Towards responsible and resilient mineral supply chains, with case studies on cobalt, antimony, and zinc

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Appendix I

Based on the supplementary information provided with Chapter 2.

Published in: Resources, Conservation and Recycling (2019), 145, 389-398, art. No.02.040

1. Literature review references

In the literature a range of features of 'responsible sourcing' were identified. These features refer to sustainability characteristics or to the scope of 'sourcing' in the supply chain. Table A1 provides an overview of these features as found in the literature review.

Type	**Features linked to 'responsible sourcing'**	**Example references**
Socially responsible sourcing	*"social" (aspects, considerations)*	Seong-Jong Hoo et al. (2010), Brown (2009), Young (2015), Zorzini et al. (2015)
	"human rights "(abuse)	Buhmann (2017), Simmons (2014), Faber et al. (2017)
	"conflict minerals" (armed groups)	Simmons (2014), Young (2015), Partzsch and Vlaskamp (2016), RSN (2011)
	"working conditions" (health, safety)	Brown (2009), Idle (2009), Henkle (2005) (Faber et al. 2017)
	"forced labour"	RSN (2011)
	"child labour"	Faber et al. (2017)
Sustainable sourcing	*"social" + "environmental"*	Upstill-Goddard et al. (2016), Wassel (2010), Guo et al. (2016) Caveen et al. (2017), Ghumra et al. (2011)
	"sustainable" or "social +economic+ environmental"	Upstill-Goddard et al. (2015), Upstill-Goddard et al. (2012), Glass (2011), Young and Osmani (2013), Nickless (2018), Ali et al (2017), Govindan et al. (2015), Dainty et al. (2011), Murthy (2013), Glass et al. (2012), Gandhi et al. (2011), Howells (2011), Oliver (2007).
	"environmental" practices/ impact/protection	Ali et al. (2017), Wall et al. (2017), Dainty et al. (2011)
	"workforce health and safety"/ "working conditions" "child labour"	Wall et al. (2017), Dainty et al. (2011)
	"community interaction"	Wall et al. (2017)
	"energy use, carbon footprint, water use, resource efficiency, and resource and reserve reporting, climate change"	Wall et al. (2017), Ali et al. (2017)
	"corruption, transparency in economic contributions (such as taxes)"	Dainty et al. (2011), Wall et al. (2017),
Scope		
Scope a: Upstream	*"upstream management"*	Zorzini et al. (2015)
	"farmers", "fishing"	Seong-Jong Hoo et al. (2010), Shepherd et al. (2017), Caveen et al. (2017)
	"OECD due diligence/ conflict minerals"	Buhmann (2017),Simmons (2014)
	"source (origin) and production of raw material"	Young (2015)
	"mineral exploration and sustainability of mining and ore processing, mining"	Nickless (2018), Partzsch and Vlaskamp (2016), Faber et al. (2017)
Scope b: Entire supply chain	*"material and product supply chains/ sourcing supply chain (BRE certification) "*	Glass et al. (2011), Upstill-Goddard et al. (2012), Upstill-Goddard et al. (2015), Ghumra et al. (2011), Howells (2011), Brankley (2011), Glass (2011), Spencer and Clarke (2009), Oliver (2007)
	"mined, extracted, and manufactured"	Murthy (2013)
	"throughout the (product) supply chain"	Glass et al. (2012)

Table A1. Features associated with 'responsible sourcing'

In the article it was concluded that the term ‘responsible sourcing’ can be considered an umbrella term for socially responsible sourcing, green sourcing and, broadest of all, sustainable sourcing. In terms of the supply chain, it can refer to management of the upstream part only or to the entire chain. An analysis was made (Figure A1) of how often these features of ‘responsible sourcing’ were identified in the literature on responsible sourcing of minerals and in the literature on responsible sourcing in other sectors.

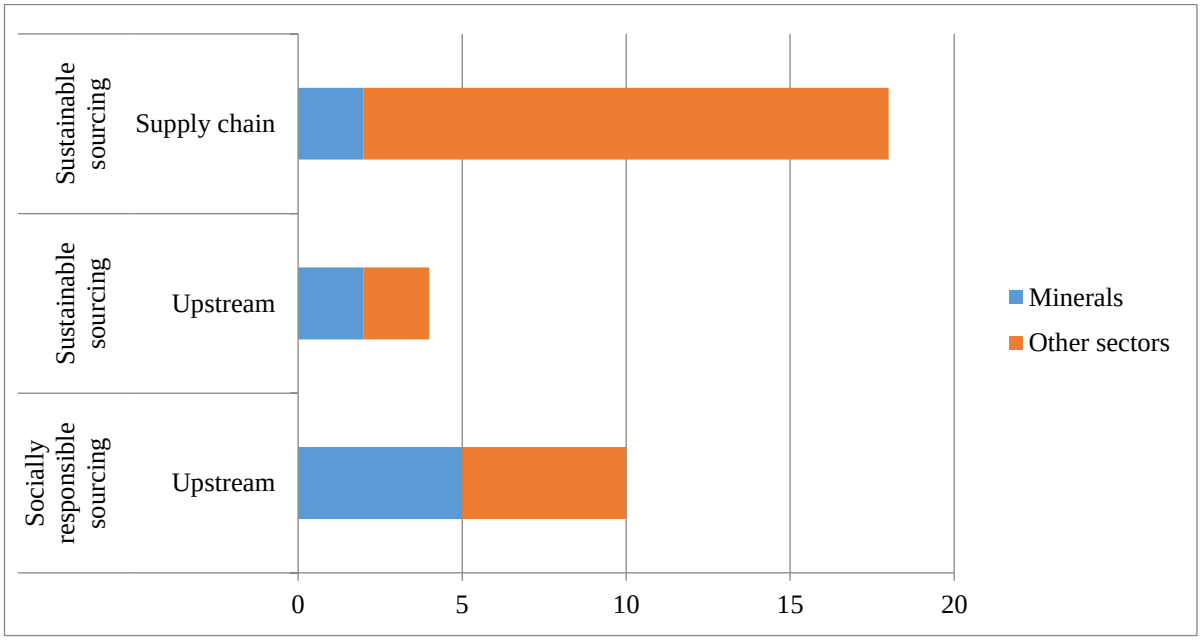

Figure A1: Analysis of the ‘features’ of ‘responsible sourcing’ as identified in the literature

2. Academic literature responsible sourcing divided by topic/sector

Topic/ Sector	Literature
Banking	1. Harvey, B., 1995. Ethical banking: The case of the Co-operative bank. Journal of Business Ethics, 14 (12), 1005-1013.
Clothing	2. Henkle, D., 2005. Gap Inc. sees supplier ownership of compliance with workplace standards as an essential element of socially responsible sourcing. Journal of Organizational Excellence. 25 (1), 17-25. 3. Jacobs, B.W., Singhal, V.R. 2017., The effect of the Rana Plaza disaster on shareholder wealth of retailers: Implications for sourcing strategies and supply chain governance. Journal of Operations Management, 1-15. 4. Responsible Sourcing Network., 2017. U.S. and European Apparel Companies Sign RSN Pledge to Call for Elimination of Forced Child Labor in Uzbekistan. https://static1.squarespace.com/static/594cbfa3440243aef3dfa1c4/t/59979a42b8a79b7b3e402a7a/1503107651507/Cotton+Pledge+Packet+Aug-2017+%281%29.pdf (accessed 10 November 2017). 5. Home Textiles Today, 2006. Socially Responsible Sourcing Is Aim of D'Angelo. https://catalogue.leidenuniv.nl/primo-explore/fulldisplay?docid=TN_gale_ofg142728825&context=PC&vid=UBL_V1&search_scope=All_Content&tab=all_content&lang=en_US (accessed 12 June 2018)
Coffee	6. Seong-Jong Joo Hokey Min Ik-Whan G., Kwon Heboong Kwon., 2010. Comparative efficiencies of specialty coffee retailers from the perspectives of socially responsible global sourcing. The International Journal of Logistics Management, 21 (3), 490 – 509. http://dx.doi.org/10.1108/09574091011089826
Construction	7. Brankley, L., 2011. Sustainable reinforcing steel scheme measures environmental impact. Concrete (London), 45 (1), 52-53. 8. Crampton, L., 2010. Pavement solution at M11 logistic centre project. Concrete (London), 44 (6), 44. 9. Chan, B., 2011. Sustainability for bridge engineers - Part 2. Structural Engineer, 89 (5), 14-15. 10. Glass, J., Achour, N., Parry, T., Nicholson, I., Upstill-Goddard, J., 2012. Responsible sourcing of construction products and materials - Results from an industry survey. 11. Glass, J., Achour, N., Parry, T., Nicholson, I. Engaging small firms in sustainable supply chains: Responsible sourcing practices in the UK construction industry. https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/14618/3/GlassetalIJASM2012.pdf (accessed 12 June 2018). 12. Glass, J. 2011., Briefing: Responsible sourcing of construction products. Engineering Sustainability, 164 (3). doi: 10.1680/ensu.1000011 13. Glass, J., Dainty, A.R.J. 2011. The sustainable construction business: A missing ingredient in creating a sustainable built environment? International Journal of Construction Management, 11 (2), 1-18. 14. Ghumra, S., Glass, J., Frost, M.W., Watkins, M., Mundy, J., 2011. Validating a set of empirically weighted sustainability indicators for construction products. Association of Researchers in Construction Management, ARCOM 2011 - Proceedings of the 27th Annual Conference, 2, 1115-1124. 15. Ghumra, S., Watkins, M., Phillips, P., Glass, J., Frost, M.W., Anderson, J., 2009. Developing a lca-based tool for infrastructure projects. Association of Researchers in Construction Management, ARCOM 2009 - Proceedings of the 25th Annual Conference, 1003-1010.

Topic/ Sector	Literature
	16. Upstill-Goddard, J., Glass, J., Dainty, A.R.J., Nicholson, I., 2015. Analysis of responsible sourcing performance in BES 6001 certificates. Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 168 (2), 71-81. DOI: 10.1680/ensu.14.00024 17. Upstill-Goddard, J., Glass, J., Dainty, A.R.J., Nicholson, I., 2016. Implementing sustainability in small and medium-sized construction firms The role of absorptive capacity Engineering, Construction and Architectural Management, 23 (4) 407 – 427. http://dx.doi.org/10.1108/ECAM-01-2015-0015. 18. Young, J., Osmani, M., 2013. Investigation into contractors' responsible sourcing implementation practice. Proceedings of the Institution of Civil Engineers: Engineering Sustainability, 166 (6), 320-329.
Food	19. Progressive Grocer. 2007. Whole Foods to Guarantee Socially Responsible Sourcing. https://catalogue.leidenuniv.nl/primo-explore/fulldisplay?docid=TN_gale_ofa166499781&context=PC&vid=UBL_V1&search_scope=All_Content&tab=all_content&lang=en_US (accessed 12 June 2018) 20. The Co-operative Group. 2009. The Co-op's responsible sourcing is quite a catch. Grocer, 232(7910), 39. https://catalogue.leidenuniv.nl/primo-explore/fulldisplay?docid=TN_gale_ofg203533752&context=PC&vid=UBL_V1&search_scope=All_Content&tab=all_content&lang=en_US (accessed 12 June 2018)
Governance	21. Spinello, R.A. 2014. Global capitalism, culture, and ethics. first ed Routledge, Abingdon-on-Thames.
Green marketing	22. Ghodeswar, B., Kumar, P., 2014. A study of green marketing practices in Indian companies. Marketing and Consumer Behavior: Concepts, Methodologies, Tools, and Applications, 2-4, 991-1010.
Materials	23. Murthy, V., 2013. Responsible glass and raw materials. Glass International, 36 (6), 12-13.
Minerals	24. Airiki, P.E., Rotter, J.P., Mark-Herbert, C., 2015. Corporate motives for multi-stakeholder collaboration- corporate social responsibility in the electronics supply chains. Journal of Cleaner Production 131, 639-648. http://dx.doi.org/10.1016/j.jclepro.2016.04.121 25. Ali, S.H., Giurco, D., Arndt, N., Nickless, E., Brown, G., Demetriades, A., Durrheim, R., Enriquez, M.A., Kinnaird, J., Littleboy, A., Meinert, L.D., Oberhänsli, R., Salem, J., Schodde, R., Schneider, G., Vidal, O., Yakovleva, N., 2017. Mineral supply for sustainable development requires resource governance. Nature, 543 (7645), 367-372. DOI: 10.1038/nature21359 26. Buhmann, K., 2017. Chinese human rights guidance on minerals sourcing: Building soft power. Journal of Current Chinese Affairs, 46 (2), 135-154. 27. Faber, B., Krause, B., Sanchez de la Sierra, R., 2017. Artisanal Mining, Livelihoods, and Child Labor in the Cobalt Supply Chain of the Democratic Republic of Congo. https://escholarship.org/uc/item/17m9g4wm. (accessed 22 January 2018). 28. Nickless, E., 2018. Resourcing Future Generations: A Contribution by the Earth Science Community. Natural Resources Research, 27 (2), 143-158. DOI: 10.1007/s11053-017-9331-x 29. Partzsch, L., & Vlaskamp, M. C., 2016. Mandatory due diligence for “conflict minerals” and illegally logged timber: Emergence and cascade of a new norm on foreign accountability. Extractive Industries and Society, 3(4), 978–986. https://doi.org/10.1016/j.exis.2016.07.003

Topic/ Sector	Literature
Minerals	30. Simmons, G.L., 2014. Conflict minerals: Responsible sourcing issues and factors impacting SEC rule. Conflict Minerals: Responsible Sourcing Issues and Factors Impacting SEC Rule, 1-110. 31. Wall, F., Rollat, A., Pell, R.S., 2017. Responsible sourcing of critical metals. Elements, 13 (5), 313-318. DOI: 10.2138/gselements.13.5.313 32. Young, S.B. 2015., Responsible sourcing of metals: certification approaches for conflict minerals and conflict-free metals. International Journal of Life Cycle Assessment, 19. DOI: 10.1007/s11367-015-0932-5
Retail	33. Abbamonte, L., Cavaliere, F., 2017. Shopping as 'Best Practice' - Analysing Walmart's Debated Sustainability Policies. Vestnik Rossijskogo Universiteta Družby Narodov: Seriâ Lingvistika, 21(1), 105-125. DOI: 10.22363/2312-9182-2017-21-1-105-125 34. Idle, T., 2009. Top of the food chain. Sustainable Business, (150), 20-21.
Seafood	35. Caveen, Lart, Duggan, & Pickerell., 2017. The Risk Assessment for Sourcing Seafood (RASS): Empowering businesses to buy responsibly. Marine Policy, 75, 1-10. https://doi.org/10.1016/j.marpol.2016.10.005 36. Shepherd, C.J., Monroig, O., Tocher, D.R., 2017. Future availability of raw materials for salmon feeds and supply chain implications: The case of Scottish farmed salmon. Aquaculture, 467, 49-62.
Supply chain management	37. Brown, G., 2009. Genuine worker participation-an indispensable key to effective global OHS. New solutions : a journal of environmental and occupational health policy, 19 (3), 315-333. 38. Govindan, K., Shankar, M., Kannan, D., 2018. Supplier selection based on corporate social responsibility practices. International Journal of Production Economics, 200, 353-379. DOI: 10.1016/j.ijpe.2016.09.003 39. Guo, R., Lee, H.L., Swinney, R., 2016. Responsible sourcing in supply chains. Management Science, 62 (9), 2722-2744. DOI: 10.1287/mnsc.2015.2256 40. Wassell, M., 2010. Responsible sourcing. Peace and Prosperity through World Trade, 259-263. DOI: 10.1017/CBO9780511723285.058 41. WANG, J. Jianbin, LI., 2017. Research on Decisions of Sourcing and Market Pricing in a Responsible Supply Chain. Chinese Journal of Management, 14(08), 1236-1243. 42. Zorzini, M., Hendry, L.C., Huq, F.A., Stevenson, M., 2015. Socially responsible sourcing: Reviewing the literature and its use of theory. International Journal of Operations and Production Management, 35 (1), pp. 60-109. DOI: 10.1108/IJOPM-07-2013-0355

Table A2: Academic literature responsible sourcing divided by topic/sector

3. Company reports

Company	Reference
Apple	Apple (2017). Environmental Responsibility Report. https://images.apple.com/environment/pdf/Apple_Environmental_Responsibility_Report_2017.pdf (accessed 20 June 2018). Apple (2016). Apple's commitment to Responsible Sourcing. https://images.apple.com/supplier-responsibility/pdf/Apple-Commitment-to-Responsible-Sourcing.pdf (accessed 20 June 2018).
Airbus	Airbus (2017). Supplier Code of Conduct. http://www.airbus.com/content/dam/corporate-topics/corporate-social-responsibility/ethics-and-compliance/Airbus-Ethics-and-Compliance-Supplier-Code.pdf (accessed 20 June 2018).

Company	Reference
ArcelorMittal	ArcelorMittal (2018). Responsible sourcing guide: http://corporate.arcelormittal.com/~/media/Files/A/ArcelorMittal/who-we-are/ArcelorMittal-Responsible-Sourcing-Guide.pdf (accessed 5 April 2017). Arcelor Mittal Responsible sourcing conflict minerals http://corporate.arcelormittal.com/sustainability/snapdown-hub/conflict-minerals-1#_ftn1 (accessed 20 June 2018).
Ardagh Group	Ardagh Group (2017) Responsible Procurement Policy. https://www.ardaghgroup.com/userfiles/files/Ardagh-Responsible-Procurement-Policy.pdf (accessed 5 April 2017). Ardagh Group (2016). Declaration on sourcing of Tin containing metals. https://www.ardaghgroup.com/userfiles/files/Ardagh-Conflict-Free-Mineral-Sourcing-Metal.pdf (accessed 5 April 2017).
Boeing	Boeing (2015) Conflict minerals policy http://www.boeingsuppliers.com/Boeing_Conflict_Minerals_Policy.pdf (accessed 5 April 2017). Boeing (2015) Supplier Code of Conduct. http://www.boeingsuppliers.com/terms_conditions/BDA-Supplier-code-of-conduct.pdf (accessed 20 June 2018).
Daimler	Daimler (2015). Sustainability report. https://www.daimler.com/documents/sustainability/other/daimler-sustainability-report-2015.pdf (accessed 20 June 2018).
Dell	Dell (2017). Supply chain Social and Environmental Responsibility Progress Report. http://i.dell.com/sites/doccontent/corporate/corp-comm/en/Documents/ser-report.pdf (accessed 20 June 2018). Dell (2017) Responsible Sourcing Policy. http://i.dell.com/sites/doccontent/corporate/corp-comm/en/Documents/conflict-minerals-policy.pdf (accessed 20 June 2018).
Hewlett Packard	Hewlett Packard (2016). Sustainability Report. http://www8.hp.com/h20195/v2/GetPDF.aspx/c05507473.pdf (accessed 20 June 2018). Hewlett Packard (2015). Supplier Code of Conduct. http://h20195.www2.hp.com/V2/getpdf.aspx/c04797684 (accessed 20 June 2018).
Norsk Hydro	Norsk Hydro Annual report: https://www.hydro.com/globalassets/1-english/investor-relations/annual-report/2016/downloads/annual-report-2016.pdf
Novelis	Novelis (2015). Rewinding our raw materials. http://novelis.com/wp-content/uploads/2015/12/Novelis-2015-sourcing-section.pdf (accessed 20 June 2018). Novelis (2015). Novelis Supplier Code of Conduct. http://2gjjon1sdeu33dnmvp1qwsdx.wpengine.netdna-cdn.com/wp-content/uploads/2015/09/Novelis-Supplier-Code-of-Conduct.pdf (accessed 20 June 2018).
Samsung	Samsung (2016). Progress Report on Responsible Cobalt Supply Chain. https://www.samsungsdi.com/upload/download/sustainable-management/Samsung_SDI_-_2016_Progress_Report_on_Responsible_Cobalt_Supply_Chain_V12.pdf (accessed 20 June 2018). Samsung (2016). Samsung Electronics Supports a Responsible Approach to Mineral Sourcing. https://news.samsung.com/global/samsung-electronics-supports-a-responsible-approach-to-mineral-sourcing (accessed 20 June 2018).
Siemens	Siemens (2017) Responsible Minerals Sourcing Policy. https://w5.siemens.com/cms/supply-chain-management/en/sustainability/responsibleminerals/Documents/Responsible_Minerals_Policy_DEC_2017.pdf (accessed 20 June 2018). Siemens (2015). Sustainability in the supply chain. Code of Conduct for suppliers and third-party intermediaries. http://w5.siemens.com/cms/supply-chain-management/en/sustainability/Documents/coc/Code_of_conduct_eng.pdf (accessed 20 June 2018).

Company	Reference
Tata Steel	Tata Steel (2018) Responsible sourcing : https://www.tatasteelconstruction.com/en_GB/sustainability/Responsible-sourcing/Responsible-sourcing (accessed 20 June 2018). Tata steel (2017) responsible sourcing of minerals:http://www.tatasteel.com/products-solutions/india/products/raw-materials-and-responsible-mining/ http://www.tatasteel.com/sustainability/sustainability-pillars/environmental-excellence/ (accessed 20 June 2018).
Toyota	Toyota (2012) Supplier CSR Guidelines http://www.toyota-global.com/sustainability/society/partners/supplier_csr_en.pdf(accessed 20 June 2018).

Table A3: References to company reports

Appendix II

Based on the supplementary information provided with Chapter 3.
Published in: Resources, Conservation and Recycling (2020), 156, art. No.104743

1. Trade flow inconsistencies

This section provides additional information about the trade flow analysis in section 3.3. Sun et al. (2019) made a similar map of the cobalt trade. The map of cobalt trade (based on 2015) from the study by Sun et al. (2019) shows flows of cobalt ores and concentrates between the Democratic Republic of the Congo and Finland, and Belgium. Their study is based on export data, but they noted that export trade flows of Democratic Republic of the Congo were not reported in the Trade Database, and that the trade amount from the Democratic Republic of the Congo was estimated by corresponding trade of other countries (Sun et al., 2019).

In our study, based on import data, we did find export flows from the Democratic Republic of Congo, but not between the Democratic Republic of the Congo and Belgium and Finland, therefore these are not shown in Figure 3.1. The BGS (2018) notes that the cobalt recorded as refined in Belgium is actually refined in China, which would explain the lack of flows between Belgium and the Democratic Republic of the Congo. An explanation for the lack of flows to Finland could be that the import of these countries is reported under a commodity code that is not specifically for cobalt, e.g. under nickel or copper products. The latter would also explain the export flows missing from Indonesia, Vietnam and the Philippines, these countries mine cobalt, do not have a refinery and export little to no cobalt.

2. HS codes of cobalt trade flows

HS code	Description
2605	Cobalt ores and concentrates
2822	Cobalt Oxides and hydroxides: commercial cobalt oxides
8105	Cobalt: mattes and other intermediate products of cobalt metallurgy, cobalt and articles thereof, including waste and scrap
282734	Chlorides: of cobalt
291523	Acids: saturated acyclic monocarboxylic acids: cobalt acetates: no results import of export data

Table B1. HS codes of cobalt trade flows (Comtrade, 2019)

3. Estimated percentage cobalt content in intermediate cobalt products

Cobalt 'product'	HS code	Estimated percentage cobalt	Source
Cobalt ores	2605	0.1% to 2.5% depending on the deposit	British Geological Survey (2009). Cobalt. https://www.bgs.ac.uk/downloads/start.cfm?id=1400 (accessed 16 April 2019)
Cobalt concentrates	2605	Up to 15%	Young, R.S., Campbell Taylor, J. (2017) Cobalt processing. https://www.britannica.com/technology/cobalt-processing (accessed 16 April 2019)
Cobalt oxides	2822	Around 79% (depending on form)	Wikipedia (2019). Cobalt (II) oxide. https://en.wikipedia.org/wiki/Cobalt(II)_oxide (accessed 16 April 2019)
Cobalt hydroxide	2822	Around 54% (depending on form)	Wikipedia (2019). Cobalt (II) hydroxide. https://en.wikipedia.org/wiki/Cobalt(II)_hydroxide
Unwrought cobalt	8105	For example, an ingot of unwrought cobalt alloy is made up of 68% cobalt. Bare hardfacing welding rots typically contain 60% of cobalt. Electric induction melted 64%.	Tariff Nomenclature (2016). Other cobalt, unwrought, powders. https://tariff.cc/en/other-cobalt-unwrought-powders (accessed 16 April 2019)
Powders	8105	Commercial cobalt-metal powders are available in purities ranging from 99% to ≥ 99.999% in many grades, particle size ranges and forms.	International Agency for Research on Cancer. (2018). Metallic cobalt particles (with or without tungsten carbide). https://monographs.iarc.fr/wp-content/uploads/2018/06/mono86-6.pdf (accessed 16 April 2019)
Cobalt matte	8105	Cobalt content in matte is around 1.5% to 2%.	British Geological Survey (2009). Cobalt. https://www.bgs.ac.uk/downloads/start.cfm?id=1400 (accessed 16 April 2019)

Table B2: Estimated percentage cobalt content in cobalt products.
*The cobalt content of cobalt ores can range from 0.1% to 2.5% depending on the deposit (BGS, 2009), while cobalt concentrates can contain up to 15% of cobalt content (Young, Campbell and Taylor, 2017). Cobalt mattes can contain 1.5% cobalt (BGS, 2009), while cobalt powders can contain 99.9% cobalt (International Agency for Research on Cancer, 2018).

4. Mined and refined cobalt production (metal content) in kiloton (kt) in 2016

Country	Mined cobalt production 2016 (kt)*	Refined cobalt production 2016 (kt)**
Democratic Republic of the Congo	69	0
China	11	45
Canada	7	6
Australia	6	3
Zambia	5	5
New Caledonia	4	3
Cuba	4	0
Brazil	4	0
Madagascar	3	3
Philippines	3	0
Finland	2	12
Papua New Guinea	2	0
Russia	2	2
Morocco	2	2
Poland	2	0
South Africa	1	1
United States	1	0
Zimbabwe	0	0
Indonesia	0	0
Botswana	0	0
Vietnam	0	0
Belgium		6
Japan		4
Norway		4
France		0
India		0
Total	**128**	**98**

Table B3. Mined and refined cobalt production (metal content) in kiloton (kt) in 2016 (BGS, 2018)

*Mined cobalt production: the production for the United States, Brazil, China and Indonesia are not provided by the countries but based on estimations by the BGS. For Russia, Morocco, South Africa, Zambia and Zimbabwe the cobalt is either metal and/or refined.

**Refined cobalt production: refined cobalt can be in the form of metal, oxides, carbonates, sulfates and many other compounds, efforts are made to avoid double-counting, but it is not always possible to be certain (BGS, 2018)

5. Cobalt mines, by-products, production 2016, mine operators and shareholders

Country	Mine Sites	Co by-product	Co prod. (t) 2016	Operator	Share-holder(s)	References*
Australia	Ravensthorpe (Bandalup)	Nickel	**920**	First Quantum Minerals	First Quantum Minerals	Indian Bureau of Mines (2017), Australian Mining (2018).
	Maggie Hays (Lake Johnston - Norilsk)	Nickel		LionOre Australia	LionOre Australia Pty Ltd	Australian Mining (2018)
	Maggie Hays (Lake Johnston - Norilsk)	Nickel		Norilsk Nickel	Norilsk Nickel	Australian Mining (2018)
	Mariners	Nickel		Mincor Resources	Mincor Resources	Australian Mining (2018)
	McLeay (Victor South, Victor)	Nickel		Independence Group	Independence Group	Australian Mining (2018)
	Cliffs (Cliffs Nickel, Mt Keith Cliffs Charterhall)	Nickel		BHP Biliton	BHP Biliton	Australian Mining (2018)
	Tapinos	Nickel		Jubilee Metals Group	Jubilee Metals Group	Australian Mining (2018)
	Tritton	Copper		Aeris Resources	Aeris Resources	Australian Mining (2018)
	Lounge Lizard Nickel	Nickel		Western Areas	Western Areas	Australian Mining (2018)
	Miitel	Nickel		Mincor Resources	Mincor Resources	Australian Mining (2018)
	Murrin Murrin	Nickel	**2800**	Minara Resources	Glencore	Australian Mining (2018), Glencore (2016)
	Mount Keith	Nickel		BHP Biliton	BHP Biliton	Australian Mining (2018)
	Savannah	Nickel	**476**	Panoramic Resources	Zeta Resources	USGS (2017b)
	Greenville/Townsville, Queensland	Nickel	**1850**	Queensland Nickel Group	Queensland Nickel Group	USGS (2017b)
Botswana	Selebi-Phikwe Mines	Nickel	**400**	Bamangwato Concessions	Gov. Botswana (94%, Norilsk Nickel 6%)	USGS (2017c), BGR Data (2019)

	Mine Sites	Co by-product	Co prod. (t) 2016	Operator	Share-holder(s)	References*
Brazil	Sante Fe	Nickel		Santa Fe Gold Corporation	Santa Fe Gold Corporation	Santa Fe Gold Corporation (2018), USGS (2017a)
	Serra do Tapa	Nickel		Horizonte Minerals Plc	Glencore	USGS (2017a), Newswire (2016)
Brazil	Vermelho	Nickel	**2500**	Horizonte Minerals Plc	Glencore	USGS (2017a), USGS (2017b), Horizonte Minerals (2018)
	Vila Oito	Nickel		Horizonte Minerals Plc	Glencore	USGS (2017a), Lara Exploration (2007)
	Fortaleza de Minas	Nickel		Votorantim	Votorantim Group	USGS (2017a), Wikipedia (2018), BGR Data (2019)
	Niquelandia, Goias	Nickel		Votorantim	Votorantim Group	BGR Data (2019)
	Santa Rita, Chino Mine	Copper		Freeport McMoran	Freeport McMoran	Freeport-McMoran (2018), Indian Bureau of Mines (2017), USGS (2017b)
	Sao Miguel Paulista	Nickel		Votorantim	Votorantim	USGS (2017b)
	Jacare	Nickel		Anglo American	Anglo American	Mining Atlas (2018b)
	Americano do Brasil, Goias			Prometalica	Prometalica	
Canada	Voisey's Bay	Nickel	**887**	Vale	Vale	Vale (2016), BGR Data (2019)
	Raglan	Nickel	**1000**	Glencore	Glencore	Natural Res. Canada (2018), BGR Data (2019)
	Sudbury	Nickel	**882**	Vale Canada Limited	Vale	Natural Res. Canada (2018), BGR Data (2019)
	Nunavik	Nickel		Canadian Royalties Inc.	Canadian Royalties Inc.	Natural Res. Canada (2018), BGR Data (2019)
	Nickel Rim South, Fraser	Nickel	**100**	Glencore Canada Corporation	Glencore	Natural Res. Canada (2018), BGR Data (2019)

	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
	Garson	Nickel		Vale Canada Limited	Vale	Natural Res. Canada (2018), BGR Data (2019)
Canada	Stobie	Nickel		Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Clarabelle	Nickel		Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Copper Cliff North	Nickel	**606**	Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019), Ontario Prospectors Association (2016)
	Creighton	Nickel		Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Coleman/McCredy East	Nickel		Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Strathcona	Nickel		Glencore Canada Corporation	Glencore	Natural Resources Canada (2018), BGR Data (2019)
	Totten	Nickel		Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Thompson	Nickel	**700**	Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Birchtree	Nickel		Vale Canada Limited	Vale	Natural Resources Canada (2018), BGR Data (2019)
	Lac des Iles	Nickel		North American Palladium	North American Palladium	BGR Data (2019)
	Rainy River	Nickel		New Gold Inc	New Gold Inc	BGR Data (2019)
China	Tangdan (Dongchuan)	Copper				USGS (2017a)
	Jinchuan	Nickel				USGS (2017a)
	Yangliuping	Nickel				USGS (2017a)
	Lala (Lalachang)	Copper				USGS (2017a)

	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
	Longshou	Nickel		Jinchuan Group	Jinchuan Group	BGR Data (2019)
	Deerni	Copper		Zijin Mining	Zijin Mining	BGR Data (2019)
Cuba	Moa Nickel S.A. (mine and processing plant)	Nickel	**3694**	Sherritt International	Government of Cuba (50%), Sherritt International (50%)	Investing News (2018), Sheritt International (2017:p19),USGS (2017a), BGR Data (2019), Brown: Sherritt reported only 50% of the total production
	Pinares de Mayari	Nickel		General Nickel Company S.A.	General Nickel Company S.A. (65%), BHP Biliton (35%)	The Diggins (2018), USGS (2017a)
	Punta Gorda	Nickel		Sherritt International	Sherritt International	Investor Intel (2014), Sheritt International (2017:p19)
Dem. Rep. of the Congo	Deziwa	Copper		Société Minière de Deziwa et Ecaille C	Gecamines	CongoMines (2018), USGS (2017a)
	Ecaille C	Copper		Zijin Mining Group Co.	Zijin Mining Group Co. Ltd	USGS (2017a)
	Dilala East	Copper		Compagnie Minière de Dilala	Gecamines	CongoMines (2018)
	DIMA (Mashamba Est, Mashamba West, Dikuluwe)	Copper		Katanga Mining	Glencore	CongoMines (2018)
	Usoke production plant	Copper	**2400**	Chemaf	Chemaf	Congomines.org, USGS (2017a), Chemaf (2018)
Dem. Rep. of the Congo	Etoile, Etoile HMS 1, Etoile HMS 2	Copper	**3800**	Shalina Resources Ltd	Chemaf	CongoMines (2018), USGS (2017a), BGR (2017)

	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
	Ruashi Mine	Copper	**3264**	Metorex	Jinchuan Group	Chemaf (2018), CongoMines (2018), USGS (2017a)
	Kababankola	Copper		Kababankola Mining Company	Gecamines	CongoMines (2018)
	Kabolela, Kipese	Copper		Société Minière de Kabolela et de Kipese (SMKK)	Eurasian Natural Resources Corporation (50%), Groupe Fleurette (50%)	CongoMines (2018), USGS (2017a)
	Kakanda, Lwita Est, Mukondo Mountain	Copper	**5100**	Boss mining	Eurasian Natural Resources Corporation	CongoMines (2018), USGS (2017a), Eurasian Natural Resources Corporation (2017)
	Kii	Copper		Congolaise des Mines et du Développement (COMIDE)	Eurasian Natural Resources Corporation	CongoMines (2018), USGS (2017a)
	Kalakundi	Copper		Société d'exploitation des Gisements de Kalukundi	Gecamines (50%), Eurasian (25%), Africo Resources (25%)	CongoMines (2018), USGS (2017a)
	Kambove, Kamoya	Copper		Compagnie Minière de Kambove (COMIKA)	Wanbao Mining	CongoMines (2018), USGS (2017a)
	Kamfundwa	Copper		Gecamines	Gecamines	Mindat (2018a), CongoMines (2018), Wikipedia (2018b)
	Musonoi	Copper		Comp. Minière de Musonoi COMMUS	Gecamines (28%), Jinchuan Group (72%)	CongoMines (2018), USGS (2017a)

Country	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
Dem. Rep. of the Congo	Kamoto, Kananga, KOV, Mashamba Est, T17, Tilwezembe	Copper	**2901**	Katanga Mining Limited	Glencore	CongoMines (2018), USGS (2017a), BGR (2017)
	Kipoi Central, Kipoi North	Copper		Société d'exploitation de Kipoi (SEK)	Tiger Resources	CongoMines (2018), USGS (2017a)
	Kisanfu	Copper		Phelps Dodge Congo	Freeport Mc Moran Copper	CongoMines (2018), USGS (2017a)
	Luishia	Copper	**480**	Miniere du Sud Katanga (CMSK)	Entreprise General Malta Forrest (60%), Gecamines (40%)	CongoMines (2018), USGS (2017a)
	Luiswishi	Copper	**6200**	Huayou Cobalt (prev. Congo Dongfang International Mining(CDM)	Huayou Cobalt	CongoMines (2018), USGS (2017a), BGR (2017)
	Mutanda North (ex-Kansuki), Mutanda South,	Copper	**24500**	Mutanda ya Mukonkota Mining (MUMI)	Glencore	CongoMines (2018), USGS (2017a),Glencore (2016)
	Mutoshi	Copper		Société Minière de Kolwezi (SMK)	Gecamines	CongoMines (2018), USGS (2017a)
	Tenke Fungurume: Fwaulu, Fungurume, Kansalawile, Kwatebala, Mambilima, Mwadinkomba	Copper	**16053**	Tenke Fungurume Mining (TFM)	China Mol.56% ,Lundin Mining,24%, Gecamines,20%	CongoMines (2018), USGS (2017a), Lundin Mining (2017)

Country	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
Finland	Hitura	Nickel		Belvedere Mining Oy	Belvedere Resources Ltd	PWC (2012), USGS (2017a), Mining Atlas (2018)
	Kevitsa	Copper	**420**	Boliden	Boliden	Boliden (2017), USGS (2017a), USGS (2017b), BGR Data (2019)
Finland	Sotkamo (formerly Talvivaara)	Nickel	**20**	Terrafame Mining	Trafigura and Solidium	USGS(2017a),Yle (2018), Talvivaara Mining Company Plc (2013), BGR Data (2019)
	Kouvervaara	Copper		Belvedere Mining Oy	Belvedere Resources Ltd	PWC (2012), USGS (2017a)
	Outokumpu	Copper		Outokumpu Oyj/Boliden Kylylahti Copper Oy	Altona mining/ Copper Mountain Mining Corporation	USGS (2017a)
	Outokumpu (Luikonlahti)	Copper		Outokumpu Oyj/Boliden Kylylahti Copper Oy	Altona mining/ Copper Mountain Mining Corporation	USGS (2017a)
	Outokumpu (Saramäki)	Copper		Outokumpu Oyj/Boliden Kylylahti Copper Oy	Altona mining/ Copper Mountain Mining Corporation	USGS (2017a)
	Outokumpu (Vuonos)	Copper		Outokumpu Oyj/Boliden Kylylahti Copper Oy	Altona mining/ Copper Mountain Mining Corporation	USGS (2017a)
	Harjavalta	Nickel		Norilsk Nickel	Norilsk Nickel	The Balance (2018), USGS (2017a)

Country	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
Indonesia	Halmahera/Weda Bay	Nickel	**400**	Eramet	PT Antam (90%), Mitsibushi (10%)	Eramet (2010), USGS (2017a)
	La Sampala	Nickel		Rio Tinto	Rio Tinto	DowntoEarth (2006), USGS (2017a)
	Sorowako (Sulawesi)	Nickel		Vale Indonesia		USGS (2017a), USGS (2017b)
	Pomalaa, Tanjung Buli, Tapunopaka	Nickel		PT Antam	PT Antam	
Morocco	Bou Azzer	Cobalt	**2081**	Compagnie de Tifnout Tiranimine (CTT)	Managem Group	USGS (2017a), Managem Group (2016
New Caledonia	Goro (VNC)	Nickel	**3188**	Goro (VNC)	Vale	USGS (2017a), Vale (2016), BGR Data (2019)
Papua New Guinea	Ramu	Nickel	**2191**	Highlands Pacific	China Metallurgical Group Corporation (75%), PNG Government (25%)	China Nonferrous Mining Corporation Limited (2016), BGR Data (2019)
	Wowo Gap	Nickel		Niugini Nickel Ltd	Resource Mining Corporation Limited	USGS (2017a), Resource Mining Corporation Limited (2016)
Philippines	Acoje/Zambalas	Nickel		Benguetcorp Nickel Mines Inc.	Benguetcorp Nickel Mines Inc.	Government of the Philippines (2018), USGS (2017a)
	Agata/Bolobolo Karihatag	Nickel		Agata Mining Ventures	Agata Processing Inc	Government of the Philippines (2018), USGS (2017a)

	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
	Berong	Nickel		Berong Nickel Corporation	Berong Nickel Corporation	Government of the Philippines (2018), USGS (2017a)
	Cagdianao, Hinatuan	Nickel		Cagdianao Mining Corporation	Nickel Asia Corp.	Government of the Philippines (2018), USGS (2017a), BGR Data (2019)
	Ipilan	Nickel		Ipilan Nickel Corp	Ipilan Nickel Corp	Government of the Philippines (2018), USGS (2017a)
	Mindoro	Nickel		Mindoro Resources Ltd	Mindoro Resources Ltd	Government of the Philippines (2018), USGS (2017a)
	Nonoc	Nickel		Philnico Industrial Corp	Philnico Industrial Corp	Government of the Philippines (2018), USGS (2017a)
Philippines	Taganito/Adlay	Nickel		Taganito Mining Corporation	Nickel Asia (65%), Pacific Metals (33.5%), Sojitz Phillipines (1.5%)	MetalBulletin (2015), USGS (2017a), Government of the Philippines (2018), BGR Data (2019)
Poland	Lubin-Malomice	Copper		KGHM Polska	KGHM	Wikipedia (2018d), KGHM (2019), BGR Data (2019)
Russia	TAIMYR PENINSULA: Talnakhskoye, Oktyabrskoye Fields	Copper	**2040**	Norilsk Nickel	Norilsk Nickel	Investor Intel (2016)
	Kola Peninsula: Tans-Baikal	Nickel		Norilsk Nickel (Kola mining and metallurgical company)	Norilsk Nickel (Kola mining and metallurgical company)	Investor Intel (2016), BGR Data (2019)
	Ufaleynickel	Nickel		Ufaleynickel	Ufaleynickel	Investor Intel (2016)

	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
	YozhUralsnickel	Nickel		Yozhuralsnickel	Yozhuralsnickel	Investor Intel (2016)
South Africa	Nkomati	Nickel	**1065**	Africa Rainbow Minerals	Norilsk Nickel Africa (50%), Africa Rainbow Minerals (50%)	BGR Data (2019)
United States	Eagle	Nickel	**650**	Eagle Nickel-Copper Mining	Lundin Mining	
Vietnam	Ban Phuc nickel mine and plant, Tha Koa	Nickel	**277**	Asian Mineral Resources (AMR)	Asian Mineral Resources	BGR Data (2019)
Zambia	Baluba center Copper mine	Copper		China Nonfer. Mining Luanshya Copper mines	China Non-fer. Mining (80%), ZZCM Investment (20%)	
	Chambishi	Copper	**2997**	Chambishi Metals plc Zambia	China Non-fer. Mining (85%), ZCCM Investment (15%)	BGR Data (2019)
Zambia	Nchanga, Konkola	Copper	**1700**	Konkola Copper Cobalt Operation	Vedanta Resources (79%), ZCCM Investment (21%)	BGR Data (2019)
	Lubambe copper mine	Copper		Lubambe copper mine	EMR Resources (80%), ZCCM Investments (20%)	
	Lumwana copper mine	Copper		Lumwana copper mine	Barrick Gold Corporation	

	Mine Sites	Co by-product	Co prod. (t) 2016*	Operator	Share-holder(s)	References*
	Mopani	Copper		Mopani copper/cobalt operation	Glencore (73%), First Quantum Minerals (17%), ZCCM Investments (10%)	BGR Data (2019)
	Muliashi copper operation	Copper		China Nonferrous Mining Corporation Limited	China Non-ferrous Mining Corp (80%), ZCCM Investments (20%)	
	Nkana	Copper			Glencore	
Zimbabwe	Trojan Mine at Bindura and Shangani Mine	Nickel	**800**	Bindura Nickel Corporation Ltd. (Mwana Africa plc)	Bindura Nickel	
	Mimosa	Nickel	**88**	Impala Platinum Holdings Ltd	Aquarius Platinum (50%), Impala Platinum (50%)	BGR Data (2019)

Table B4. Overview of cobalt mines globally

*References can be found in the article and in the end of this appendix.

6. World Governance Index

	Political Stability and Absence of Violence/Terrorism	Mined cobalt production 2016 (BGS 2018)	Refined cobalt production 2016 (BGS 2018)
Congo, Dem. Rep.	-2,23	68822	400
Philippines	-1,38	2554	
Russian Federation	-0,95	2100	2100
Zimbabwe	-0,62	409	
China	-0,5	10500	45046
Papua New Guinea	-0,5	2191	
Brazil	-0,38	3600	400
Indonesia	-0,37	350	
Morocco	-0,31	2081	2081
Madagascar	-0,29	3370	3273
South Africa	-0,14	1101	1101
Zambia	0,14	4725	4725
Vietnam	0,23	134	
United States	0,4	690	
Poland	0,51	1670	
Cuba	0,69	3694	
Botswana	0,99	248	
Finland	1	2308	12393
Australia	1,05	6012	3200
Canada	1,26	6969	6355
Belgium	0,44		6329
Japan	0,98		4305
Norway	1,2		3541
France	-0,1		119
India	-0,95		100
Total negative WGI score		**-7,76**	**-5,85**
Total Positive WGI score		**6,27**	**6,07**

Table B5: World Governance Index – PV weighted to cobalt mined and refined production. World Governance Index (2019).

7. Environmental Performance Indicator

Country	Environmental Performance Indicator (2016)	Mined production country (t) (BGS, 2018)	Refined production (t) (BGS, 2018)
Australia	87	6012	3200
Botswana	71	248	
Brazil*	79	3600	400
Canada	85	6969	6355
China*	65	10500	45046
Cuba	79	3694	
DRC	42	68822	400
Finland	91	2308	12393
Indonesia*	66	350	
Madagascar	37	3370	3273
Morocco	74	2081	2081
New Caledonia			2531
Papua New Guinea	48	2191	
Philippines	74	2554	
Poland	81	1670	
Russia	84	2100	2100
South Africa	71	1101	1101
United States	85	690	
Vietnam	59	134	
Zambia	66	4725	4725
Zimbabwe	59	409	
Belgium	80		6329
France	88		119
India	54		100
Japan	81		4305
Norway	87		3541
Total Production		**123528**	**97999**
Weighted EPI		**56**	**71**

Table B6: Environmental Performance Indicator weighted to cobalt mined and refined production (based on Hsu, A. et al., 2016).)

8. Most important current nickel-cobalt primary production routes

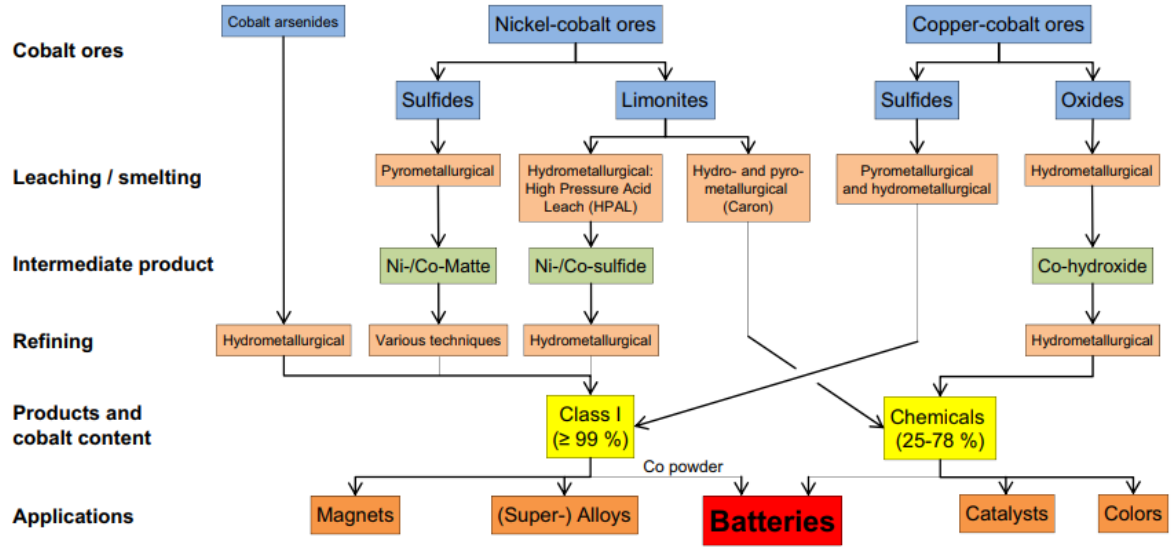

Figure B1. Most important current nickel primary production routes, intermediate products, nickel content and applications.

Source: Schmidt, T., Buchert, M., Schebek, L. Investigation of the primary production routes of nickel and cobalt products used for Li-ion batteries. Resources, Conservation and Recycling, 112, 107–122. http://dx.doi.org/10.1016/j.resconrec.2016.04.017

Examples of leaching/smelting on site:

- *At the Moa Bay mine there is the Moa Bay nickel smelter "Moa uses an open-pit mining process to mine lateritic ore, which is processed using high-pressure acid leaching on-site into mixed sulphides containing nickel and cobalt".(Sherritt, 2019, https://www.sherritt.com/English/operations/metals/Moa/default.aspx ,accessed August 2019)*
- *At the Rio Tuba Nickel mine in the Philipiines, Coral Bay Nickel Corporation operates a Hydrometallurgical Processing Plant (HPP) to produce nickel and cobalt sulfide from existing stockpiles of low grade nickel ores from the Rio Tuba nickel mine (Coral Bay Nickel, 2019, http://coralbaynickel.com/, accessed August 2019)*
- *At the Nchanga mine in Zambia , Konkola copper mines operates the Konkola smelter (Konkola Copper Mines, http://kcm.co.zm/our-operations/mining-process/ , accessed August 2019)*
- *At the ruashi mine in the Democratic Republic of the Congo Meteorex operates a modern solvent extraction electro-winning plants (Meteorex, 2019, http://www.metorexgroup.com/mine/ruashi-mining/ ,accessed August 2019)*

9. Map of the Central African Copper Belt giving an overview of DRC's industrial and artisanal copper cobalt mines

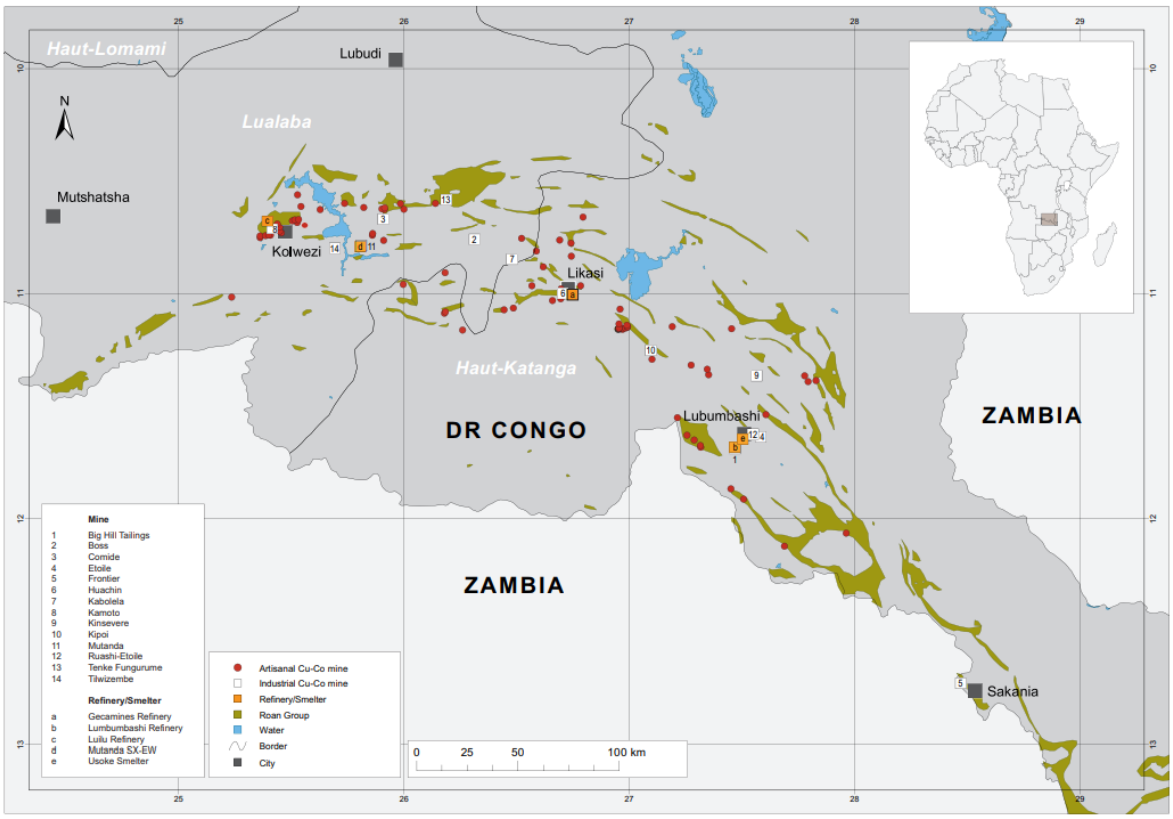

Figure B2: Map of the Central African Copper Belt giving an overview of DRC's industrial and artisanal copper cobalt mines as well as refineries and smelters (BGR 2017b)

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Appendix III

Based on the supplementary information provided with Chapter 4.
Published in: Resources, Conservation and Recycling (2022), 186, art. No.106586

1. Balancing price feedback loops

Supply chain disruptions lead to a (perceived) lack of supply or increase in demand. This will result in a price increase that can incentivize investments in new production (balancing feedback loop B1), recycling (balancing feedback loop B3), research on substitution / improving material properties (balancing feedback loop B5) or to emergency stockpiling (balancing feedback loop B5). Investments in new production (B1) increase the ore supply, after a significant time delay (Sprecher et al., 2015). This time delay depends on the type of new production. According to Van de Camp (2018) the development of a new mine can take 7 to 10 years, while reopening a mine that is in care and maintenance, or expanding a mine has a time lag of 1.5 to 3 years. There can also be instantaneous new production by an increase in recovery rates from the host's production process, or to extract it from the host metals tailings.

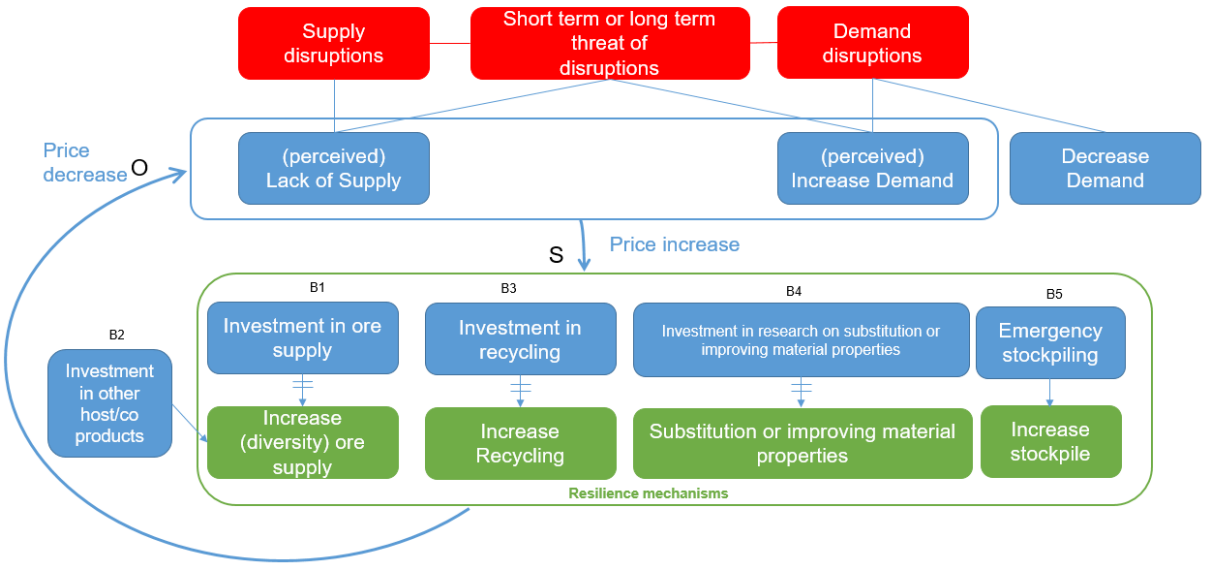

Figure C1. Summary of the main balancing price feedback loops.

These are also illustrated in Figure 1 in the article. The red rectangles represent supply and demand disruptions or threats of supply or demand disruptions. The blue arrow represent the balancing feedback loops, linked to balancing feedback loops 1 to 5. The green rectangles represent the resilience mechanisms.

2. Top 10 largest antimony producers between 1929 and 2018

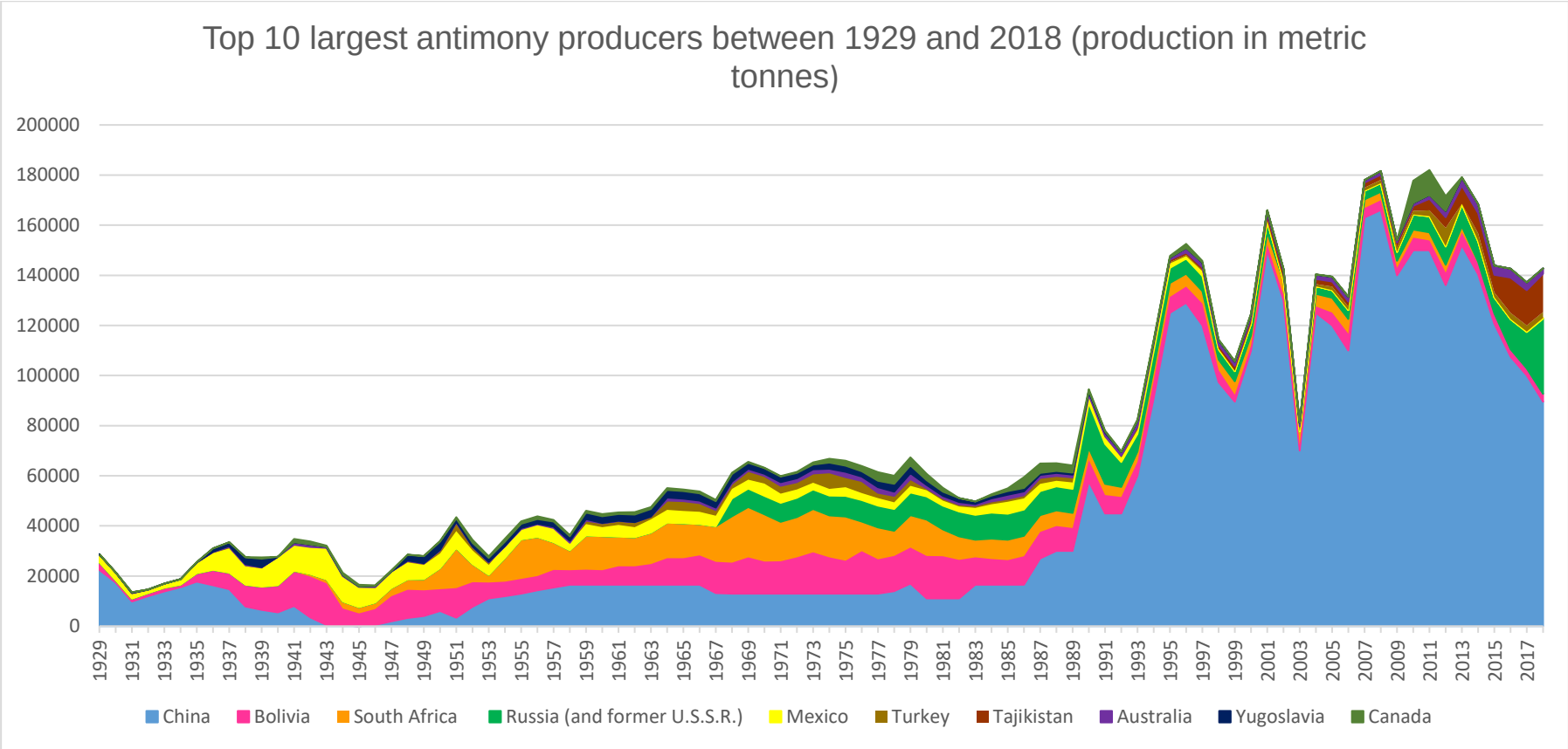

Figure C2. Top 10 largest antimony producers between 1929 and 2018 (production in metric tonnes).
Data from 1932 until 1993 is from the USGS archive. Of note: the data differs per publication, often it is adjusted in later years, data from earlier years is used and sometimes it is an estimate (USGS, 2021).

3. HHI antimony mine production country level 1929-2018

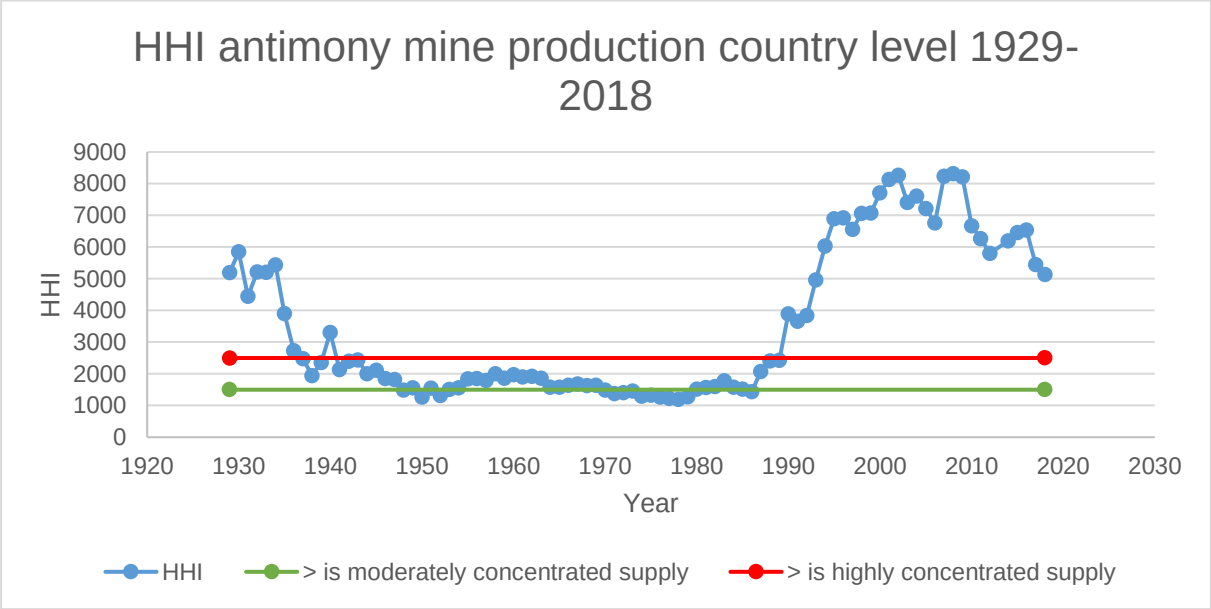

Figure C3. The HHI of global antimony production by country from 1929 to 2018 (USGS, 2021). Above the green line (1500-2500), the supply is moderately concentrated, above the red line (HHI>2500), the supply is highly concentrated.

4. Price-production correlation for price cycles

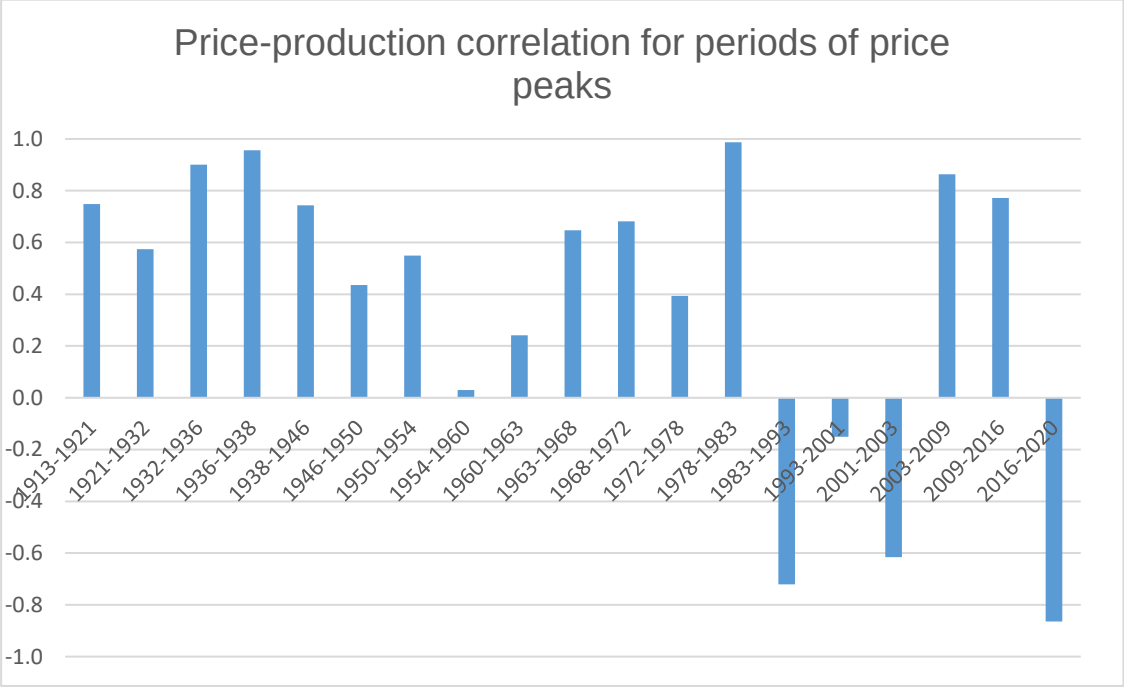

Figure C4. Price-production correlation from 1913-2020 of price cycles.
Price cycles are from the lowest price point to the lowest price point based on the global antimony production and price (Argusmedia, 2021, US Antimony, 2020, USGS, 2011, USGS, 2012, USGS, 2017b).

5. Antimony mines globally (2018)

Country	Sb prod. 2018 (t)	Mine	Commodities	Sb prod. 2018 (t)	Total per country	Operator and abbreviation	Parent company and abbreviation	References
China	89600	Xikuangshan (mines north of Lengshuijiang)	Sb	*18600* (2)	*89600*	Hunan Hsikwangshan Sb Import & Export Co. Ltd (Twinkling)	Hunan Non - Ferrous Holding Group (100% owner) China Minmetals Co. Ltd (Hunan. G.)	ResearchinChina (2016), hksts (2020)
		Multiple, including Wenshan Zhou Muli	Sb, Au	*18000* (2)		Multiple (a) (Multiple Huac)	Huachang Group and others (Multiple)	Research in China (2016), Bräuninger et al. (2013), Antimony CN (2021)
		Woxi mines (Xiangxi)	Au, Sb, W	*14000* (2)		Hunan Gold Corporation (Hunan. G.)	Hunan Gold Corporation (Hunan. G.)	Zhang et al., 2019, Research in China (2016), ResearchandMarkets (2016)
		Huaihua (Longwangjiang)	Au, Sb, As	*14000* (2)		Hunan Gold Corporation (Hunan. G.)	Hunan Gold Corporation (Hunan. G.)	Zhang et al., 2019, Research in China (2016), ResearchandMarkets (2016)
		Banpo	Sb	*10200* (2)		Guizhou Dongfeng Mining Group Co., Ltd. (Guizhou)	Jiefu Corporation (Jiefu)	Jiefu Corporation (2018)
		Gaofeng and Tonkeng-Changpo	Sn-Pb-Zn-Sb	*9300* (2)		Guangxi China Tin Group Co. Ltd (Guangxi)	China Government (Govt CHN)	ResearchInChina (2016), AntimonyCN (2008)
		Unidentified		*5500* (2)		China Antimony Corporation (Ant corp)	Minmetals Nonferrous Metals Co., Ltd. (MNFM)	ResearchinChina (2016)
Russia	30000	Olympiada comprising Vostochny and Zapadny pits	Au, Sb	23602	30802	Polyus (PLZL)	Polyus (PLZL)	Polyus (2018)
		Sentachan	Au, Sb	7200		GeoProMining (GPM)	GeoProMining (GPM) (GPM)	GeoProMining (2020)
Tajikistan	15200	Jijikurt deposit of Sughd region/ Soghd region	Hg, Sb	*14000* (1)	*14000*	JV Anzob (Tajik American Limited Liability Company) (Anzob)	51% Tajik government, 49% American Comsup commodities Inc. (Govt TJK Comsup)	Cac-Geo (2013), Azernews (2019), USGS (2019)
Country	**Sb prod. 2018 (t)**	**Mine**	**Commodities**	**Sb prod. 2018 (t)**	**Total per country**	**Operator and abbreviation**	**Parent company**	**References**

Bolivia	3110	San Jose mine, Nor Chichas, Quijarro	Sn, Ag, Sb	*2500* (2)	*3110*	Small scale mining operations cooperatives (Small MO)	Small scale mining operations cooperatives (Small MO)	USGS (2015), International Business Publications(2017)
		Caracota, Chilcobija, Espiritu Santo mines	Sb	*610* (2)		Fundestano de Oruro S.A. (Oruro)	Empresa Minera Unificada S.A. (EMUSA)	USGS (2015), International Business Publications(2017)
Myanmar	2640	Tha Byu Mine	Sb	*1890* (1)	*2315*	Tha Byu Mining Co. ltd (Tha Byu)	SAMCON Co. Ltd (Samcon) and Star Sapphire Co. Ltd (Sapphire)	Geological Society (2017)
		Unidentified		*425* (1)		No. 1 Mining Enterprise (ME1)	Government Myanmar (100%) (Govt MMR)	(Australian Government, 2019b).
Turkey	2400	Turhal	Sb	2400	2400	Özdemir Antimuan Madenleri A.S (Özdemir)	Koza Holding (Koza)	Antimuan (2020), Dunne (2019), Koza Holding (2020)
Australia	2170	Costerfield	Au, Sb	2173	2173	Mandalay Resources Australia Pty Limited (MDN)	Mandalay Resources (MDN)	Australian Government (2019a), Mandalay Resources (2019), Mandalay Resources (2020a), Mandalay Resources (2020b)
Iran	600	Sirzar Mine	Sb	*461* (1)	*567*	Part Gowal Gity Company (Part Gowal)	Ubar Mining International LLC (70%) (Ubar)	FinancialTribune (2016), PartGowal (2020)
		Sefidabeh mine	Sb	*106* (1)		Part Gowal Gity Company (Part Gowal)	Ubar Mining International LLC (70%) (Ubar)	FinancialTribune (2016), PartGowal (2020)
Kyrgyzstan	370	Kadamzhay Mine and Terek Fields	Sb	*370* (2)	*370*	LLC Tereksai Zhashtary and LLC Huacin (Tereksai)	ATF Bank (70.4%) (ATF Bank)	UNECE (2019), USGS (2019b), AntimonyWorld (2020)
Laos	300	Bokeo	Sb	*300* (3)	*300*	Sin Rung Roj Supply Co., Ltd (Sin Rung)	Sin Rung Roj Supply Co., Ltd (Sin Rung)	Findaminingjob (2020)
Kazakhstan	300	Ust-Kamenogorsk	Pb, Sb	*260* (1)	*260*	Kazzinc (Kazzinc)	The general investor is Glencore International AG.(Glencore)	Kazzinc (2020)
Mexico	260	San Jose (Wadley) mines, S.L.P.	Au, Ag, Sb	*256* (1)	*256*	US Antimony (UAMY MX)	US Antimony (UAMY)	US Antimony (2017)

Country	Sb prod. 2018 (t)	Mine	Commodities	Sb prod. 2018 (t)	Total per country	Operator and abbreviation	Parent company	References
Vietnam	240	Mau Due mine	Sb, Pb, Zn	421	421	HGM - Ha Giang Mineral Mechanics JLC (HGM)	Ha Giang Mineral Mechanics JLC (HGM)	Krassmann (2019), HGM (2020), Do Khac Hung (2019)
Ecuador	50	Unidentified		*50* (3)	*50*	Empresa Nacional Minera (ENM)	Government Ecuador (govt ECU)	BNAmericas (2021)
Pakistan	28	Vashouk and Dalbadin	Sb	*28* (4)	*28*	MTEQ Pakistan (Pvt.) Ltd. (MTEQ)	MTEQ Pakistan (Pvt.) Ltd. (MTEQ)	USGS (2020b)
Guatemala	25	Chocoyos and Asuncion	Au, Sb	*12.5* (4)	*25*	Entre Mares de Guatemala (EMG)	Bluestone Resources (Bluestone)	ICEFI (2014)
		Juan Bosco	Au, Sb	*12.5* (4)		Minera San Rafael, S.A. (MSR)	Pan American Silver (PAAS)	ICEFI (2014)
Honduras	12	Mine in Yoro	Unidentified	*12* (3)	*12*	Lachansa co sa (Lachansa)	Lachansa co sa (Lachansa)	Metals1 (2020)
Total	**147305**			**146689**				

Table **C1**: Overview of individual antimony mines, operators and the estimated production in 2018 and made-up abbreviations for Figure **C6**.

Notes

a) Multiple, possibly including Yunnan Muli Sb, Huachang Mining Limited,Shenyang Huachang Non-Ferrous Mining Co.,Ltd, Shenyang Five Star Mining Co.,Ltd, Guangzhou Antimony Star Mining Co.,Ltd and Hunan Changde Mining Corporation.

(1): Reported production year other than 2018 (2015, 2016, 2017, 2019, 2020)

(2): only the capacity is known, not the production: China and Bolivia, ratio capacity to reported overall production:

China: only the capacity of the refined production of Sb in 2016 was identified. Most companies are integrated and have mining and refining/smelting facilities. For some companies' mines were found, but for most only the refined production, this Sb is likely originating from multiple mines. According to Research in China (2016) there are roughly 71 Sb producers in China, of which 5 companies together contribute more than 80% of the country's total production. The total production in 2018 in China was estimated at 89600 tonnes. Assuming the production ratio per company remained similar since 2016, 80%, or 71600 tonnes is estimated to be produced by the five companies. The remaining 20% is produced by the 66 other unknown companies.

(3) Link between mine and company is unconfirmed and production in 2018 is unidentified.

(4) Production in 2018 is unidentified

6. Locations of Sb mines and SoRs 2018 in South-East Asia

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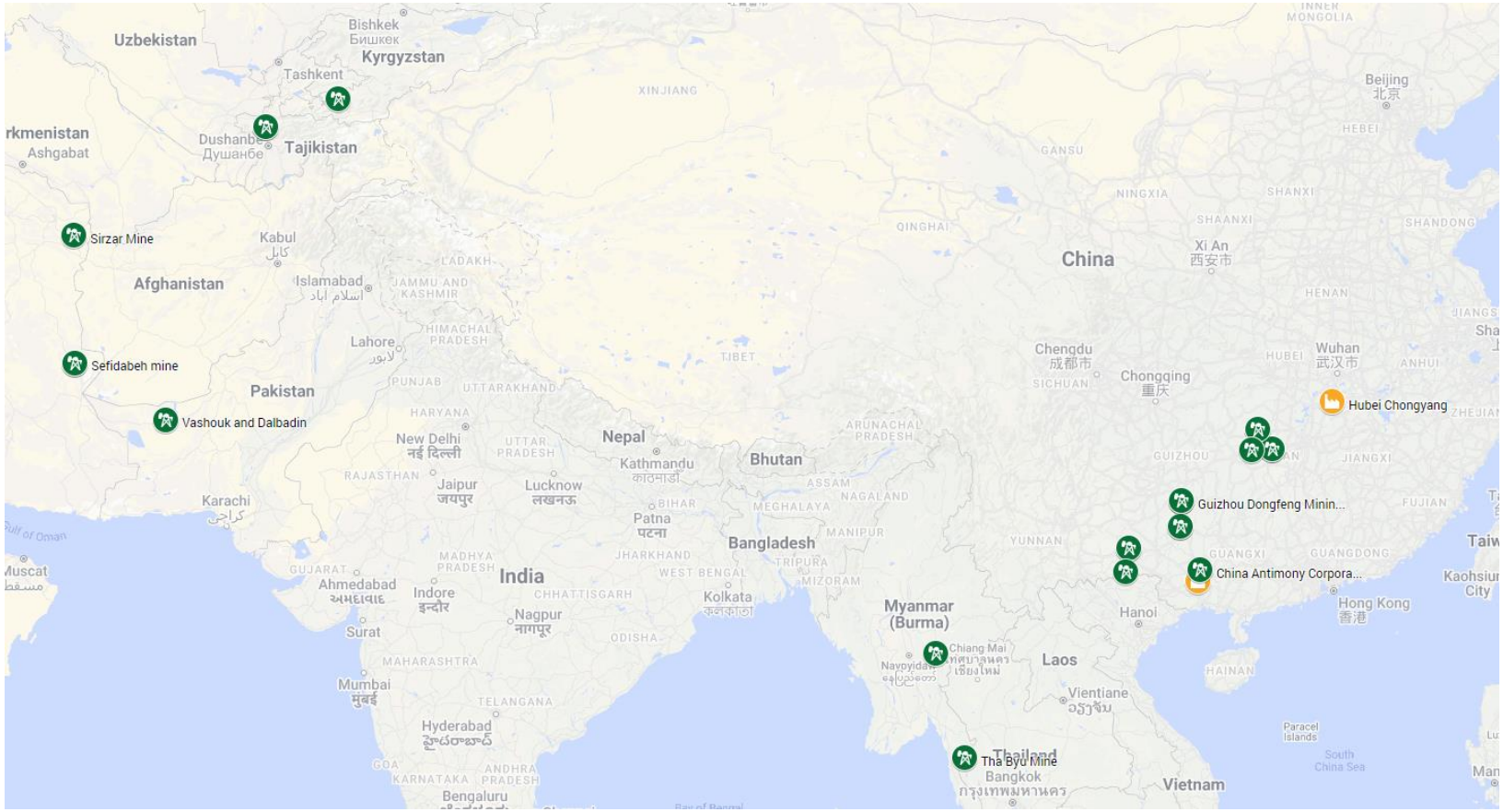

Figure C5. Locations of Sb mines and SoRs 2018 in South-East Asia. Most of the mines in China had refineries in the same location, or only one of the locations was identified and they are owned by the same company. The complete map and more details on the mines and SoRs (e.g. name, production) can be found via https://www.google.com/maps/d/u/0/edit?mid=1Vjw7eNEx0twrsh0hFOxHrBg-nS3nzbNS&usp=sharing

7. Antimony smelters or refineries (SoRs) globally (2018)

Country	Operators and abbreviations	Parent companies and abbreviations	Products	(Estimated) SoR production (tonnes)	Annual Capacity (tonnes)	Year of production	References
Belgium	Campine SA (Camp.)	Campine SA (Camp.)	Metal, Antimony (Tri)Oxide	5538 (1)	10000	Historically	Anderson (2019)
Belgium	Umicore (Umi.)	Umicore (Umi.)	Metal, sodium antimonate	3323 (1)	6000	Historically	Grund et al. (2012), Anderson (2019).
Bolivia	Empresa Metalurgica Vinto (EMV)	Government Bolivia	Metal	3323 (1)	6000	2015	USGS (2015), Vinto (2018)
Bolivia	Empresa Minera Bernal Hermanos S.a. (EMBH)	Empresa Minera Bernal Hermanos S.a. (EMBH)	Trioxide	1052 (1)	1900	2015	USGS (2015), International Business Publications(2017)
Bolivia	Fundestano de Oruro S.A. (Oruro)	Empresa Minera Unificada S.A., 100% (EMBH)	Metal	609 (1)	1100	2015	USGS (2015)
Bolivia	Operaciones Metalurgicas S.A. (OMSA)	Operaciones Metalurgicas S.A. (OMSA)	Metal	1661 (1)	3000	2015	USGS (2015)
China	Yunnan Muli Antimony Industry Co. Ltd. (Yunnan.)	Yunnan Muli Antimony Industry Co. Ltd. (Yunnan.)	Oxides, refined Sb	5538 (1)	10000	2016	ResearchinChina (2016)
China	China Antimony Chemicals Co. Ltd. (Ant. Chem.)	China Antimony Chemicals Co. Ltd. (Ant. Chem.)	Oxides	7753 (1)	14,000	2016	ResearchinChina (2016)
China	China Antimony Corporation (Ant corp)	Minmetals Nonferrous Metals Co., Ltd. (MNFM)	Oxides (flame retardant additives)	6645 (1)	12000	2016	ResearchinChina (2016)
China	Dongguan Jiefu Flame-Retarded Materials Co. Ltd. (Dongguan)	Jiefu Corporation (Jiefu)	Oxides	5538 (1)	10,000	2016	ResearchinChina (2016)
China	Guangxi China Tin Group Co. Ltd (Guanxi)	Government China (Govt China)	Refined Sb	11076 (1)	20000	2016	ResearchinChina (2016)
China	Guizhou Dongfeng Mining Group Co., Ltd. (Guizhou)	Jiefu Corporation (Jiefu)	Refined Sb, Oxides	12183 (1)	22000	2016	ResearchinChina (2016)
China	Hubei Chongyang (Hubei.)	Hubei Chongyang (Hubei.)	Metal, trioxides	2215 (1)	4,000	Historically	Anderson (2019)
China	Hunan Gold Corporation (Hunan. G.)	Hunan Gold Corporation (Hunan. G.)	Oxides, refined Sb	33227 (1)	60000	2016	ResearchinChina (2016)

Country	Operators	Parent companies and abbreviations	Products	(Estimated) SoR production (tonnes)	Annual Capacity (tonnes)	Year of production	References
China	Hunan Hsikwangshan Sb Import & Export Co. Ltd (Twinkling.)	Hunan Non - Ferrous Holding Group (100% owner) (HNFH)	Oxides, refined Sb	22151 (1)	40000	2016	ResearchinChina (2016)
France	PCDL Lucette (Lucette)	Advanced Metallurgical Group (AMG)	Metal	5261 (1)	9500	Historically	Anderson (2019), AMG-nv (2021)
France	Sudamin Holdings (successor Societe Industrielle et Chimique de L'Aisne (SICA)) (Sudamin)	Advanced Metallurgical Group (AMG)	Metal, Trioxide	6645 (1)	12000	Historically	Anderson (2019), AMG-nv (2021)
Iran	Part Gowal Gity Company (Part Gowa)	Ubar Mining International LLC (Ubar)	Metal (96.99% Sb ingots)	106		2018	FinancialTribune (2016), PartGowal (2020)
Mexico	US Antimony (UAMY M.)	US Antimony (UAMY)	Gravity/Flotation Concentrates, Oxides, Metals	256		2018	US Antimony (2017)
Tajikistan	Isfara Hydro Metallurgical Plant (Isfara)	Government (100%) (Govt Taj.)	Metal	500		2016	USGS (2019c)
United States	US Antimony (UAMY U.)	US Antimony (UAMY)	Oxides and metals	400		2017	US Antimony (2017), USGS (2019c)
Total				135000	241500		

Table C2: Sb smelters or refineries 2018. Estimated production and operators/parent companies with made-up abbreviations for figure S6.

(1): The production is based on the ratio of the capacity to the total estimated production of ~135 kt.

Based on the import of antimony ores and concentrates (see also trade flows), there are also processing facilities in India, South Korea, Thailand, Vietnam, Italy and Japan. Possible producers include Yamanaka Group (Yamanaka Group, 2021) in Japan, Youngsun Chemical Co. Ltd and Thai Uniper Industries (Youngsun and Essen Corporation, 2010) in Thailand. Hindustan Zinc -HZL in India (Indian Bureau of Mines, 2020) and Korea Zinc (Korea Zinc, 2018) in South Korea. The production in 2018 per company is unknown. In Italy and Vietnam, no smelters or refineries were identified. These countries are exporting jointly ~11 kt of antimony products and ~8 kt of oxides (based on 99.5% grade). *The production of Campine SA could originate from recycling. It is a company that recycles car batteries and produces antimony trioxide (Antimony, 2019).

8. Antimony supply chain links between companies

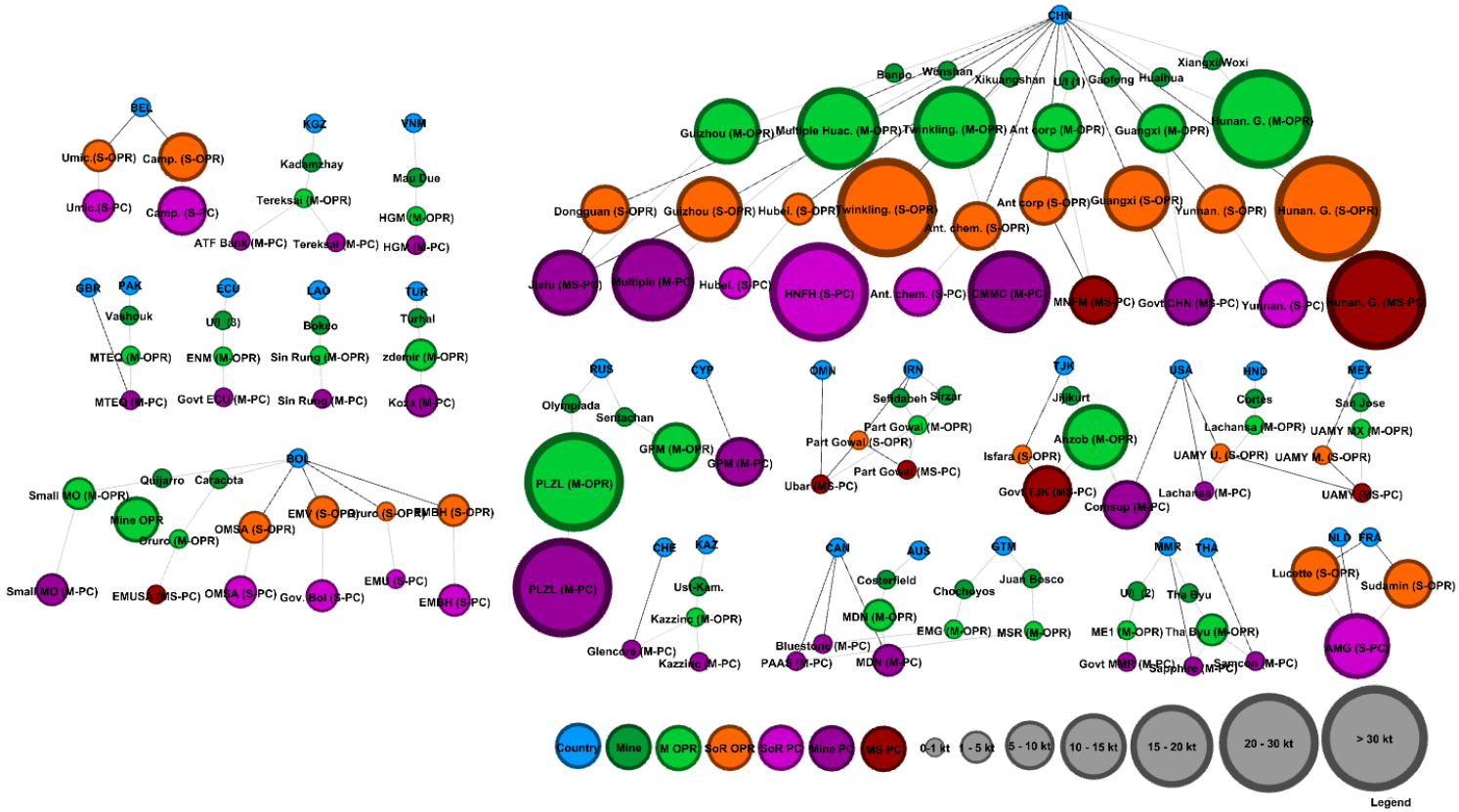

Figure C6. Antimony supply chain links between companies. The size of the company nodes is linked to their production, the size of the countries and mines is not linked to production (all minimum). M=Mine, S=SoR, MS= Mine/SoR, OPR=operator, PC=parent company. Of note is that the mine and SoR operator can be the same company, and if no other parent company was identified, the operator is included as parent company. The abbreviations and references for the links can be found in table C1 and C2.

9. Comparison of trade flows and antimony production (mined and refined)

We used UN Comtrade (2020) to analyse net imports/exports by country. The total net import globally of antimony "ores and concentrates" was ~112 kt in 2018. According to USGS (2004) both clean antimony sulfide concentrate, and Chinese antimony concentrate contain at a minimum 60% antimony. The total net import of "antimony oxides" globally was ~62 kt in 2018 (based on the average grade of 99.5%, USGS, 2004) and the total net import / export of "unwrought antimony and powders" was globally 42 kt in 2018 (with a grade of 99.5%,USGS, 2004).

There are 5 countries (Morocco, Peru, Virgin Islands, Mozambique, Zimbabwe) that had a net export of antimony ores and concentrates in 2018 but did not mine it in 2018 according to the statistics of the USGS. In 2016 and 2017 these countries did not import antimony ores and concentrates (except for Peru, who imported only a small amount), possibly the exports are from previous years. Two of these countries (Morocco and Peru) did mine antimony in the past but ceased production in 2009 and 2012. According to Roskill (2018), there were artisanal antimony ores exported from Morocco, Mozambique and Ecuador (there are flows between Ecuador and Peru). As Zimbabwe is close to Mozambique, the flows from these countries could be explained by artisanal mining.

In the identified countries with SoRs there is a total net export of 58 kt of Sb oxides and 29 kt of Sb unwrought/powders. This is much lower than the estimated production of the SoRs (148 kt), this difference can be explained by manufacturing of Sb products in the countries of the SoRs (China, France and the United States). The estimated Sb SoR production of Belgium is close to the net import of antimony products (unwrought) and to the net export of oxides (10483). The estimated Sb SoR production of Bolivia, China and France are relatively high compared to the imports and exports. In China and France, the low quantity of export could be explained by national manufacturing of Sb products. Based on the import of antimony ores and concentrates (see also trade flows), there are additional SoRs in India, Italy, Japan, South Korea, Thailand and Vietnam. These countries were exporting antimony oxides in 2018 as well.

10. Antimony trade flows and mine production 2018

Exporters (partners of import reporters)	2018 mine production tonnes (antimony content)	Import ores and concentrates (tonnes)	Export Antimony ores and concentrates (tonnes)	Net exports Antimony ores and concentrates (tonnes)	Estimated production SoR (tonnes) (see ref table C1)	Import antimony oxides (tonnes)	Export antimony oxides (tonnes)	Net export oxides (tonnes)	Export Antimony and articles thereof; unwrought, powders (tonnes)
Mining countries									
Russian Federation	30000	0	47008	47008		1476	74		4
Myanmar	2640	0	5413	5413			3580	3580	1173
Turkey	2400	132	1234	1103		773	34		276
Australia	2170	11	8001	7990		429	1		
Iran	600								
Kyrgyzstan	370		1536	1536					10
Lao People's Dem. Rep.	300			658					
Kazakhstan	300					6			
Viet Nam	240	7288	66			572	1		7664
Ecuador	50					12			
Pakistan	28			164		208			
Guatemala	25								
Honduras	12			50					
Mining and refining countries									
China	89600	91192	6582		106326	1229	40671	39442	26052
Tajikistan	15200		32000	32000	500				4033
Bolivia (Plurinational State of)	3110		1812	1812	6645		2586	2586	195
Mexico	260		155	155	256	1024	1274	250	19

Exporters (partners of import reporters)	2018 mine production tonnes (antimony content unless otherwise noted)	Import ores and concentrates (tonnes)	Export Antimony ores and concentrates (tonnes)	Net exports Antimony ores and concentrates (tonnes)	Estimated production SoR (tonnes) (see ref table C1)	Import antimony oxides (tonnes)	Export antimony oxides (tonnes)	Net export oxides (tonnes)	Export Antimony and articles thereof; unwrought antimony, powders (tonnes)
Refining countries (SoRs)									
Belgium			3	3	8861	700	11183	10483	95
France					11906	1642	7040	5398	17
USA		96	59		400	23198	1029		106
Countries that are likely refining									
Japan		178	5			4098	2356		315
Thailand		1914	1193			5737	3234		2169
Rep. of Korea		1390				3119	1679		1022
Italy		1843	188			3881	412		25
India		7614	108			3324	303		2023
Net exporters Sb ores and conc.									
Peru		37	2142	2105		79			999
Morocco			1534	1534		3			
Br. Virgin Isds				965					
Mozambique				486					
South Africa			309	309		400	1		5
Zimbabwe				121		1			

Table **C3.** Antimony trade flows and mine production 2018 (UN Comtrade and USGS, 2020).

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Appendix IV

Based on the supplementary information provided with Chapter 5.
Submitted to: Journal of Industrial Ecology (2024)

1. Elasticity (mid-point) of zinc demand and supply 2015-2019

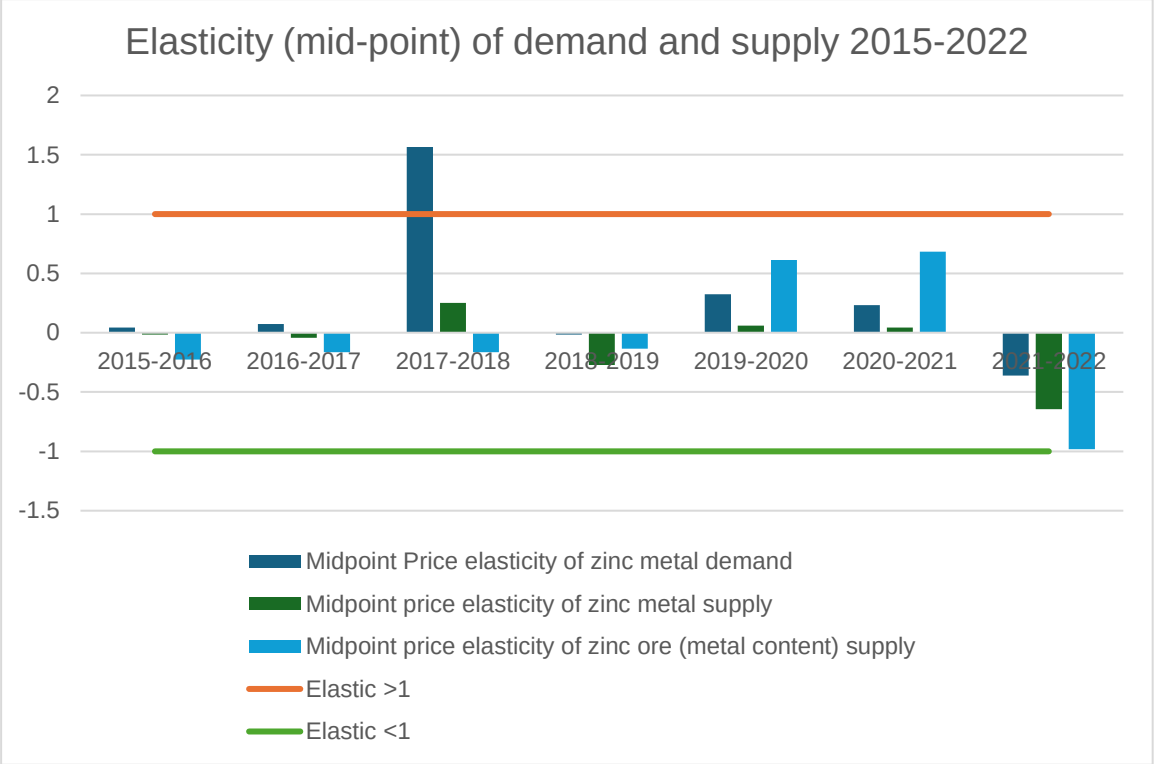

Figure D1 Elasticity (mid-point) of zinc demand and supply 2015-2022. Production (zinc mine and smelter production) (BGS, 2023), zinc use (demand) from S&P Capital IQ (S&P Capital IQ, 2023).

2. Top 5 producers mining zinc by country (tonnes metal content) 2015-2022

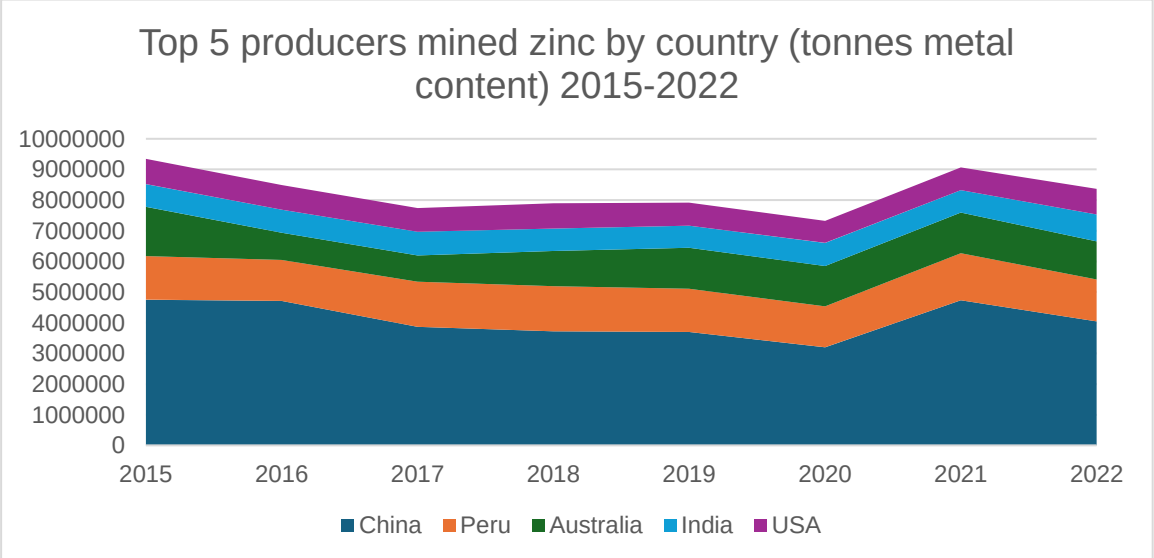

Figure D2. Top 5 producers mined zinc by country (tonnes of metal content) from 2015 to 2022 (BGS, 2023)

3. HHI mine production by country and by mine 2015-2022 (BGS, 2023), (S&P Capital IQ, 2023)

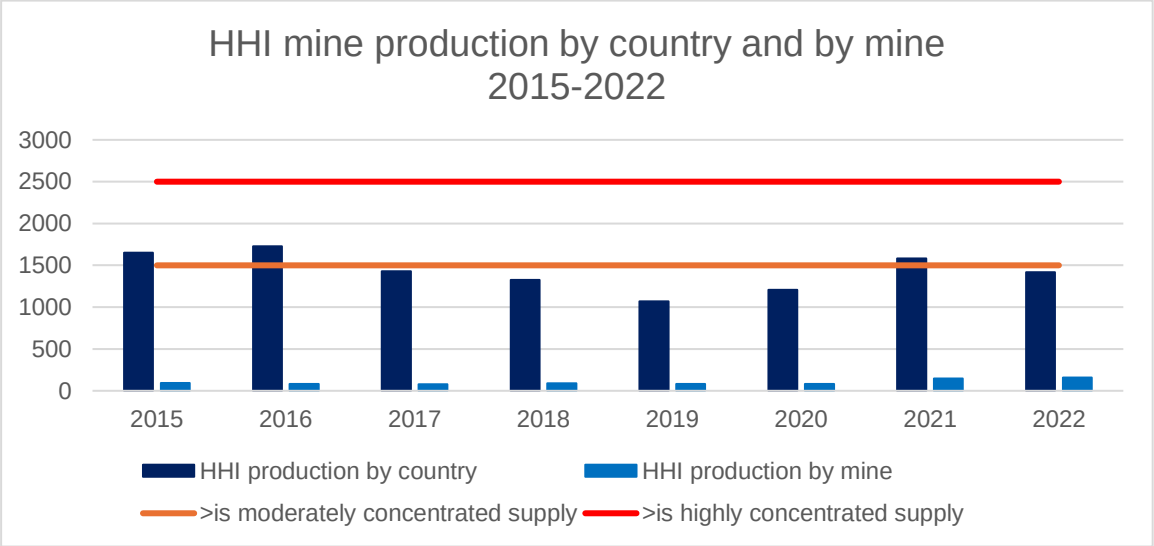

Figure D3. HHI mine production by country and by mine 2015-2022 (BGS, 2023), (S&P Capital IQ, 2023)

4. HHI company mine production 2015-2022 (S&P Capital IQ, 2023)

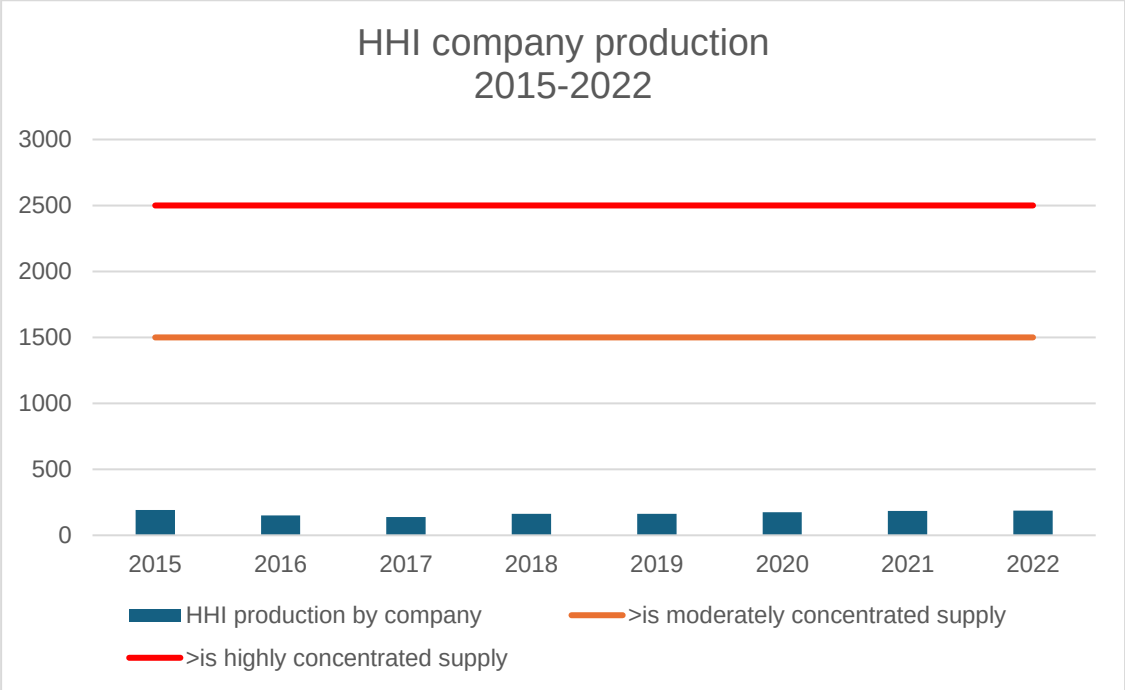

Figure D4. HHI company mine production 2015-2022 (S&P Capital IQ, 2023)

5. HHI smelter production by country (2015-2022) and by smelter (capacity) (BGS, 2023). For smelter capacity references, see Table 1 in main article.

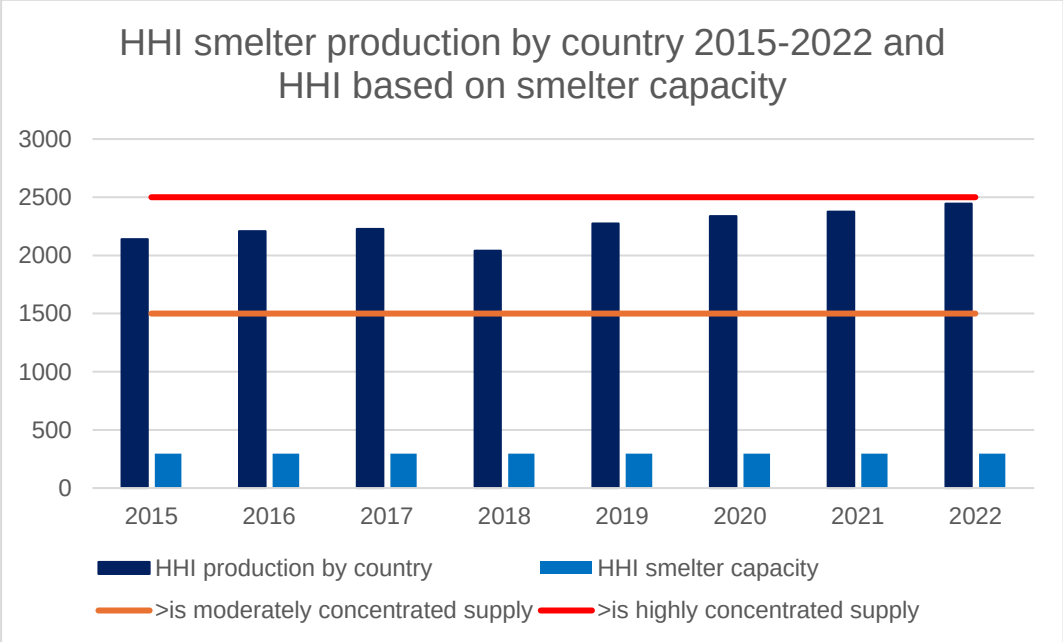

Fig D5. HHI smelter production by country (2015-2022) and by smelter (capacity) (BGS, 2023). For smelter capacity references, see Table 1 in main article.

6. Annual zinc, copper and lead prices

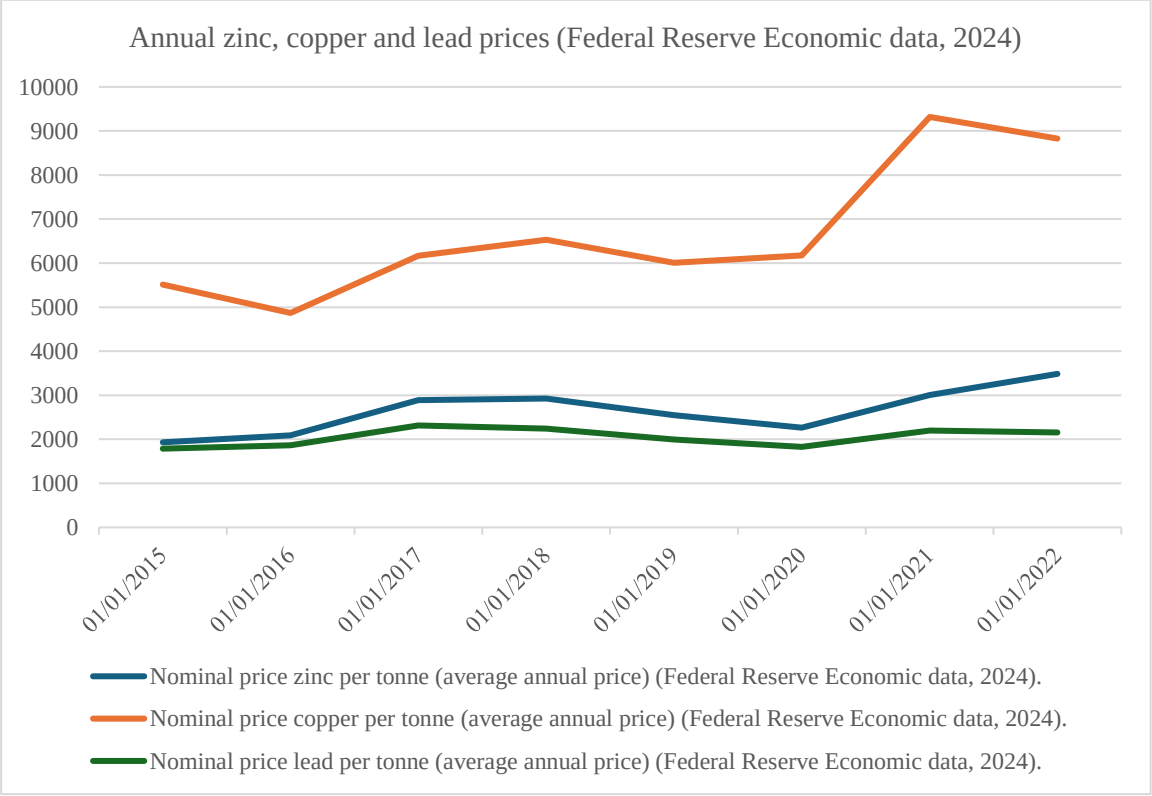

Figure D6. Annual zinc, copper and lead prices

7. Zinc trade flows 2019

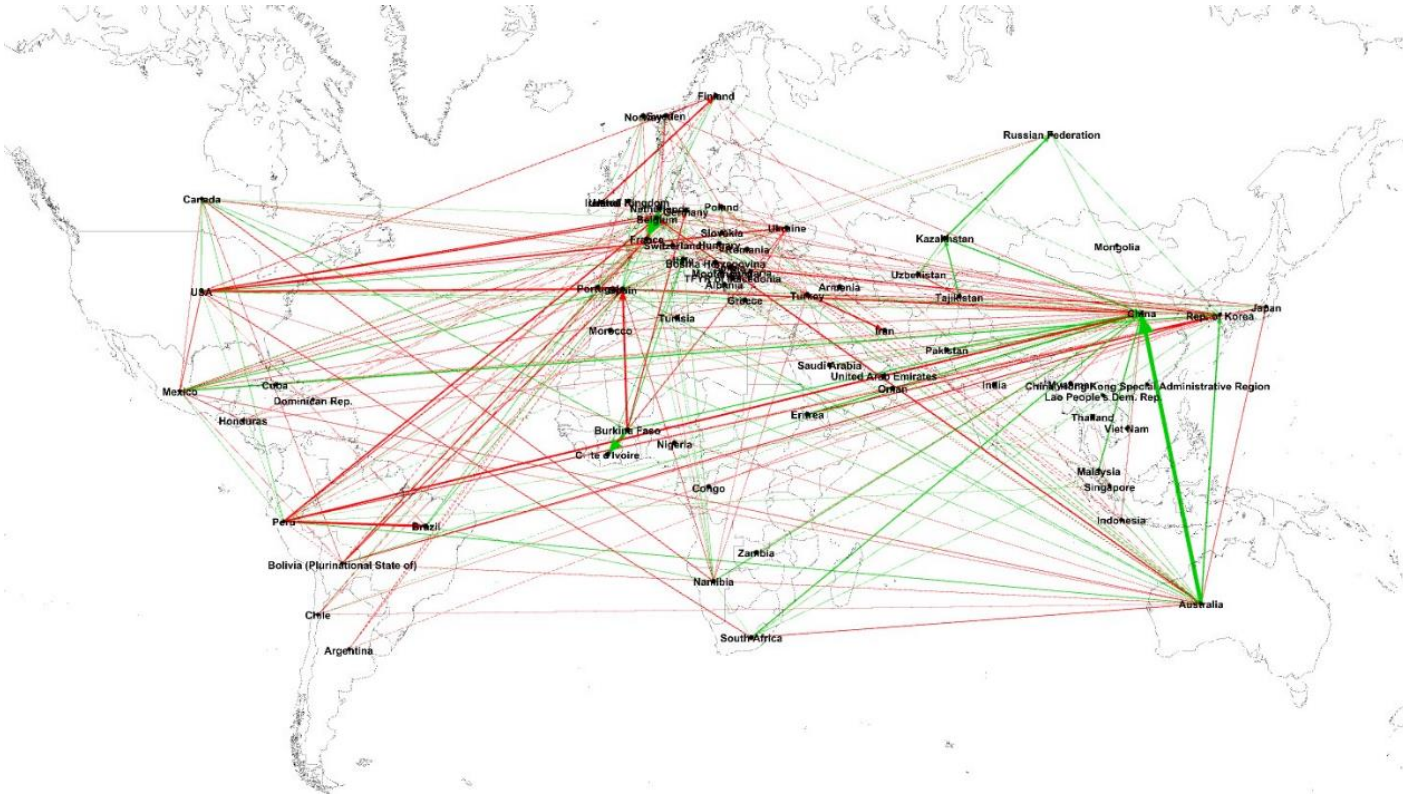

Figure D7 Trade flows 2019 (CEPII, 2023), green: zinc ores and concentrates (HS 260800) and orange: zinc unwrought flows merged (HS 790111, HS 790112, HS 790120), only including flows >75,000 metric tonnes. The size of the flows is ranked by the quantity of the flows. (Gephi, 2024)

8. Comparison of zinc trade flows 2020 to 2019

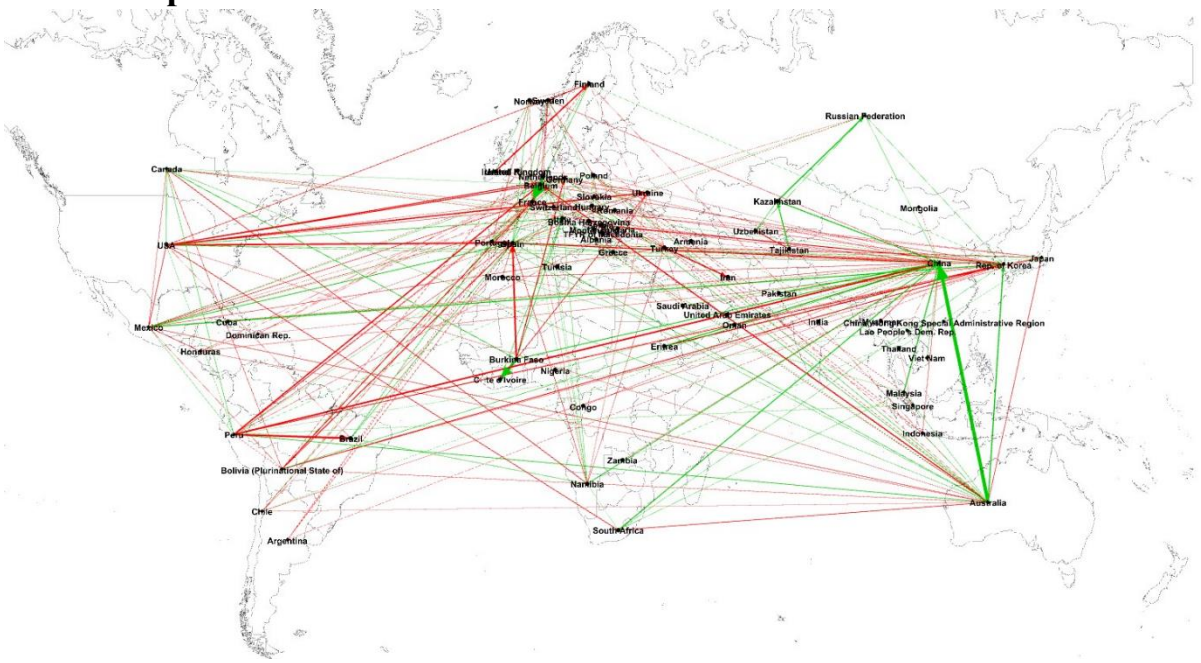

Figure D8. Comparison of quantity (metric tonnes) of zinc ores and concentrates (HS Code 260800) exported in 2020 compared to 2019. Red flows represent a decrease in exports and green flows represent an increase export. Size of flows is linked to the differences in quantities. (CEPII, 2023), (Gephi, 2024)

9. Comparison of zinc trade flows 2020 to 2019

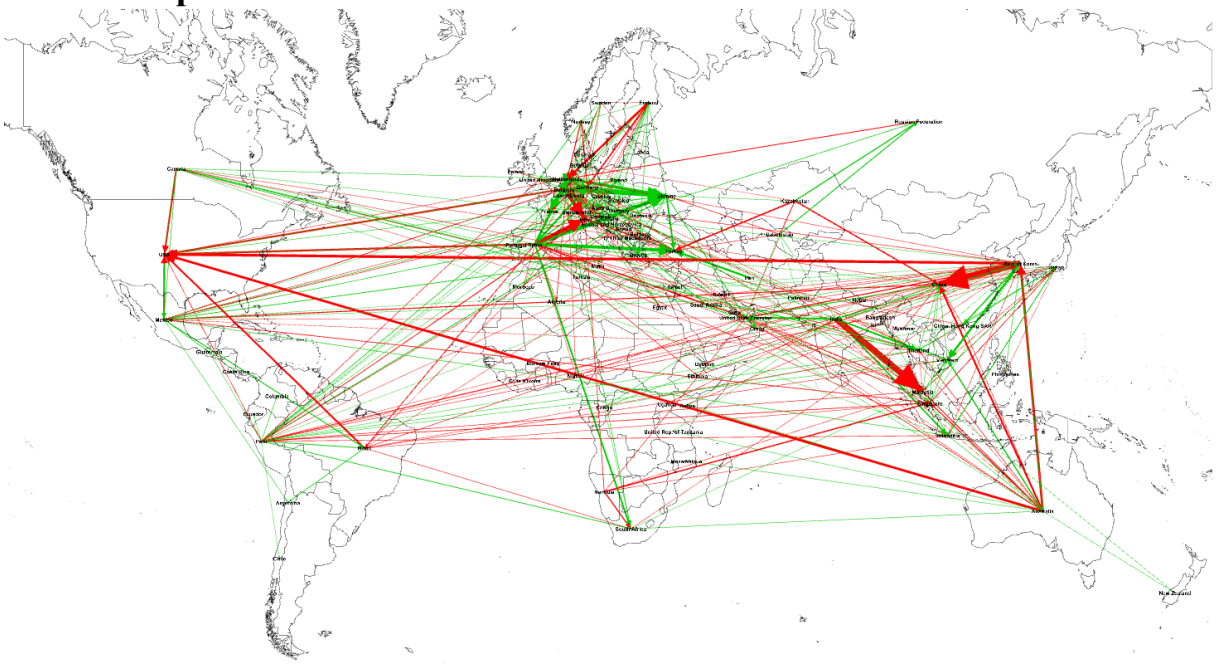

Fig. D9 Comparison of quantity (metric tonnes) of all (the sum of) unwrought zinc flows (HS codes 790111, 790112 and 790120) exported in 2021 compared to 2020. Red flows represent a decrease in exports and green flows represent an increase export. (CEPII, 2023) The size of the flows is ranked by differences in quantities. (Gephi, 2024)

10. Relation between resilience mechanisms and attributes

Attributes	Resilience Mechanism	Explanation	Connection to Price Feedback Loops
Resistance (absorptive capacity)	**Price feedback Loops and diversity of supply**	The ability to maintain supply function by having multiple sources of zinc, such as various mines and suppliers, reducing dependence on any single source.	**B1 (Main Loop)**: High prices can lead to increased investment in new mines and sources, enhancing diversity. **B2**: High prices may influence diversification in by-product processing.
	Stockpiling	Maintaining reserves to buffer against disruptions and ensure a continuous supply.	**B5**: High prices lead to stockpiling as a resistance mechanism; however, excessive stockpiling may contribute to reinforcing loop R1.
Rapidity (restorative capacity)	**Price Feedback Loops**	Mechanisms that allow the system to quickly adjust by responding to price changes.	**B1 (Main Loop)**: Incentivizes faster investment in production to meet increased demand. **B3**: Encourages quicker investments in recycling to address supply issues.
	Material Substitution (and Improved Material)	Developing alternative materials or improving existing ones to address supply shortages or reduce dependency on a single material.	**B4**: High prices spur research and development for substitutes or material improvements, allowing rapid adjustment to supply disruptions.
Flexibility (adaptive capacity)	**Material Substitution (and Improved Material)**	Ability to switch to alternative materials or improve properties to adapt to changing conditions.	**B4**: Investment in substitutes and improved materials as a flexible response to price increases.
	Diversity of Supply	Adapting to supply disturbances by utilizing various suppliers and sources.	**B1 & B2**: Diverse sources and investments in multiple suppliers enhance flexibility by mitigating the impact of price increases and supply disruptions.

Table D1. Relation between resilience mechanisms and attributes

11. List of interview participants and type of organisation

Date	Participant	Position	Company/Organisation
02 07 2020	Anonymous		Glencore
26 08 2022	P. Kindt	Managing Director Head of Commodities, Food & Agri - NL Head of Metals, Mining & Fertilizers - EMEA	ING
11 07 2023	Anonymous		Zinc company (smelter)
11 07 2023	Anonymous		Zinc company (smelter)
08 08 2023	Joao Jorge	Director of Market Research and Statistics	International Lead and Zinc Study Group (ILZSG)

Table D2. List of interview participants and type of organisation

12 Zinc production and prices 2015-2022

Year	Mine production (million tonnes) (BGS, 2024)	Zinc metal (slab) production (million tonnes) (BGS, 2024)	Nominal price per tonne (average annual price) (Federal Reserve Economic data, 2024).	Real price base year 2015 (calculated based on nominal price and rate of inflation)
2015	13.413387	13.851276	1932	1932
2016	12.532841	13.7818	2090	2063
2017	11.9254	13.602975	2891	2795
2018	12.227675	13.088955	2922	2759
2019	12.483251	13.646643	2550	2366
2020	11.530291	13.843431	2267	2078
2021	13.531145	13.987191	3003	2629
2022*	12.610036	13.354966	3485	2825

*2022 is added later in 2024 when BGS data on 2022 became available

Table D3. List of interview participants and type of organisation

13 Zinc production and prices 2015-2022

Smelter	Company	Country	Year*	Production (metric tonnes) p/a	Capacity (metric tonnes) p/a	Reference
Hobart (Risdon)	Nyrstar	Australia	2023		280000	Nystar (2023a)
Sunmetals	Sun Metals Corporation Pty Ltd	Australia	2020	230000		Sun Metals (2020)
Balen	Nyrstar	Belgium	2022		400000	S&P Global (2022)
Três Marias	Nexa Resources	Brazil	2023		192200	Nexa Resources (2023b)
Juiz de Fora	Nexa Resources	Brazil	2023		96900	Nexa Resources (2023c)
Plovdiv	KCM Group	Bulgaria	2020		200000	SeeNews (2020)
Trail operations	Teck	Canada	2023		295000	Teck (2023)
Cezinc	CEZinc (Glencore)	Canada	2022	260000		CEZinc (2023)
Zhuzhou	Zhuzhou Smelter Group Co Ltd	China	2014		555000	Shanghai Metals Market (2014)
Huludao	Huludao Zinc Industry Co.	China	2017		390000	Shanghai Metals Market (2017)
Hanzhong	Hanzhong Zinc Industry Co.	China	2008		350000	Youser (2018)
Henan Yuguang Zinc Industry	Henan Yuguang Gold & Lead Co.	China	2020		300000	S&P Global (2020)
Sihuan	Sihuan Zinc & Germanium Technology	China	2018		150000	Shanghai Metals Market (2018b)
Yunnan Jinding Zinc	Yunnan Jinding Zinc Corporation Ltd.	China	2020		100000	Shanghai Metals Market (2018b)
Hanyuan Junlei	Hanyuan Junlei Zinc Industry	China	2018		40000	Shanghai Metals Market (2018b)
Hanyuan Yuanfu	Yuanfu Zinc	China	2018		30000	Shanghai Metals Market (2018b)
Baiyin	Baiyin nonferrous group co. ltd zinc	China	2017	280300		Shanghai Metals

						Market (2018a)
Smelter	**Company**	**Country**	**Year***	**Production (metric tonnes) p/a**	**Capacity (metric tonnes) p/a**	**Reference**
Yunnan Chihong	Yunnan Chihong Zinc and Germanium Co. Ltd.	China	2012	160000		Sulhuric Acid (2012)
Shaoguan	Zhongjin Lingnan Nonferrous Metals	China	2023	120000		Asian Metal (2023)
Kokkola	Boliden	Finland	2022	294000		Boliden (2023a)
Auby	Nyrstar	France	2022		172000	S&P Global (2022)
Nordenham	Glencore	Germany	2022	164700		Glencore (2023a)
Chanderiya	HLZ India (Hindustan zinc)	India	2023		558000	HZL India (2023a)
Dariba	HLZ India (Hindustan zinc)	India	2023		240000	HZL India (2023c)
Debari	HLZ India (Hindustan zinc)	India	2023		92000	HZL India (2023b)
Binanipuram	Edayar Zinc Limited	India	2023		38000	Binaniindustries (2023)
Bafgh zinc smelting	Bafgh Zinc smelting Co.	Iran	2020		30000	Supplierss (2020)
Zanjan, Dandi & Bandar Abbas	Iran Minerals Processing Co.,	Iran	2018		25000	Parsikan Iran PJSC (2018)
Qeshm	Qeshm Zinc Smelting co.	Iran	2023		22000	Signal Hire (2023)
Isfahan zinc smelting	Isfahan zinc smelting company	Iran	2020		15000	Financial Tribune (2020)
Crotone	Portovesme srl (Glencore)	Italy	2023		150000	Portovesme srl (2023)
Iijima zinc refinery	Akita Zinc Co., Ltd. (AZC)	Japan	2020		210000	Siegmund et al. (2020)
Hachinohe	Hachinohe Smelting Co., Ltd.	Japan	2023		112000	Wood Mackenzie (2023c)
Hikoshima	Hikoshima Smelting Co. Ltd	Japan	2023		77000	Wood Mackenzie (2023b)
Annaka smelter and refinery	Toho Zinc	Japan	2023		50000	Toho zinc (2023)
Ust-Kamenogorsk Metallurgical Complex	Kazzinc (Glencore)	Kazakhstan	2023		167000	Kazzinc (2023)
Metalurgica Met-Mex Penoles plant Torreon	Penoles	Mexico	2022	237127	350000	Penoles (2023)

Smelter	Company	Country	Year*	Production (metric tonnes) p/a	Capacity (metric tonnes) p/a	Reference
Bayannur	Bayannur Zijin Non-ferrous Metals Co. Ltd.	Mongolia	2022	213000		(ZiJn, 2022)
Budel	Nyrstar	Netherlands	2022		315000	Reuters (2022)
Odda	Boliden	Norway	2022	181000	200000	Boliden (2023b)
Cajamarquilla	Nexa Resources	Peru	2023		344400	Nexa Resources (2023a)
Miastecko Slaskie	Huta Cynku	Poland	2017		100000	Pietrzyk et al. (2017)
Boleslaw	ZGH Boleslaw	Poland	2017		100000	MiningMagazine (2017)
Chelyabinsk	JSC	Russia	2019		200000	Argusmedia (2019)
Onsan	Korea Zinc	South Korea	2023		560000	WoodMacKenzie (2023a)
Seokpo	Youngpoong Corp	South Korea	2023		400000	Reuters (2021)
San Juan De Nieva	Asturiana de Zinc (Glencore)	Spain	2020	510000		Glencore (2023b)
Tak	Padaeng Industries	Thailand	2023		110000	Padaeng Industr7 (2023)
U.S. zinc Corps (recycler)	Votorantim Metais SA	USA	2018		116000	USGS (2022)
Clarksville	Nyrstar	USA	2018		101000	USGS (2022)
Almalyk	JSC Almalyk Mining-Metallurgical Complex (AMMC)	Uzbekistan	2021	110000		Minex Eurasia (2022)
Jinchengjiang Chengyuan	Chengyuan Mining & Smelting Co.	Vietnam	2022		14000	WoodMackenzie (2022)

Table D4. Zinc smelters globally including their capacity or production.
*Year of the source with the capacity or year of production

14. List of (temporary) closures of zinc (and lead) operations due to the coronavirus outbreak (Reuters, 2020)

Date	Company	Country	Output duration	Mine	Prod. 2019 (tonnes)	Production 2020 (tonnes)	Difference
13/02/2020	Henan Yuguang Gold and Lead	China	Cuts output by 50%	Smelter	~300000	Halved during outbreak -temporarily	Unknown
18/03/2020	Nexa Resources	Peru	Closes	Cerro Lindo	126310	95427	-30883
				Atacocha	16668	9614	-7054
				El Porvenir	54689	34867	-19822
24/03/2020	Hindustan Zinc Ltd	India	Halts operations for a few weeks	Rampura Agucha	452129	466000	13871
				Sindesar Khurd	160646	139348	-21298
				Zawar Group	67011	76081	9070
				Rajpura-Dariba	42792	45822	3030
26/03/2020	Sumitomo Corporation	Bolivia	Suspends operations	San Cristobal	206000	140000	-66000
26/03/2020	Vedanta	South Africa	Placed under care and maintenance	Gamsberg	85244	135420	50176
				Black mountain mine	27052	26241	-811
26/03/2020	Vedanta	Namibia	Shut down by the end of April due to operational issues.	Skorpion mine and refinery	66712	17742	-48970
26/03/2020	Glencore	Canada	Shut down, could reopen before May 4	Matagami operations	43800	52200	8400
13/04/2020	BHP and Teck Resources	Peru	shuts for two weeks (500,000 t was expected)	Antamina mine	303300	427800	124500
14/04/2020	Newmont	Mexico	Shut down	Penasquito	117843	172819	54976

Table D5. List of (temporary) closures of zinc (and lead) operations due to the coronavirus outbreak (Reuters, 2020).

15. Monthly zinc prices and stocks

Commodity Price - 6/1/2018 to 6/1/2023 - Monthly		
Date	***LME-SHG Zinc 99.995% Cash (USD/tonne)***	***LME-Zinc SHG Warehouse Stocks (tonnes)***
01/2020	2212	49,775
02/2020	2010	75,200
03/2020	1895	73,800
04/2020	1934	100,850
05/2020	1993	99,575
06/2020	2037	122,550
07/2020	2308	187,975
08/2020	2491	220,125
09/2020	2388	212,575
10/2020	2514	219,200
10/2020	2776	220,500
11/2020	2729	202,225
12/2020	2557	291,750
01/2021	2776	269,725
02/2021	2805	270,500
03/2021	2913	291,925
04/2021	3044	281,550
05/2021	2967	253,600
06/2021	3029	245,025
07/2021	2994	236,425
08/2021	2976	205,750
09/2021	3447	196,800
10/2021	3289	157,150
11/2021	3590	199,575
12/2021	3606	154,850
01/2022	3688	143,900
02/2022	4233	139,950
03/2022	4151	95,350
04/2022	3939	83,575
05/2022	3183	82,800
06/2022	3412	69,725
07/2022	3532	77,150
08/2022	3014	53,625
09/2022	2736	44,825
11/2022	3050	41,225
12/2022	3003	32,025

Table D6. Monthly zinc prices and stocks (S&P Capital IQ, 2023).

16. Commodity trading companies that are involved in the zinc trade: zinc operations, warehouse and logistics capability

Company and main office (country)	Total revenue USD (2017)	Corp. status	Reg. in (country)	Zinc operations	Warehouses and logistics capability	References
Glencore, Switzerland	205.5 billion	Public	Jersey	Zinc operations (10): Kazzinc integrated producer (69,7% shares) in Kazakhstan, McArthur River Mine and Mount Isa Mines in Australia, Nordenham plant in Germany, Portovesme zinc smelting and refning in Italy, Asturiana de Zinc, smelter in Spain, Kidd operaions, General Smelting and CEZinc smelter in Canada and Volcan mine in Peru.	Glencore Port Operations (Australia) and Project Terminal Port Chancay in Peru. "Access World Group", a global network of port and warehouse facilities was sold by Glencore in 2023.	Trafigura (2018), Glencore (2023), IISD (2019), Mining (2023)
Trafigura, Switzerland	136.4 billion	Private	Singapore	Nyrstar's operating business is wholly owned by Trafigura. Nyrstar owns two zinc mines in the United States: East Tennessee mines and Middle Tennessee mines. It owns four smelters in Europe: Auby (France), Balen/Pelt (Belgium), Budel (the Netherlands), Stolberg (Germany), two smelters in Australia: Hobart and Port Pirie and one in the United States: Clarksville	Owner of Trafigura Maritime Logistics. Trafigura operates 60 warehousing sites in 30 different countries worldwide, with more than 4,000,000m2 of owned and leased storage capacity. Trafigura owns Impala Terminals to manage metals and infrastruture assets. It has operations in South America, Africa and the United States. In Peru it has expended a warehousing and blending facility at Callao, into the country's largest sit for zinc concentrates.	Trafigura (2018), Nyrstar (2023), Trafigura (2022). Trafigura (2023)
Koch industries (subs. Koch Metals Trading Ldt)		Private		No ownership of zinc mines or smelters found	KBX is subs. of Koch Industries. KBX is comprised of four subsidiaries: KBX Logistics, KBX Rail, KBX Int. and KBX Technology Solutions. Koch logistics owns warehouses in the U.S.	IISD (2019:19), Koch Metals (2023), KBX (2023), Koch logistics (2023)
Mercuria, Switzerland	104 billion	Private	Switzerland	Only investments in mining operations (e.g. in Vast Resources, producing zinc concentrate in Romania)	Mercuria partly owns Henry Bath, a metals warehousing, storage and handling business.	Trafigura (2018), Energy Industry Review (2018)
Gunvor Group, Switzerland	63 billion	Private	Cyprus	No ownership of zinc mines or smelters found	Warehouse ownership unknown	Trafigura (2018

Company	Total revenue USD (2017)	Corporate status	Registered in (country)	Zinc operations	Warehouses and logistics capability	References
Noble Group, Singapore	46 billion (2016)	Public	Bermuda	No ownership of zinc mines or smelters found	Warehouse ownership unknown	Trafigura (2018), IISD (2019:19)
Mitsubishi Corporation Mineral Resources Group, Singapore	75 billion, metal trading 10 billion	Public	Japan	No ownership of zinc mines or smelters found (only investments in copper mines)	The subsidiary company Gaussy Inc. is a logistics and warehouse company.	IISD (2019:19), Mercuria (2014), MitsubishiCorp (2022)

Table D7. Commodity trading companies that are involved in the zinc trade: zinc operations, warehouse and logistics capability

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Acknowledgements

Completing this PhD thesis has been a challenging and rewarding experience, and I am deeply grateful to everyone who contributed to making this journey possible. I faced quit some hurdles along the way and without your support, encouragement, and guidance, this achievement would not have been possible.

First and foremost, I wish to express my gratitude to my supervisor, Professor René Kleijn. From the very beginning of this journey, your unwavering support, optimism, and confidence in my abilities were a constant source of motivation. Your practical feedback and insightful suggestions kept me focused and on track, even when the path seemed uncertain, thank you for believing in me. I would also like to extend my sincere thanks to Professor Arnold Tukker for his invaluable ideas, critical reviews, and support throughout this process. Your extensive expertise and sharp eye for areas of improvement have been instrumental in shaping this thesis into its final form. A special thanks goes to Dr. Jaco Huisman, whose encouragement and vision helped me at the very start of this journey. Thank you for initiating the idea of pursuing a PhD, connecting me with the CML team at Leiden University, and for our productive collaboration on my first paper. I am also grateful to Dr. Benjamin Sprecher for your invaluable assistance and enthusiastic collaboration on three of my papers. Your meticulous feedback, both on the content and the writing, greatly enhanced the quality of my work and your passion for the topic has been inspirational. I would also like to acknowledge Nabeel Mancheri and Anton Löf for their pleasant cooperation and significant contributions to Chapters 4 and 5 of this thesis. To the colleagues in the CERA project and my fellow researchers at CML, thank you for creating a collaborative and intellectually stimulating environment.

Finally, I would like to thank my family and friends for their moral support and encouragement throughout the years. Particularly to my husband and to my mother, thank you for your unwavering support, patience, and understanding. And to my son, you have been my sunshine, and you remind me every day of what truly matters. This PhD journey has been a shared effort, and I am very grateful to everyone who played a part in it. Thank you all for helping me turn this aspiration into a reality.

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Susan (van Eijk) van den Brink was born on April 17, 1989, in Arnhem, the Netherlands. She attended the Thomas A Kempis College, where she completed her secondary education. Susan went on to pursue a degree in *International Development Studies* at Wageningen University, during which she also completed a minor in *Criminology* at Utrecht University. On February 29, 2012, she earned a master's degree in *Criminology* from Utrecht University, specializing in '*green criminology*'.
In 2011, Susan interned at the environmental crime unit of INTERPOL in Lyon, France, where she gained experience in international environmental crime investigations. After finishing her master's, she returned to INTERPOL in 2013, where she worked until the end of 2015 as a project assistant. In this role, she focused on analysing the illegal trade of waste and pollution-related crimes. From 2016 to 2021, Susan worked as a research associate with the Sustainable Cycles (SCYCLE) research team, initially hosted by the United Nations University Institute for Environment and Human Security and later by the United Nations Institute for Training and Research.
In 2017, Susan began her PhD at the Institute of Environmental Sciences at Leiden University. Her doctoral research was part of the CERA project, which aimed to develop a unified certification for the sustainable sourcing of minerals in Europe, incorporating environmental, social, and financial dimensions. Her PhD research was supervised by Prof. Dr. René Kleijn and Prof. Dr. Arnold Tukker. Since completing her PhD thesis, Susan has worked as a postdoctoral researcher on the MaDiTraCe Project at the Institute of Environmental Sciences.

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