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Cost allocation and incentive mechanisms for environmental protection in the tin solder supply chain

Summarised results for decision makers in the industry

Based on reports by

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Section I 1.5 and Section III 2.1

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Abstract: Cost allocation and incentive mechanisms for environmental protection in the tin solder supply chain

The research project "Cost allocation and incentive mechanisms for the environment, climate protection and resource conservation along global supply chains" (project number 3722 14 101 0) commissioned by the German Environment Agency investigated (dis)incentives for and barriers to the implementation of environmental measures as well as the exchange of information between different actors along selected global supply chains. The project focused on five supply chains from raw material to the end product that represent key sectors of the German industry with a high potential for environmental and human rights risks: cotton-readymade garments; tin – tin solder; natural rubber – car tyres; coffee – coffee for consumption; iron ore – quality steel for automotive industry. It aimed to provide guidance to business and policy makers to facilitate the practical implementation of effective environmental upgrade measures along these global supply chains and to allocate the distribution of the resulting cost and benefits more equitably. This report consolidates the research findings for the tin-solder supply chain. It is a compilation of texts already published in other reports with the purpose of informing decision makers in the tin solder supply chain.

Kurzbeschreibung: Kostenverteilungs- und Anreizmechanismen für den Umweltschutz in der Zinn-/Lötzinn-Lieferkette

Das vom Umweltbundesamt in Auftrag gegebene Forschungsprojekt „Kostenallokation und Anreizmechanismen für Umwelt-, Klima- und Ressourcenschutz entlang globaler Lieferketten" (Forschungskennzahl 3722 14 101 0) analysierte (Fehl-)Anreize und Barrieren für die Umsetzung von Umweltschutzmaßnahmen sowie den Informationsaustausch zwischen verschiedenen Akteur*innen entlang ausgewählter globaler Lieferketten. Das Projekt konzentrierte sich auf fünf Lieferketten, die Schlüsselsektoren der deutschen Industrie mit einem hohen Potenzial für Umwelt- und Menschenrechtsrisiken darstellen und betrachtet diese vom Rohstoff bis zum Endprodukt: Baumwolle – Konfektionsware, Zinn – Lötzinn, Naturkautschuk / Autoreifen, Kaffee – Konsumkaffee, Eisenerz – Qualitätsstahl für die Automobilindustrie. Das Projekt soll Unternehmen und politischen Entscheidungsträger*innen als Orientierungshilfe dienen, um die praktische Umsetzung wirksamer Umweltschutzmaßnahmen entlang der globalen Lieferketten zu erleichtern und die daraus resultierenden Kosten und Nutzen gleichmäßiger zu verteilen. Dieser Bericht fasst die Forschungsergebnisse für die Zinn-/Lötzinn-Lieferkette zusammen. Der Bericht ist eine Zusammenstellung von Texten, die bereits in anderen Forschungsberichten veröffentlicht wurden, mit dem Ziel Entscheidungsträger*innen in der Zinn-/ Lötzinnlieferkette zu informieren.

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1 Introduction and background of the research project

The research project "Cost allocation and incentive mechanisms for the environment, climate protection and resource conservation along global supply chains", commissioned by the German Environment Agency, investigates (dis)incentives for and barriers to the implementation of environmental upgrading activities as well as the exchange of information between different actors along selected global supply chains. The report addresses the issue that the implementation of environmental upgrading activities is often accompanied by significant costs (both financially and in terms of resources and expenditure). Observations from the research conducted in the project confirm that these costs are often unevenly distributed among the actors involved in the setting of global supply chains - the costs are often higher for the less powerful and financially weak suppliers, while the benefits from the implementation of environmental protection measures (e.g. improved reputation) are focused to a greater extent on more powerful and financially stronger, larger purchasing companies. This can hinder the effective implementation of environmental and climate protection as well as cooperation between supply chain actors. For this reason, the report is intended to provide guidance to businesses and policy makers to facilitate the practical implementation of environmental upgrading activities along global supply chains and to improve the distribution of cost and benefits in the process.

The project focuses on global supply chains from raw material to the end product that represent key sectors of the German economy with a high potential for adverse environmental impacts. We analyse the following five supply chains:

- Cotton and the manufacturing of cotton-based ready-made garments
- Tin and tin solder for the manufacturing of electronics
- Natural rubber and car tyres for the automotive industry
- Coffee for retail and consumer brands
- Iron ore and quality steel for the automotive industry

Building on the findings this report will synthesise the overall project findings, ultimately resulting in a roadmap combining seven instruments that appear most promising to more equitably distribute costs and benefits and thus support the effective implementation of environmental upgrading activities in the global **tin-solder supply chain.** These instruments were chosen based on a qualitative assessment of all materials collected throughout the project implementation – consisting of an extensive literature review, workshops and interviews with practitioners and various industry experts. They were mentioned repeatedly as being the most promising approaches to environmental upgrading, cost-benefit sharing and cooperation between different stakeholders along global supply chains. Some are already in use, while most are not yet used or still in pilot phases in the analysed supply chains.

Chapter 2 contains a supply chain profile for the tin solder industry. By focusing on the market design, e. g. market structures, pricing mechanisms, power structures in the value chain and barriers for mainstreaming environment protection in the supply chain, this chapter lays the ground for the analysis of how to promote sustainable supply chain management (SSCM) in the industry. Chapter 3 maps the main environmental impacts in the tin solder supply chain and provides an overview of the SSCM instruments already in use by garment producers and their suppliers or that are currently emerging. Chapter 4 presents a roadmap for the introduction of SSCM instruments that can deliver meaningful incentives to reduce GHG emissions along the tin

solder supply chain at all stages. The roadmap was created in close collaboration with companies from the tin solder supply chain. Additionally, it is backed by research, interviews with other industry representatives and workshops.

By considering SSCM instruments and related incentive mechanisms that go beyond current practice, the report aims to support industrial actors as well as those who regulate, finance or otherwise support these sectors in furthering an equitable distribution of costs and benefits, supporting the effective implementation of environmental upgrade activities along global supply chains.

2 Supply chain profile for tin

This chapter is an excerpt of the report "Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Analysis of the cotton, tin, natural rubber, coffee and iron ore supply chains" (Strasser et al. 2024). The supply chain profile for the tin-solder supply chain contains background information on the commodities, an explanation of the market structure, the functioning of the value chain, pricing mechanisms and power relationships, an indication of how the industry addresses its environmental impacts as well as an outlook on market, consumer and technology trends that will likely shape the future composition and functioning of the value chain. The chapter ends with lining out selected institutional incentive mechanisms and barriers for environmental upgrading of coffee supply chain.

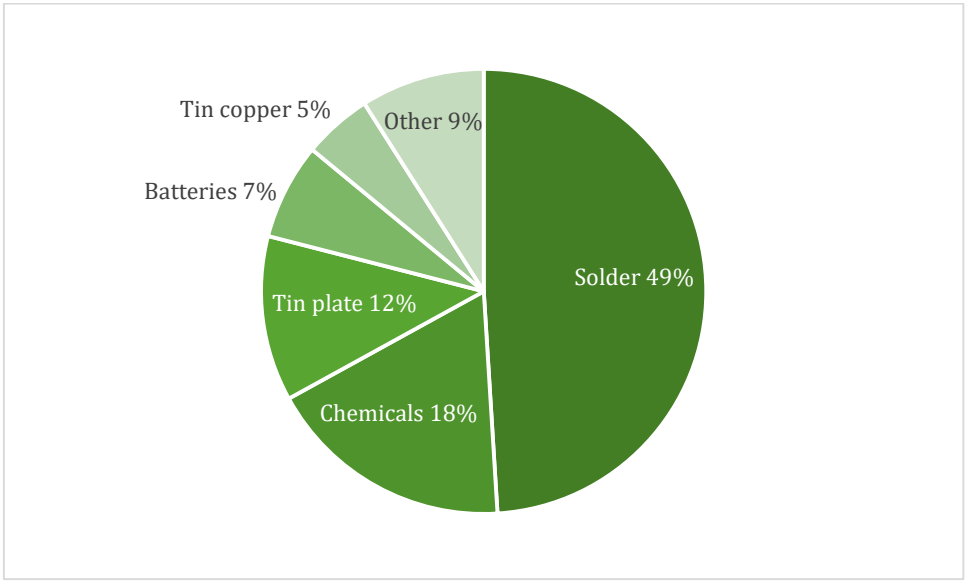
2.1 Introduction/Background

Tin is a metal and component with various applications, ranging from soldering and tinplate production and electroplating. Tin evolved into an indispensable element in the global economy, contributing to a growing number of products and processes (ITRI n.d.). In Europe, the status of tin is approaching criticality, while it is already considered a critical metal in China and the U.S. (ITA 2020a).

Tin has played a vital role throughout history, dating back 5,000 years when it was combined with copper to create bronze. It was highly valued for strengthening copper and used in tools, weapons, and jewellery. Over time tin's importance grew, leading to the development of solder, pewter, and tin plating; nowadays, tin is also used in chemical production and as coatings (ITA 2020a). Globalisation has impacted the tin industry by expanding market access and stimulating cross-border trade. However, it has also led to market price fluctuations, an increased focus on responsible sourcing and, in recent years, sustainability.

Tin, as a chemically versatile metal, has numerous applications in various sectors (see Figure 1) with the primary application in electronics (mainly as solder) (BGR 2014; BGR 2020; ITA 2020b). Additionally, tin is used in alloy production, flat screen manufacturing, solid fuel cells and lithium-ion batteries (BGR 2014; BGR 2020).

Figure 1: Global tin use by application in 2019



Source: adelphi, based on information from ITA (2020b)

According to First Tin, the semiconductor industry is a large consumer of tin as electronic solder, with the industry forecasted to double between 2021 to 2028 due to new emerging technologies like 5G and electric vehicles. Tin is also widely used in the photovoltaic sector, which has been experiencing considerable growth and is also projected to double by 2030 (First Tin 2023).

Europe has several historical tin mining regions and continues to produce tin in Spain, Portugal, as well as in regions bordering Germany and the Czech Republic, with many of the tin production projects aimed at reviving the historic mining operations. Russia has a significant mining production, and in Spain tin is produced as by-product of other mining activities. Germany's CRIRSCO compliant tin resources are approximately 308,000 tonnes along with 207,000 tonnes non-compliant resources . Germany's tin demand is around 20,700 tonnes of refined tin and 200 tonnes of tin oxides per year; there is a demand for secondary tin as well, but the exact quantities are unknown (ITA 2020a). Given the high reliance on suppliers of tin, the following profile focuses on the supply chain for tin solder used for the manufacturing of electronics.

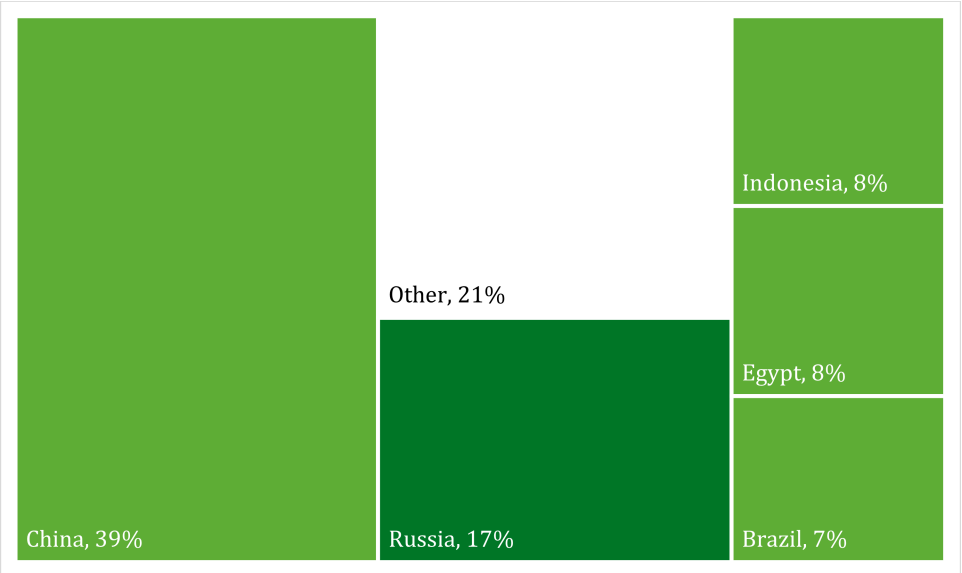
2.2 Market structure

The tin industry operates on a relatively smaller scale compared to other mining sectors. With an annual production of only 300,000 tonnes, there are approximately 30 tin smelting companies and around 1,000 larger mining sites.

Tin is produced from the mineral cassiterite; it contains various impurities that are removed during concentration, smelting or refining (International Tin Research Institute n.d.). Mining of cassiterite is performed by artisanal and small mines (ASM), as well as by larger scale producers (ITRI n.d.). ASM has a high share of around 27% in global tin production (BGR 2020).

According to the ITA (2020a) the global tin resources were estimated to be around 15.4 million metric tonnes (in 2019). The current global tin reserves are estimated to last a minimum of 18 years, while the resources could extend to at least 50.4 years, according to ITA. The geographical locations of tin reserves are shown in Figure 2.

Figure 2: Global tin reserves in 2019



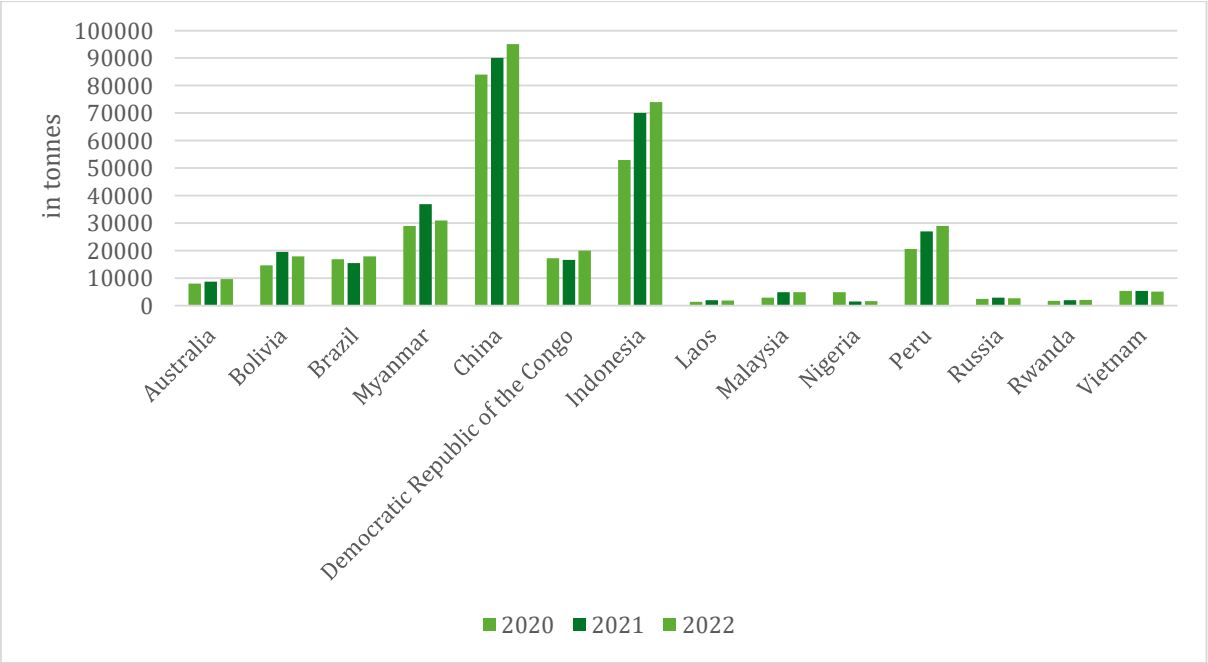
Source: adelphi, based on information from ITA (2020a)

According to Li et al. (2021) the production of tin is highly concentrated, with nine countries accounting for more than 90% of the global output. Similarly, the consumption of tin has largely

taken place in ten countries which collectively make up around 80% of the world's total tin consumption (Li et al. 2021).

Global tin mine production has risen steadily from 2020 to 2022, as seen in Figure 3. China and Indonesia lead the way, with China's output projected to increase from 84,000 tonnes in 2020 to 95,000 tonnes in 2022, and Indonesia's production estimated to rise from 53,000 tonnes to 74,000 tonnes. Myanmar also experienced growth, with production expected to reach 31,000 tonnes in 2022. Bolivia and Brazil are anticipated to produce approximately 18,000 tonnes each in 2022, with Brazil seeing an increase from 16,900 tonnes in 2020 and Bolivia from 14,700 tonnes. However, Nigeria's tin production declined from 5,000 tonnes in 2020 to an estimated 1,700 tonnes in 2022 (U.S. Geological Survey 2022; U.S. Geological Survey 2023b).

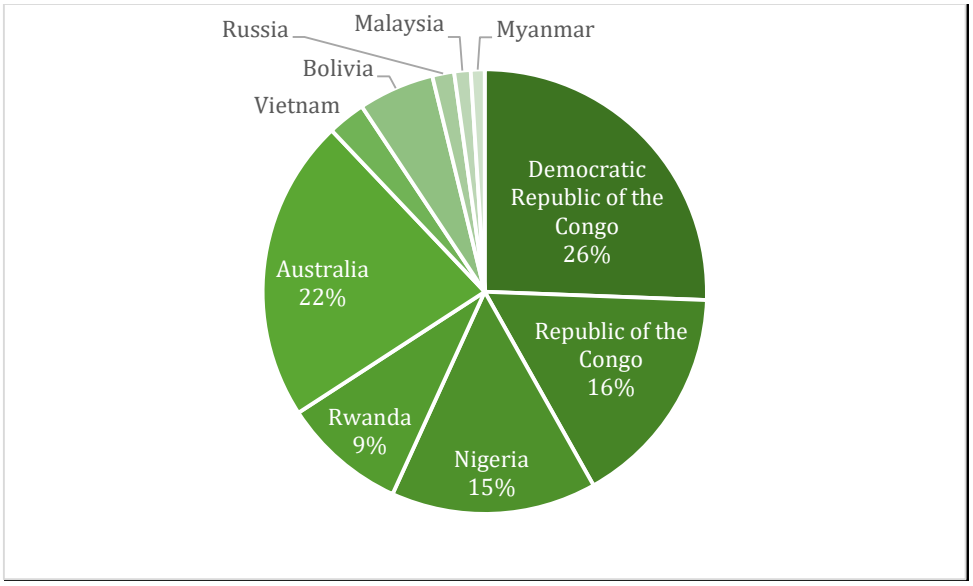
Figure 3: Mine production of tin in tonnes 2020 - 2022



Source: adelphi, based on information from (U.S. Geological Survey 2022; U.S. Geological Survey 2023b)

The primary countries **exporting tin ore** are predominantly found in the Global South. As seen in Figure 4 in Africa, the main exporters include the Democratic Republic of the Congo, the Republic of the Congo, Nigeria, and Rwanda. Beyond Africa, Australia stands out as a significant exporter as well, accompanied by a handful of countries scattered across South-East Asia and South America. To a large extent, the top ten tin ore exporting countries (see Figure 4) do not match the main countries that mine tin (see Figure 3). This is because large tin mining countries like China also refine and consume the refined tin.

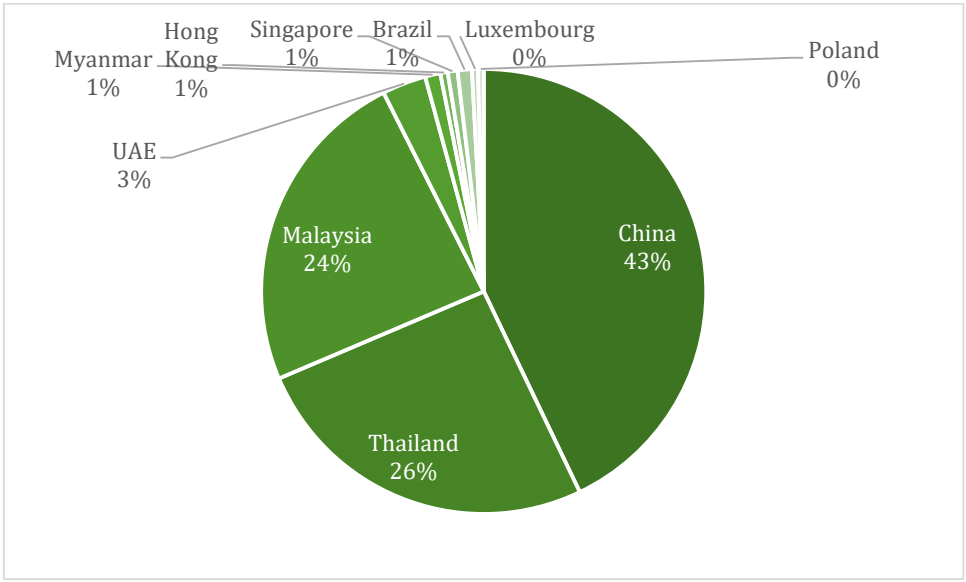
Figure 4: Top 10 exporters of tin ore by share of value in 2021



Source: adelphi, based on information from OEC (2023f)

The **import market of tin ore** as seen in Figure 5 is dominated by countries such as China, Thailand, Malaysia, and the United Arab Emirates (UAE). These nations represent the main importers due to their substantial industrial sectors which heavily rely on tin for various applications.

Figure 5: Top 10 importers of tin ore by share of value in 2021

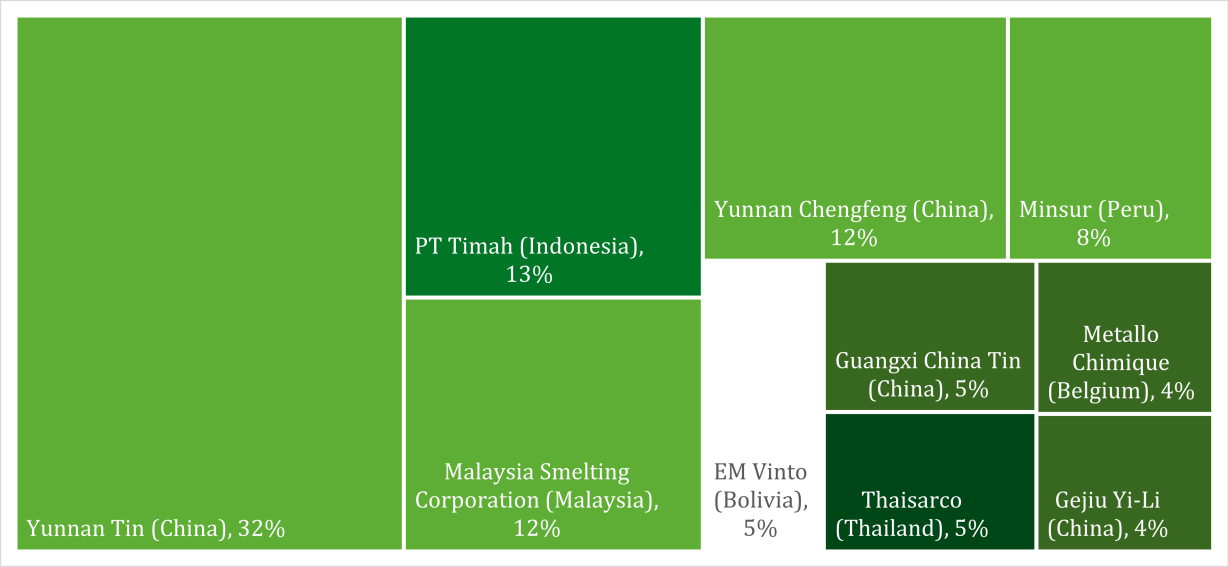


Source: adelphi, based on information from OEC (2023f)

Global refined tin production is concentrated mainly in China, Indonesia, Peru, Brazil, Malaysia, Bolivia and Thailand (Li et al. 2021). The major refined tin consumers are China, the U.S., Japan, Germany and Korea, with China being the leader in global tin consumption (Li et al. 2021). Most of refined tin consumers rely mainly on imports, while China is fulfilling their demand mainly from their own resources (ibid.) in addition to importing large quantities from Myanmar (BGR 2020).

According to the ITRI (2022) the global landscape of tin production in 2017 as seen in Figure 6 was dominated by a handful of key corporations. At the forefront of tin's production was China's Yunnan Tin, with the highest output. PT Timah from Indonesia demonstrated the strength of integrated tin mining on a global scale. The South American company, Minsur from Peru made a notable contribution to the global tin supply. The Malaysia Smelting Corporation (MSC), managed significant tin smelting and refining facilities, further contributing to the world's tin supply. Thaisarco, an established tin production organisation in Thailand, also made a significant impact on the tin production industry.

Figure 6: Leading tin producing companies worldwide in 2017, based on share of production output



Source: adelphi, based on information from ITRI (2022)

Tin's secondary market is a vital part of the global tin industry. One of the main benefits of tin is that it can be recycled easily without losing any quality, allowing it to be refined to high-quality levels (ITRI n.d.). Due to tin's high price, recycling is an economically feasible option and viable business model (BGR 2020).

According to the International Tin Research Institute, the amount of recycled tin has been increasing in recent years, making a positive contribution to the sustainability and circularity of the industry. Considering the re-use of recovered tin alloys like solders, brass, bronzes, and lead alloys, secondary materials make up more than 30% of all tin use in an average year. These alloys can be re-used without having to be re-refined to pure tin (ITRI n.d.).

Approximately two-thirds of Germany's refined tin requirement is imported and distributed by three significant trading firms (trading firms in the tin industry are referred as "brands"), which indicates an oligopolistic market structure, with the majority imports being sourced primarily from Southeast Asia and Belgium. The remaining portion is sourced from the open market, predominantly from South America. German companies like Wilhelm Grillo Handelsgesellschaft mbH and ThyssenKrupp Metallurgical Products GmbH play a critical role here, tying the extraction to end-product manufacture and forming a vital connection in the value chain (Elsner 2014).

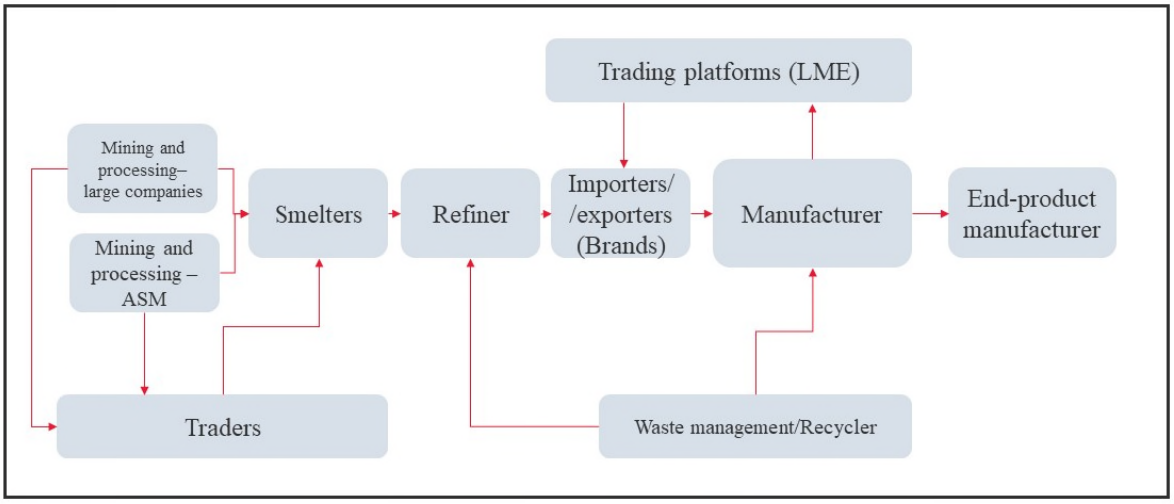
There seems to be limited available data on tin solder manufacturing and export/import. Based on existing literature, it is noted that China, being one of the major consumers and producers of refined tin, utilizes over 60% of this material in the form of solder within the electronics industry (Yang et al. 2018). Indonesia exports soldering tin, but the amount thereof is small

compared to the exports of pure tin bar (Nangoy and Bernadette 2022). According to the UN Comtrade database[1] the exports and imports of tin are clustered into the following categories: tin bars, rods, profiles and wire (HS6[2] 800300), and pickling preparations for metal surfaces; soldering, brazing or welding powders and pastes consisting of metals and other materials (HS6 381010). There are no detailed HS codes specifically for tin solder. According to the data extracted from UN Comtrade database[3], the main importers of tin products (by value) are China, Mexico, U.S., Hong Kong SAR (China), and India.

2.3 The tin value chain

The tin supply chain encompasses a wide range of actors, each playing distinct roles in adding value as seen in Figure 7. There is a moderate concentration of mine production, with a handful of entities dominating the market – e.g. Chinese firms like the Yunnan Tin Company, which have a significant influence (Bundesanstalt für Geowissenschaften und Rohstoffe 2014). However, 27% of tin is produced by ASM, which often lacks regulation and is often associated with negative impacts on the environment and human health. Despite these issues, the relatively large amount of ASM in the commodity extraction plays an important role in driving economic growth in underdeveloped and rural areas by generating more income opportunities. Small-scale mining activities are predominantly concentrated in Southeast Asia, Central Africa (specifically Rwanda, Burundi, and the Democratic Republic of the Congo [DRC]), as well as Brazil and Bolivia (Bundesanstalt für Geowissenschaften und Rohstoffe 2020). The mining operations, depending on the mining type, require different levels of investments. For example, open-pit mines can be operated with simple tools and hence are often run by family-businesses, according to an interview with an industry expert.

Figure 7: Tin value chain



Source: adelphi, adapted from Franken (n.d.), Versik Maplecroft (2017) and expert interviews

According to Vasters and Franken (2020) and interviews with industry experts conducted as part of this research, once the ore is mined, it undergoes processing and concentration, increasing the tin content, then moves on to smelters, which convert the enriched ore into a more usable form of tin. Traders purchase tin from both large companies and ASMs and sell it to

[1] The UN Comrade database is an online platform containing detailed trade data by product categories.

[2] The Harmonized System (HS) is a classification system for goods and products.

[3] Import data extracted for (BGR 2020) HS6 800300 and HS6 381010.

smelters based on the highest bid (Hodal 2012). The smelters rarely operate only with one mine or one trader, according to industry experts. Usually, the smelters acquire tin from several different mines or traders, making the tracking of the origin of tin ore challenging. Following the smelting and refining processes, the tin is then ready for trading on international platforms such as the London Metal Exchange (LME), although only a small percentage of tin is actually traded on these platforms according to industry experts.

Intermediaries like LME at this stage contribute value by absorbing the risk of price fluctuations by storing tin in global warehouses and maintaining market liquidity (more detailed information on the LME in Chapter 3.2.4). For companies, in order to trade on LME, it is a requirement to register themselves as **importers/exporters (brands[4])**. The importers/exporters (brands), enhance value by overseeing various export-import tasks such as handling import taxes, declarations, and related activities. **Manufacturers** subsequently acquire tin from them. This phase involves the transformation of the refined tin into various products like solders, tin plates, chemical products, and tin alloys (Pines 2022) and the selling of the components directly to **end product manufacturers**. The relatively high price of tin enables the recycling, which reintroduces tin from used products and waste materials back into the value chain.

According to interview results, around one fourth of mining in Indonesia takes place offshore, which creates a substantial environmental hotspot due to harming the coral reefs and other marine species. Additionally, mining conducted onshore poses other environmental challenges, particularly in relation to the movement of materials and the resulting depletion of fertile soils. The emergence of tin mining in Myanmar approximately five to six years ago has raised concerns as well. In this case, tin is directly sent to China without adequate information on the mining processes e.g. the location of mining (document of origin) or mining license, which hampers transparency and oversight. Tin mining in central Africa, specifically in regions such as the DRC, presents safety issues that require addressing, according to interviews with industry experts.

Table 1: Main environmental impacts in the tin value chain

Supply chain segments	Environmental impacts
Mining	Destruction of flora and fauna: caused by large-scale underground mining operations or open-pit mining, which requires land clearance to access the minerals.
	Marine ecosystem destruction: depleted land-based tin deposits have caused an increase in offshore mining, damaging coral reefs and mangrove swamps that are vital to marine species.
	Poor and improper waste management: practices in tin ore mining harms the water and soil. Mining generates mineral waste which can contaminate water and soil, affect the topography as well as lead to radiation exposure.
	Changes in topography: mining and mining waste causes changes in topography and lead to un-restorable and non-cultivatable land, as well as erosion.
	Toxic exhaust gases: roasting processes produce exhaust gases like sulphur dioxide as well as flue dust which can be hazardous to workers and environment.

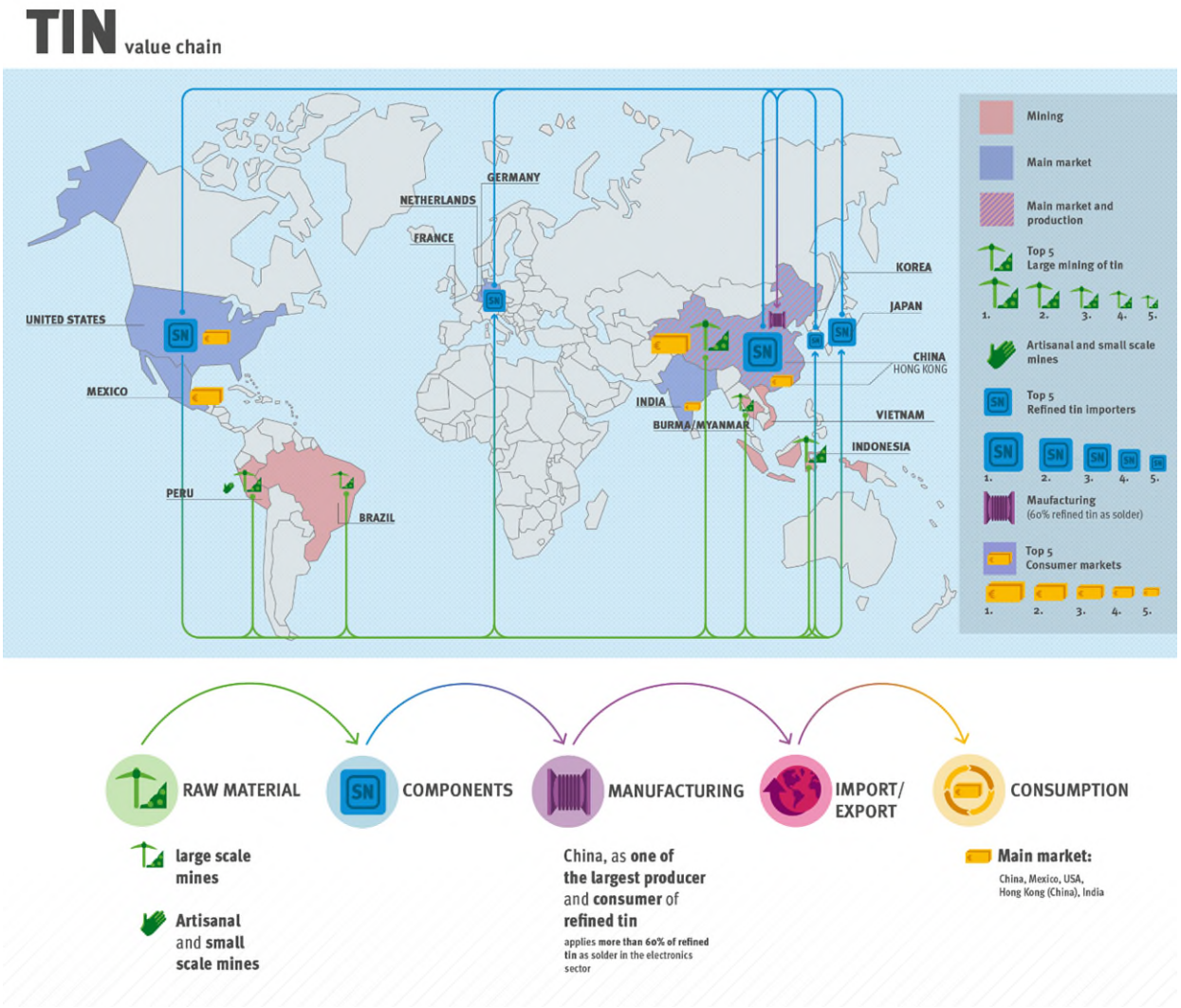
[4] The importers/exporters who register themselves in the LME are called "brands" which is a specific term for the tin industry. Unlike in other sectors, these brands are not consumer facing entities rather traders of tin.

Supply chain segments	Environmental impacts
Processing	High energy consumption in processing stages; use of non-renewable energy sources; increase in GHG emissions
	Untreated contaminated water: tin ore beneficiation requires large amounts of water. Untreated water can result in the release of contaminants and negatively impacting nearby communities and ecosystems in terms of water availability and quality.

Source: adelphi, based on information from Raw Material Outlook Platform (2023), BGR (2020) and Omotehinse and Ako

Based on the data presented in this chapter, Figure 8 shows in a thematic map selected key structures (main producer/consumer markets; actors) and processes (e.g. product flows) in the tin value chain:

Figure 8: Selected key structures and processes of the tin value



Source: adelphi, based on material and data from this text

2.4 Pricing

The price of tin is primarily driven by the principles of supply and demand, which are influenced by a variety of global macroeconomic and industry-specific factors. According to Saulich (2023), tin is traded on the London Metals Exchange (LME), which is one of the world's leading platforms for industrial metals. Other significant global exchanges include the Chicago Board of Trade, the New York Mercantile Exchange, and the Shanghai Futures Exchange (SHFE). The LME operates physical warehouses, but only a small percentage of contracts are fulfilled through physical delivery. These exchanges and trading venues serve as marketplaces for buyers (industrial processors/manufacturers and commodity traders) and sellers (producers of refined tin) or brands (traders). Financial institutions also use these trading platforms, but for hedging risks and speculation. The price formed on the LME serves as an internationally recognised reference for the traded metals, and in addition to facilitating trade, institutions like the LME play a role in regulating the industry and setting standards by defining minimum purity requirements for the traded metals and establishing requirements for responsible sourcing and disclosure of information regarding the origin of the metals, in response to public pressure (Saulich 2023). According to an interview with an LME representative, two different types of contracts are traded on the London Metals Exchange: physically settled contracts, which is applicable for tin, and cash settled. The LME operates warehouses in various regions, including North America, the Middle East, South America, and Asia. However, as mentioned above, only a small portion of the world's tin production actually goes through an LME warehouse. There are no LME warehouses in China, Russia, or Africa.

The long-term prices of tin are linked to the LME price, which reflects a global price for delivery to any LME warehouse, and is used throughout the value chain, with percentages added or subtracted depending on the position of the actor in the value chain. According to industry experts, Price Reporting Agencies (PRA) also impact tin prices by collecting and consolidating market prices. However, the tin price leads to higher volatility due to the market's small size. The LME acts as a balancing structure, allowing different actors (like brands/traders) to take advantage of high tin prices by delivering to warehouses and subsequently lowering prices. In order to participate in the LME, the seller is required to register as a brand and provide a certificate to verify the purity of the tin, its form, and the company's adherence to human rights standards. The registered importers/exporters (brands) collectively set the LME price. The buyers can then purchase tin from any LME warehouse. However, the traders and producers of refined tin prefer to sell directly to purchasers, with the LME warehouse serving as a last resort. Banks, on the other hand, insist that the producers participate in the LME for insurance reasons. In the case of bankruptcy by refined tin producers, the bank can still deliver some material from the LME warehouses and recoup some of the funds. There are no mechanisms for integrating the environmental or climate costs into the price of tin.

According to expert interviews, 90% of the net revenues from tin mining are paid to miners. The rest is distributed among other actors in the value chain. According to a German tin solder manufacturer, they plan their operations one year ahead, and therefore purchase two thirds of the needed tin quantities directly from their suppliers/brands, which means they enter into contractual agreement for one year with their suppliers. The remaining third is bought during the year as needed. In these cases, the LME price of tin is used as reference during the tin purchase. As a result, there is no pricing negotiations, as the listed price is used. The brands/suppliers add their premium to the LME price to cover their operations.

According to the data listed on LME website (see Figure 9), the LME tin official price curve had significant fluctuations during 2022 and 2023 with a price peak of $34,000 per ton in May 2023 and the lowest price around $28,000 per ton in June 2023.

Figure 9: LME tin price 2018 - 2023

Source: LME (2023)

The global COVID-19 pandemic significantly affected the tin sector in various ways, as indicated by several sources. According to the U.S. Geological Survey (U.S. Geological Survey 2021), the decline in global tin use, which began in 2019, continued through 2020, likely exacerbated by the disruptions caused by the pandemic in mining and manufacturing industries worldwide. However, despite years of stagnation, the consumption of canned foods during the pandemic led to an expected increase in tinplate usage (U.S. Geological Survey 2021).

In Myanmar, the impact of impact COVID-19, in addition to mine flooding and border restrictions, has tightened traditional sources of tin ore (U.S. Geological Survey 2021). The pandemic also resulted in temporary closures of smelters in China due to COVID-19 mitigation measures (U.S. Geological Survey 2023b) as well as worldwide. The price of tin experienced significant fluctuations due to the pandemic's impact on raw material prices. While the price of tin increased, the demand decreased initially due to restrictions on human resources and transportation barriers. However, the electronics and automotive markets showed signs of recovery in 2021, leading to an increase in tin demand (MarketsandMarkets 2022).

2.5 Power relationships

The landscape of governance in the tin value chain is fragmented, despite the tin market's relatively small size and limited number of market players, reflecting the varying degrees of influence exerted by the actors.

Power within the tin value chain exhibits a regional concentration. China serves as a prime example, dominating the market through an integrated supply chain comprising local mines, smelters, and industries engaged in the application of processed and refined tin. This dominance is further reinforced by China's status as the principal global importer of tin. The current chapter focuses on actors outside of Chinese tin market, since Chinese market structures differ from markets in rest of the world.

The miners, especially the ASMs, sell the tin to local traders who collect the metal from different sources and sell further to smelters. These traders sometimes finance the mining operations of ASMs. According to expert interviews, the ASMs may be in a weaker position relative to the traders, since they may not have a choice with whom to engage in business activities, or they might lack the updated pricing information. Following Gereffi et al.'s (2005) approach, the relationship between ASMs and traders can be described as a captive relationship. According to

industry experts, switching to more sustainable mining practices in ASM would also require getting the traders on board. The LSMs, however, in comparison to the ASMs, are in a more powerful position, as the LSMs can possess more resources for investments in technologies to drive efficiency, or as larger actors can have closer ties with the governments (as in the case of Indonesia, where there is one state-controlled integrated tin company).

Some smelters adopt an integrated approach to supply chain governance by owning their mines, in this case, following Gereffi et al.'s (2005) approach the relationship would be hierarchical structure based on integrated firm. However, the more common practice is cooperation with a range of mines and miners. The relatively small size of the tin market occasionally precipitates shifts in power dynamics among actors. In times of deficit, miners might gain an upper hand due to an increased bargaining power driven by smelters' dependence on raw materials. On the whole, miners are reported to secure around 90% of the net profits from tin, with the balance distributed among smelters with the tin price set on the LME market.

Manufacturers, i.e. the purchasers of refined tin, usually opt for the most economical supplier, maintaining relationships with multiple sources (brands) and switching mainly based on price differentials. Since the quality requirements are mandated by LME, the purity of the purchased tin is assumed to comply with standards. These purchasing practices suggests a captive market with buyers purchasing from several suppliers. The price disparities among the brands predominantly stem from the premium added on the base tin price, intended to offset operational costs such as import taxes and other overheads. In addition to cost considerations, manufacturers (purchasers of refined tin) can impose various requirements on their suppliers, e.g. compliance with certain certification schemes or sustainability standards.

The end consumers/purchasers of tin-containing end-products have some power to dictate sustainability requirements for the industry by driving the demand for responsibly sourced tin. According to Diprose et al. (2022), the major electronics companies established the Tin Working Group (TWG) in 2021, which was driven by public pressure for enhancing sustainability and traceability in the tin supply chain. The public pressure began with a UK-based NGO, Friends of the Earth, and their Indonesian branch; they documented the social and environmental impacts of tin production in Indonesia and received widespread media coverage. However, the TWG faced challenges, including a lack of commitment to sustainable practices and corporate motivation. Despite this, the TWG garnered support from influential political and economic entities, facilitating the spread of sustainable practices in Indonesia's tin industry. This requires ensuring that these entities receive some benefits, even if those benefits are not directly tied to the regulatory goals (Diprose et al. 2022).

International NGOs, media outlets (Hodal 2012), and major companies in the worldwide electronics supply chains advocated for sustainability, which empowered Indonesia's government and the national tin corporation to reinforce their dominance in domestic debates over regulatory power and market dominance. However, these efforts are frequently motivated more by the intent to dominate the market and control the revenue generated from tin production, rather than sincere dedication to sustainability standards (Diprose et al. 2022).

Purchasing practices

The main business models to source tin can be summarised as is in Table 2:

Table 2: Dominant business models and governance in the tin value chain

Business model	Type of buyers	Governance	Type of relationship	Procurement procedure
Mix of key & occasional suppliers	Smelters	Hierarchical in case of integrated firm; relational		Price dominant
Mix of key & occasional suppliers	Manufacturers	Captive	Short- to medium term contracts	Highly competitive; price dominant

Source: adelphi, based on classification from Gereffi et al. (2005) and information from expert interviews

The manufacturers of tin-components purchase tin directly from brands. These manufacturers hold the pricing power, as the marketplace is relatively competitive with the stock price as reference for short-to-medium term contracts, according to one actor. However, in recent years some manufacturers have started including sustainability aspects in their assessment of brands, which in turn can reduce the number of players from whom the manufacturers are able to purchase tin. There are some smelters with integrated supply chains, but most of them cooperate with several different miners and/or traders. The power structures between the miners and smelters can shift depending on the market situation.

2.6 Addressing environmental impacts

The landscape of governance in the tin value chain is fragmented, despite the tin market's relatively small size and limited number of market players, reflecting the varying degrees of influence exerted by the actors.

Power within the tin value chain exhibits a regional concentration. China serves as a prime example, dominating the market through an integrated supply chain comprising local mines, smelters, and industries engaged in the application of processed and refined tin. This dominance is further reinforced by China's status as the principal global importer of tin. The current chapter focuses on actors outside of Chinese tin market, since Chinese market structures differ from markets in rest of the world.

The miners, especially the ASMs, sell the tin to local traders who collect the metal from different sources and sell further to smelters. These traders sometimes finance the mining operations of ASMs. According to expert interviews, **the ASMs may be in a weaker position relative to the traders**, since they may not have a choice with whom to engage in business activities, or they might lack the updated pricing information. Following Gereffi et al.'s (2005) approach, the relationship between **ASMs and traders** can be described as a **captive relationship**. According to industry experts, switching to more sustainable mining practices in ASM would also require getting the traders on board. **The LSMs**, however, in comparison to the ASMs, are in a **more powerful position**, as the LSMs can possess more resources for investments in technologies to drive efficiency, or as larger actors can have closer ties with the governments (as in the case of Indonesia, where there is one state-controlled integrated tin company).

Some **smelters** adopt an integrated approach to supply chain governance by owning their mines, in this case, following Gereffi et al.'s (2005) approach the relationship would be **hierarchical structure based on integrated firm**. However, the more common practice is **cooperation** with a range of mines and miners. The relatively small size of the tin market occasionally precipitates **shifts in power dynamics** among actors. In times of deficit, miners might gain an upper hand due to an increased bargaining power driven by smelters' dependence

on raw materials. On the whole, miners are reported to secure around 90% of the net profits from tin, with the balance distributed among smelters with the tin price set on the LME market.

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Purchasing practices

The main business models to source tin can be summarised as is in Table 3:

Table 3: Selected sustainability schemes for mining sector, covering tin

Sustainability schemes	Implementation of sustainability requirements beyond commitment and reporting[6]	Sustainability commitments in company policies	Sustainability reporting requirements	Requires traceability and tracking of origin of raw material, i.e. mine secondary source	Requires supply chain due diligence on conflict risks and human rights violations[7]
Global reporting			✓		

[5] The original report was not available online anymore at the time of writing this paper.

[6] May include due diligence on conflict risks and human rights violations

[7] May include sustainability commitments, reporting requirements and raw material tracking

initiative (GRI) *					
International Finance Corporation (IFC) *	✓				
Initiative for responsible Mining Assurance (IRMA) *	✓				
Mining Association of Canada (MAC) *	✓				
International Council of Mining and Metals (ICMM) *		✓	✓		
Regional Certification Mechanism (RCM) **					✓
ITRI Tin Supply Chain Initiative (iTSCi) **					✓
Certified Trading Chains (CTC) **	✓			✓	

*** Commodities covered in the scheme: all, including tin**

****Commodities covered in the scheme: tin, tungsten, tantalum and gold**

Source: adelphi, adapted from Kickler and Franken (2017)

The manufacturers of tin-components purchase tin directly from brands. These manufacturers hold the pricing power, as the marketplace is relatively competitive with the stock price as reference for short-to-medium term contracts, according to one actor. However, in recent years some manufacturers have started including sustainability aspects in their assessment of brands, which in turn can reduce the number of players from whom the manufacturers are able to purchase tin. There are some smelters with integrated supply chains, but most of them

cooperate with several different miners and/or traders. The power structures between the miners and smelters can shift depending on the market situation.

2.7 Current/future trends and developments

An important trend in recent years has been the increased focus on responsible sourcing and purchasing practices, partly in response to regulations such as the EU Conflict Minerals Regulation and the Dodd-Frank Act in the U.S., as well as growing consumer awareness and demand for ethically sourced products. This has led to the establishment of various industry initiatives aimed at promoting responsible sourcing, such as the RMI and ITSCI (more on voluntary certification initiatives and schemes in Section 232.6). Table 4 shows the main market, consumer and technology trends.

Table 4: Market, consumer and technology trends

Market trends	► Upward trend in demand for electronics increases the demand for tin, which in turn leads to rising tin prices ► Increasing focus on responsible sourcing from end-consumers and different market players leads to more sustainable and informed purchasing practices ► Increasing application of voluntary schemes by industry actors downstream ► Increasing price of tin creates more lucrative business opportunities for recycled tin. At the same time, the demand for recycled tin is driven by manufacturer motivation for more sustainable sourcing practices as well as policies which support recycling of tin (e.g. under the green deal) ► Increasing price of tin can lead to exploration of new mining locations and opportunities or revival of old mines in the EU
Consumer trends	► Growing consumer awareness and demand for ethically sourced products
Technology trends	► Technologies for traceability and transparency (e.g. blockchain)

Sources: adelphi, based on information from Franken (2019) and expert interviews

2.8 Institutional incentive mechanisms and barriers

Environmental legislation in producing countries

According to industry experts, some governments of tin producing countries have taken several steps in implementing mechanisms to address the environmental concerns of mining tin. For example, mandatory **environmental impact assessments** (EIA) have been established as a requirement before commencing the mining activities, which in the case of LSM are meticulous enough, according to industry experts. That stated, in the case of ASM, they can be either non-existent or fake. Also, the EIAs may lack independent data, particularly in monitoring water quality and formalisation processes. This information scarcity greatly impedes the ability to track the effects of mining activities and provide recommendations to local governments regarding the adoption and enforcement of local laws (Germanwatch e.V. 2021). Even though the governments have set up regulations, they might not have the capacities to enforce them. In addition, corruption can hinder the enforcement of the policies.

As an example of local policies, in the case of Indonesia, robust controls on recultivation (restoration of the land used for mining) have been put in place, mandating miners to contribute to a designated fund which, after the mining operations have ended and the land has been re-cultivated, will be returned to the mining company. However, research findings indicate that the implementation of reclamation obligations in the example of Bangka Belitung island has been inadequate. Despite the presence of sanctions outlined in the reclamation law, their effectiveness in promoting optimal reclamation practices has been limited. This situation has prompted an amendment to the law, emphasising the need for stricter enforcement by the authorities. The amendment aims to address the shortcomings and enhance compliance with reclamation obligations (Haryadi et al. 2023).

Environmental legislation in consuming countries

The tin industry is set to experience significant changes due to policy trends that impact its value chain. These include the Directive on corporate sustainability due diligence (not yet adopted), which requires companies to monitor and mitigate adverse human rights and environmental impacts. The CSRD requires large and listed companies to disclose social and environmental risks and impacts. The *EU Circular Economy Action Plan* (CEAP) promotes recycling and waste reduction, potentially increasing the demand for tin recycling, which in turn can support the growing demand for recycled tin.

Insights from the interviews emphasise that the introduction of new legislation, such as that implemented by the EU, may have limited impact on the tin market due to its concentration in specific regions. China and the U.S. currently dominate the market, and their influence prevails despite regulatory changes. This underlines the importance of considering the prevailing dynamics and influence of major players in the industry. However, larger companies, who make tin purchases in bulk and exert more purchasing power, can have also a larger influence and a trickle-down effect on the less transparent regions. According to expert interviews, the dynamics between China and the West will become an important question in the future. There is a need for more cooperation and transparency. Establishing a circular economy of rare minerals in the West and extracting rare metals from urban mines[8] could provide leverage for the West in future cooperation with China.

Interview results also show that, in the case of central Africa, particularly in the DRC, the mining of tin is regulated under the *Dodd-Frank Wall Street Reform and Consumer Act* of 2010, the first piece of legislation that forced companies to implement due diligence in their operations. According to this legislation, companies are obligated to disclose whether any conflict minerals originated from the DRC or its neighbouring countries. If sourced from these regions, companies are obligated to provide a Conflict Minerals Report, which is subject to auditing by an independent private auditor. The report outlines the due diligence measures undertaken, including details on the facilities involved in conflict mineral production, the country of origin, and the chain of custody of these minerals (IEA 2022).

Trade agreements and policies

Government policies can have an impact on the global tin industry. Indonesia has been a leading country in exports of tin, but due to the government's desire to support domestic smelting industry, tin export was banned, which affected the global tin prices. The ban was then lifted due to budget deficits (Pines 2022).

According to industry experts, the government of Rwanda is actively driving companies to embrace modern business practices, affected by global pressure to produce conflict-free and

[8] Urban mining is the process of recovering rare metals from discarded waste electrical and electronic equipment (WEEE).

environmentally friendly materials. However, it is important to consider the limitations posed by economic feasibility, particularly for smaller mines that lack sufficient financial resources. In contrast, larger mining companies with varying profit margins are in a better position to meet environmental standards. Striking a delicate balance in regulations becomes crucial as there is no "average" mine, and the unique circumstances of each operation must be considered. China's role in global tin trade (both demand and supply) may be a decisive factor in the future, as it can be expected that China will continue consolidating its hegemony in the tin market.

Transparency

Transparency in the tin supply chain is a critical issue, as highlighted by industry experts in interviews. Stock exchanges play a vital role in promoting transparency and responsible practices. Notably, the LME falls under the requirements of the Modern Slavery Act, mandating companies to disclose measures taken against forced labour and human trafficking in their supply chains. Ensuring the traceability of raw materials is increasingly important, leading to the application of innovative technologies and solutions. However, it remains a challenge, as non-compliant tin can still be smuggled into the supply chain undetected. The lack of a single standard for reporting sustainability poses additional difficulties, and the consolidation of collected data for publication would be beneficial. Regarding the facilitation of cooperation between actors along the supply chain, several incentive mechanisms and barriers were identified. One major challenge is the difficulty in ensuring traceability when a company has multiple suppliers; it is hard to track the origin of materials and ensure compliance with sustainability standards. Even integrated companies sometimes source materials from different locations due to price fluctuations, which further hinders traceability and collaboration efforts. China, accounting for approximately 60% of tin production, operates differently in terms of tin trading. Chinese-produced tin is primarily used within China and not traded on international markets. Consequently, the Chinese government is reluctant to share comprehensive information regarding the tin supply chain. This poses an obstacle to achieving full transparency within the global tin market.

In order to enhance the transparency in the supply chain, the International Tin Mining Association introduced the ITSCI Programme, which involves tagging tin mining production, enabling better visibility and traceability throughout the supply chain. ITSCI promotes the responsible sourcing of 3T minerals from conflict-affected and high-risk areas. Aligned with OECD Minerals Guidance, it aims to prevent conflict financing, human rights abuses, and bribery in mineral supply chains (iTSCi n.d.). According to expert interviews, currently, there is no general duty for due diligence and the implementation of schemes like ITSCI are voluntary. However, shareholders are increasingly demanding audits to ensure responsible practices are upheld in mining. Interview results also show that, in the case of central Africa, particularly in the DRC, the mining of tin is regulated under the Dodd-Frank Wall Street Reform and Consumer Act of 2010 (IEA 2022).

Outlook

According to the industry report released by the ITA (ITA 2020a), the recycling of tin is expected to gain more significance as demand continues to rise. The report highlights a long-term upward trend in demand for tin, which is further supported by significant reserves and the potential for an increase in tin recycling. As prices for tin increase, it is anticipated that exploration activities will also expand. Industry experts suggest that these higher prices may serve as a motivation for exploring mining sites within the EU. The potential economic benefits resulting from the rising prices of tin are likely to stimulate the search for new mining locations. The demand for tin is projected to grow due to its extensive applications across various industries. However, the report emphasises the importance of sustainable and transparent tin mining practices in order

to maintain the positive reputation of tin and ensure confidence in the supply chain for downstream buyers.

3 Sustainable supply chain management approaches and instruments

This chapter is an excerpt of the report "Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Business approaches and instruments of sustainable supply chain management" (Grüning et al. 2024). The chapter shows which approaches and instruments for SSCM are used in the tin and tin-solder supply chain and to what extent. The information is based on desktop research, interviews with industry experts and consultation with an Expert Advisory Board comprising individuals from business, civil society and academia. The chapter concludes with a matrix in which the observed and described SSCM approaches and instruments are categorised.

3.1 Main environmental impacts in the tin supply chain

Environmental hotspots along the tin value chain, from mining to solder production, present several challenges, including water usage and contamination, soil degradation, marine ecosystem damage, air pollution, and waste management. Tin mining, in particular, undermines environmental stability, contributes to **pollution** (Nurtjahya et al. 2017) and results in the **destruction of the natural environment** (Yang et al. 2018). This sector, besides producing mining outputs, significantly alters land use and landscapes in ways that are often irreversible (Harahap et al. 2018) . **Land-clearing** for mining and using land as **waste dumps** for barren rock can lead to irreversible **topographical changes** and **soil degradation** (Vasters and Franken 2020). These practices complicate recultivation efforts and introduce pollutants like **acidic water** and increased **radioactivity** into the environment (Vasters and Franken 2020). Offshore tin extraction significantly damages marine ecosystems and **impacts biodiversity**. Mining operations reduce **water quality**, altering the sea bed and consequently affecting biodiversity (Nurtjahya et al. 2017). The **sediment clouds** resulting from these operations damage marine flora and fauna, including corals, even at considerable distances from the extraction point (Vasters and Franken 2020). In Bangka Belitung, Indonesia, the mining process has resulted in a 40% decrease in plankton species and a 70% drop in seagrass variety compared to less mined waters, along with a notable decline in coral reef-associated fish populations (Nurtjahya et al. 2017). These changes in marine habitats have adversely affected local fisheries, leading to significant economic impacts on local communities (Nurtjahya et al. 2017). In addition, the degradation and deposition activities along the coastlines of islands where tin is mined have negatively impacted ecosystems, affecting up to 70% of the Bangka Belitung coastlines (Vasters and Franken 2020). Rivers receiving tin sedimentation have shown a nearly 30% **reduction in fish species**, indicative of considerable ecological disturbances in riverine ecosystems due to mining activities (Nurtjahya et al. 2017).

While the mining stage of the supply chain exhibits the most prominent environmental impacts, subsequent steps also contribute to ecological concerns. Specifically, the processing and refining stages can lead to **water contamination** and **greenhouse gas (GHG) emissions**, especially if non-renewable energy resources are utilised (Vasters and Franken 2020). During the processing phases, untreated contaminated water can include hazardous metals such as arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), mercury (Hg), lead (Pb), and zinc (Zn). In terms of air quality, dust emissions during the processing stages may contain hazardous metals such as arsenic (As), cadmium (Cd), lead (Pb), and mercury (Hg), accompanied by sulphur dioxide (SO2), total volatile organic compounds (TVOC), and polychlorinated dibenzo-p-dioxins/furans (PCDD/F). The specific composition of these emissions can vary, with additional pollutants like particulate matter (PM10) and nitrogen oxides (NOx) potentially present, depending on the

ore's properties and the nature of the deposits. Table 5 provides an overview of these environmental impacts across various stages of the tin value chain.

Table 5: Main environmental impacts along the tin supply chain

	Mining	Processing		Solder production
		Smelting	Refining	
Water/ Chemicals	Untreated contaminated and acidic water	Untreated contaminated water. Main pollutants metals such as As, Cd, Co, Cu, Hg, Pb, Zn.		
Land use/ Soil	Onshore: land clearance, soil degradation, changes in topography, erosions, coarsely structured soil Offshore: change in seabed			
Energy		GHG emissions, in case of use of non-renewable energy sources		
Air	Dust particles	Dust emissions containing metals like As, Cd, Pb, Hg, SO2, TVOC, and PCDD/F. Depending on the characteristics of the ore and the deposits, additional pollutants may include particulate matter and nitrogen oxides.		
Waste	Hard rock waste, which can be radioactive	Tailings	Slag	
Biodiversity	Onshore: reduced fish stock in rivers Offshore: damage to collar reefs and mangroves, biodiversity loss, reduced fish stock			

Source: own illustration (adelphi), based on information from Vasters and Franken (2020), Nurtjahya et al. (2017) and expert interviews.

3.2 Sustainable supply chain management approaches and instruments used in the coffee supply chain

The tin industry, characterised by its fragmentation and the dominance of key global players in specific regions, faces challenges in implementing sustainable practices. According to Harayadi et al. (2023), mining activities are synonymous with environmental degradation and it is challenging to find a sustainable mining environment, an idea which is also supported by experts interviewed in the context of this study. The buyers of refined tin, such as solder and semiconductor producers, alongside smelters and other entities, are all important actors in mitigating the environmental impacts of tin listed in Table 2 (cf. also chapter 3.2 of Strasser et al. 2024). These stakeholders, particularly solder producers and Original Equipment Manufacturers[9] (OEMs), can hold significant influence over the industry's sustainability direction with their purchasing practices, following a coercive sustainable supply chain management (SSCM) strategy. However, according to experts, the adoption of sustainable measures is often met with resistance upstream, especially from miners who might be reluctant to implement (additional) sustainability approaches and measures due to the associated costs. In addition, the demand of tin as a product is assured, which can lead to confidence on the upstream actor's side that the product will be purchased regardless, even without any additional implemented measures. Also, the widespread presence of informal Artisanal and Small-scale Mining (ASM) adds to the complexity of implementing sustainable mining practices.

In order to address the environmental impacts of tin mining, there are different **government-enforced compulsory approaches and instruments,** such as laws, regulations, mandatory environmental impact assessments (EIAs), and risk assessments. The EIAs, as described in more detail in a report by Strasser et al. 2024), are required before the mining operations can begin, and need to be performed by the miners and at their cost. However, as discussed by (Strasser et al. 2024), the effectiveness of the EIAs remain questionable, due to the significant share of ASM operations that may operate with minimal oversight. In order to adhere to local laws, the companies are generally required to establish internal management systems for responsible sourcing in addition to investing into long-term supply-chain partner development, according to interview partners. In the case of Indonesia, in regions such as Bangka Belitung, the regulatory framework has been criticised for not being visionary enough to prevent environmental degradation (Haryadi et al. 2023). Despite local regulatory efforts aimed at managing the extraction of tin in a sustainable manner, challenges persist, highlighting significant issues such as a lack of supervision, poor implementation of sustainability principles, and inadequate enforcement of post-mining environmental and social obligations (Monteiro et al. 2021). This indicates that regulation, particularly in the upstream sector, remains a problematic area (Haryadi et al. 2023).

Voluntary sustainability programmes are a common method to promote responsible mining practices through strategies like reporting, monitoring, and independent verification. These initiatives address various concerns including human rights, environmental management, and corporate governance (Franken et al. 2020). Many of the approaches and instruments in the industry were first established as a response to tackle human rights issues, however the approaches also contain aspects related to environmental impact mitigations. With regard to the approaches and instruments that are discussed in Chapter 2, mainly **buyer-individual and**

[9] It should be noted that a limited number of solder producers list sustainability approaches on their websites. Among the several reviewed companies, only two demonstrated clear sustainability instruments. The scarcity of sustainability disclosures among solder producers led to an examination of OEMs and their approaches, due to their significant influence on to the upstream supply chain actors.

buyer-collective voluntary approaches are observed (some of which might overlap). In addition, there are several **third-party offered profit-focused approaches and instruments,** and a smaller number of **supply chain collective approaches** that are applied on a **voluntary** basis. Several of the approaches and instruments described in the following sections are applied by selected buyers or suppliers in the industry and do not apply to all stakeholders.

In the tin industry, power dynamics between buyers and suppliers fluctuate with market conditions, yet buyers maintain a degree of leverage in guiding suppliers towards more sustainable business practices. OEMs[10], who procure either refined tin or tin-containing components, are more exposed to their customers, which subjects them to public scrutiny if the sustainability of their end-products is questioned. As a result, despite the shifting power relations, it is predominantly these OEMs and the solder producers at the downstream end of the supply chain that are steering the industry towards environmental protection as part of a **coercive strategy**.

Most common approaches and instruments in the tin industry are **buyer-individual/collective voluntary approaches and instruments**. Many companies, especially large, public organisations, often apply sustainability commitments and targets which are made public in their yearly sustainability and/or ESG reports. ROHM Semiconductor's approach includes a comprehensive focus on environmental issues which are detailed in their CSR Procurement Guidelines (ROHM 2017).

In response to the US Dodd-Frank Act and the EU Conflict Minerals Regulation, ROHM Semiconductor established the ROHM Group Procedures for Responsible Mineral Procurement (ROHM n.d.). Under the initiative, the company conducts a Mineral Procurement Survey Process in line with the OECD Due Diligence Guidance, which involves requiring suppliers to engage with the Responsible Minerals Initiative's (RMI) Responsible Mineral Assurance Process (RMAP)-certified smelters. With this, ROHM ensures involved tin smelters have undergone or completed third-party audits, including RMAP, and collaborates with suppliers to initiate such audits where necessary. By reviewing RMI and smelter websites, ROHM verifies participation and audit schedules. According to survey results published on ROHM's website, 100% of smelters were RMAP-certified. In addition, the company sets annual auditing goals for tin suppliers. The website indicates that in the financial years 2022 and 2023, audits were conducted on two suppliers of 3TG[11] metals, with one supplier in 2022 agreeing to enhance their operational procedures to meet ROHM's requirements minerals (ROHM n.d.).

In the case of Apple Inc., as described in their annual progress report "People and Environment in Our Supply Chain," the company is actively mapping 3TG smelters and refiners, and achieved 100% assessment compliance in 2022 (Apple 2023). Their Supplier Code and Standards, which are annually updated, cover a range of areas including labour, health, safety, and environmental management, adhering to international guidelines from the ILO, UNGPs, OECD, and the Responsible Business Alliance (RBA) Code of Conduct. Addressing the tin supply chain, Apple has focused on responsible mineral procurement by conducting regular smelter and refinery audits, including surprise assessments (a classical measure within a coercive SSCM strategy) to ensure compliance with required standards. These assessments are carried out globally by independent, third-party auditing firms accredited to meet international standards and often

[10] It should be noted that a limited number of solder producers explicitly list sustainability approaches on their websites. Among the reviewed companies, only two demonstrated clear sustainability instruments. One was identified as having a comprehensive sustainability framework, while another company was holding ISO 14001 certification. This scarcity of sustainability disclosures among solder producers led to examination of OEMs, who have influence on the sustainability practices and who's instruments and approaches influence other actors upstream the tin supply chain.

[11] 3TG stands for tin, tantalum, tungsten and gold

certified by the RBA. Based on the Apple's progress report, the company ensures its suppliers adhere to its requirements by engaging in **capability-building** activities, which help suppliers quickly rectifying non-compliance issues, and by providing ongoing **training,** including virtual learning materials which are distributed via supplier communication programme, and access to experts for personalised coaching. The company has established a $50 million Supplier Employee Development Fund (SEDF) which is dedicated to expanding workers' rights awareness, empowering employee voices, and broadening educational and skill-building opportunities within the supply chain and local communities (Apple 2023). The report remains ambiguous when it comes to whether the fund covers supplier-focused capability-building and training designed to ensure compliance with Apple's supplier requirements. Consequently, it remains uncertain who finances these capability-enhancing activities. According to expert interviews, Apple as a large public company may be exposed to public scrutiny in case of unethical practices, therefore their approaches for ensuring ethical and environmentally sound supply chains as well as supplier capacity building is above the industry average, and not the standard practice. However, their top-down approach to ensuring SSCM is a clear indication of a coercive strategy.

In order to enable supply chains transparency, some companies publish the lists of smelters and refiners with whom they engage in business activities (**buyer-collective voluntary approach and instrument)**. In the case of Apple, the company makes their Smelter and Refiner List public (Apple 2022a). ROHM does not publish the names of the companies with whom they cooperate with, however, they indicate on their website that 100% of their suppliers are certified by the RMAP of the RMI (ROHM n.d.). The RMI publishes on their website the lists for tin smelters who are participating in RMAP and are willing to complete the RMAP audit as well as the smelters who are already conformant with RMAP audits (**supply chain-collective voluntary approach and instrument)** (RMI n.d.). Smelters that voluntarily choose to participate in the RMAP are required to **pay for their audits** (RMI n.d.). The RBA Foundation, established in 2015, supports the Responsible Business Alliance's (RBA) activities, focusing on responsible mineral sourcing while utilising public funding to develop special programmes, research projects, and tools for public benefit in this area (RMI n.d.). The RBA also manages the RMAP audit fund, which provides **financial assistance for initial assessments** for new eligible fascilities, and **upstream due diligence** activities (RMI n.d.).

In case a smelter or refiner is removed[12] from the RMI list for not meeting their requirements, the buyer might stop business activities with the supplier (both **punishment-based approaches**). However, some industry experts argue that relying on certified smelter lists, such as RMI's, may not accurately reflect on-the-ground realities. They claim that the RMAP smelter list is unreliable and inconsistently applied. This information can lead buyers to de-risk by avoiding challenging supply areas needing investment, favoring easier sources instead.

There are several **third-party offered voluntary profit-focused approaches and instruments** applied in the tin supply chain. Suppliers can apply for certification schemes as discussed in (Strasser et al. 2024). Certification for ISO 14001 seems to be the industry standard, as seen on company websites like AIM Metals & Alloys LP, PT Timah and Minsur (PT TIMAH TBK n.d.; AIM Metals & Alloys LP 2019; Minsur 2022). PT Timah, an integrated company, allocates a budget for various certifications related to waste management, emission, and remediation, (Harahap et al. 2018). However, taking into consideration the large scale of ASMs in the tin supply chain there is limited evidence that (voluntary) certification schemes improve working conditions or miner capacities (Franken et al. 2020). Issues such as unrecognised land titles

[12] In addition to not adhering to the RMAP, smelters can be removed from the list due end of economic activity or due to smelters decision not to continue participating in the program.

complicate responsible sourcing, potentially **increasing costs without external financial support** (Franken et al. 2020). Research by (Matthysen et al.) suggests that increased regulation in ASM might negatively impact the socioeconomic status of miners. This is supported by (Hilson et al. 2016), who highlight the limitations of certification schemes (and other voluntary sustainability initiatives) in supporting ASM development. According to the civil society organisation Electronics Watch, the example of mining cooperatives in Bolivia (**supplier-collective voluntary approach**) highlights the challenges miners face in adopting sustainable practices (Electronics Watch 2023). Miners struggle financially due to late payments from smelters and fluctuating tin prices, which makes it difficult to invest in modernising equipment as required by evolving environmental regulations. Despite these constraints, mining cooperatives in Bolivia are addressing their environmental impact. With limited resources, they have innovated by developing systems to recycle water, substituting harmful solvents with less polluting alternatives like soap, and reprocessing minerals typically discarded as waste. In addition, the lack of access to credit further hinders their ability to adopt sustainable practices. However, a potential solution lies in a **cooperative approach with smelters** to access affordable and sustainable financing (Electronics Watch 2023). Similarly, in industrial mining, identifying and managing additional costs, from compliance to on-site improvements, remains a challenge, according to (Franken et al. 2020).

The Tin Code standards are designed for global tin mining, smelting, and recycling operations and aim for harmonised reporting, progressive improvement. They also include provisions for third-party verification, especially benefiting small-scale and artisanal miners (**supplier-collective voluntary approach**) (ITA n.d.a). Initiated by the producers, the Tin Code provides a systematic format for providing information to buyers. Originally a voluntary initiative, the International Tin Association's (ITA) requires its members to adhere to the Tin Code and publish the reports on ITA's platform. For example, the smelting company Thaisarco adheres to the International Tin Association's (ITA) Tin Code, focusing on risk identification and regular mine visits, with findings published in their yearly mine-visit reports (Thaisarco 2022).

The London Metal Exchange (LME) has introduced a Responsible Sourcing Policy for LME-Listed Brands, focusing on ensuring supply chains respect human rights and avoid contributing to conflict financing or corruption (LME 2024). In addition, the policy mandates that all producers manage environmental risks at their facilities (**third-party offered voluntary profit-focused approaches and instruments**). By December 31, 2023, producers had to demonstrate their implementation of the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas, and submit ISO 14001 and ISO 45001 certificates to demonstrate their environmental and safety management systems. Non-compliance can result in the LME suspending or delisting the brands (LME 2024). According to the LME presentation "ESG Transparency on the Exchange" (2022), the exchange collects information on 160 data points listed on LMEpassport which cover, among others, data related to the GHG emission reporting (scopes 1, 2, and 3), ISO 14001, and the ITA Tin Code. In this presentation the LME acknowledges the potential of **green premiums** to promote sustainable practices and aims to empower its users to base their procurement choices on ESG criteria. This will be enabled by analysing and pricing of relevant sustainability and ESG data and pricing premium into contracts (Hanson 2022). However, this practice is not yet available.

According to Loch et al. (2023), the above-mentioned RMI is the only organisation that has a programme targeting the tin industry, which in turn poses some limitations for the smelters, since they don't have alternative programmes to switch to. In addition, there is limited visibility for the downstream actors in terms of where the smelters source their metal from (Loch et al. 2023). The **chain of custody/traceability** is a **buyer-individual approach**, ensuring that suppliers meet the sustainability criteria set by the downstream actors (e.g. through tier-specific

supplier code of conduct) (van den Brink et al. 2019). One of the traceability approaches in use is the iTSCi scheme[13], established after 2010, which has been functioning effectively but also has its own challenges (Postma et al. 2021). Focused primarily on mines, iTSCi involves tagging and sealing sacks of mineral concentrate. If the seals are cut, it indicates potential tampering with the minerals, allowing for follow-up actions. By 2019, the scheme covered more than 2,000 mines (Pact n.d.); however, some industry experts question the scheme's effectiveness, particularly due to the management of mining sites where contraband tin can still be smuggled in between the audits by upstream actors. Ensuring the traceability would require permanent on-site representation of the **downstream buyers at their own cost**, however this approach is too expensive to implement. In addition, it would require set-up costs from the supplier's side. While different traceability schemes and approaches ensure market access for the mines under these schemes (Franken et al. 2020), the associated costs must be covered by the miners.

According to some industry experts, it is very challenging to track exactly from which mine the supplied tin originated without having integrated supply chains. The smelting and refining company Thairasco, however, determines the origin of tin by requesting origin information for each transaction (buyer-individual voluntary approach and instrument). According to the Thairasco's public due diligence report (Thaisarco), this approach ensures the transparency for the mineral origin and its supply chain, the supplier names and locations. One interviewed industry expert confirmed that this approach could be successfully applicable by other companies and in different countries. However, this would require investment by the companies into the development of internal processes and supply chain tracking capacities.

One company interviewed for this study has taken a more unique approach to tackle this challenge of transparency and environmental-protection data by developing its own supplier auditing standards (**buyer-individual voluntary approach)**. This was motivated by the company's assessment that existing public standards and guidelines are not meticulous enough to address all relevant sustainability issues in tin mining. By setting its own standards, this company pursues a coercive strategy and ensures that it only works with a select group of suppliers who meet these criteria and discontinues their engagement with the remaining suppliers (**punishment-based approach**). The company pointed out that suppliers are not offered financial incentives or price-premiums for meeting these standards.

The tin supply chain has seen the development of various voluntary sustainability initiatives aimed at addressing industry impacts, involving multiple stakeholders. The initiative the Tin Working Group (TWG)[14], supported by companies like Apple, includes aid for land reclamation and helps secure external funding for sustainable land reclamation projects area (**civil society-enabled voluntary impact-focused approaches and instrument)** (TWG 2015). The TWG has also created the TWG Incentives Guide, outlining approaches for responsible tin mining in Indonesia, and developed best practice guidelines, offering broader applicability within the industry (TWG 2015).

Emerging approaches:

Blockchain: leading mining companies and downstream industries are adopting and improving innovative data exchange techniques, such as decentralised databases like blockchain, to enhance their operations (Franken et al. 2020). One of the key advantages of this technology is its ability to share information among participants securely and without manipulation, while maintaining business confidentiality (Franken et al. 2020). However, Franken et al. (2020)

[13] ITSCI framework to assist companies with traceability, due diligence and audit requirements from purchasing 3T minerals, from the DRC, Burundi, Uganda and Rwanda.

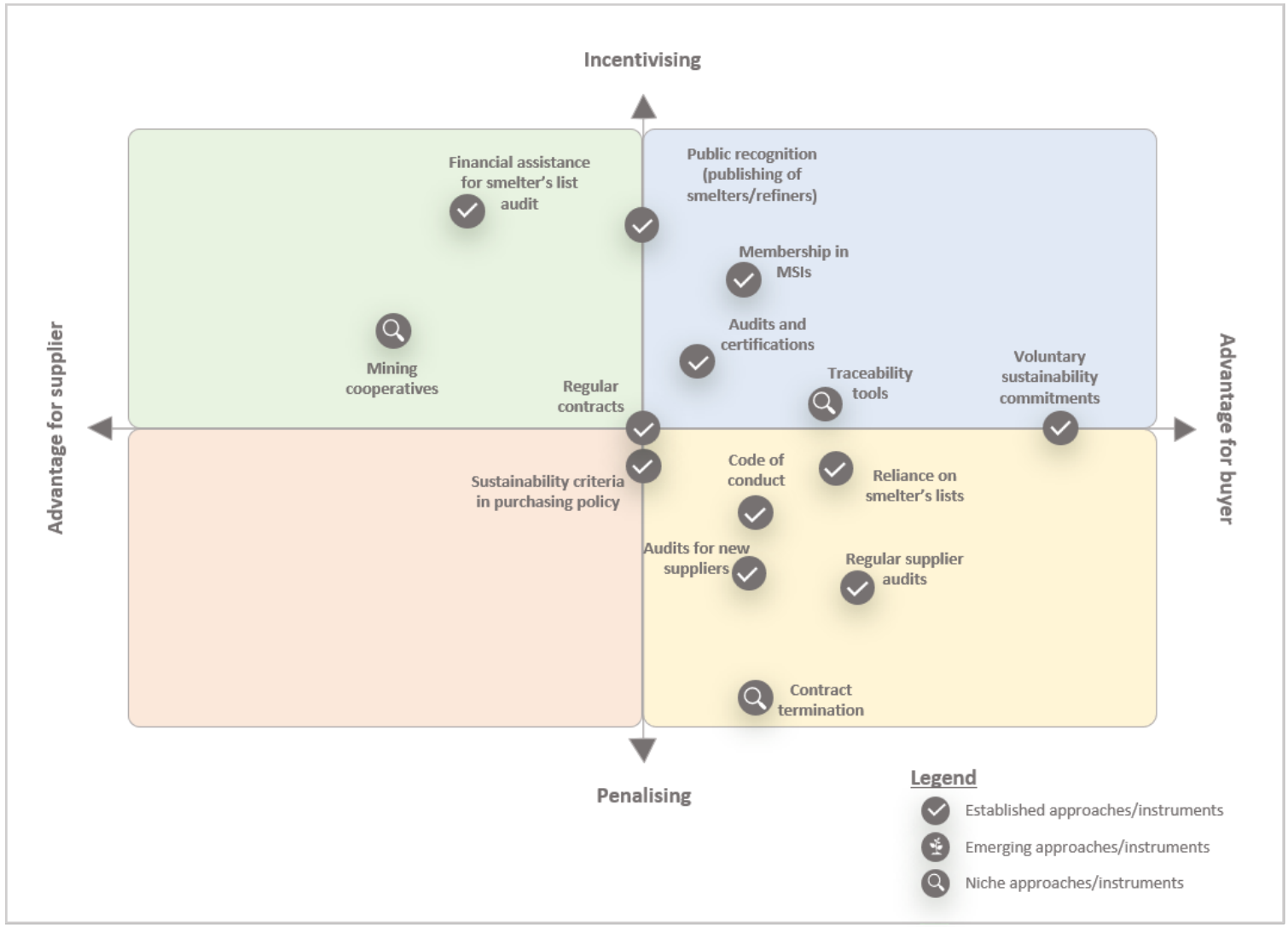
[14] The TWG activities were focused and located in Indonesia.

highlight a challenge: ensuring the accuracy of the data initially entered into the system. Addressing this issue effectively requires robust on-the-ground monitoring and capacity-building efforts (Franken et al. 2020). The use of blockchain technology is currently being tested in pilot projects to improve traceability and accountability within the supply chain. For instance, Apple has implemented blockchain traceability for their 3TG minerals supply chain as of 2022, as reported in their conflict mineral disclosure report (Apple 2022b). It is not clear to what extent the suppliers were involved in setting up this system or were simply following Apple's standard (coercive) practices. In addition to pilots, there are some examples where the blockchain technology is applied on a company level, such as in the case of one smelter in Uganda (Adetimilehin 2023). The RMI has provided guidelines on using blockchain in mineral supply chains (RMI 2020). However, this approach is not yet a standard in the industry. A key challenge in utilising blockchain for mineral traceability lies in verifying physical transactions, which could be addressed by integrating it with a reliable sustainability scheme, particularly in the relevant locations (van den Brink et al. 2019).

Circular economy: due to its properties and economic value, tin can be recycled without sacrificing quality (ITA n.d.b). This presents an opportunity for the tin industry to close the loop on tin usage by prioritising reuse and recycling, and by contributing to enhanced resource productivity, reduced energy consumption and emissions, as well as minimised waste disposal (ITA n.d.b). A leading example is Apple, which has committed to using only recycled materials in its products. As of 2021, their efforts have led to achieving 100% recycled tin utilisation according to their 2022 Environmental Progress Report (Apple 2023). Additionally, a company interviewed for this study reported sourcing 75% of their tin from recycled sources, highlighting the growing trend towards circular practices within the industry. According to the company, the cost of recycled tin is similar to the price of virgin tin, however, the recycled metal has lower GHG impact.

Placing the described business approaches and instruments observed in the tin ore-solder industry in a matrix, according to the definition of (perceived) distributional fairness (advantage for supplier/advantage for buyer) and approach to influence the desirability of the requested changes for the business partner (incentivising/penalising) presented in Chapter 2 and Chapter 5, the following pattern emerges:

Figure 10: Matrix of instruments and approaches in the tin supply chain



Source: own illustration (adelphi).

4 Roadmap for the tin-solder supply chain

This chapter is an excerpt of the report "Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Roadmaps for the implementation of sustainable supply chain management approaches and instruments" (Grüning et al. 2025). It presents an exemplary roadmap for the implementation of supply chain management instruments to improve the cost-benefit sharing and sharing of environmental information in the tin-solder supply chain. The roadmap can assist companies in the sector and other stakeholders in advancing the environmental performance of suppliers and sub-suppliers primarily through incentives and cooperation. The roadmap includes a description of the environmental upgrading target, tailored sustainable supply chain management instruments, key actors for implementation, interactions between the instruments, and necessary framework conditions.

4.1 Environmental target and background

The majority of CO_2 emissions across the tin supply chain are a result of the smelting and refining process. Focusing efforts on this stage is important for achieving GHG reduction targets, as it offers the greatest potential for significant impact. According to the International Tin Associations (ITA) report "Life Cycle Assessment of Tin Production" 74% of GHG emissions are emitted during the smelting and refining stages (ITA 2023). Vasters and Franken 2020 support these findings, noting that one ton of crude tin production requires non-renewable fuels like coal and fuel oil, along with significant electrical energy for electric furnaces for tin ore reduction, which leads to significant GHG emitted during the processing stage of tin. During the mining phase, major emissions stem from the application of diesel to power the equipment used for mining (Rüttinger et al. 2020).

Industry expert interviews confirm the importance of addressing GHG emissions. A solder producer interviewed in the frame of this study mentioned that their companies' environmental initiatives began with GHG accounting and reduction measures due to client requests, particularly from producers of consumer electronics.

The interviewed solder producer, after beginning GHG accounting and aiming to reduce their emissions, sought suppliers with lesser GHG footprints. This led them to switch to purchasing tin from recyclers within the EU. This might reflect a broader industry trend. For instance, electronics producer brand Apple has shown a preference for recycled tin in their products (Apple 2023). Additionally, supplier requirements for GHG accounting are highlighted in the CoC for tin recycling companies (Aurubis 2022). However, the industry experts have indicated a lack in availability of recycled metal (including tin) to cover all the future demand.

Based on discussions with industry practitioners and literature review, we selected an environmental upgrade target that was considered as relevant and ambitious to develop a roadmap for the tin supply chain. The following target was defined on this basis:

Environmental upgrade target – tin
Within 15 years, GHG emissions are reduced throughout the tin supply chain but particularly during the smelting phase.

Unlike the development of roadmaps for the cotton (see chapter 2.2, WP3) and iron ore-steel (chapter 2.4, WP 3) supply chains, which involved collaboration with a focal company, the roadmap for the tin supply chain had to be created without such a partnership. Instead, it was

developed based on the findings of the first and second work package of this research project (Strasser et al. 2024; Grüning et al. 2024), a comprehensive literature review, and interviews with industry experts and practitioners.

Due to the lack of a concrete focal company, discussion with experts in workshops and interviews were informed by a fictional scenario that reflects typical characteristics of companies active within the supply chain. The scenario was developed by the project team based on an interview with an integrated tin company. It is focussed on the fictional integrated tin company A, which owns several tin mines and operates smelting and refining facilities, producing solder. It is registered as a brand on London Metal Exchange (LME). The company serves global electronics manufacturers and establishes annual tin sales contracts, typically during LME Week.

Company A has identified the smelting phase as the primary source of its GHG emissions, followed by transportation. Although the company has initiated GHG accounting, it is still in the early stages. While clients occasionally inquire about GHG accounting, they have shown limited interest in purchasing carbon-neutral tin due to higher price, despite the company's offer.

Clients of Company A located in the EU must, in the future, comply with the CSDDD, which requires the implementation of climate transition plans addressing Scope 1, 2, and 3 GHG emissions (Haythornthwaite et al. 2024; Watershed 2024). This requirement may drive EU-based clients to intensify their efforts to reduce Scope 3 emissions, thereby influencing both upstream and downstream partners in the supply chain. Additionally, many clients will fall under the CSRD and associated ESRS. This directive mandates, among others, that companies disclose their Scope 1, 2, and 3 GHG emissions, along with associated risks, and report on the actual or potential impacts across their entire value chain, including operations, products and services, business relationships, and supply chain (European Parliament and Council of the European Union 2023).

Within the scenario, company A utilises a range of SSCM tools and approaches that, although not initially intended for GHG emission reduction, positively impact this environmental target. Additionally, the company has begun participating in initiatives directly addressing GHG emission reduction within the tin supply chains. They aim to prioritise this topic in their sustainability strategy in the coming years.

As an LME brand, Company A complies with the LME's responsible sourcing policy, which mandates, among others, ISO 14001 certification and adherence to OECD guidelines on responsible supply chains. The LME also collects data on some other metrics, such as adherence to the Tin Code. It adheres to local environmental laws and regulations.

When sourcing tin from mining cooperatives, Company A collaborates with those that comply with local environmental laws and have completed the necessary environmental impact assessments. The company facilitates connections to the electricity grid, which it financed for its operations, allowing cooperatives to reduce reliance on high-emission generators.

Additionally, Company A is a member of industry associations like the ITA and contributes to initiatives targeting emission calculations in the tin industry. The company also supports suppliers, such as mining cooperatives, by assisting with environmental liabilities. For example, if a cooperative lacks funds for a necessary study, Company A may provide an advance payment to help them secure the required licenses.

Achieving the specific environmental target presents several challenges and barriers. Company A believes it is possible to meet the target, despite technological barriers like high energy consumption in smelting and refining. The company already uses clean energy for most

operations but offsetting the remaining carbon emissions would incur additional costs. However, clients are reluctant to pay for carbon-neutral products due to the competitive market's focus on affordability (Strasser et al. 2024). Company A generally secures about 80% of its contracts with clients a year in advance. Fluctuating tin prices[15] can influence the company's willingness to invest in sustainability initiatives. According to the report authors, if prices are volatile, the company might prioritise maintaining cost stability and competitiveness over incurring extra expenses. Low market prices could restrict the funds available for sustainability efforts, indicating that such uncertainty can lead to hesitation in committing to long-term investments in these areas.

4.2 Description of the roadmap

The roadmap is designed to serve as a guide for companies within the tin supply chain, particularly targeting smelters. It aims to provide practical guidance on effectively addressing GHG emissions. This roadmap was developed through research, drawing on findings and insights from previous project reports (Strasser et al. 2024; Grüning et al. 2024). It incorporates newly proposed instruments based on current SSCM practices, with adaptations and innovations inspired by more advanced industries. The development process included interviews and workshops with stakeholders from companies, civil society, academia, and technical experts, which helped refine and adjust the roadmap.

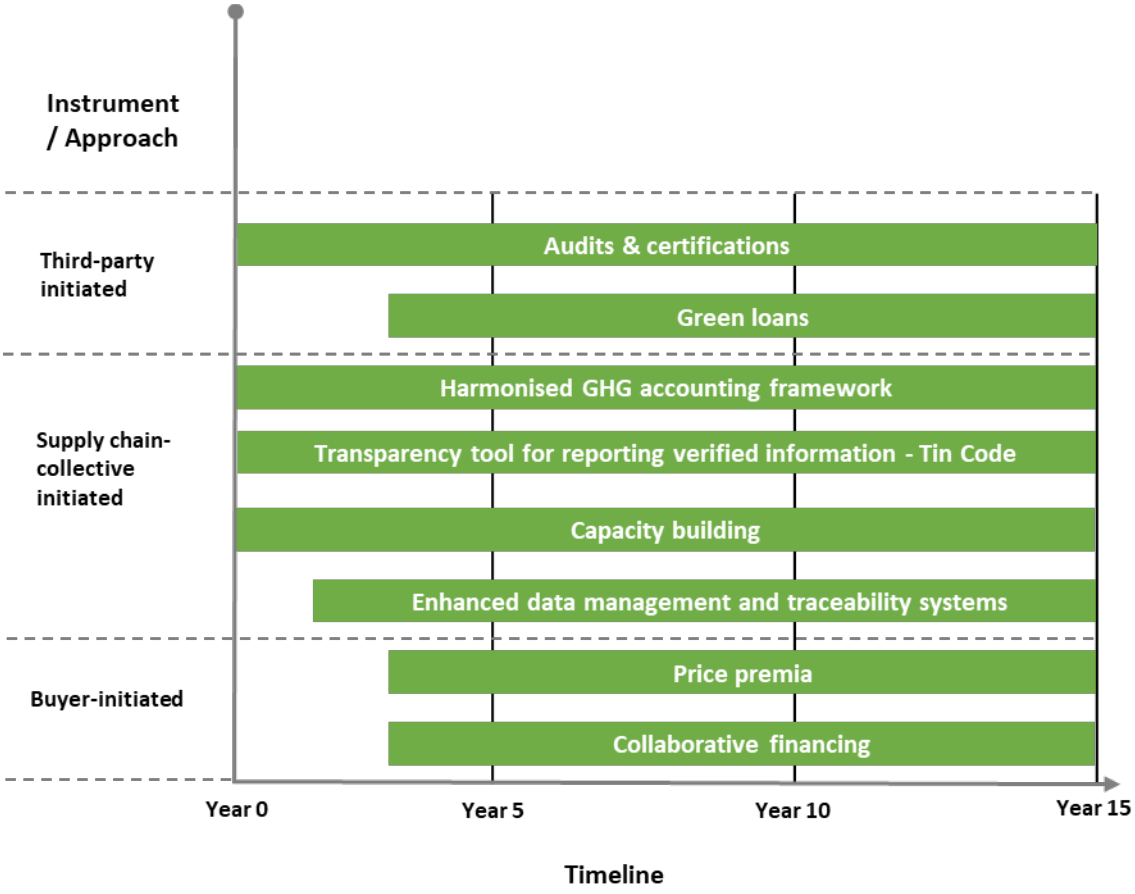
It is important to note that this roadmap is not a depiction of the current state of GHG emission management within the supply chain. Instead, it provides a vision of what could be achieved in the future. While it offers examples of SSCM instruments and incentive mechanisms, it does not cover all possible approaches. The roadmap's applicability may vary depending on a company's specific supply chain, structure, business model, and geographical location.

Figure 11 shows that a combination of instruments initiated at the collective level of the supply chain, by individual companies (usually the buyer) and third parties is proposed. These approaches and instruments are designed to span over 15 years or more, aiming to meet environmental targets aligned with the Paris Agreement's goal of limiting global warming to 1.5°C. This involves reducing GHG emissions by 45% by 2030 and achieving net zero by 2050 (UN n.d.). Not all instruments are introduced right from the start. For example, instruments such as 'price premiums', 'green loans' and 'collaborative financing' come into play once other instruments such as 'harmonised GHG accounting framework' and 'transparency tools' are in place.

Each approach and instrument and the specific activities recommended for the respective actors, are explained in detail in the sections 4.2.1to 4.2.6. A more detailed description of the interconnections and dependencies between different approaches and instruments in the roadmap is presented in section 4.3.

[15] This volatility arises because tin is a commodity, and its prices are determined by market rather than by the producers themselves. For more information, refer to report Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains (Strasser et al. 2024).

Figure 11: Roadmap for improved environmental performance in the tin-solder supply chain



Source: own illustration

4.2.1 Instrument 1: Harmonised GHG accounting framework

Achieving significant GHG emission reductions in the tin supply chain requires accurate and comparable GHG accounting of companies and their operations. This requires tools that enable efficient and reliable measurement and tracking of GHG emissions. Larger companies might afford external carbon accounting services or licenses for specialised tools, but these options can be expensive for smaller companies. Additionally, many tools and service providers rely on average emission factors, which can introduce inaccuracies. This is problematic because emission factors can vary significantly across different geographical regions. While platforms and GHG accounting standards, such as the GHG Protocol, allow the incorporation of average emission factors for purchased products and services to simplify calculations, this approach might not fully capture the actual upstream GHG emissions of companies sourcing from diverse regions. Consequently, this can lead to inaccuracies in comparisons. Therefore, it would be beneficial to develop a harmonised GHG calculation framework specifically tailored to the tin industry.

This proposed new instrument, 'harmonised GHG accounting framework' is a **supply chain-collective voluntary instrument**, and should be based on established standards like the GHG Protocol, incorporating inputs from actors across the entire supply chain by leveraging their expertise. By doing so, it will streamline GHG calculation processes, making data collection more manageable for all participants. Additionally, the framework should provide access to relevant emission factors, which may vary significantly by geographical region.

The ITA has initiated efforts in this direction through the "Life Cycle Assessment of Tin Production" project (ITA 2023). This initiative generates an accurate global LCA figure for refined tin, providing a baseline for updates and targets, and offering climate change-related information requested by actors.

Other industries, such as steel and aluminium, have compared industry-specific GHG accounting frameworks to harmonise emissions reporting, addressing discrepancies and facilitating accurate emissions tracking (Columbia Center on Sustainable Investment n.d.). Such harmonised, industry-specific framework for the tin industry will offer a comprehensive overview of its carbon footprint, simplifying data collection, emission calculations, and reporting. It can also serve as a baseline reference for monitoring companies' progress and developing key performance indicators for emission reduction throughout the supply chain.

Table 6: Key actors and actions for implementing a harmonised GHG accounting framework

Key Actor	Actions for Implementation
MSIs and/or industry association (e.g. ITA)	- Provide a platform for industry stakeholder knowledge exchange and collaboration; engage with relevant actors (such as individual companies, topical GHG accounting/LCA experts) to develop sector-specific GHG accounting framework.
Individual companies (at each level of the supply chain)	- Participate in the initiative by providing data on emissions and supply chain practices, including data on energy consumption, production processes, and transportation logistics; engage suppliers to encourage them to support framework development by sharing relevant data on emissions and supply chain practices and participating in pilot projects.
Research Institutions/GHG accounting and LCA experts	- Conduct studies to validate emission factors and framework effectiveness; provide scientific insights.

The development and implementation of this instrument requires various resources from key actors. Industry associations (e.g. the ITA) can facilitate this process. However, the facilitation process and engaging the right experts (Research Institutions/GHG accounting and LCA experts) is both lengthy and costly. The funding can come from industry association member contributions and government grants. Individual companies require data management systems and training resources, which are supported internally and guided by industry associations. Suppliers need technology for data sharing and training/capacity building (instrument 5) on the framework. The capacity building can be provided by MSIs/industry associations, or by clients/sourcing companies. Given that industry decarbonisation is a key component of many national decarbonisation strategies, governments could play an important role by developing financial instruments for the development of relevant tools and services. By offering grants for the development of GHG calculation tools, harmonised frameworks, emission factor calculation and verification, and carbon accounting capacity building, the governments can incentivise the adoption of these tools and frameworks.

Key levers for successful implementation include building trust through transparency and open communication, showcasing the environmental and economic benefits of the framework, leveraging the unique strengths and expertise of each actor group, and maintaining engagement through regular updates and transparent communication. In addition, it is important that governments and/or financial market players (FIs, stock exchanges, etc.) provide clear guidance

on how the developed harmonised GHG accounting framework can be used for mandatory reporting ensuring a level playing field for all business participants.

4.2.2 Instrument 2: Enhanced data management and traceability systems

Accurate calculation GHG emission requires the input data of supply chain operations as precise as possible. The supply chains of tin, from mining to smelting, can be complex. In scenarios where a company operates an integrated structure, proving the tin's origin is straightforward. In order to collect and assure accurate data, companies apply the instrument 'enhanced data management and traceability systems', which can be based on **individual companies using third-party offered approaches** (see e.g. Grüning et al. 2024, chapter A.6.2) or individual companies requesting proof of origin information for each transaction (see e.g. Grüning et al. 2024, chapter 5.2). However, complexity increases when a company sources tin ore from multiple locations (especially when involving ASMs). Given the complexity and cost associated with full traceability in the tin supply chain, particularly with ASM, a more feasible approach might involve implementing a tiered traceability system. For this purpose, mining operations could be grouped based on common characteristics, such as geographic region or mining method, rather than tracing each individual source. This approach would maintain a level of traceability and transparency sufficient for GHG accounting while reducing the financial and logistical burdens on smaller companies and ASMs.

Table 7: Key actors and actions for implementing enhanced data management and traceability systems

Key Actor	Actions for Implementation
MSIs and/or industry associations	- Take a leading role in coordinating the design of such systems; provide a centralised platform for collaboration and ensure that the system aligns with industry standards and goals. - Offer guidance by sharing best practices and advocating for a tiered data management and traceability approach; monitor the implementation of the system, evaluate its impact, providing feedback to technology providers for continuous improvement; provide a collaborative setting where companies can discuss how traceability can be done more cost efficiently. - If needed: determine a trusted third party for the verification of data provided by individual actors to the centralised system.
Company	- Apply the system in their operations; define traceability requirements, lead the integration with existing processes.
Third-party technology provider	- Provision of the digital infrastructure; ensuring data security; third-party verification of the data, if necessary.

The development of such an instrument can prevent individual companies from developing their own in-house systems, which can be a lengthy and costly process and lead to different data protocols which may have compatibility issues. A system developed under the leadership of an MSI or industry association would ensure the accuracy and comparability of input data. This standardisation is crucial for establishing a level playing field, because it ensures the correctness of the data, which in turn is a significant factor for the effective adoption of instrument 1.

The MSIs and/or industry associations should allocate resources to research the best available technology and lead the development of such a tiered traceability system. The financing of such an instrument would require funds which may come from membership fees and/or government grants. By pooling resources through membership fees and government grants, the financial burden is shared, making the system more accessible to all companies, including smaller ones. In addition downstream actors can provide financial assistance by funding pilot projects, as demonstrated by Apple's support for a blockchain-based traceability pilot project (Apple 2022). Such a collaborative funding model reduces individual costs and incentivises participation of wider range of relevant actors by demonstrating the shared benefits of improved data management and traceability.

4.2.3 Instrument 3: Audits and certifications

Process certification frameworks, such as ISO 14001, allow companies some flexibility in selecting significant environmental aspects to target, enabling companies to address key areas like waste reduction, energy efficiency, or carbon footprint as necessary. These certifications encourage continuous improvement through structured EMS, using a Plan-Do-Check-Act (PDCA) approach to meet sustainability targets (ISO 2021).

While a **third-party, voluntary, profit-focused instrument** provides credibility and certifies that company adheres to sustainability practices, it also serves as an incentive for cost allocation across company operations. Certification requirements drive resource allocation and operational focus towards environmental and social responsibility. Furthermore, by including process certification requirements in CoC's they create incentives for suppliers and partners to align with the required sustainability standards.

Additionally, companies that are registered as LME brands are required to provide evidence of third-party audit or assurance audits. It's important to note that the platform functions primarily as a transparency mechanism with a core focus on human rights and conflict mitigation. While LME requests evidence from third-party audits on various sustainability aspects, it often relies on existing third-party certifications rather than conducting audits directly (with certain exceptions in specific human-right scenarios). Thus, any GHG targets or environmental initiatives should be viewed as complementary to the social issues within the tin supply chain. Recognising these interconnected challenges ensures that environmental goals are pursued in a way that also considers critical human rights issues, aligning companies' practices with broader industry standards and enhancing the scalability and practical impact of its sustainability efforts.

Table 8: Key actors and actions for implementing audits and certification

Key Actor	Actions for Implementation
Company Management	- Establish an environmental policy which covers all relevant SSCM tools that are used to achieve the environmental upgrade target; Establish clear commitment to environmental protection, climate change mitigation and compliance by integrating audits and certifications into the company's strategic goals; allocate resources and appoint responsible personnel to oversee the implementation process. - Develop and maintain the EMS conduct internal audits to prepare for external assessments and ensure continuous improvement.

Key Actor	Actions for Implementation
Suppliers	- Collaborate with the company to ensure that operations meet the required sustainability standards; provide necessary documentation and data for audits and certifications.
Third-Party Auditors	- Conduct thorough and unbiased assessments of the company's practices; provide feedback and recommendations for improvements to meet certification requirements.

To effectively implement audits and certifications, actors require a variety of resources. Company management needs financial resources and strategic guidance, typically provided through internal budgeting and external consultancy. Sustainability and compliance teams require access to training programmes and tracking tools, supplied by internal human resources departments and external bodies. Suppliers and partners require information on compliance standards and support, facilitated by the company's procurement team.

In addition to these transactional elements, achieving certifications often requires significant investment to improve environmental performance, such as upgrading production processes, implementing energy-efficient technologies, and reducing waste.

The successful implementation of this instrument depends on several key levers. Clear communication of audit criteria ensures that all actors understand the expectations and requirements. Integrating audit processes into daily operations helps maintain consistency and efficiency. Efficient use of technology for data handling streamlines the collection and reporting of environmental metrics, enhancing accuracy and accessibility. Additionally, fostering a culture of continuous improvement encourages proactive identification of areas for enhancement throughout the organisation and its supply chain.

Specific framework conditions in the sector can enhance the effective uptake of audits and certifications. For instance, regulatory incentives and a supportive policy environment can drive companies to prioritise and invest in certification processes. Public awareness and client demand for sustainable practices tied to price premiums also play a critical role, creating a market-driven incentive for companies to uphold certification standards.

4.2.4 Instrument 4: Transparency tool for reporting verified information - the Tin Code

The Tin Code is a global Environmental, Social and Governance (ESG)standard and transparent reporting mechanism adopted voluntarily by the tin industry to demonstrate a commitment to continuous improvement across exploration, mining, smelting, and recycling operations. Designed for global applicability, the Tin Code facilitates harmonised reporting and progressive improvement, with provisions for third-party verification. This instrument is initiated by producers.

This **supplier-collective voluntary instrument** provides a systematic format for sharing information with buyers. By covering (among others) GHG topics, the Tin Code offers transparency into a company's status and progress in these areas, aiming to achieve greater accountability and environmental responsibility.

Table 9: Key actors and actions for implementing a transparency tool for reporting verified information (the Tin Code)

Key Actor	Actions for Implementation
Industry association (e.g. ITA)	- Provide the framework and platform for reporting; ensure standards are clear and accessible; offer guidance and support to stakeholders.
Individual companies	- Adopt the Tin Code and integrate it into operations; collect relevant ESG and GHG data; submit reports to the platform.
Clients	- Encourage compliance by prioritising purchases from Tin Code adherents; support transparency and sustainability initiatives within the supply chain.

To implement this instrument effectively, actors require various resources. The ITA needs funding to develop and maintain the reporting platform and provide guidance, supported by membership fees, industry partnerships, and potential grants from governmental and/or environmental organisations. Tin producers require financial resources for data collection, reporting systems, and technology upgrades, typically sourced from internal budgets.

This instrument enables access to information for a wide range of actors. It could serve as a tool to communicate information from the harmonised GHG accounting framework (instrument 1), and to demonstrate adherence to various audits and certifications (instrument 3). This instrument could also be linked to price premiums (instrument 6), meaning that companies adhering to the Tin Code could potentially receive higher prices for their products, reflecting their commitment to sustainability and responsible sourcing. This premium would serve as an incentive for companies to meet and maintain the standards outlined in the Tin Code, rewarding sustainable practices and encouraging wider adoption within the industry.

Key levers for successful implementation of this instrument: ITA can foster industry-wide collaboration and promote the benefits of transparency and sustainability to encourage adoption. Tin producers should integrate sustainability goals into their core business strategies and leverage technology for efficient data management and reporting. Third-party verifiers must maintain independence and credibility to ensure trust in the verification process, using innovative audit techniques to streamline assessments. Buyers can advocate for industry-wide adoption of the Tin Code and utilise their purchasing power to drive demand for compliant tin products.

4.2.5 Instrument 5: Capacity building and training programmes for suppliers

Actors like mining cooperatives may require access to information tailored to be easily understandable and applicable to their operations. A MSI, similar to the Tin Working Group in Indonesia (Grüning et al. 2024) or the ITSCI programme in Africa (ITSCI 2020), can effectively provide these training programmes. By collaborating with downstream companies and other actors, such initiatives enhance environmental sustainability within the supply chain.

This newly proposed supply-chain collective instrument includes programmes that offer targeted education on sustainable practices, emissions reduction, and efficient resource management, helping suppliers align with industry expectations and regulatory requirements. The desired effect is to foster a culture of continuous improvement and innovation among suppliers. Through workshops, seminars, and on-site training, suppliers can learn best practices

and access the latest technologies, improving their operational efficiency and enhancing their ability to participate in global markets that prioritise sustainability.

Table 10: Key actors and actions for implementing capacity building and training programmes for suppliers

Key Actor	Actions for Implementation
Companies	- Provide technical assistance, training and resources to help their suppliers improve their environmental practices; support the identification of training needs of the mining cooperatives as important input for the development of the relevant training materials.
Mining cooperatives	- Actively participate in training sessions; apply learned practices to their operations.
MSIs/Industry associations	- Coordinate the initiative and align stakeholders; develop targeted training modules; organise workshops to facilitate learning from industry experts and peer sharing; establish certification programmes to acknowledge suppliers who successfully complete training and adopt sustainable practices, partner with international organisations and financial institutions to offer grants for training, provide technical assistance to help suppliers implement new practices, and set up monitoring systems to track their progress.

To implement the training programmes effectively, actors require various resources. Mining cooperatives need access to tailored training materials and on-site support, provided by local industry associations and in their native language. Companies must allocate financial and logistical resources to support training initiatives, ensuring cooperatives have the necessary tools and materials. Local industry associations and NGOs require funding and expertise to develop comprehensive training content, which can be sourced from partnerships with companies and governmental agencies. Government agencies can provide financial support via grants for development of training materials. Clients can offer financial support directly to Industry Associations or NGOs.

Key levers for successful implementation include a participatory approach to curriculum development, ensuring training materials are relevant and practical. Engaging local trainers and using local languages and contexts will enhance understanding and application. Additionally, creating demonstration sites can provide hands-on learning experiences. Collaboration and open communication among all actors will drive the initiative's success.

Capacity building and training programmes are essential and vital for the effective implementation of all other instruments.

4.2.6 Instrument 6: Price Premiums

Robust audit (both internal and third-party) and certification processes are crucial for ensuring Decarbonisation efforts at both company and supply chain levels can be costly and require significant investments. Currently, the burden of these investments falls on the respective companies, as they are expected to comply with sustainability requirements set by clients without affecting the final product price.

The new proposed instrument of price premiums, **a buyer-initiated voluntary instrument**, addresses this challenge by providing direct financial incentives for sustainable practices. The goal is to incentivise actors in the supply chain to adopt and maintain sustainability practices. Paying a price premium for more sustainable and low-carbon tin could enable these actions. The LME, already gathering extensive ESG and sustainability information through its LME Passport, has considered setting premium prices for sustainable tin (Grüning et al. 2024). Low GHG emissions could be one of the criteria for justifying such a premium price.

Table 11: Key actors and actions for implementing price premiums

Key Actor	Actions for Implementation
Stock exchanges, such as LME	- Develops and maintains the framework for assessing sustainable practices and pricing systems for linking price premium to sustainability metrics, including lower GHG emissions.
Company	- Invest in sustainable practices and technologies to qualify for the premium pricing; document and report their decarbonisation and sustainability efforts through tools such as Tin Code and platforms like the LME. - Incorporate premiums into procurement procedures, inform suppliers about the premium framework, and assess the impact of premiums on sourcing; conduct market research to understand consumer willingness to pay premiums for sustainable tin, and devise strategies to convey the value of premiums to buyers.
Suppliers	- Invest into decarbonisation efforts and maintain them; apply traceability tools to assure source of sustainable and low carbon tin. - Participate in training and verification/auditing processes.
Clients	- Commit to purchasing sustainable tin at a premium price.

In order to implement this instrument, companies need financial investments for sustainable technologies and practices, supported by internal budgets and potential grants from governments or loans. They also need access to reporting tools. Their suppliers need access to finance for making investments into decarbonisation measures as well as access to traceability tools (where applicable) to assure transparency in the supply chain. Buyers require clear guidelines and information on premium pricing, facilitated by the stock exchanges such as LME. The LME needs resources to develop and maintain the framework, potentially funded by membership fees and industry partnerships.

Key levers for successful implementation include fostering strong collaboration between buyers and suppliers to ensure commitment to premium pricing. Transparency in reporting by the LME is important for building trust. Buyers can leverage their purchasing power by committing to sustainable tin purchasing in year-ahead contracts, driving demand for sustainable tin. Open communication and shared goals among all actors will enhance the effectiveness of this instrument.

Price premiums are connected to all other instruments, either by using them to assure the low GHG emissions of purchased tin or by serving as a means to finance carbon reduction measures in the supply chain. Additionally, clients' commitment to paying a premium for greener tin can be crucial for companies to apply for green loans (instrument 7) and collaborative financing (instrument 8).

4.2.7 Instrument 7: Green loans

Investing in energy efficiency or transitioning to cleaner energy for smelting operations often requires substantial financial resources. A green loan is a type of financing that allows borrowers to allocate funds specifically for projects that advance environmental goals. This instrument assists borrowers in conveying the environmental sustainability of their operations and supply chain (World Bank Group 2021).

This **third-party initiated, profit-focused voluntary instrument** involves financial institutions developing green loans specifically tied to decarbonisation efforts in the tin industry, offering favourable terms such as lower interest rates and longer pay-back periods. These loans could provide companies with access to green finance, accelerating their decarbonisation initiatives. Additionally, local governments, with a vested interest in industrial decarbonisation, could support the development of these instruments by subsidising or securing the loans, further enhancing their attractiveness and feasibility.

Table 12: Key actors and actions for implementing green loans

Key Actor	Actions for Implementation
Financial institutions	- Develop framework of and offer green loans, requiring resources to design loan products with favourable terms, such as lower interest rates and longer pay-back periods; ensure the green loan aligns with the World Bank's green loan principles.
Company	- Prepare proposals detailing how projects funded by the loan will deliver clear environmental benefits; assess, measure, and report these benefits; communicate evaluation processes for selecting projects to receive loan proceeds; explain management of environmental and social risks; manage proceeds by crediting them to a dedicated account or tracking them to ensure transparency and integrity; report outcomes using qualitative and quantitative indicators, such as energy capacity improvements and GHG emissions reductions (World Bank Group 2021).
Clients	- Can support companies with applying for green loans by committing to purchasing sustainable or low carbon tin through offtake agreements at a premium price, thereby reducing the credit risks for the bank.

To effectively implement this instrument, various actors require specific resources. Financial institutions need capital to fund loans and expertise to develop suitable loan products, which can be sourced from internal financial reserves and partnerships with government programmes. Companies require detailed project proposals and financial documentation, prepared by internal teams or with the help of external consultants. Local governments can provide subsidies, guarantees, and the regulatory framework, funded through government budgets and potentially international environmental funds. Development banks, such as the European Bank for Reconstruction and Development (EBRD), play a special role by offering financial support, technical assistance, and investment security. The EBRD, for instance, supports the development of green financial systems to accelerate the transition to a green, low-carbon economy by increasing the scale and depth of local financial markets (EBRD n.d.). These banks often bridge funding gaps, particularly in emerging markets, facilitating projects that align with sustainable development goals.

Key levers for successful implementation include financial institutions establishing clear criteria for loan approval and offering competitive terms to attract companies. Companies should align their projects with sustainability and carbon reduction goals and demonstrate potential impact and viability. Local governments can provide incentives and supportive policies, facilitating partnerships between actors.

Green loans require successful uptake, for which enhanced data management and traceability systems (instrument 2), audits and certifications (instrument 3), and the transparency tool (instrument 4) are important. Price premiums (instrument 6) and offtake agreements from clients can be used for providing financial institutions with assurance that companies will see a return on green investments.

4.2.8 Instrument 8: Collaborative financing

Access to green finance such as green loans/credit or other financial instruments may be challenging, particularly for suppliers such as smaller miners and mining cooperatives due to various reasons (e.g. poor credit ratings, lack of awareness about access to green finance). Additionally, some cooperatives may experience financial difficulties, particularly in regions where liquidity issues may arise from delayed payments by smelters (Grüning et al. 2024). These financial constraints can hinder their ability to invest in newer, energy-efficient technologies. Additionally, the price of tin is largely influenced by market demand, resulting in shifting power dynamics that are not strictly hierarchical. Miners understand that their extracted tin will eventually sell, irrespective of timing. This understanding can contribute to hesitancy in investing in further sustainability initiatives, as immediate market conditions often take precedence over long-term environmental commitments, especially when combined with financial constraints and uncertainty (Strasser et al. 2024).

A **newly proposed buyer initiated voluntary instrument** is collaborative financing (which is also closely interlinked with green loans). Buyers play an important role by leveraging their relationships (and credibility) to connect them with financial institutions. They can enhance the creditworthiness of cooperatives by providing financial guarantees, which reduce the perceived risk for lenders. Buyers also contribute by sharing the costs and risks of green investments, such as covering part of the interest payments or funding sustainability projects. Additionally, they can negotiate with financial institutions to secure more favourable loan terms, including lower interest rates and extended repayment periods. This approach could enable cooperatives to access green finance (e.g. green credit/loans), enhancing the energy and resource efficiency of their operations. Additionally, cooperatives may lack the knowledge to access these types of green and collaborative financing options. Support from smelters or industry associations would be invaluable in sharing the necessary knowledge and assisting with the preparation of required documentation, thus facilitating smoother access to financial resources.

Table 13: Key actors and actions for implementing collaborative financing

Key Actor	Actions for Implementation
Suppliers, e.g. mining cooperatives	- Engage with smelters and industry associations to understand green collaborative financing options; prepare and submit necessary documentation for financing.
Company	- Continue offering support (such as advanced payments to support cooperative liquidity covering part of interest payments, support negotiations for lower interest terms and longer pay-back periods); collaborate with stakeholders to

Key Actor	Actions for Implementation
	develop and promote green collaborative financing models; partner with cooperatives to offer financial support and guidance; facilitate timely payments to improve liquidity for cooperatives.
Industry Associations	- Provide training and resources on accessing green collaborative finance; assist cooperatives in preparing documentation and navigating financial processes.
Financial institutions	- Develop and offer green loan products (instrument 7) tailored to the needs of mining cooperatives; provide favourable terms to encourage uptake.

To successfully implement collaborative financing, various actors in the mining sector must coordinate resources and expertise. Mining cooperatives need both financial support and strategic guidance, which can be provided through partnerships with smelters and industry associations. These cooperatives often require assistance in preparing necessary documentation, a role that industry associations and financial consultants can fulfil to streamline processes and meet regulatory standards. The focal company plays an important role by providing advanced payments and leveraging its expertise in financial management, with support from internal resources and partnerships with financial institutions. In turn, industry associations need adequate funding to develop and deliver training programmes, which can be financed through membership fees and external grants. Financial institutions are crucial in designing green loan products, enabled by their financial reserves and enhanced by government incentives.

Key levers for effective implementation include fostering robust, trust-based partnerships between cooperatives and smelters, ensuring that cooperatives receive the financial support and guidance needed for growth. Industry associations should prioritise accessible training and development resources to build cooperatives' capacities, while the company can use its influence to promote collaborative financing models that benefit the entire value chain. Financial institutions play an essential role by offering competitive loan terms and working directly with stakeholders to tailor loan products to their specific sustainability and operational needs. Through open communication, shared sustainability goals, and coordinated efforts, actors in collaborative financing can create a resilient financial support system that empowers cooperatives, enhances industry standards, and contributes to sustainable development across the sector.

Collaborative financing benefits from enhanced data management and traceability systems (instrument 2), which supports accurate and efficient data handling. Additionally, transparency tool (instrument 4) can be used to verify the relevant sustainability information

4.3 Discussion of the roadmap for the tin-solder supply chain

The instruments presented in this roadmap are designed to achieve environmental upgrades for actors throughout the tin-solder supply chain. It includes only those instruments that, based on expert input and literature review, are expected to have the greatest impact on achieving additional significant GHG emission reductions in the industry. This roadmap is not intended to serve as a comprehensive guide to implementing SSCM for GHG emission reduction.

The roadmap includes four supply chain-collective initiated instruments, among which three are newly proposed. The Harmonised GHG Framework serves as a foundational instrument, facilitating accurate and comparable carbon accounting and enhancing transparency across the

supply chain. Complementing this, the newly proposed Data Management and Traceability instrument introduces a tiered approach, allowing companies to verify tin sourcing without pinpointing its direct origin. This method is particularly vital due to relatively large amount of ASMs in the supply chain, where direct tracing is both costly and, as some experts argue, unnecessary. Capacity building is another important instrument, ensuring that a diverse range of stakeholders, especially ASMs, can access essential knowledge on implementing these initiatives effectively. This empowerment is key to equipping suppliers with the necessary skills and understanding. Additionally, the use of Tin Code as transparency tool plays an important role in communicating sustainability efforts, providing stakeholders with insights into a company's status and progress.

The roadmap also includes two third-party initiated instruments. Audits and certifications provide critical assurance and compliance with established sustainability standards, thereby reinforcing trust and reliability in the companies' environmental practices. Additionally, effective uptake of green loans as a financial instrument that can be supported by instruments such as enhanced data management and traceability systems audits and certifications, and the transparency tool.

Furthermore, two buyer-initiated instruments address specific financial and operational challenges faced by miners and cooperatives. Collaborative financing emerges as a strategic solution, particularly for miners or cooperatives struggling to access green finance, such as green loans. In this context, larger entities, like smelters, can facilitate access to green finance, enabling these cooperatives to invest in more sustainable practices. Additionally, the concept of price premiums has been highlighted in workshops and stakeholder interviews as a crucial mechanism for achieving sustainability in the tin supply chains. While upstream actors often expect their suppliers to fulfil various sustainability requirements, downstream actors frequently bear the financial burden without the ability to incorporate price premiums. This imbalance underscores the need for fair pricing strategies that reflect the true cost of sustainable practices.

Several key hurdles were highlighted that impede progress toward achieving environmental sustainability and decarbonisation in the tin supply chain. One major roadblock is the absence of incentives for applying sustainable supply chain instruments, largely due to a lack of engagement by downstream metal users in providing financial incentives. The unattainability of price premiums further exacerbates this issue. The reluctance of companies to pay a premium for sustainably produced tin a significant bottleneck, which places the financial burden solely on upstream actors. To accelerate progress toward a sustainable and carbon-neutral industry, clients must adopt fair pricing practices that reflect the true cost of sustainability efforts.

To address the reluctance of companies to pay a premium for sustainably produced tin and ensure that sustainability efforts are equitably supported, the regulatory framework should adapt in several, strategic ways. Governments and regulatory bodies could provide subsidies or grants to offset the costs associated with sustainable practices, thereby encouraging more companies to adopt them. Additionally, creating preferential market access or procurement policies for sustainably produced tin, such as prioritising it in public procurement, can stimulate demand and encourage companies to recognise the value of paying a premium.

Additionally, it is important to acknowledge that while environmental sustainability topics within the tin industry may not be as advanced as in other industries, such as coffee or cotton, industry experts emphasise that GHG targets and environmental initiatives should complement social issues within the tin supply chain. By recognising these interconnected challenges, companies can pursue environmental goals in a manner that also addresses critical human

rights issues, thereby aligning practices with broader industry standards and enhancing the scalability and practical impact of sustainability efforts.

List of references

This report is a compilation of content from the following research reports. The literature cited in this report is accessible in the list of references of the respective reports.

Grüning, C., Jüde, J., Martin, K., Strasser, J., Tran, C., Grabs, J. (2025): *Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains. Roadmaps for the implementation of sustainable supply chain management approaches and instruments*. German Environment Agency (Hrsg.). Texte 04/2025. https://doi.org/10.60810/openumwelt-7704

Grüning, C., Jüde, J., Martin, K., Strasser, J., Tran, C., Hofstetter, J. (2024): *Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains. Business approaches and instruments of sustainable supply chain management.* German Environment Agency (Hrsg.). Texte 161/2024. https://doi.org/10.60810/openumwelt-7629

Strasser, J., Garcia, B., Grüning, C., Tran, C., Martin, K., Hannak, J., Jüde, J., Becker, M., Grabs, J., Hofstetter, J. (2024): *Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains. Analysis of the cotton, tin, natural rubber, coffee and iron ore supply chains.* German Environment Agency (Hrsg.). Texte 06/2024. https://doi.org/10.60810/openumwelt-6390

Strasser, J., Grüning, C., Martin, K., Tran, C., & Jüde, J. (2025). *Cost allocation and incentive mechanisms for environmental, climate protection and resource conservation along global supply chains - Recommendations for selected incentive mechanisms*. German Environment Agency (Hrsg.). Texte 73/2025. https://doi.org/10.60810/openumwelt-7752