



Leveraging Open Data for Enhanced Visibility and Security in Critical Minerals Supply Chains

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Research Context – Critical Minerals

Critical Minerals are minerals with high economic importance and high global supply risks

Source: BEIS UK (2023)

Examples of Critical Minerals Used in Advanced Technologies

Solar panels –
Arsenic, Germanium,
Indium, Tellurium



Battery storage –
Cobalt, Graphite,
Lithium, Manganese



Wind turbines –
Aluminum, Rare
Earth Elements



National defense –
Chromium, Gallium,
Scandium



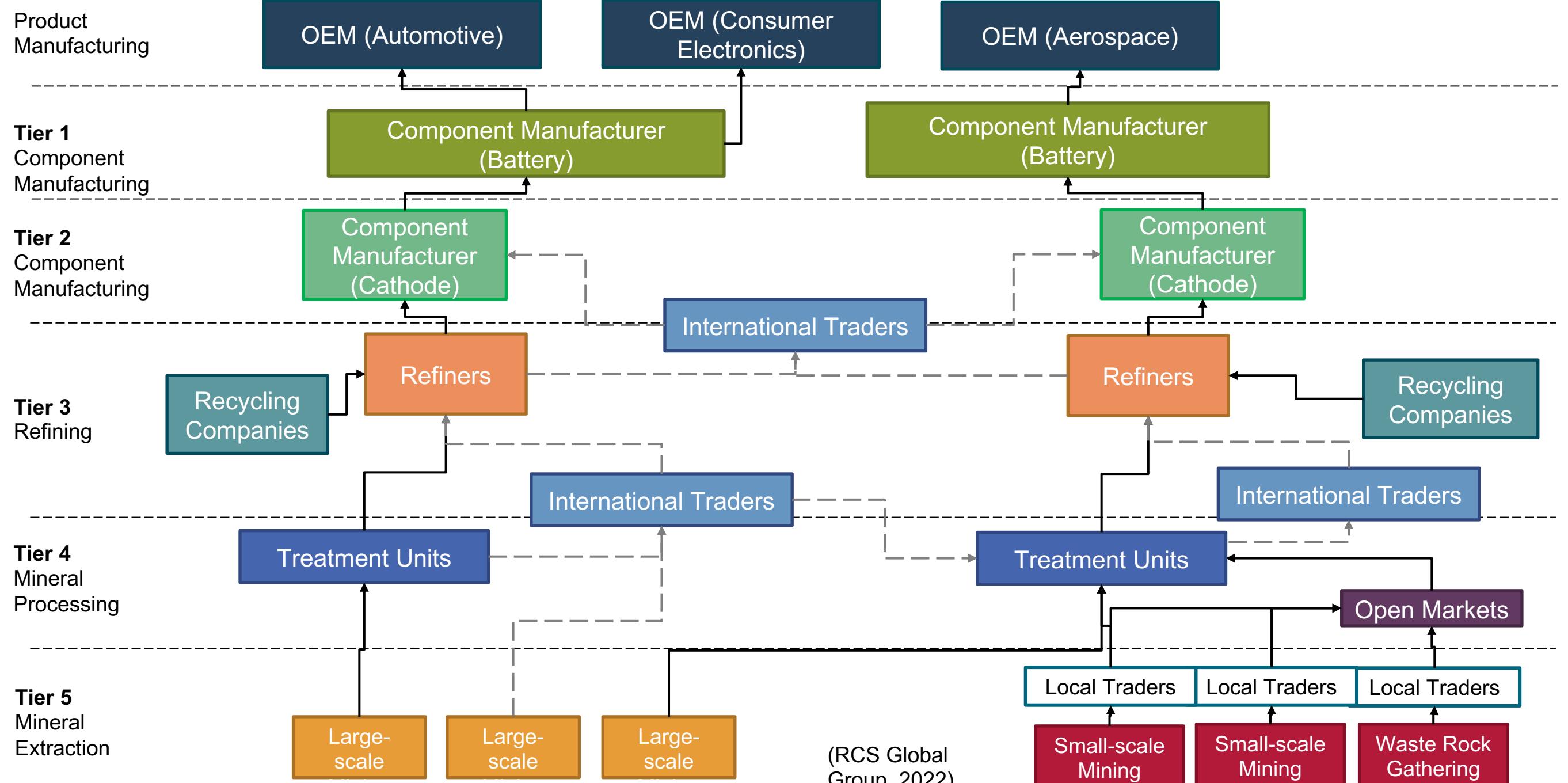
Aviation –
Niobium, Tantalum,
Vanadium



Source: GAO analysis of agency documents; Photos: Stockadrik/tongpatong/Rawf8/swisshippo/muratart/stock.adobe.com. I
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Research Context - Global Supply Chain Issues



Research Context - Global Supply Chain Issues

Tesla pauses German production after Red Sea shipping attacks

Delays in delivery of parts result in suspension of manufacturing at factory near Berlin for two weeks

● Middle East crisis - latest updates



Source: Tesla (2024)

Tier 4
Mineral
Processing

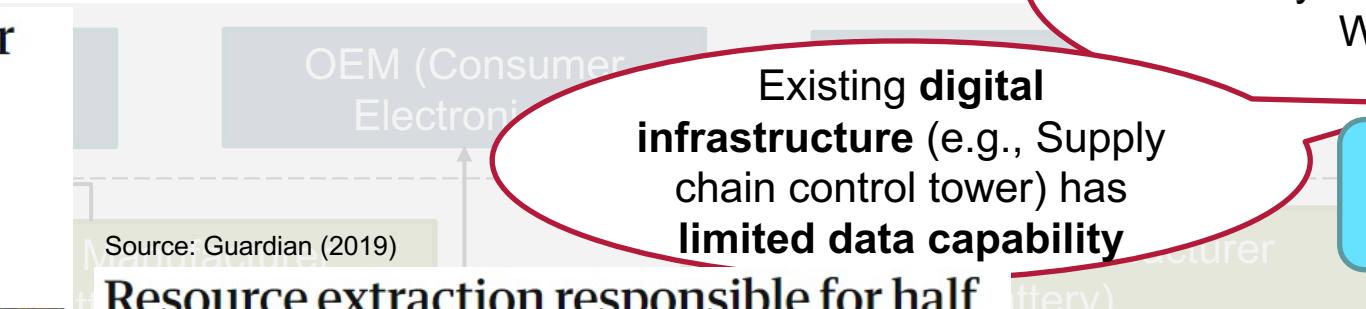
Treatment Units

Tier 5
Mineral
Extraction

Large-scale

Large-scale

Large-scale



Resource extraction responsible for half world's carbon emissions

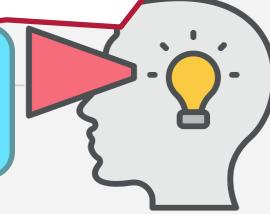
Extraction also causes 80% of biodiversity loss, according to comprehensive UN study



(RCS Global Group, 2022)

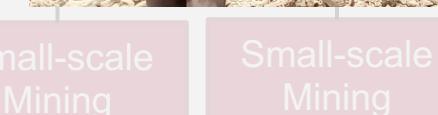
Limited end-to-end visibility, usually only till Tier 1,2 (Who? What? How?)

Industrial Problems



Source: The Independent (2023)

'Here it is better not to be born': Cobalt mining for Big Tech is driving child labor, deaths in the Congo

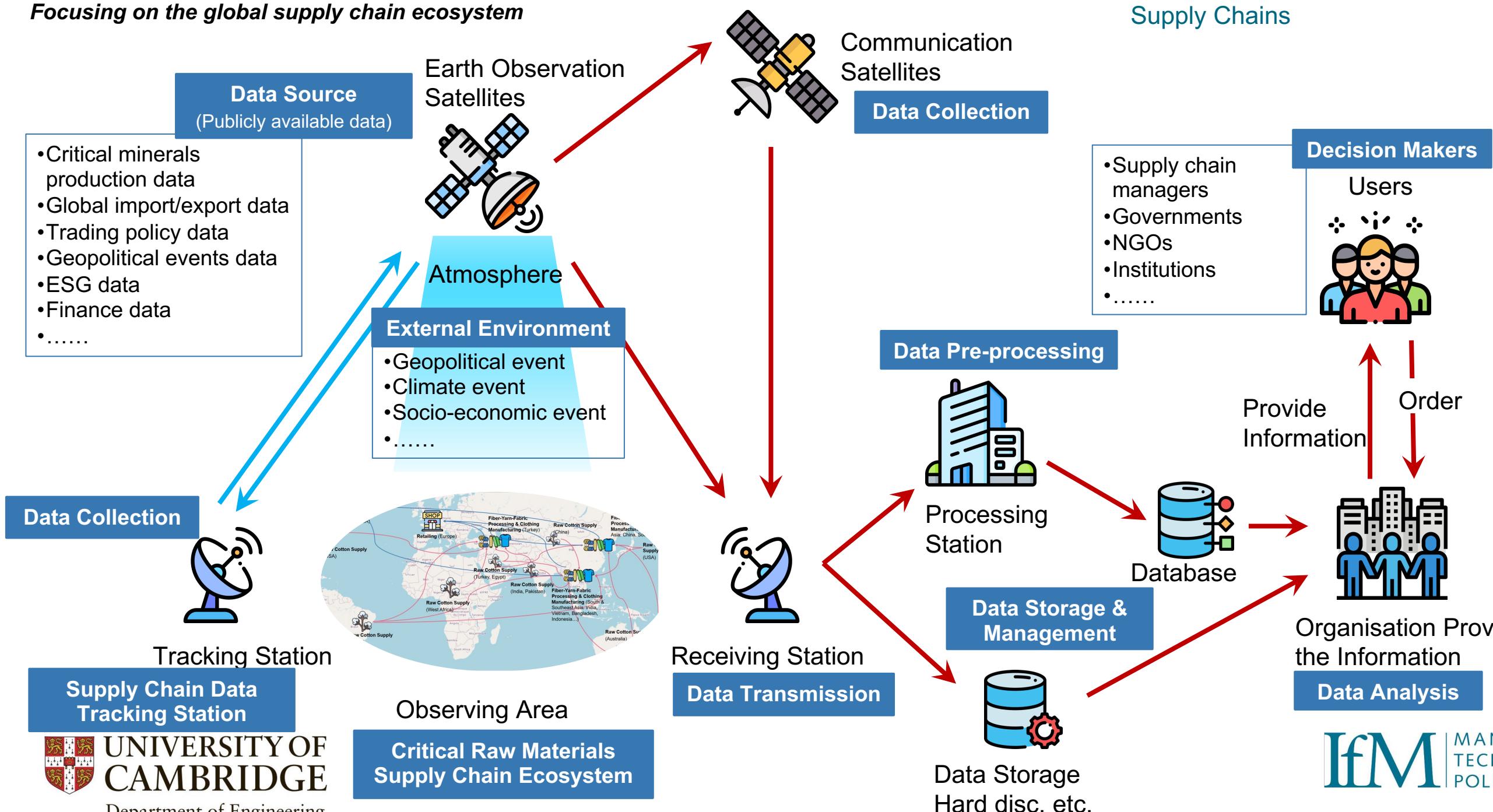


Waste Rock Gathering

Global Supply Chain Observatory as the Solution

Focusing on the global supply chain ecosystem

To leverage **open data** for increasing the supply chain **visibility** of the Critical Minerals Supply Chains



Literature Review

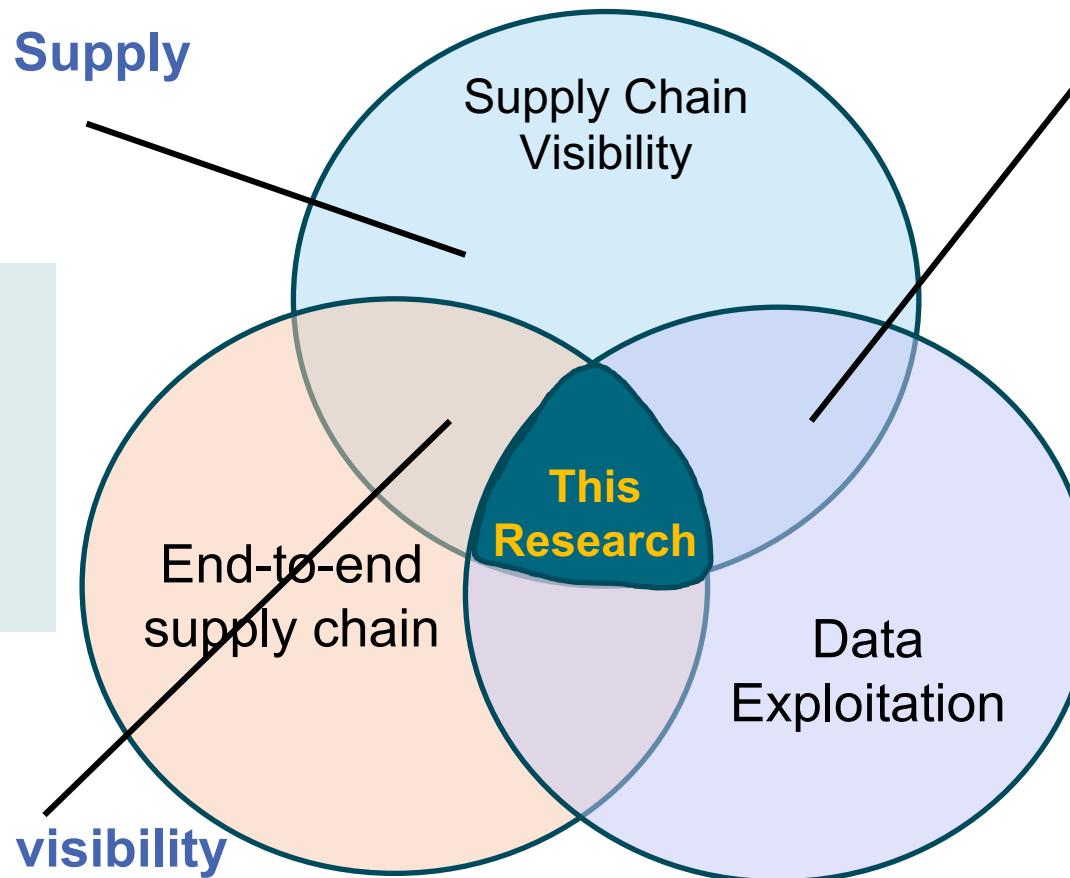
Definitions & Requirements of Supply Chain visibility

(Barratt & Oke, 2007; Swink et al., 2023)

Supply Chain Visibility is the understanding of the entire supply chain processes, encompassing different **dimensions** and requiring accurate, and relevant **data** in usable formats

Existing supply chain visibility research mainly focus on part of the supply chains

(van den Brink, 2020; Manley et al., 2022)



Data exploitation process for supply chain visibility

(Srinivasan et al., 2019; Nikolopoulos et al., 2021)

- Lack of **systematic** approach for using data to create visibility
- More attentions should be paid on data validation and data storage for sustained use

- Most studies focused on midstream supply chains (Manufacturers and their direct suppliers / customers)
- Tier-end supply chains are less studied (especially beyond tier-2 suppliers)
- End-to-end supply chain studies are very limited

Research Questions & Objectives

Questions:

RQ: How can open data be used to foster visibility and identify vulnerabilities within the critical minerals supply chains?

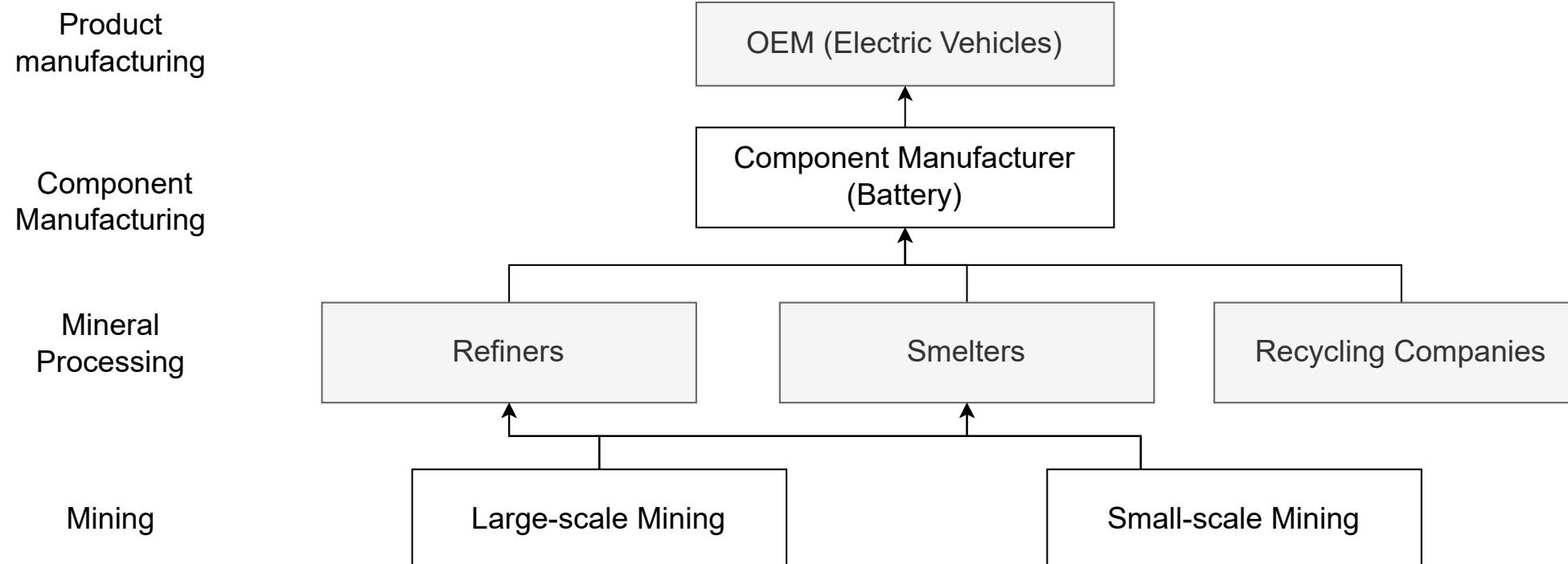
Objectives:

- Investigate the process of data exploitation for supply chain visibility
- Determine what types of vulnerabilities can be identified and how

Research Design

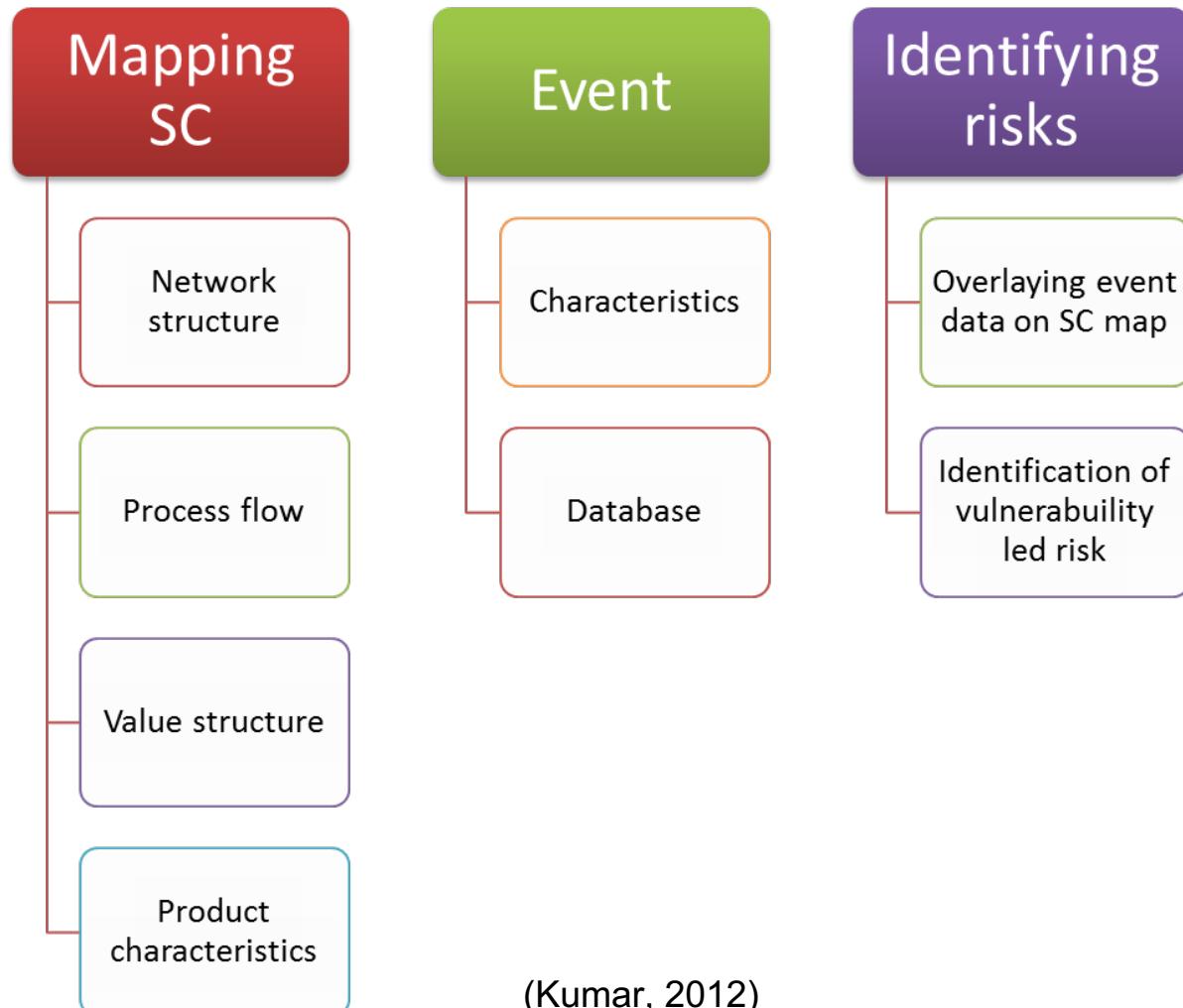


- Cobalt as an illustrative case
- Scope of this study covers the cobalt lifecycle from mining to end-product manufacturing
- Cobalt-containing battery and electric vehicles (EV) as representative industries in the downstream SC

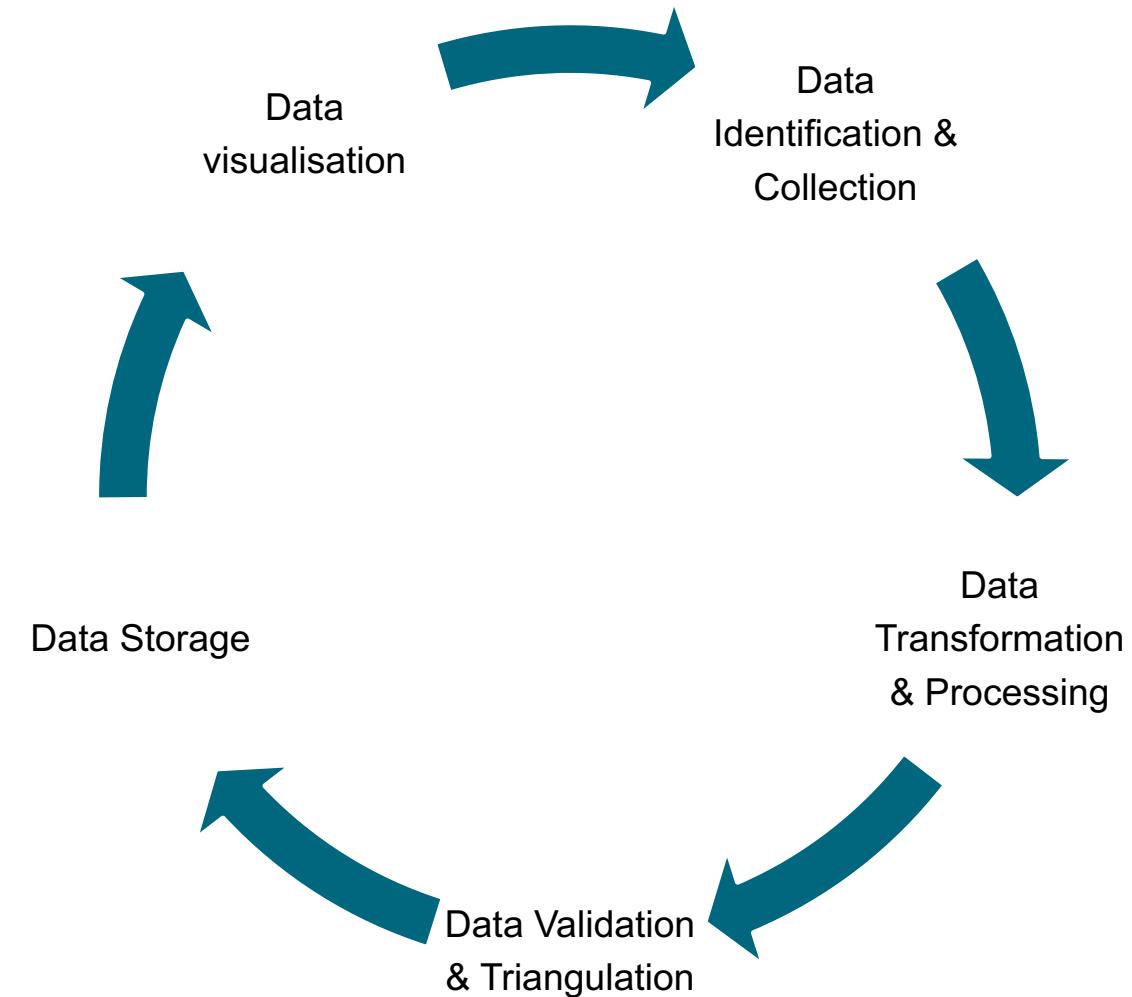


Research Design

The framework



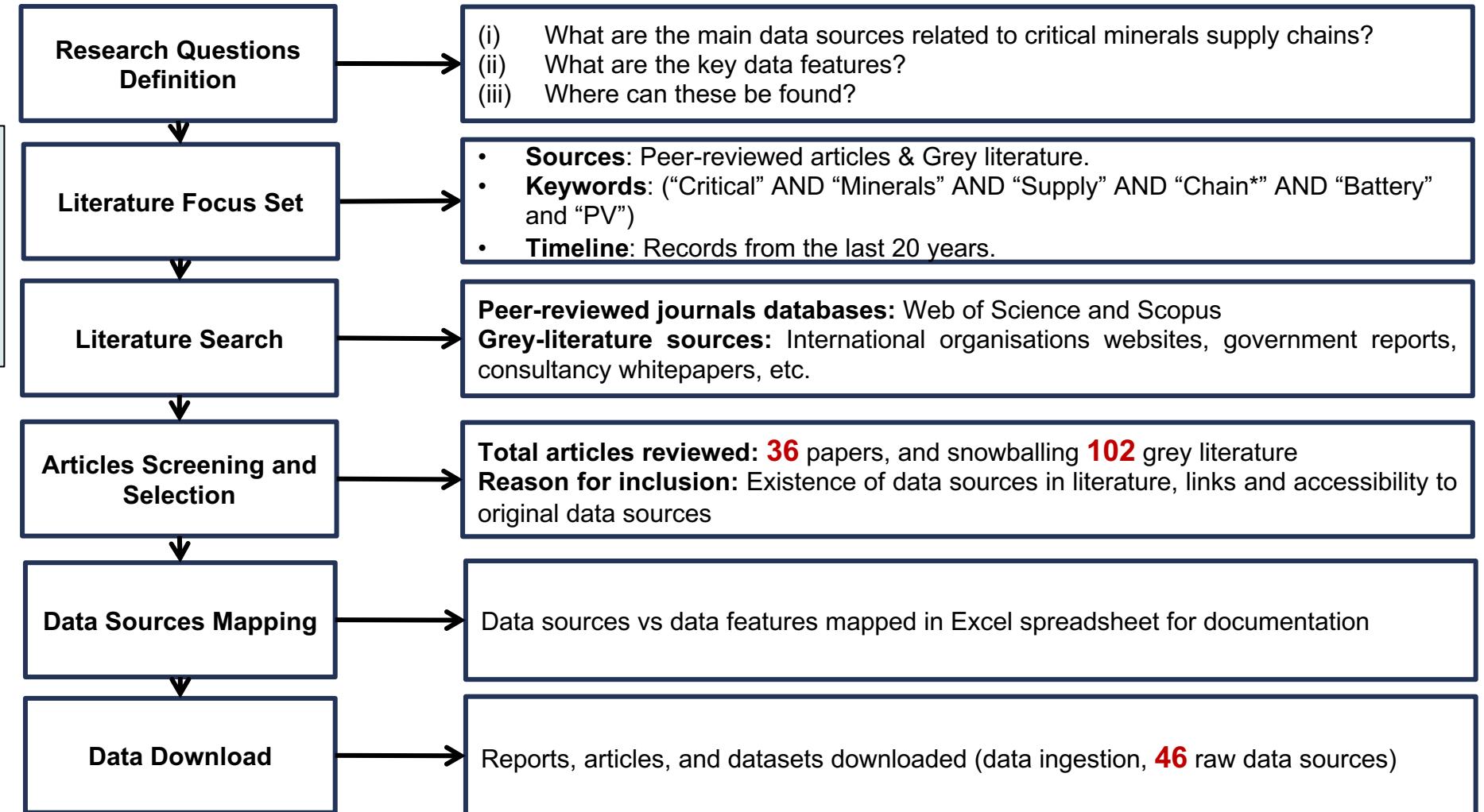
The steps (adapted from big data analytics steps)



Research Design

Data Identification and Collection

Identify **data points** and **open data sources** related to critical minerals through literature review on peer-reviewed articles and grey literature



Research Design

Main Data Points & Sources

Public institutions

Industry associations/
Research Institutes

Private Companies

SCV Dimensions	SCV Data Points	Data Source	Data Details
Supply Chain Structure	Deposit	US Geological Survey (USGS) (2019)	US critical mineral resources professional paper; Secondary data
	Mine	British Geological Survey (BGS) (2017)	Latest version of cobalt commodity review; Secondary data
	Processing facility	Responsible Minerals Initiative (RMI) (2023)	Global processing facility information offer by an industrial association
	Battery manufacturing plants	National Renewable Energy Laboratory (NREL) (2024)	Online database; Data available only for North America region
		Ratel Consulting LLC (2023)	Secondary data collected by a consulting firm
	EV manufacturing plants	Automotive from Ultima Media (2021)	Commercial company online database; Secondary data
	Recycling facilities	NREL (2024)	Online database; Data available only for North America region
Supply	Production/ Output	BGS (2024)	World Mineral Production report; Secondary data
		USGS (2024)	Mineral Commodity Summaries 2024 report; Secondary data
		Austrian Ministry of Finance (AMF) (2024)	Published as World Mining Data (online database); Secondary data triangulated with BGS and USGS data sources
Risk	Small-scale mining activity / human rights issue	International Peace Information Service (IPIS) (2022)	Primary data collected by the research institute through site visiting
	Extreme weather	Intergovernmental Panel on Climate Change (IPCC)	IPCC 5 th Assessment Report (AR5); Projected regional average change in seasonal and annual temperature and precipitation extremes; Data generated from climate models using other secondary data
	Political stability	World Bank (2023)	Worldwide governance indicator (WGI) – Political stability and absence of violence (PV); Data generated from statistical models using other secondary data

Research Design

Data Transformation & Processing

- Three stages of data
- Transformed to standardised formats (e.g., csv)
- Data entry error checking
- Location data geocoding

Data Validation & Triangulation

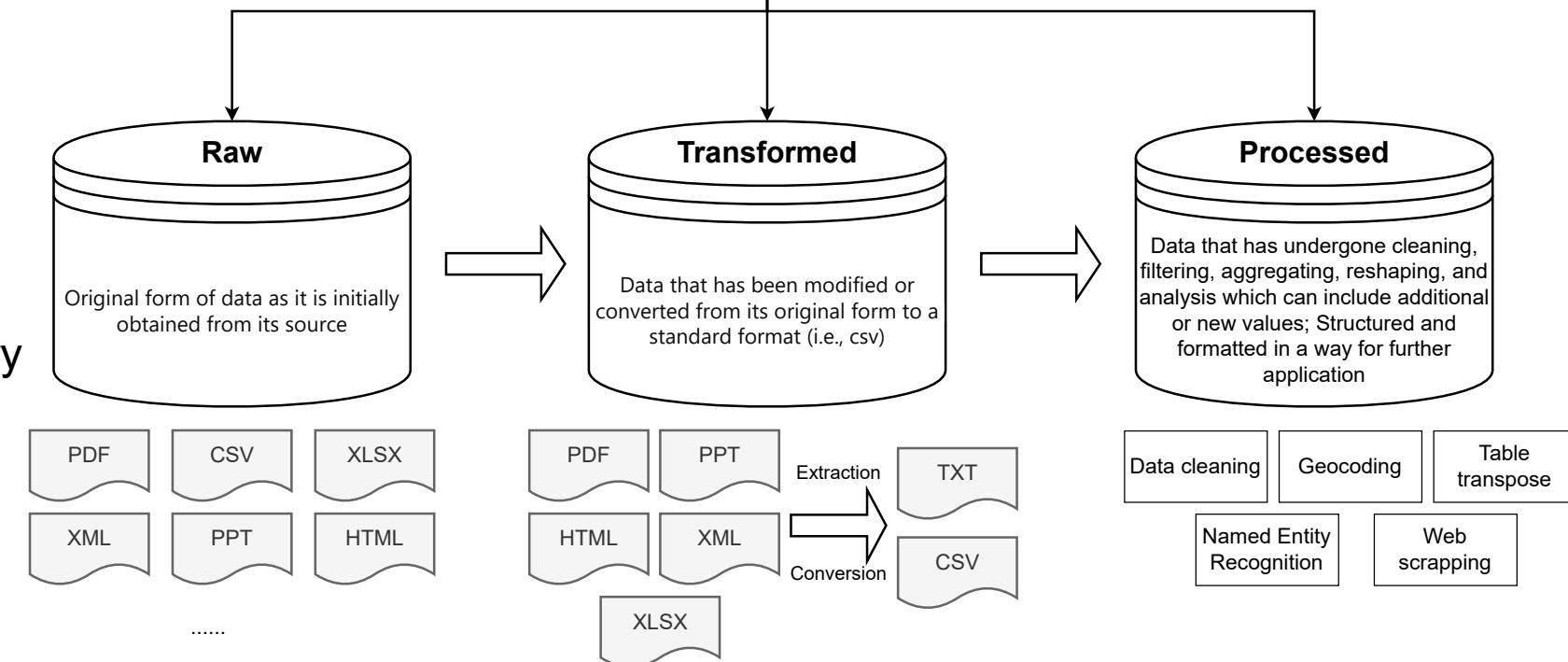
- Priority is given to government data sources
- Location data validation through Satellite imagery
- Verification of data representing different supply chain stages to ensure consistency

Data Storage

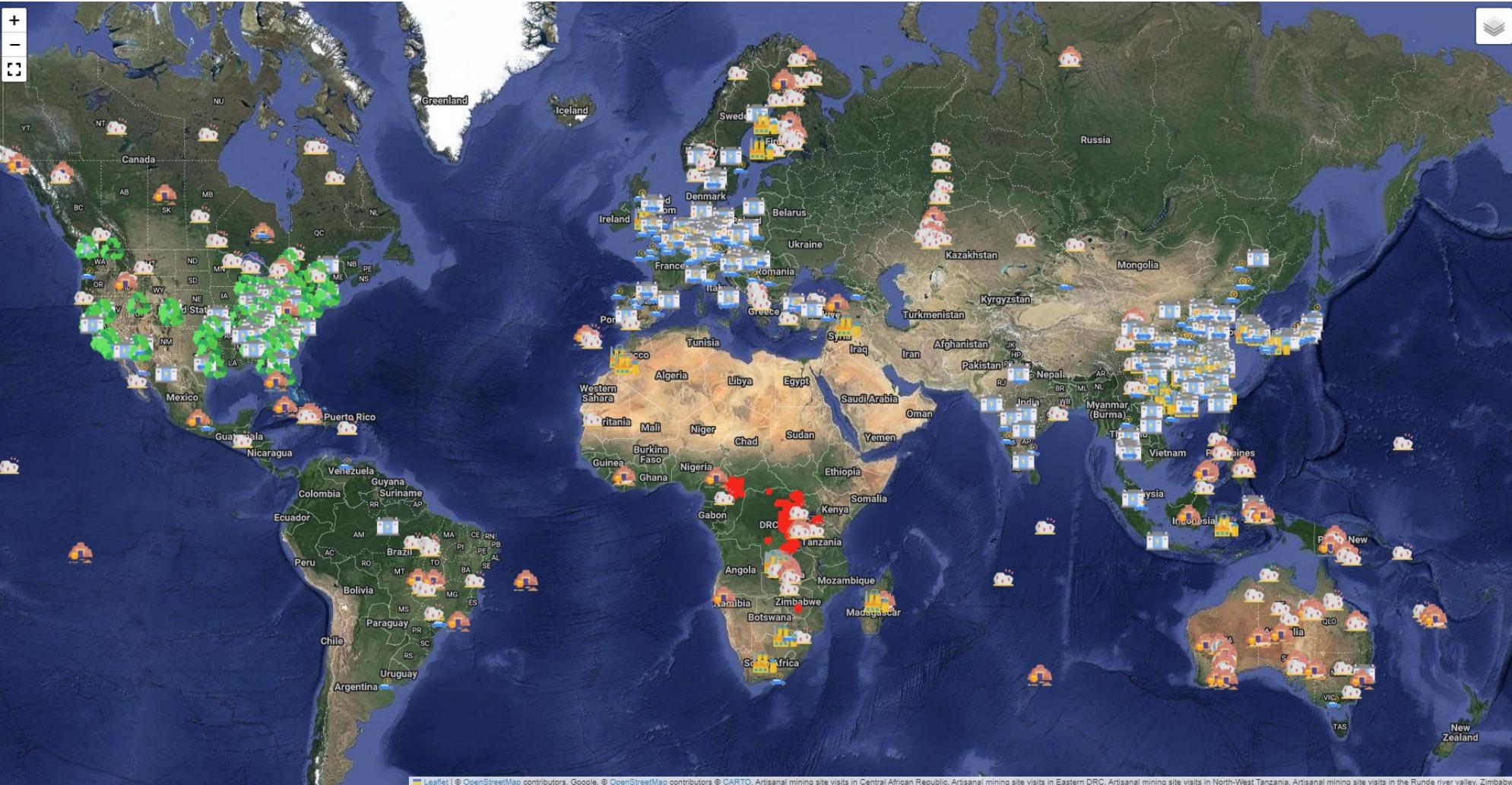
- Sort data based on data types.
- Develop a Google Cloud Platform (GCP) data storage hierarchy for ease of automated data storing and retrieval

Data Visualisation

- Map visualisation through layer overlaying, in HTML format
- Tools & Platform: Google Map API, Python Folium Library



Results & Discussion – (1) Global Cobalt Supply Chain Structure

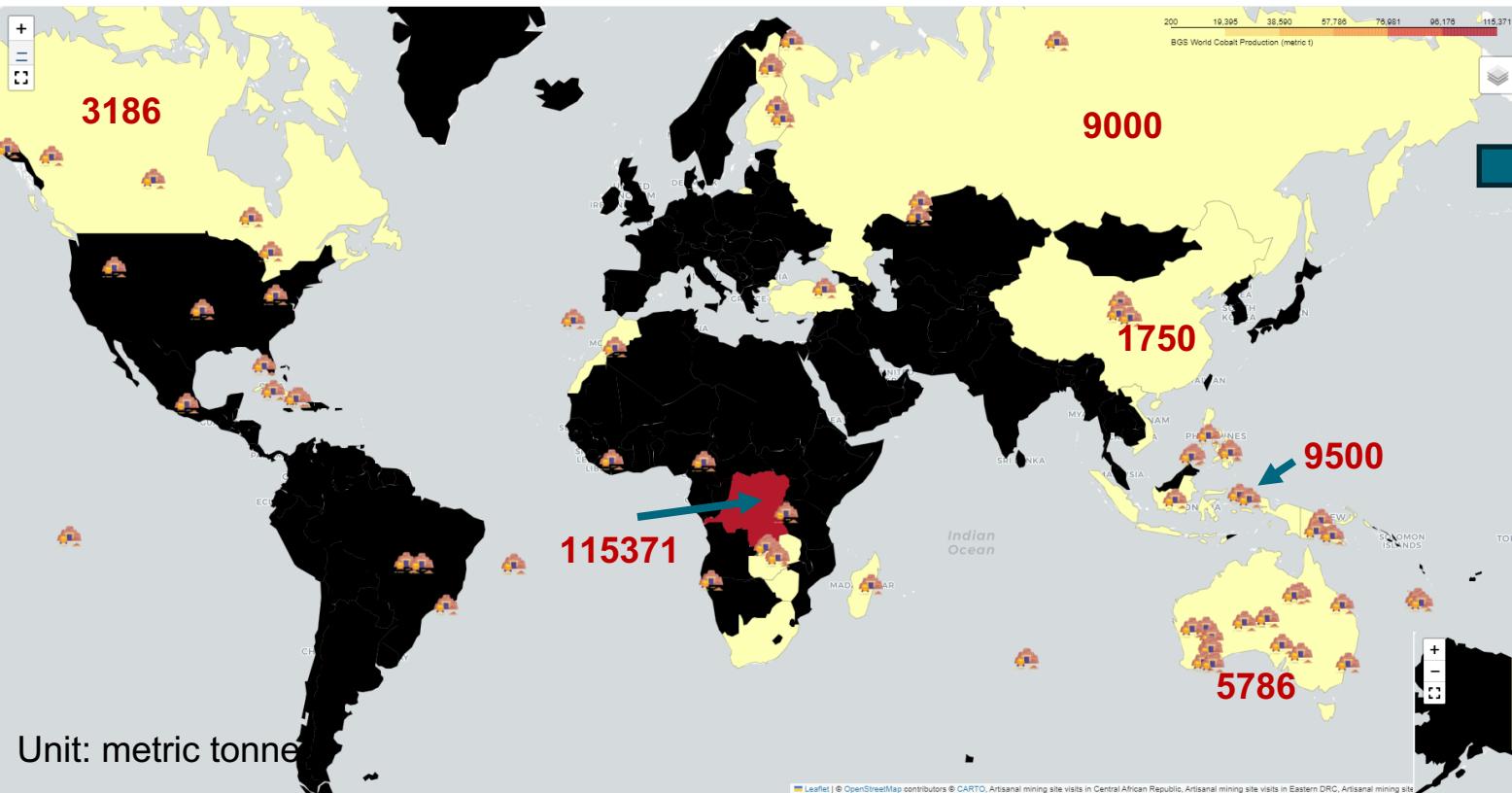


- Cobalt mines are primarily located in Democratic Republic of Congo (DRC), Indonesia, Russia, and Australia; 82 mines in total were identified, with 41 being operating mines (BGS, 2024).
- Processing facilities are predominantly located in China.
- Battery and EV manufacturing plants are concentrated in Asia-Pacific, North America and Europe
- Processing and manufacturing of cobalt-containing components occur in geographically disparate locations, often distant from the mining sites



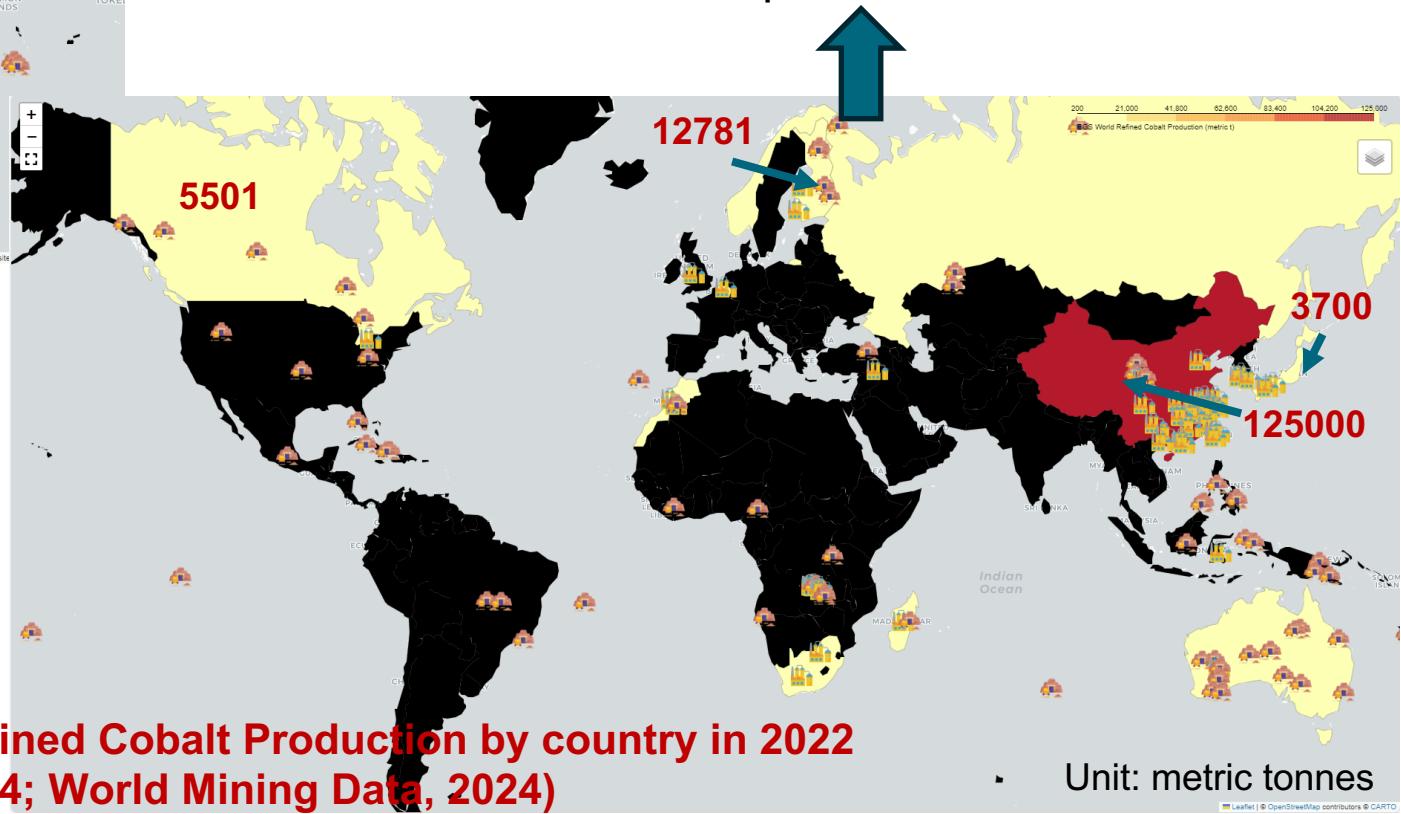
Results & Discussion – Global Cobalt & Refined Cobalt Production

World Cobalt Production by country in 2022 (BGS, 2024; World Mining Data, 2024)



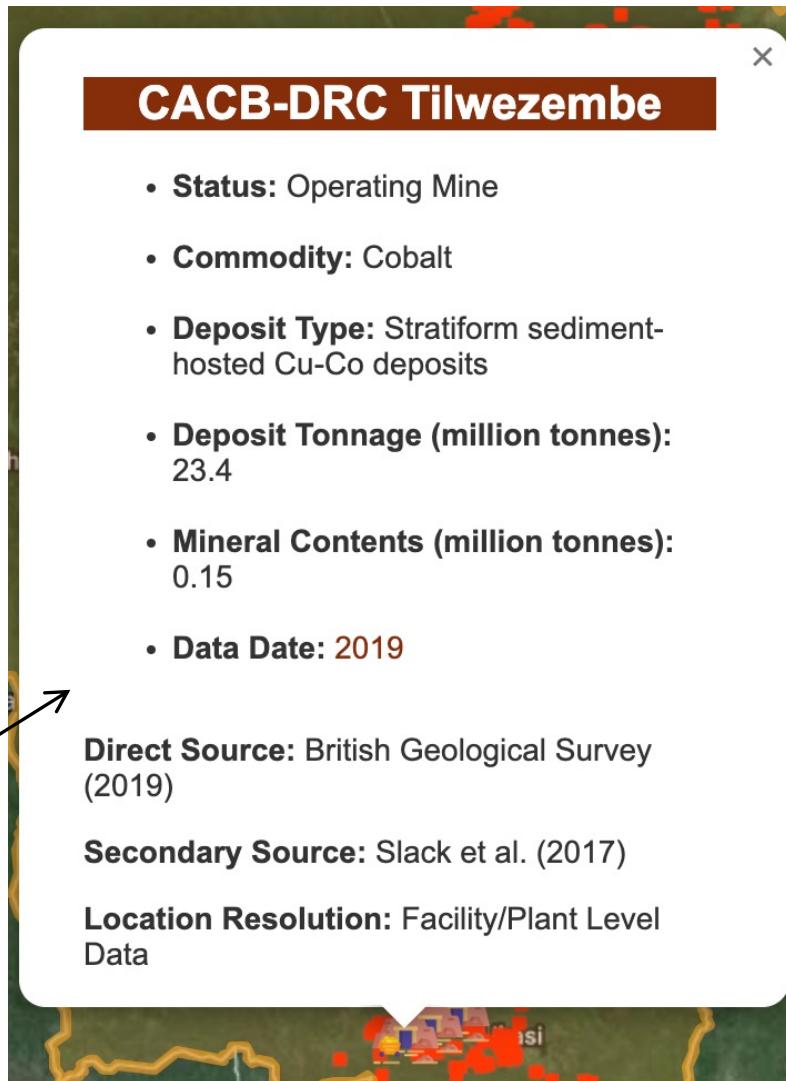
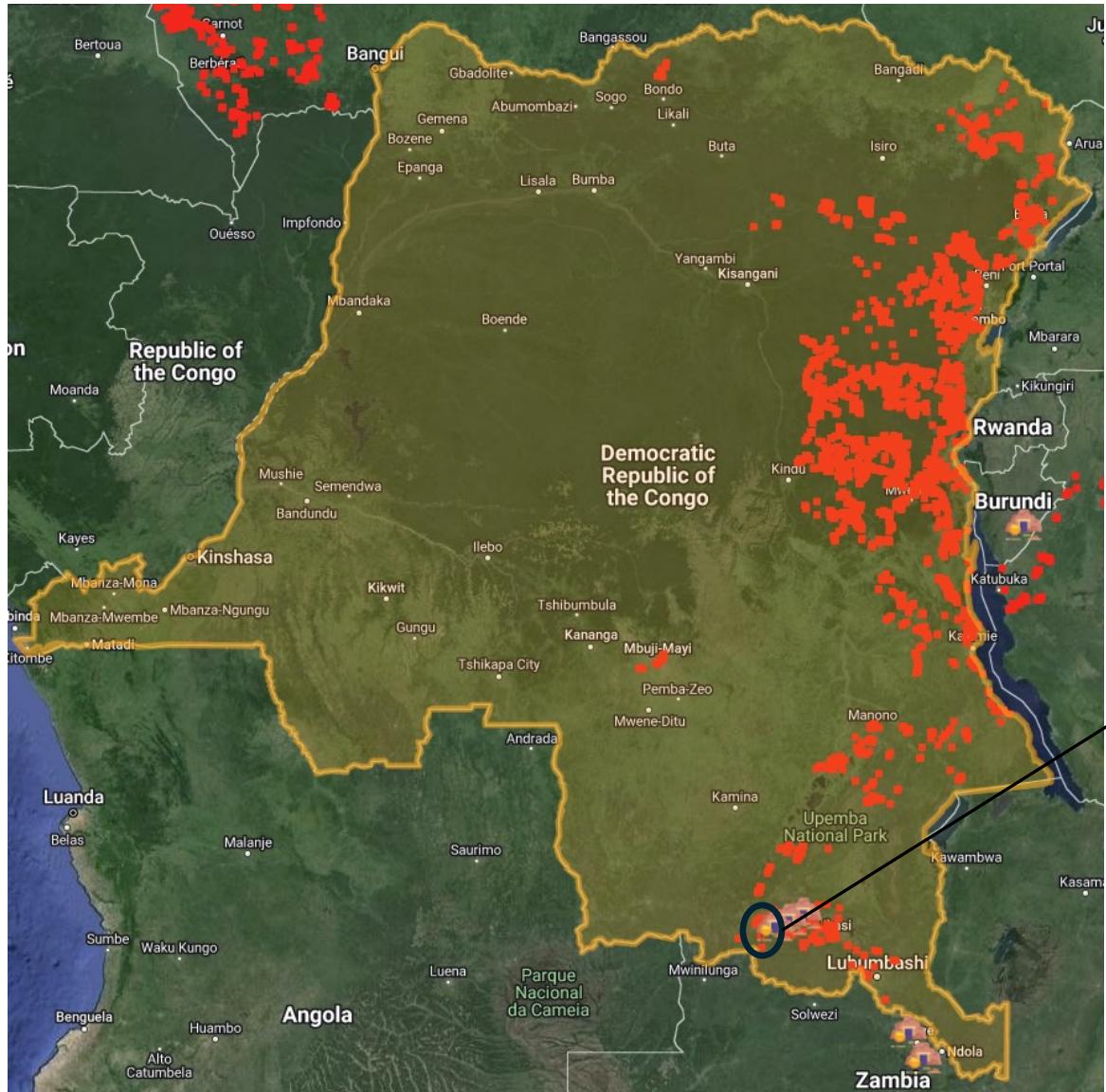
69.9% of cobalt was mined in DRC in 2022

China accounts for over 80% of the world's refined cobalt output



- Concentrated distribution of global cobalt supply chains leading to supply concerns

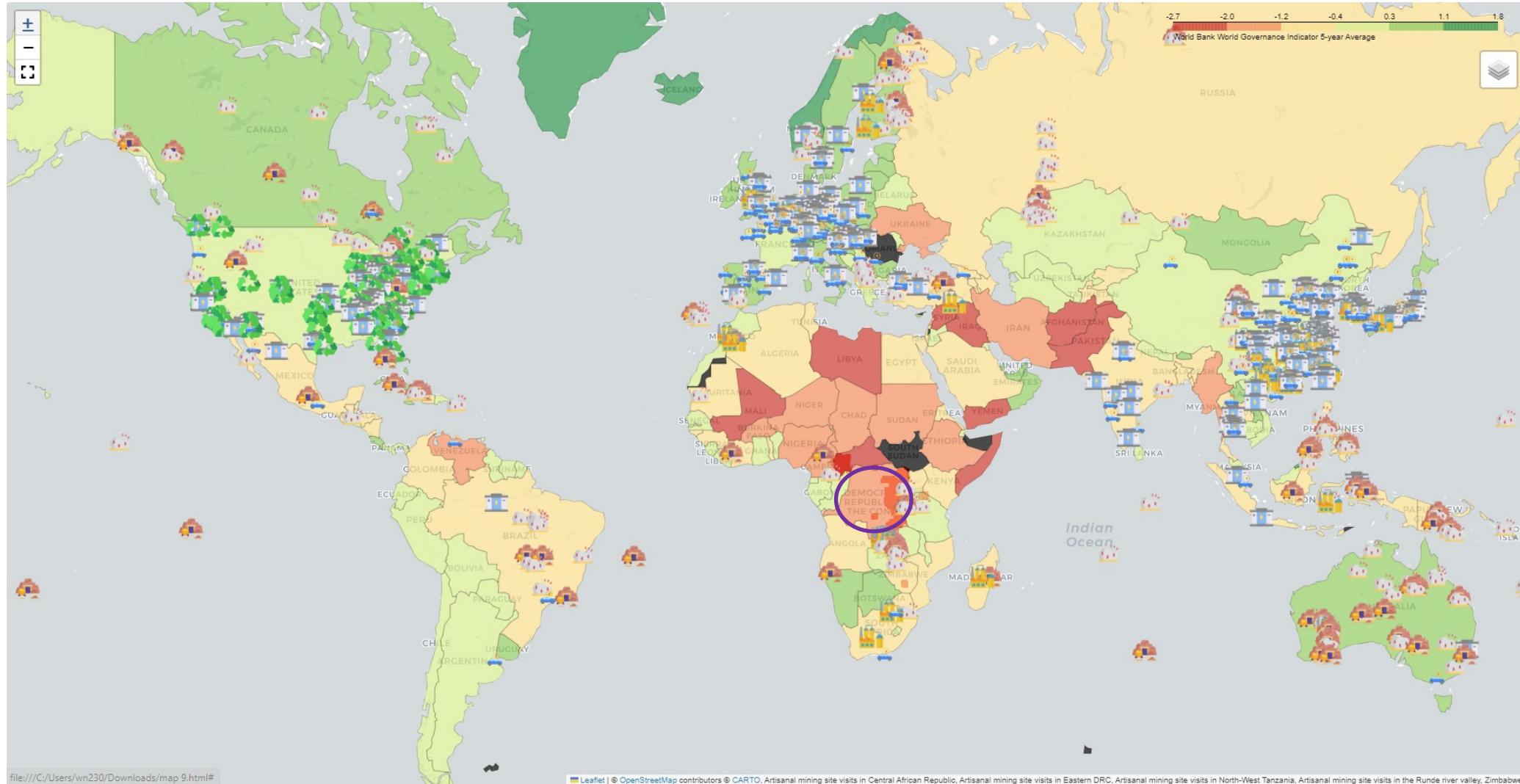
Results & Discussion – Sustainability Concerns about Human Rights



- Artisanal mining is small-scale, often informal, mining activity carried out by individuals or small groups using basic tools, typically without regulatory oversight
- Associated with **child labour** issues and low levels of safety measures (Cobalt Institute, 2023)
- 12% of Cobalt outputs in DRC are from Artisanal mining, being mixed with cobalt produced by regulated mines



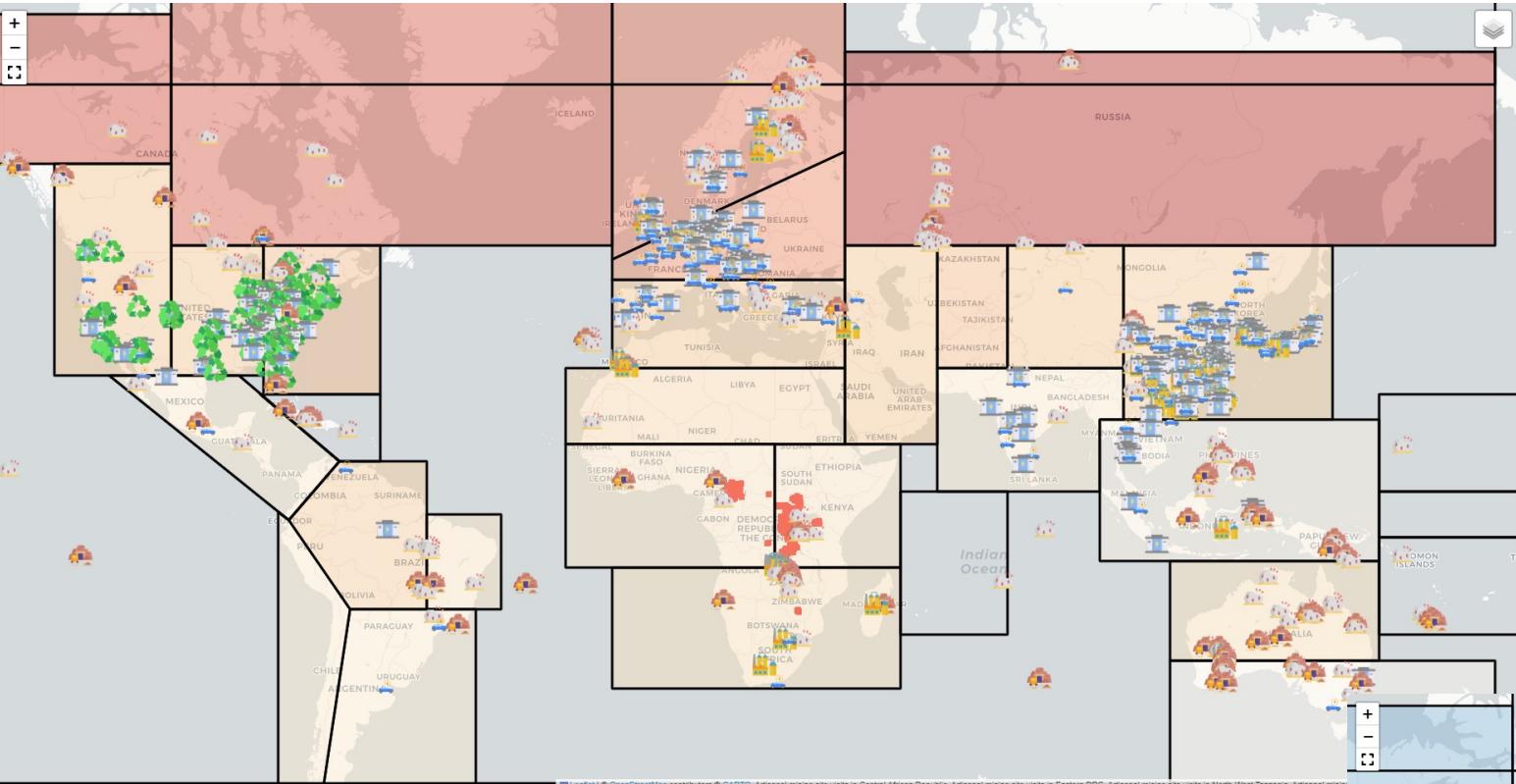
Results & Discussion – Political Instability



- DRC has lowest score out of all the countries that are involved in the mapped cobalt supply chain
- Conflicts with Rwanda (**near mining areas**) involving killings and political violence
- Threaten the global cobalt supplies in terms of disrupted operations, considering DRC accounts for **70% of the global supply**

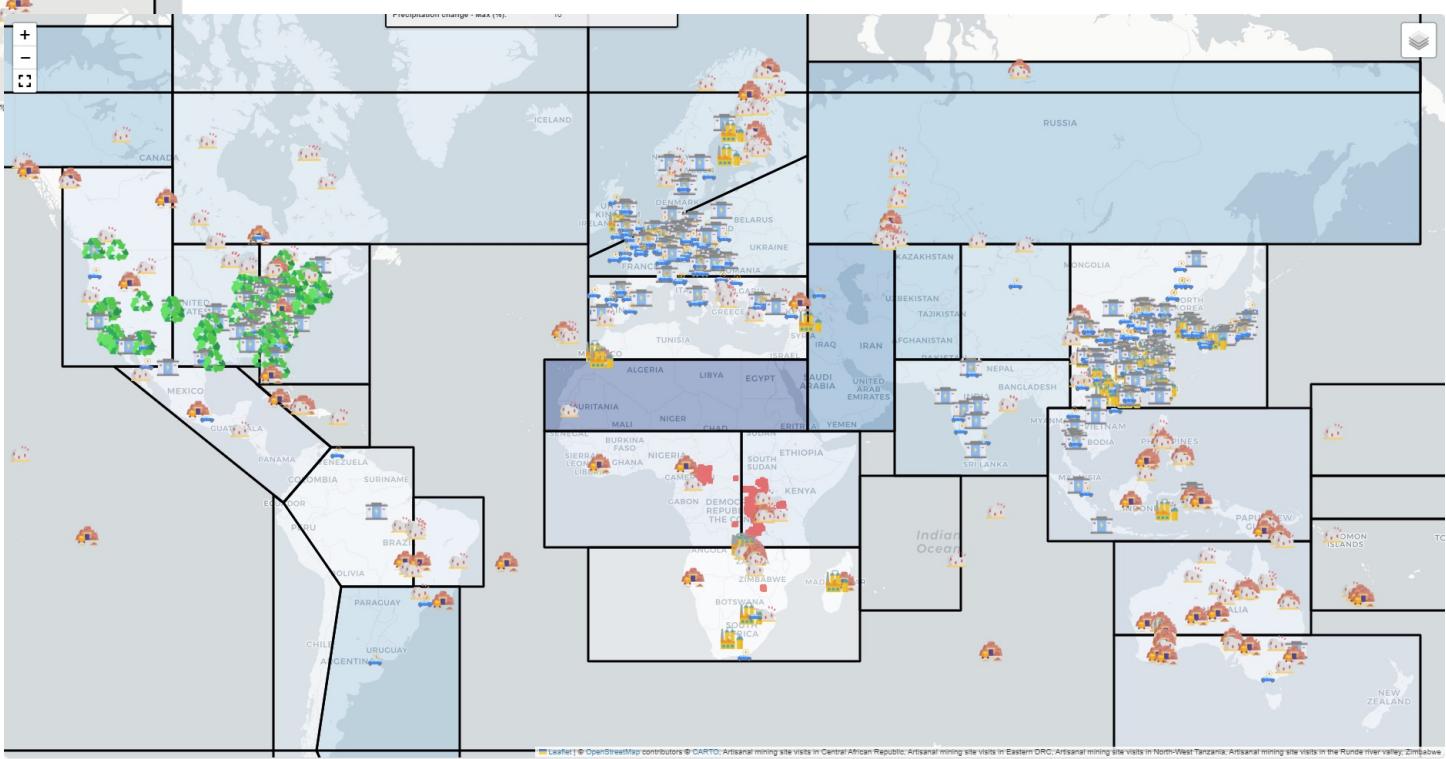
5-year average of World Bank Governance Indicator - Political Stability and Absence of Violence/Terrorism (World Bank, 2023)

Results & Discussion – Extreme Weather



IPCC AR5 projected regional average change in temperature (top) and precipitation (bottom) extremes in 2035 (RCP 8.5 scenario)

- Heat waves, flooding and landslides caused by heavy precipitation can disrupt mining activities and transportation
- Darker colour represents an **increased frequency and intensity** of extreme precipitation and temperature events
- Indicating which parts of the cobalt supply chain are more vulnerable to extreme weather



Results & Discussion

Data challenges in terms of reliability and timeliness

Challenges	Example	Next step
Data discrepancy	As high as 90% discrepancy was also observed in Turkey cobalt production in 2022 between British Geological Survey data and World Mining Data by Austrian Federal Ministry of Finance	Validating through other data points such as import and export data or mining company reports
Data latency	Data publish frequency is quite low (every 5 years) from the Geological Survey, not able to capture the latest deposit and mine locations	Collecting from news

Contribution

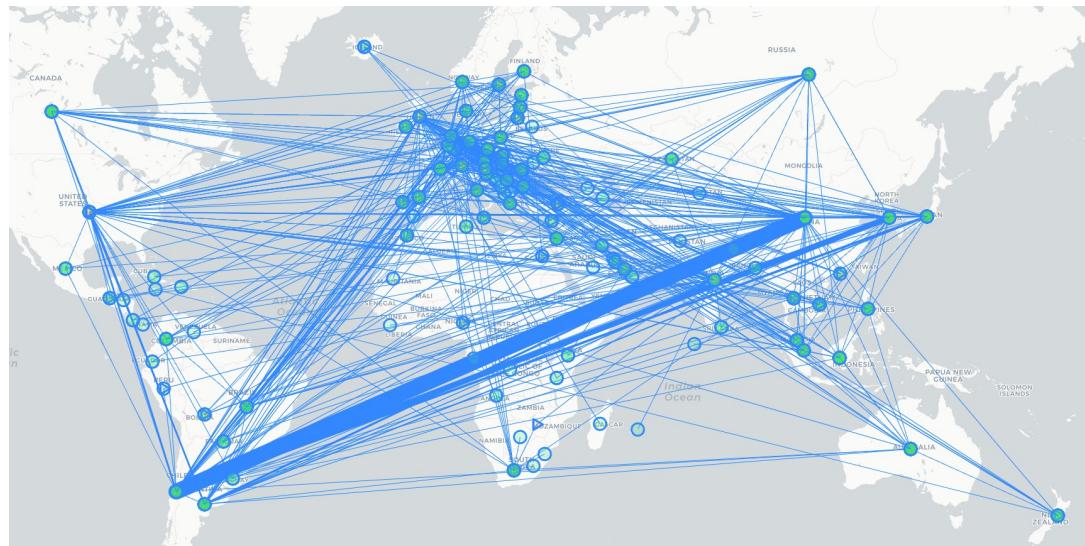
Theory

- Uncover the inherent characteristics and potential utilities of open data in developing the end-to-end supply chain visibility
- Provide empirical examples of utilising open data for supply chain research

Practice

- Provide a practical instrument policymakers, aiding in the identification of bottlenecks, constraints, and potential risks associated with supply disruptions

Next Steps



- Mapping of **interconnections** between SC tiers and network flow directions to determine regional dependencies
- Further analysis

Image source: Industrial Resilience Research Group (2024)



VS



Public open data

Private data

- Comparing the differences in results between using public and private data
- For **academic** purposes, to explore the potentials of public open data: Whether public data can provide **greater or similar** visibility as compared to the private data

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