recyclers could also offer higher prices because they faced lower compliance costs[27,28] and many refuse to handle lead bearing solder.

3.7 Results: Recycling

The following section presents a view on the product recycling stage of the tin supply chain, with information gathered primarily via desk-based research.

3.7.1 Processes

In China, formal collection channels compete with informal collectors. It has been estimated that 3-5 million people in China live off informal recycling practices.[29] A typical Chinese waste hierarchy is presented below:[30]



[27] Also indicated by a metal recycler with whom we followed up information from an interview

[28] Also found in previous work by Anthesis on Chinese waste policy

[29] Tan et al., 2017 - https://www-sciencedirect com.gate3.library.lse.ac.uk/science/article/pii/S0959652617302408

[30] Previous work by Anthesis on Chinese waste policy

3.7.1.1 Actors in China's waste hierarchy

Neighbourhood buying points: Groups of people who manage waste in residential areas. Often an agreement is made with the housing management committee to allow these operations to be set up and they are typically located in the grounds of residential complexes. Historically these have been operated by the informal sector. However, in recent years transferring the operation of neighbourhood buying points to the formal sector has been a focus of regional authorities, with mixed results.

Traders in recyclables: Traders who purchase and transport the recyclables they buy. They Pin the informal sector that collect recyclables in public places. This would include gathering recyclables from the public recycling bins (as well as misplaced recyclables in general waste), neighbourhood recycling/dry waste bins or items found on the street (i.e. litter).

Waste pickers: People in the informal sector that collect recyclables in public places. This includes gathering recyclables from the public recycling bins (as well as misplaced recyclables in general waste), neighbourhood recycling/dry waste bins or items found on the street (i.e. litter). More information is provided in section 3.7.3.1.

Mobile buying points: These are primarily used by buyers and pickers of recyclables but may also be used by members of the public. They typically consist of a small truck, a balance for weighing recyclables and large sacks to store the separated fractions. Often they are located on the street, or under flyovers, and move on once they have a full load.

Local consolidation points: These are a fixed alternative to the mobile trading points. They may also be used by mobile trading points to sell material. They are generally small with the primary activity being bulking. However, they may also carry out some basic sorting activities.

Waste merchants: Waste merchants take the recyclables from small consolidation points or mobile trading points and prepare them for delivery to the recycler. For cardboard this would involve baling, and for plastics shredding is often used to size reduce material (in particular for PET) prior to delivery to the recycler.

Reprocessing facilities: Facilities which reprocess materials for example, plastic recyclers producing recycled polymer or paper mills. Many of these facilities are privately owned businesses.

3.7.2 Waste product generation

Formal WEEE collection has increased rapidly in recent years to about 50%. However, for mobile phones it is still below 20%.[31] Consumer behavior is the biggest contributor to this as recycling mobile phones has not been normalized with some consumers having several unused phones at any one time.

[31] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

3.7.3 Waste product recycling

When PCB containing tin from devices are collected, the economic value of recycling gold, copper and platinum group metals is much higher than recycling tin.[32] Hence tin is not recycled from circuit boards at scale, because all operators (formal and informal) are focused on other materials. Tin is only really targeted specifically, at other stages of the supply chain. When waste mobile phones are incinerated, the risk of or arsenic and cadmium being mobilized is high, so increasing the formal recycling of these waste products can minimise this risk. Another negative impact of poor waste management is the effect on both human life and the environment when obtaining gold or platinum off waste products. Chemical leaching is often used in this process which is problematic because often appropriate protection and disposal is not practiced. A further issue is waste tin being in mixed metal mixes so requires further separation, though there is some innovation here like magnet technology which allows for efficient separation of tin from conveyor belts in material recovery facilities.[33]

3.7.3.1 Informal recycling practices and health risks

It has been estimated that 3-5 million people in China live off informal recycling practices. In China, informal waste collectors often specialize in collecting one specific type of recyclable. The incomes of waste collectors are comparable to basic manual jobs in factories. Some workers are full time and others collect recyclables to supplement their incomes. Whilst these informal recycling collection activities in China are not legal, they are common practice.[34]

There are several health risks associated with informal recycling practices waste pickers are susceptible to in China. Hazardous wastes in e-waste are not limited to lead, but also include polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs), which can cause immune system abnormalities, skin problems and alter neurodevelopment. To separate e-waste components, informal recyclers often burn the PCBs in open air, with the waste discarded in rivers or wastewater systems. This causes toxic emissions both by air and water, to the detriment of both the recycler and natural environment.

3.7.4 Recycling processes[35]

Several methods exist for obtaining tin from printed circuit boards – though this is rarely done because often there is no economic basis for doing so. Thermal treatment (e.g. Pyrolysis) is a very effective way of obtaining tin. This involves heating the PCB to 250-400°C. However, thermal treatment releases hazardous chemicals like PCCD/Fs and PBDD/Fs. Depopulation involves using heat or chemicals followed by mechanical processes to remove components for reuse and precious/base metals for recovery. Lastly, Hydrometallurgy is a recycling method used that has

[32] Call to a scrap PCB recycler

[33] Hanley., 2018 - http://www.recyclingwasteworld.co.uk/in-depth-article/how-modern-separation-equipment-is-increasing-metal-recovery-rates-at-mrfs-ferrous-and-non-ferrous/176662/

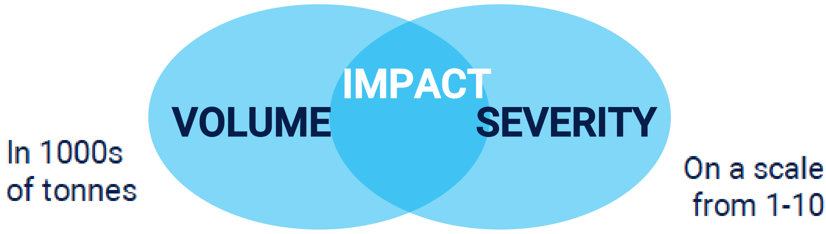
[34] Previous work by Anthesis on Chinese waste policy

[35] Yang et al., 2017 - https://pubs.acs.org/doi/abs/10.1021/acssuschemeng.7b02903

lower operating temperatures and less environmental impacts. This produces hazardous waste, in which other valuable metals are contained.

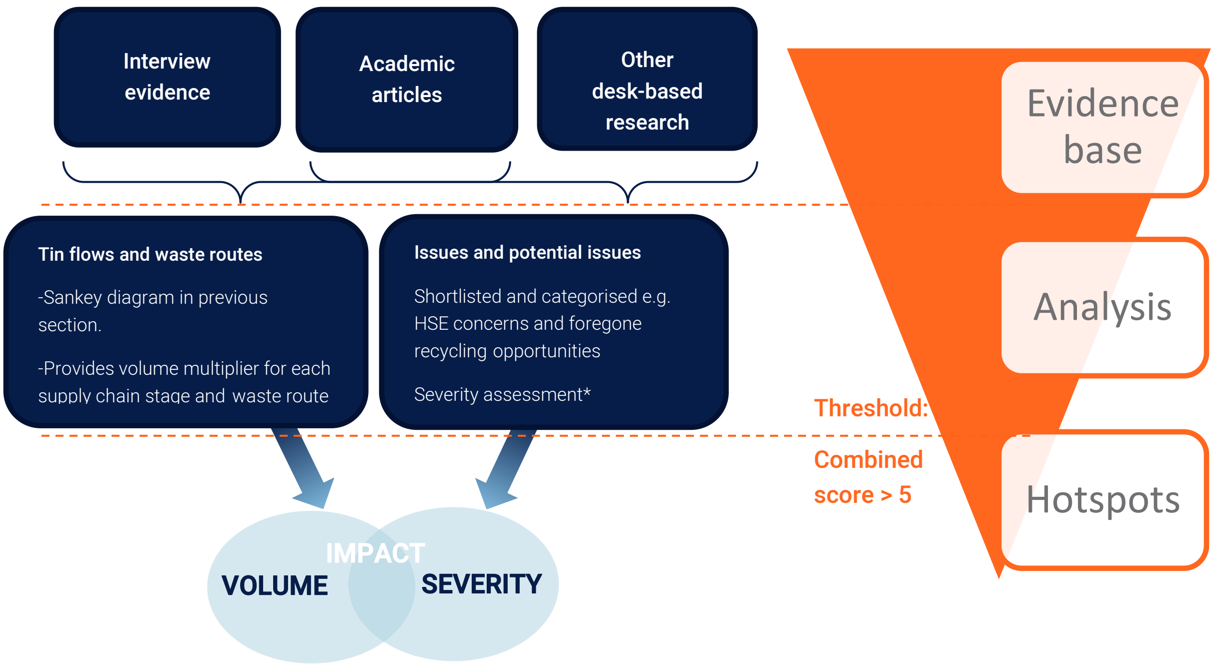
4. Hotspot analysis

The following hotspot analysis provides a structured approach to prioritise potential interventions. For each supply chain stage, the potential for further recycling, improved waste disposal, less waste generation and better HSE management was evaluated. The volume of tin production, combined with the severity of sustainability concern, was used to indicate impact. The main concerns for key sustainability impacts at each supply chain stage are presented in the following section.



4.1 Hotspot analysis: Methodology

The logic behind our structured methodology is as follows:



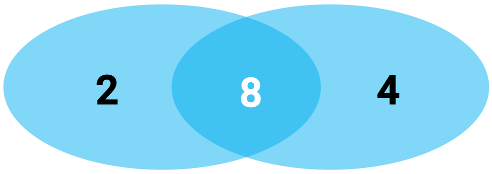
4.1.1. Severity assessment

The severity score is the result of the scores from the environmental, social and health concerns being added together. Each issue was codified according to the categories below. For each issue-category combination, points were added to the Severity score. Variable scoring ranges allowed for categories to be weighted differently. The maximum possible score was 12. Severity scores were adjusted, to reflect whether the severity applied uniformly to the tonnage identified. Severity criteria are provided below:

4.2 Hotspot analysis: Mining

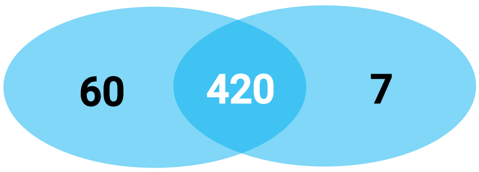
Issues of concern around mining, weighted by impact, are as follows:

4.2.1 Tin ore from conflict regions



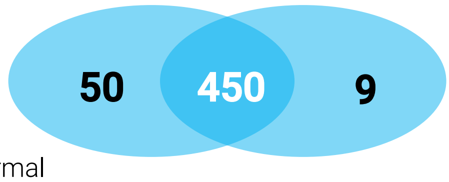
Tin has been classified as a conflict mineral as its extraction has been known to finance conflict in the DRC and surrounding countries though there are industry led initiatives which have shown to tackle this. In China however, 2,000 tonnes, equivalent to around 1% of total tin mined in this supply chain, of tin imports were from SDN listed companies based in Myanmar which has been cause for concern.

4.2.2 Tailings improperly stored



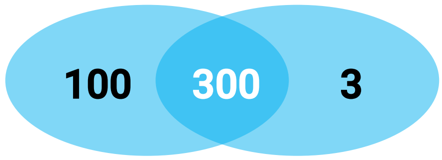
Approximately 60,000 tonnes, which is the equivalent of around 35% of tin mined in this supply chain, of tailings are improperly stored during the mining process. Tin tailings need to be appropriately stored to prevent environmental and health impacts. Additional benefits include allowing further tin extraction if tin grade of tailings is high enough and allowing for secondary use of tailings once new technologies become available.

4.2.3 Informal mining practices



Artisanal and Small-scale Mining operations are less efficient, less safe and environmentally sound. These operations are common in Indonesia and DRC.[36] An estimated 50,000 tonnes, equivalent to around 30%, of tin used in this supply chain is at risk of being sourced from informal mining practices. China will rely on imports from such operations in the near future.[37] A case study on artisanal mining follows this section.

4.2.4 Improving Tin recovery



Combinations of gravity and flotation have been shown to be able to improve cassiterite mining. Current yields are around 65%. Approximately 55% of tin, equivalent to 100,000 tonnes, of the tin being mined has potential to have greater tin recovery.

4.2.5 Case study: Artisanal and Small-scale mining

Artisanal and Small-scale mining (ASM) operations can have significant environmental, social, and health impacts. The potential environmental impacts of ASM include degrading farmland and polluting waterways through dumped tailings, which affect local food production and fish stocks relied upon for food.[38] Deforestation and biodiversity loss are also common environmental implications of ASM operations.[39]

Some ASM's are located in conflict regions and controlled by armed groups. This results in the abduction of children and women who are forced to join the armed groups.[40] Consequently, forced and child labor can be seen in some ASM's, exposing people to hazards that can cause disease, death and injury.[41] Furthermore, conflict between ASM and Large Scale Mining often occur, resulting in violent interactions.[39]

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[36] International Institute for Sustainable Development (IISD)., 2017 - https://www.iisd.org/sites/default/files/publications/igf-asm-global-trends.pdf

[37] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

[38] UN Environment., 2017 - http://web.unep. org/chemicalsandwaste/sites/unep.org.chemicalsandwaste/files/mercury/QSG_english.pdf

[39] Buxton., 2013 - https://pubs.iied.org/pdfs/16532IIED.pdf

[40] Kim., 2006 - https://search.proquest.com/openview/60b83b3f3e8b666bac190da234ca69ff/1?pq-origsite=gscholar&cbl=32013

[41] Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF)., 2017 - https://www.iisd.org/sites/default/files/publications/igf-asm-global-trends.pdf

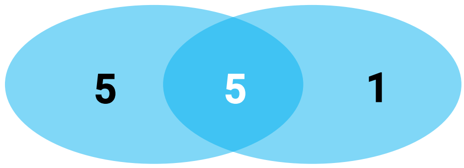
ASM presents multiple health and safety hazards for workers. Drilling and blasting processes result in the inhalation of dust and fine particles which can cause respiratory diseases.[42] Scarce use of earplugs by workers to protect their ears from the noise and vibrations generated by mining equipment can cause temporary or permanent speech interference and hearing loss.[43]

ASM operations are concentrated in Asia, Sub-Saharan Africa and Latin America. With China's growing rate of mineral consumption, China will rely on imports from AMS operations in the near future.[44]

4.3 Hotspot analysis: Smelting

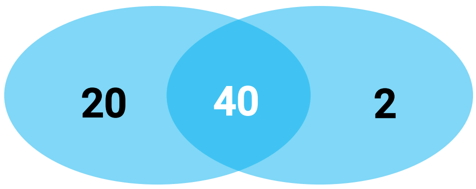
The issues of concern around smelting, weighted by impact, are as follows:

4.3.1 Slags are not fully utilized



Approximately 5,000 tonnes, equivalent to 5% of total tin smelted, is discarded in the tin smelting process in the form of slags which are not fully utilized. Critical minerals like Niobium (used for capacitators) and Tantalum (used in high-grade steel) are not recovered from slags. This is currently untapped potential, though tin slags are less valuable than other smelted commodities.

4.3.2 Non-compliant smelters



Previous reports have suggested a significant proportion of tin is at risk of being smelted in non-compliant smelters.[45] A conservative estimate for this volume is 20,000 tonnes, which equates to around 15% of tin smelted in this supply chain. China has become stricter in the environmental demands they put on tin smelters. Reports have suggested many non-compliant smelters risk being closes completely.[46] This could increase prices and make sourcing tin more difficult in the short term but would improve practice overall.

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[42] International Institute for Sustainable Development (IISD)., 2017 - https://www.iisd.org/sites/default/files/publications/igf-asm-global-trends.pdf

[43] UN Environment., 2017 - http://web.unep.org/chemicalsandwaste/sites/unep.org.chemicalsandwaste/files/mercury/QSG_english.pdf

[44] Yang et al., 2018 - https://www.sciencedirect.com/science/article/pii/S0048969718312373

[45] Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF)., 2017 - https://www.iisd.org/sites/default/files/publications/igf-asm-global-trends.pdf

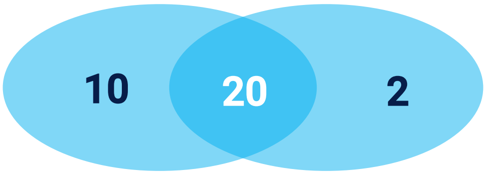
[46] Burton, Lian., 2016 - https://www.reuters.com/article/us-metals-tin-smelters-idUSKCN10K0GS

4.4 Hotspot analysis: Converting and Assembling

The following issues of concern were observed in the conversion and assembly stages of the supply chain.

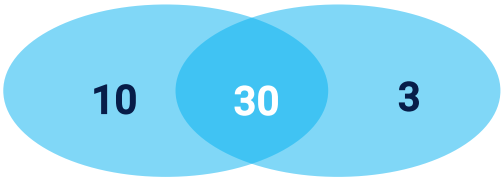
4.4.1 Inadequately disposed waste[47]

Approximately 10%, equivalent to 10,000 tonnes, of tin is inadequately disposed of in both converting and assembling stages of the supply chain. Some lead-bearing solder can be disposed in the general waste and uncertified companies are disposing of waste unsafely.



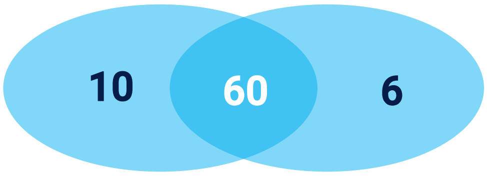
4.4.2 Foregone recycling opportunities[47]

Solder scraps that could be recycled are sometimes discarded in the general waste. An estimated 10,000 tonnes, equivalent to 10%, of tin smelted is discarded in both the converting and assembling stages of the supply chain which could be recycled. Solder is expensive, so this is only an issue when small amounts are produced, but the distributed lack of scale is a challenge to sustainable waste management.



4.4.3 Inadequate environmental safeguards in recycling plants[47,48]

Many recyclers lack the necessary air treatment equipment. This risk is associated with around 10%, or 10,000 tonnes, of tin that is smelted. One recycler even had to operate at a safe distance from a developed urban area because of its pollution.

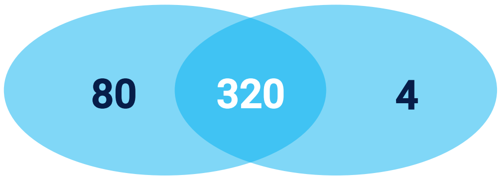


4.5 Hotspot analysis: Recycling

Issues of concern around recycling, weighted by impact, are as follows:

4.5.1 Waste electronics not collected through formal systems

Studies estimate that 50% of mined tin goes into electronics.[49] The tin content in non-recycled e-waste



[47] Several interviews with solder manufacturers and PCB assemblers

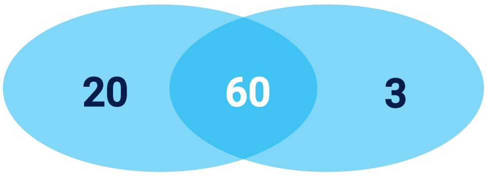
[48] Calls to contracted recyclers and waste disposal companies to validate findings

[49] Global Tin Use., 2017

represents 35% of that mined annually.[50] Approximately 80,000 tonnes, equivalent to 80% of tin in this supply chain at the end of life, is not collected by formal waste management systems. The proportion that is therefore not collected for recycling is considerable.

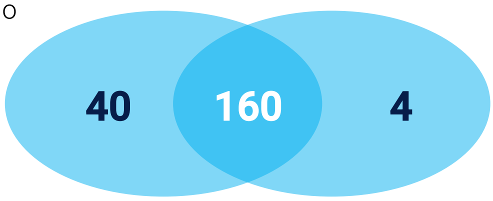
4.5.2 Tin in PCBs not recycled

Of the PCB's which are collected for recycling by formal systems, approximately 80% of the time the tin is not recovered. This is estimated to be equate to around 20,000 tonnes of tin. This is because when PCBs are collected for recycling, other commodities like copper are often the target meaning the tin content can be lost.



4.5.3 Informal collection and recycling of e-waste

Waste electronics can be collected by informal actors, who do not have access to adequate health and safety protections. Approximately 40,000 tonnes of tin, equivalent to around 40% of tin in the landfill from this supply chain, is collected through the informal sector. In reality this volume is most likely much larger than this estimation, however a conservative estimate was made for this hotspot analysis.



4.6 Hotspot analysis - summary

Following structured analysis, we propose the following priorities for further intervention:

Mining

Tin tailings need to be stored properly to prevent environmental degradation and to allow for future uses such as further refining or upcycling in construction materials. If tin is sourced from artisanal and small-scale mining operations, there is a greater risk of associated social and environmental issues and the ongoing scrutiny of this supply chain should remain a focus.

Smelting

Inadequate environmental safeguards may result in tough sanctions as the Chinese government is taking the issue increasingly seriously. Non-compliant smelters may close and while this could disrupt short term supply, it would improve standards overall.

Conversion and assembly

Although many waste types are generated they are often recovered, as tin and solder are expensive. Where there are losses, the issue is generally caused by the limited scale as the small amounts are

[50] Golev et al., 2016 - https://www-sciencedirect-com.gate3.library.lse.ac.uk/science/article/pii/S0956053X16305281

not worth recovering. The conditions by which collectors and recyclers are operating however, are of concern, with few environmental safeguards and little visibility.

Collecting and recycling

Large amounts of waste electronics are never collected by formal organisations. Instead, informal collectors handle the material, which is unsafe. Of the devices that are collected, tin is not a priority for recovery is often discarded. In processing, tin often being mixed with other metals so requires further separation.

5. Potential interventions and recommendations

Following research, structured analysis and prioritization, the following potential interventions by stakeholders in the supply chain for tin were identified as priorities:

- Aggregation – Currently the amount of recycled tin is relatively small and the existing supply is dispersed between multiple recyclers each holding a small quantity of recycled tin. This creates barriers on how much recycled tin is used in practice. Consequently, there is need to improve the economics of tin recovery by supporting aggregators of scrap from conversion and assembly and PCBs through either investment, coordinated effort (e.g. a common master agreement) or incentivization. This would help to make tin collection economically viable for recyclers operating to the required standard and stop the limited losses into landfill.
- Separation – Investment and further research into the development of separation technologies at end of life for tin, to enable greater recovery for when PCBs are collected at end-of-life.
- Engagement – Reaching out to ongoing projects around the world, to learn from best practice and to activate ideas in startup on improving resource efficiency for tin, particularly around applications for mining tailings.
- Dialogue – Improve the recyclability of tin via better product design and specification in consultation with recyclers, also working towards the greater recovery of components via depopulation, e.g. through standardizing of solder alloys.
- Develop – New reliable sources of recycled tin through investment and participation in take back programs, education in new markets and certification.

5.1 Recommendations on next steps

Following on from these priority interventions, we recommend the following next steps for stakeholders in the tin supply chain in China:

- Discuss the overall appetite for aggregation, investment and cross supply chain dialogue with OEMs, recyclers/collectors and brands to improve practice generally, as well as the economics of collection and processing.
- Engage with projects on mining and new material separation technologies to discuss scalability and partnership, to help take the locally focused ideas global.
- Promote the findings in this report to provoke discussion among stakeholders.