The Rare Earth discovery in Kiruna and its impact on European supply security

IRTC 2023
Pierre Heeroma
SVP Strategic Projects

Based in the Swedish orefields

LKAB mines around 80 % of all iron ore within the EU

1890

LKAB is one of Sweden's oldest industrial companies and is owned by the Swedish state

48.8

Net sales of SEK 48.8 billion in 2021

12

The group is present in 12 countries

3.4

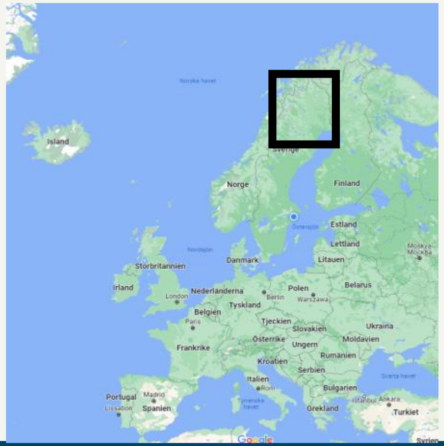
Approximately SEK 3.4 billion investments towards carbon-free processes and products in 2021

4 500

Average number of employees

27

27 million tonnes iron ore products were delivered in 2021



Our iron ore products

Climate-efficient high-grade iron ore products for the global steel industry

Blast furnace pellets

Direct reduction pellets

Fines

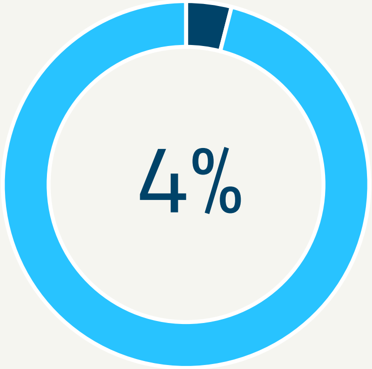
Our climate impact today

-84%

CO_2-emissions are reduced with 84 percent since 1960 with today's pellet production

700 000

Tonnes of carbon dioxide



4% of Swedish industry's total emissions of carbon dioxide

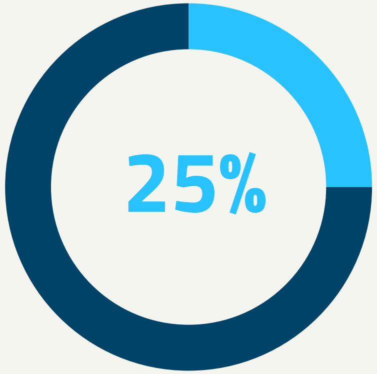
The industry’s climate impact today

2.6 billion

Tonnes carbon dioxide totally from the iron and steel industry

7%

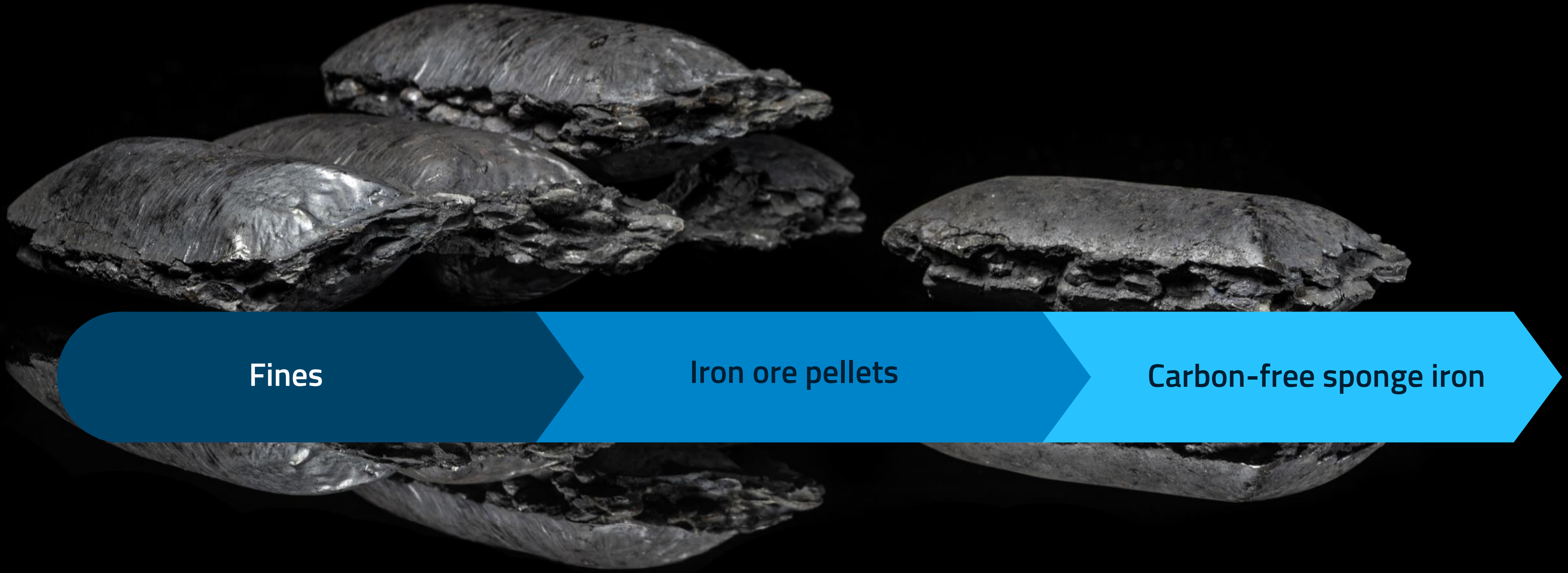
Of all carbon dioxide emissions globally



25% of global industry carbon dioxide emissions

We take a step forward in the value chain

From iron ore pellets to carbon-free sponge iron



Fines

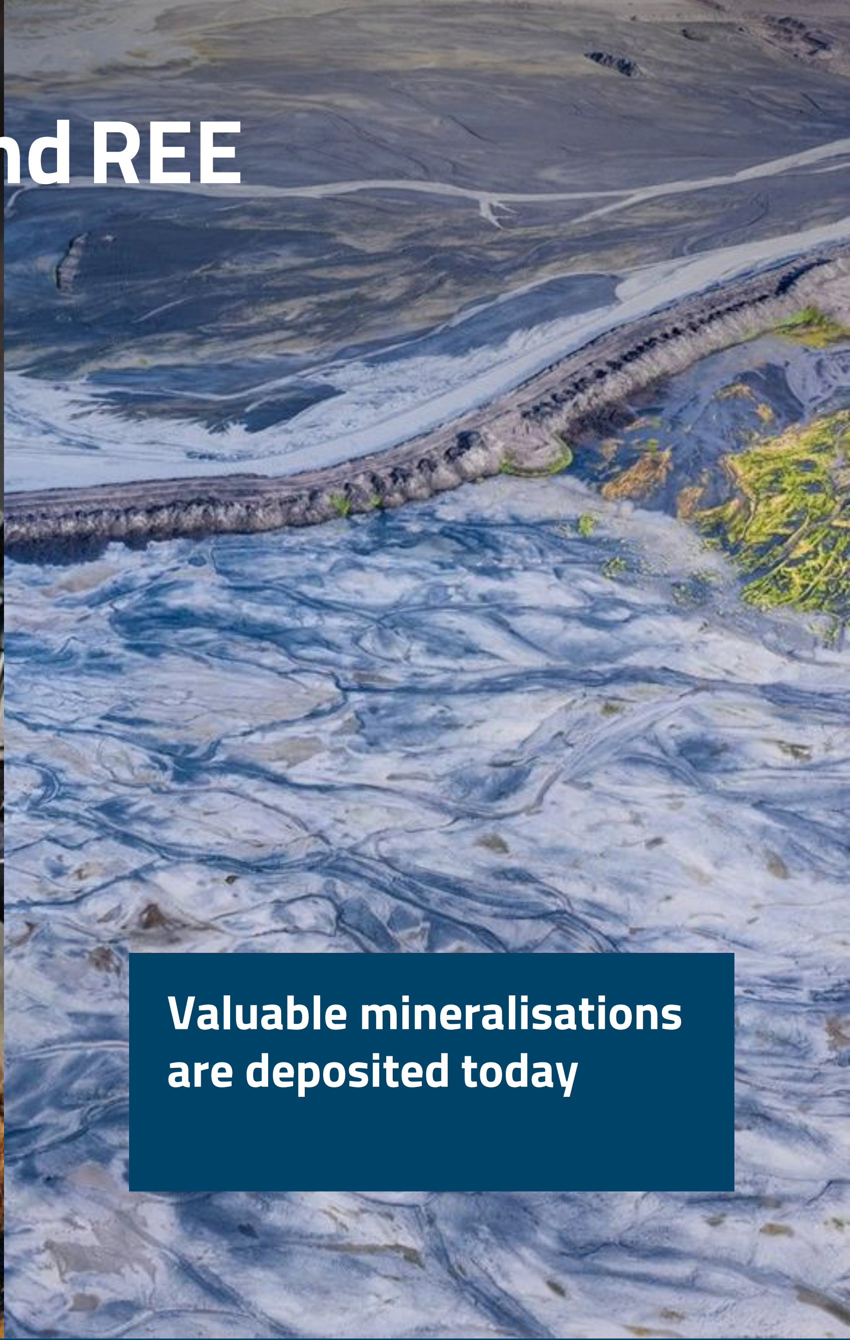
Iron ore pellets

Carbon-free sponge iron

LKAB can become Europe’s home for P and REE

>4 billion tonnes of mineral resources and reserves
Iron, Phosphorus and Rare Earth Metals

Large-scale iron ore production beyond 2060



Valuable mineralisations are deposited today

Per Geijer: Mineral resource

Per Geijer	**Tonnage**	**Fe**	**P**	**TREO**
Iron ore deposit	Mt	%	%	%
Mineral resource	585	50,5	2,41	0,18

Potential to supply:

- **30% Europe's REE demand**
- **7 times Sweden's mineral fertilizers demand**

Mineral fertilisers enable 50 percent of the world's food production

- Europe is dependent on phosphorus imports
  - 2020, CIS excluded (~8,3 million tonnes)

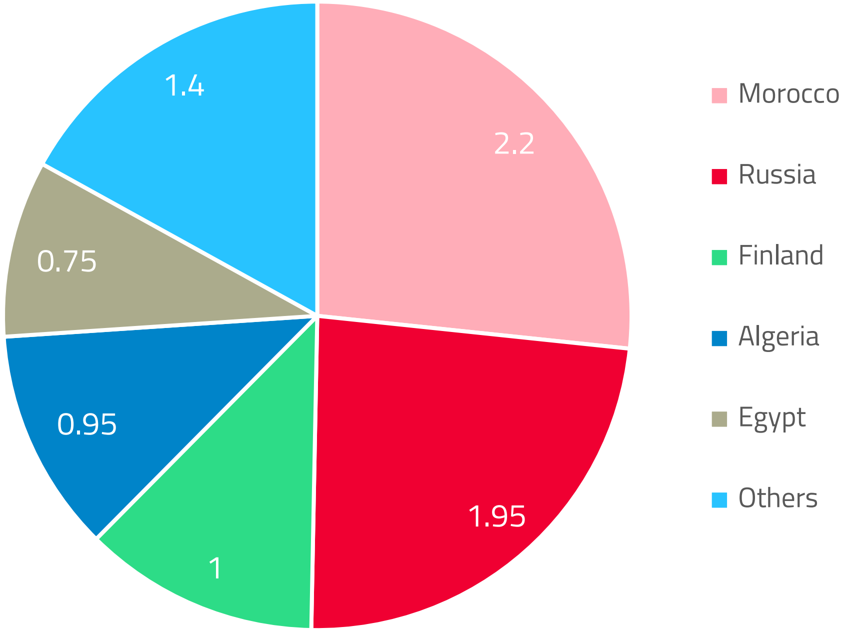
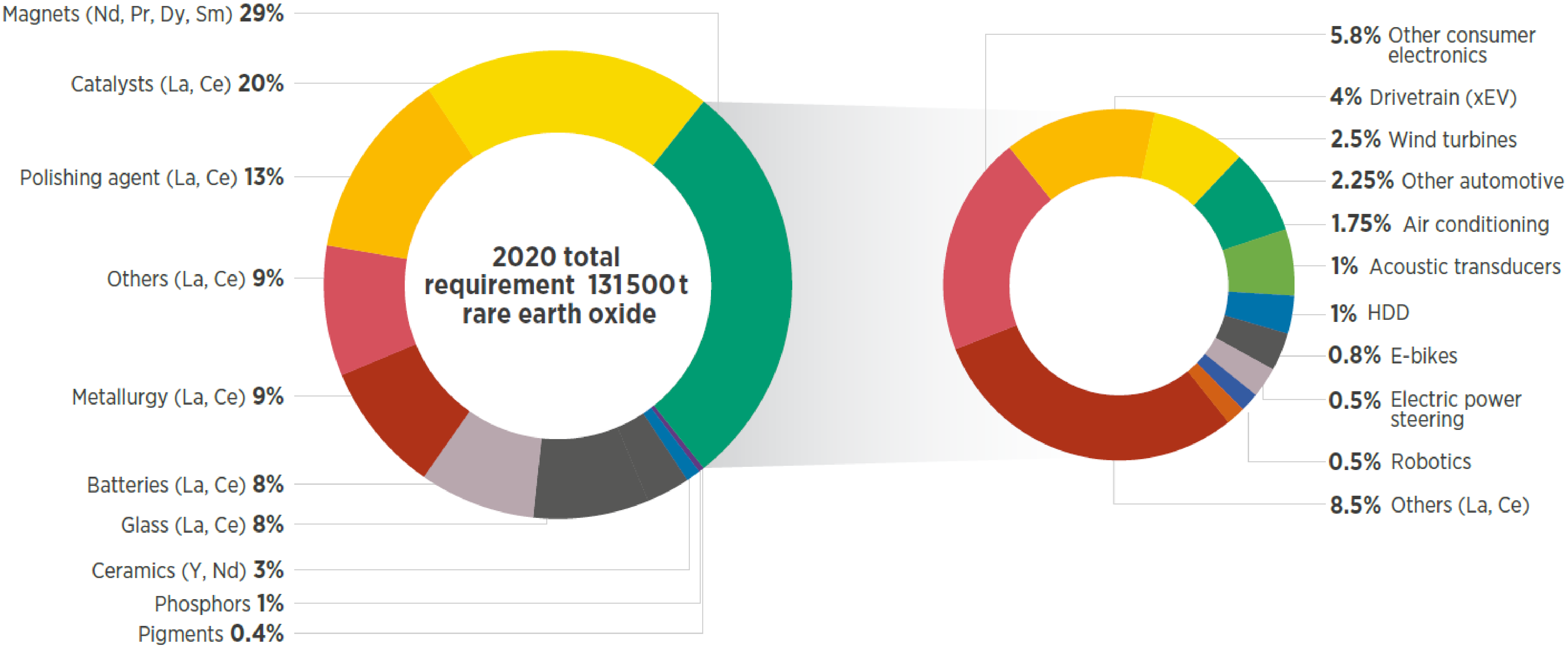


Figure 1: Rare earth demand by end use sectors and breakdown of magnet demand by mass, 2020

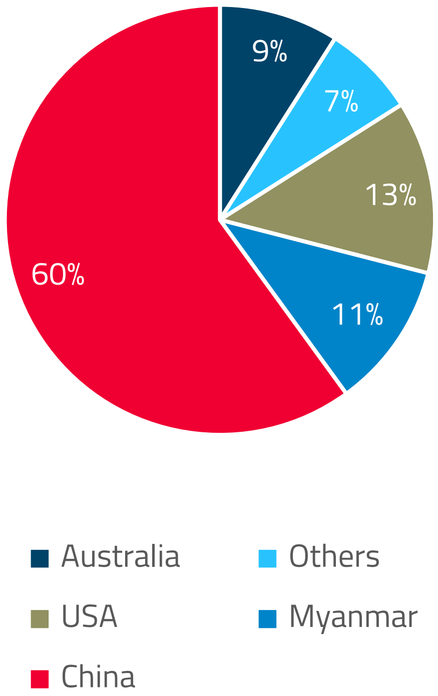


Source: Roskill, 2021; BGR, 2021.

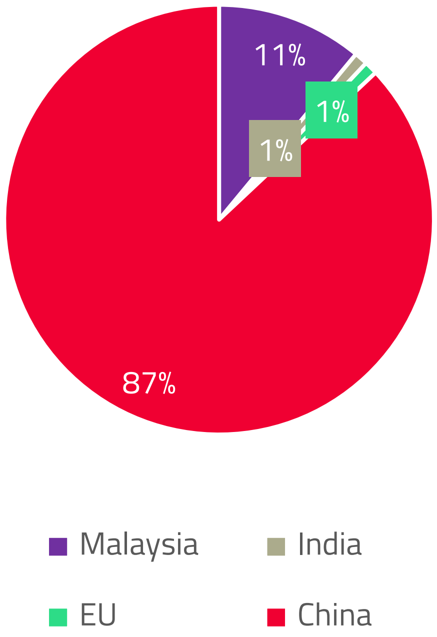
Note: Ce = Cerium; Dy = Dysprosium; HDD = hard disk drives; La = lanthanum; Nd = neodymium; Pr = praseodymium; Sm = samarium.

Europe needs rare earths
but has no extraction and marginal refinement

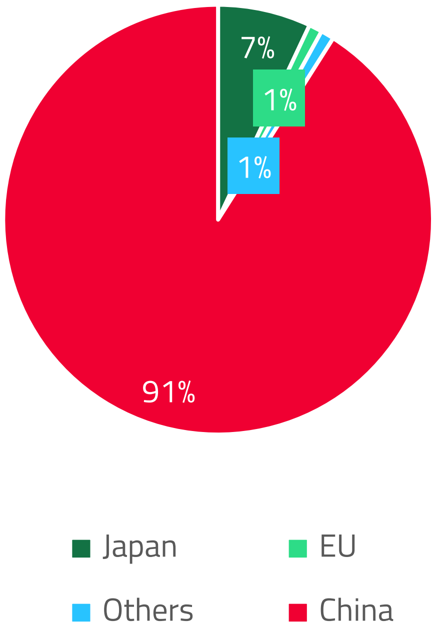
Rare earth oxide mining



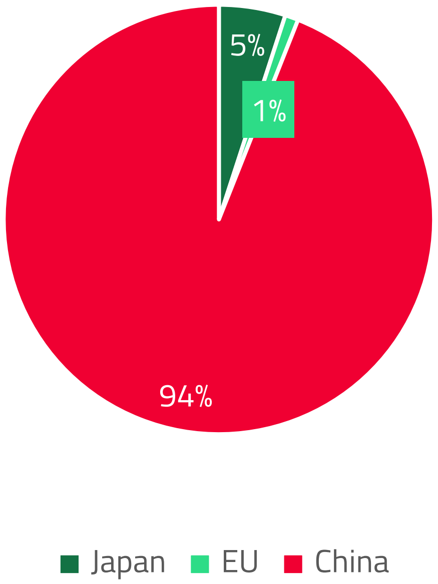
Rare earth oxide processing



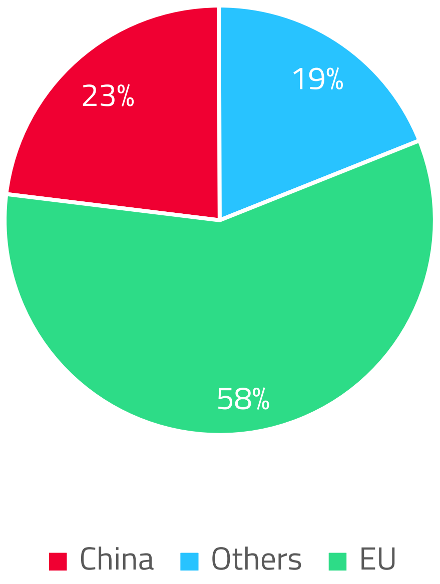
Rare earth metals



Permanent magnets

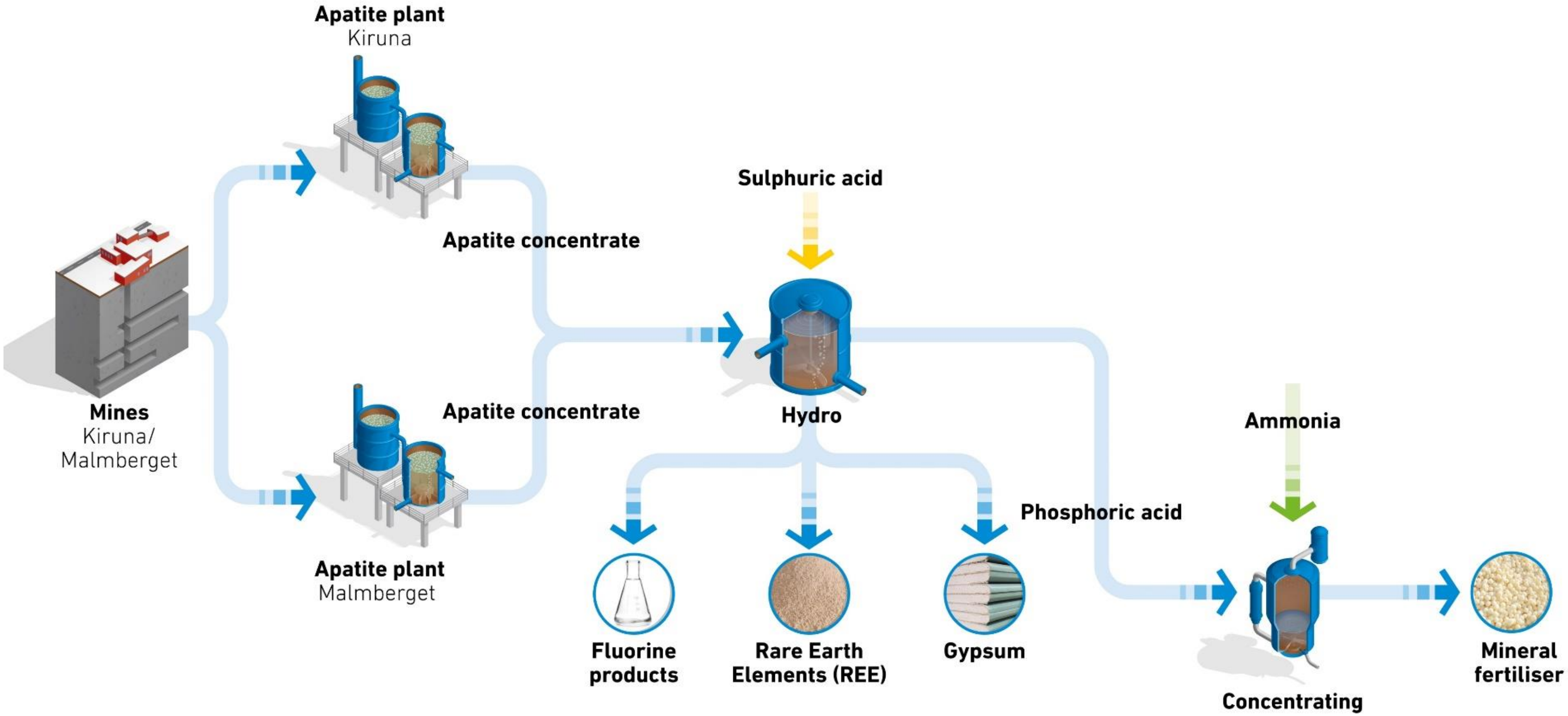


Example: Wind turbines

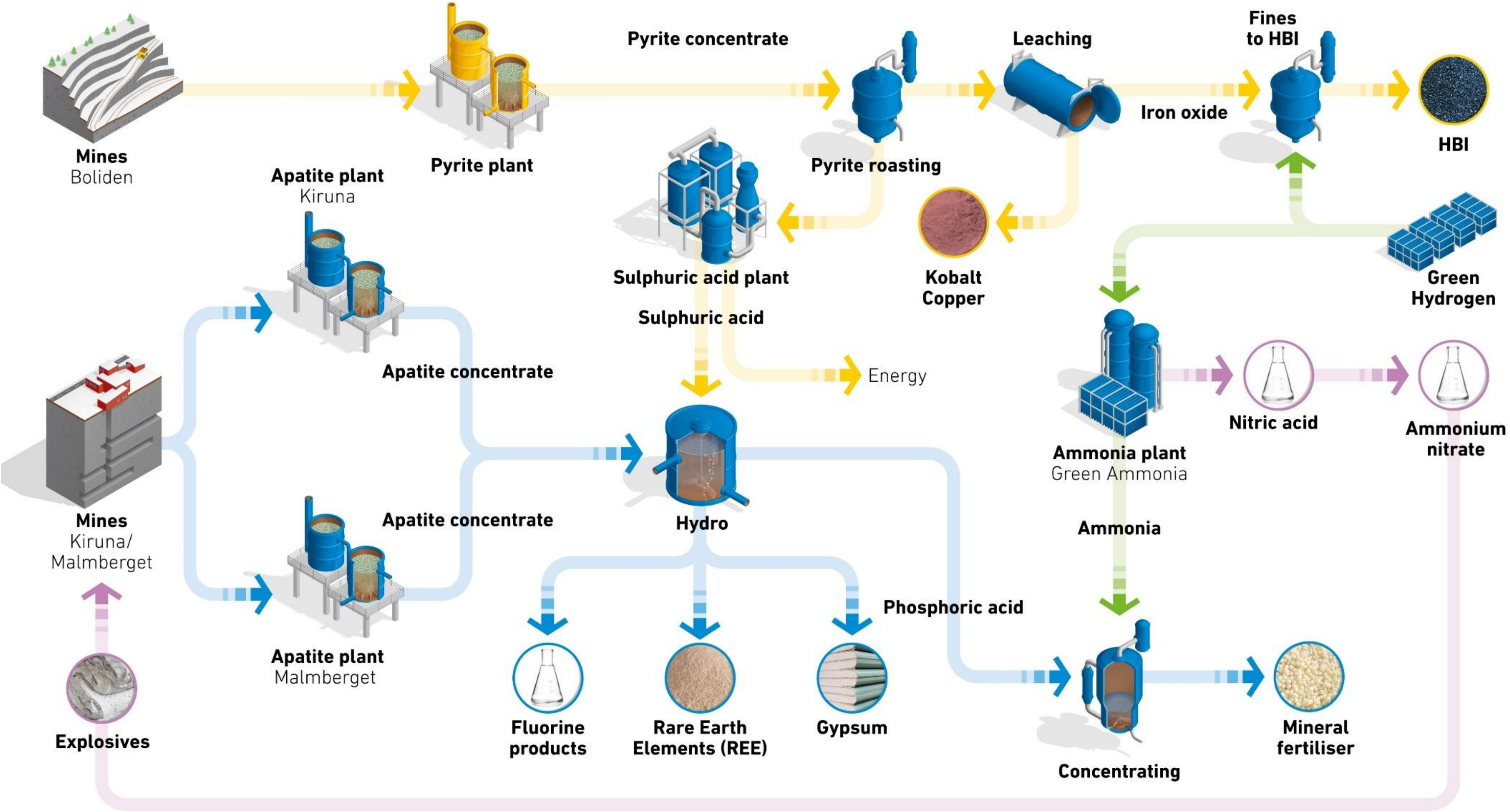


Source: European Raw Materials Alliance, combined data from Roskill 2018; Adamas Intelligence 2019; Peteves 2017; Carrara et at 2020; IEA 2021; USGS 2021

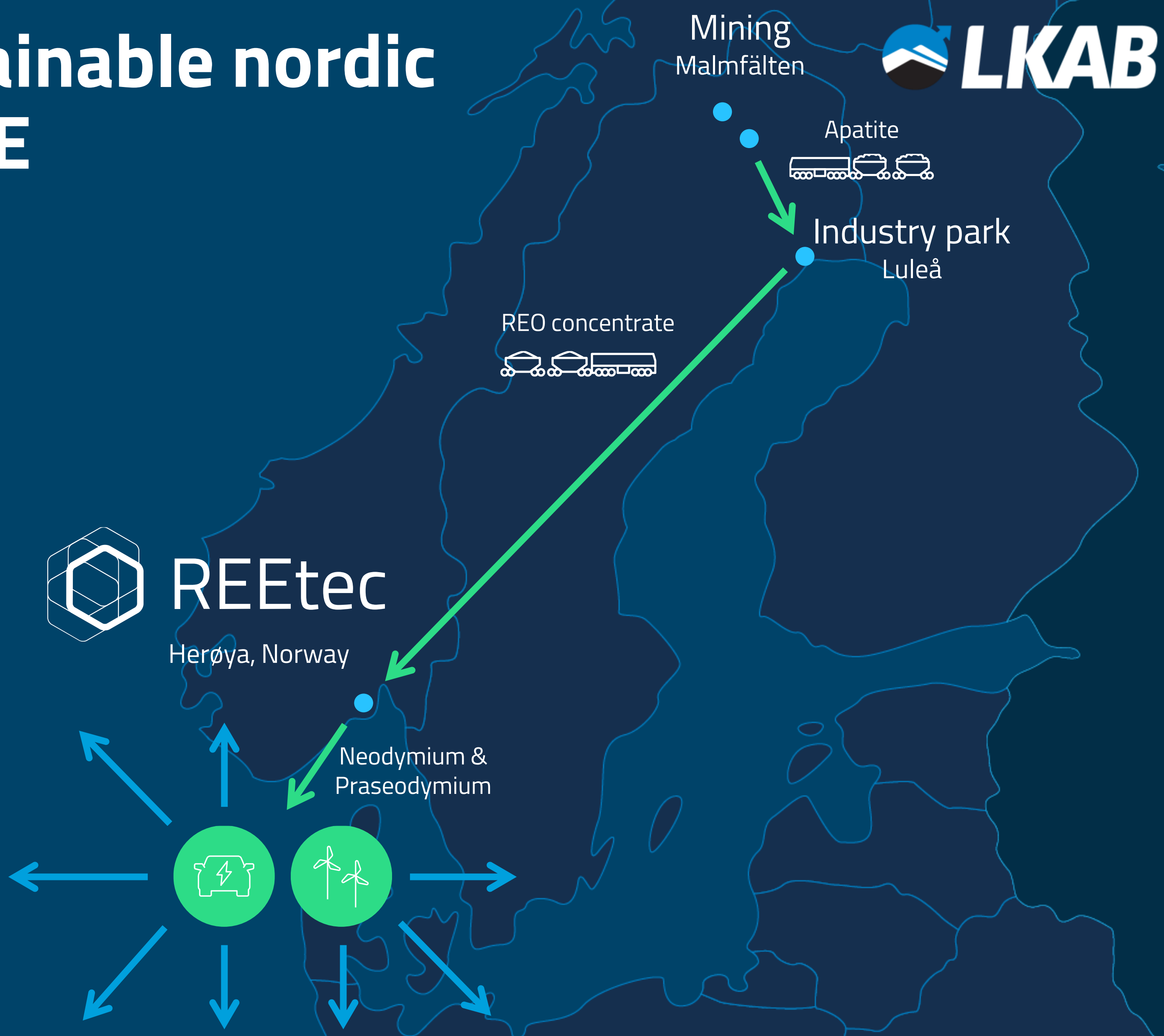
LKAB's future fossil-free production



Circular and fossil-free production



A strong and sustainable nordic value chain for REE



Mining
Malmfälten

LKAB

Apatite

Industry park
Luleå

REO concentrate

REEtec
Herøya, Norway

Neodymium &
Praseodymium

Challenges to overcome

Industry and policy makers need to work to together to decrease risks and enable European production

Social and political license to operate

Mining at great depths

Capacity on the railway and harbours

Access to renewable energy

Access to land and permitting

Value chain perspectives

Identify resources and projects

Competence supply

Technology development

Green financing

Fossil-free electricity

From ….

- Globalisation
  - Free trade
  - Unfair trade
  - Limited European production
- Limited exploration and mining
- Not in my backyard
- Lack of holistic view and jugement
- Increasingly complex and lengthy permitting processes
- Short term view

to ….

- Globalisation
  - Free trade
  - Fair trade
- Value chain
- Critical raw materials are strategic for Europe
  - Exploration and production in Europe
  - Strategic stocks
  - Balancing opposing interests
  - Efficient permitting processes
- Long term strategy

LKAB

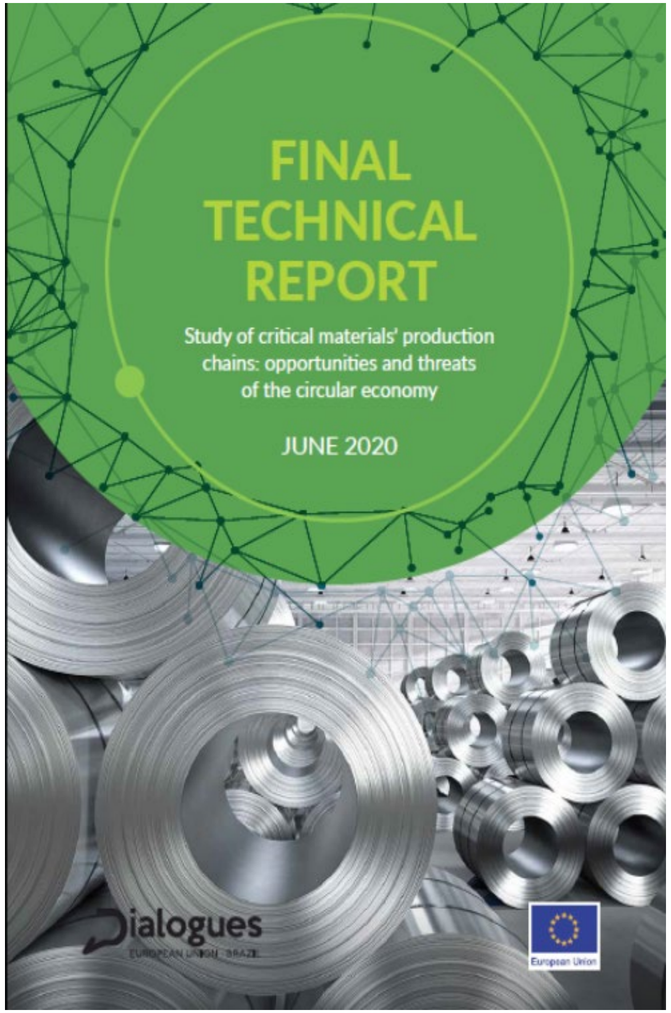
IRTC 2023 – RAW MATERIALS FOR A SUSTENAINABLE FUTURE

Niobium as a critical raw material for the world and strategic for Brazil

Carlos Peiter – Centro de Tecnologia Mineral-CETEM, Brazil
Tiago Braga – Instituto Brasileiro de Informação em Ciência e Tecnologia-IBICT, Brazil
Gian Andrea Blengini – Politecnico di Torino-PoliTO, Italy (JRC-DG GROW)
Fernando Castro, Lucia Helena Xavier, Adelson Castro, Ligia Marcela Alvarado – Centro de Tecnologia Mineral-CETEM, Brazil
Efigenia Rossi – Escola de Engenharia de São Carlos-EEUSP, Brazil
Marzia Traverso – Aachen Universitatea-INAB, RWTH

Lille, FR
15-17th Feb. 2023

The background report



FINAL TECHNICAL REPORT

Study of critical materials' production chains: opportunities and threats of the circular economy

JUNE 2020

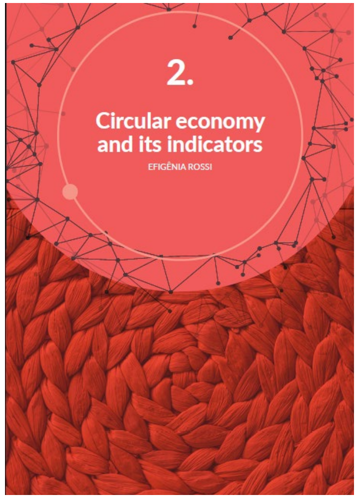
Dialogues
EUROPEAN UNION · BRAZIL

European Union

1.

Critical and strategic raw materials

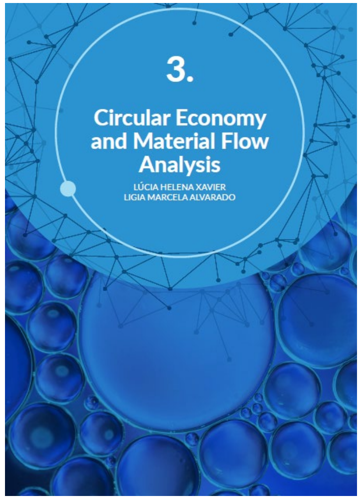
CARLOS CESAR PEITER



2.

Circular economy and its indicators

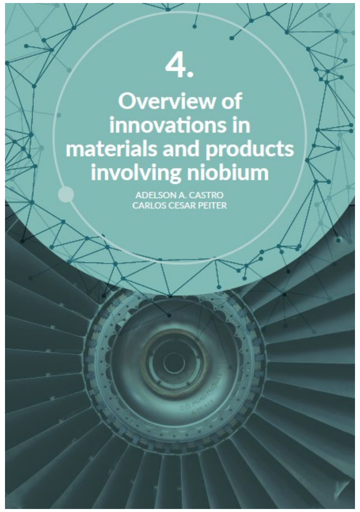
EFIGÊNIA ROSSI



3.

Circular Economy and Material Flow Analysis

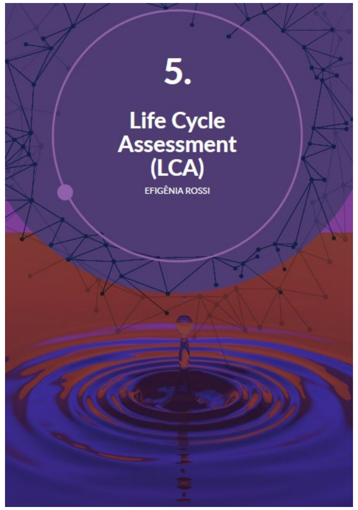
LÚCIA HELENA XAVIER
LIGIA MARCELA ALVARADO



4.

Overview of innovations in materials and products involving niobium

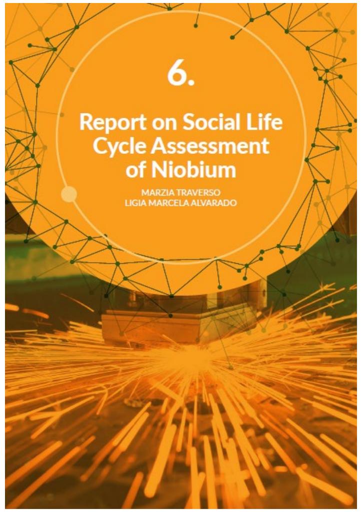
ADELSON A. CASTRO
CARLOS CESAR PEITER



5.

Life Cycle Assessment (LCA)

EFIGÊNIA ROSSI



6.

Report on Social Life Cycle Assessment of Niobium

MARZIA TRAVERSO
LIGIA MARCELA ALVARADO

Partnerships

Brazilian research institutions:
CETEM, IBICT, EESC-USP

European research institutions:
JRC/EC (Ispra, IT) and INAB-RWTH Aachen University (GER)

Brazilian Company:
CBMM (cooperation agreement)

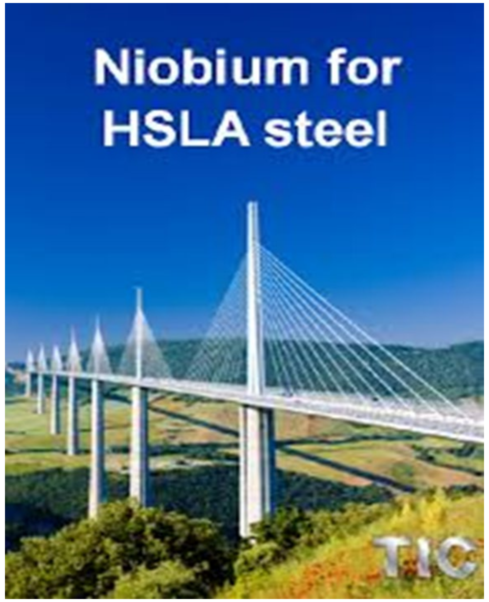
Funding : EU Brazil Sectoral Dialogues, nineth call (2018) and **Ministry for Science, Technology & Innovation, Brazil**

Source: http://sectordialogues.org/projetos/estudo-das-cadeias-produtivas-dos-materiais-criticos-oportunidades-e-ameacas-da-economia-circular

Why is Niobium important ?

Steels for pipelines, structural and stainless steels, superalloys, superconductors, catalysts, optolenses, capacitors

Steel for pipelines



Superconductors (e,g. CERN Particle accelerator Large Hadron Collider , 27 Km long)

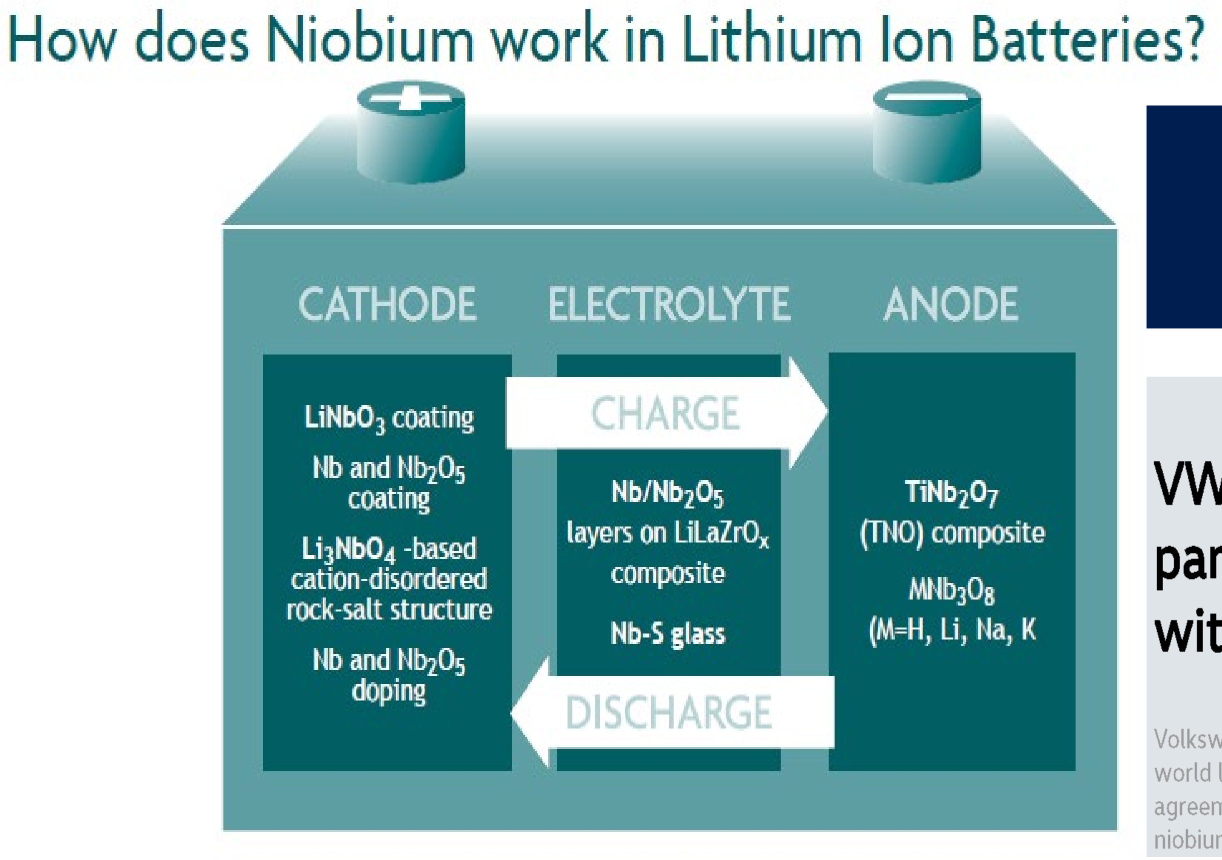
Superalloys for jet engines

Under development Nb/ Ti oxides anodes for lithium ion batteries

Structural steel for car, trucks, buses, etc

Source: Photos available at various internet sites.

Nb contributions to innovations in energy storage and generation



How does Niobium work in Lithium Ion Batteries?

CATHODE

- $LiNbO_3$ coating
- Nb and Nb_2O_5 coating
- Li_3NbO_4 -based cation-disordered rock-salt structure
- Nb and Nb_2O_5 doping

ELECTROLYTE

- Nb/Nb_2O_5 layers on $LiLaZrO_x$ composite
- Nb-S glass

ANODE

- $TiNb_2O_7$ (TNO) composite
- MNb_3O_8 (M=H, Li, Na, K

Source: https://niobium.tech/Pages/Gateway-Pages/PDF/Briefings/Niobium_in_Li-Ion_Batteries

Home / News / VW Caminhões e Ônibus and CBMM sign an unprecedented partnership for the development of automotive batteries with Niobium

VW Caminhões e Ônibus and CBMM sign an unprecedented partnership for the development of automotive batteries with Niobium

Volkswagen Caminhões e Ônibus, a pioneer in the development and serial production of electric trucks in Latin America, and CBMM world leader in the production and sale of Niobium products, enter into a new partnership to encourage electric mobility. The agreement aims to develop and apply ultra-fast recharge batteries for use in electric vehicles designed by the automaker. The u niobium for this purpose is unprecedented in the global automotive industry.

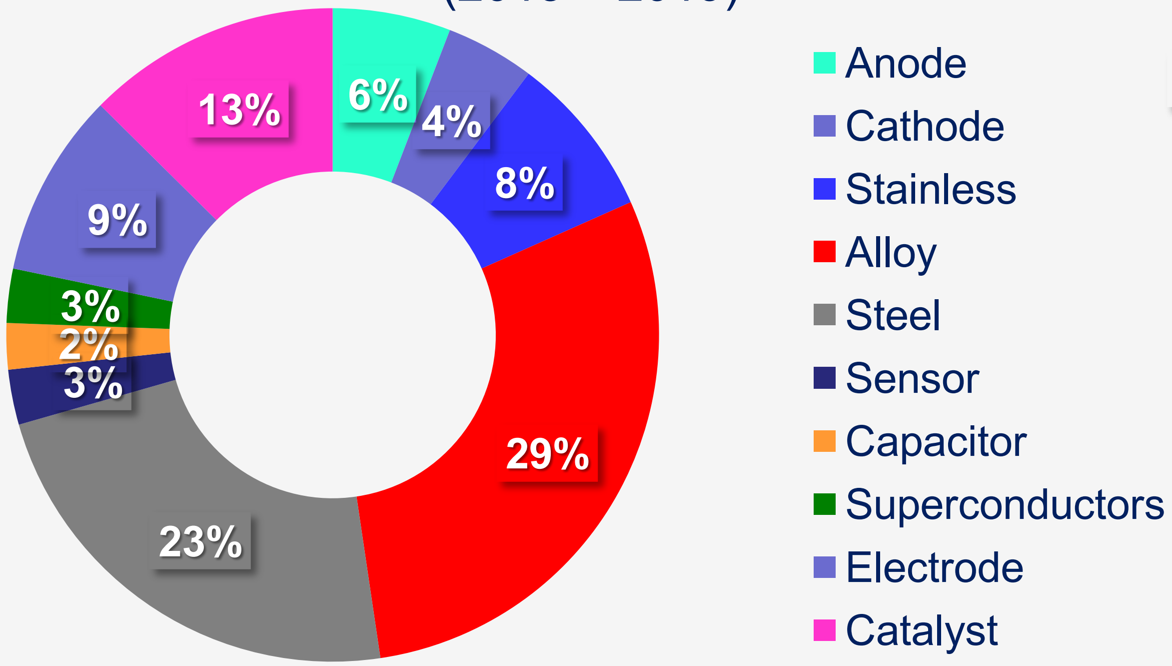
Source:https://www.vwco.com.br/noticias/270?lang=en_US

Niobium in S&T and Innovations

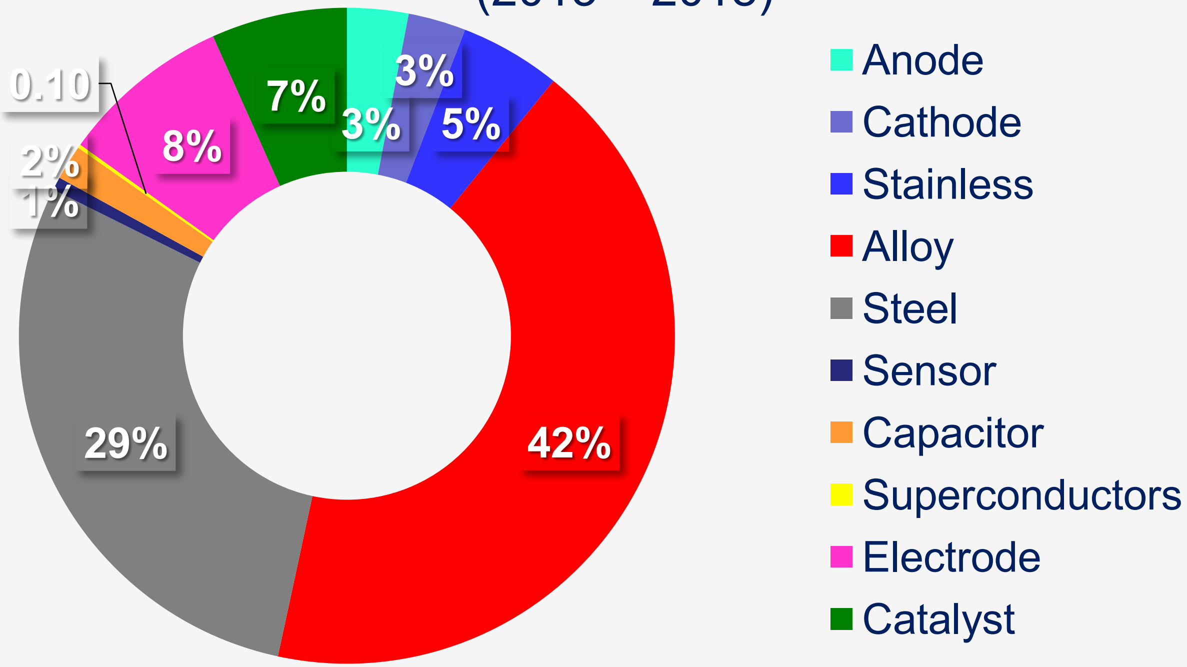
Results from 4.953 papers sample and from 3.092 patents sample collected 2013-2019

Steel making and metallurgical use higher shares and energy applications growing

Percentage of scientific papers by application (2013 – 2019)

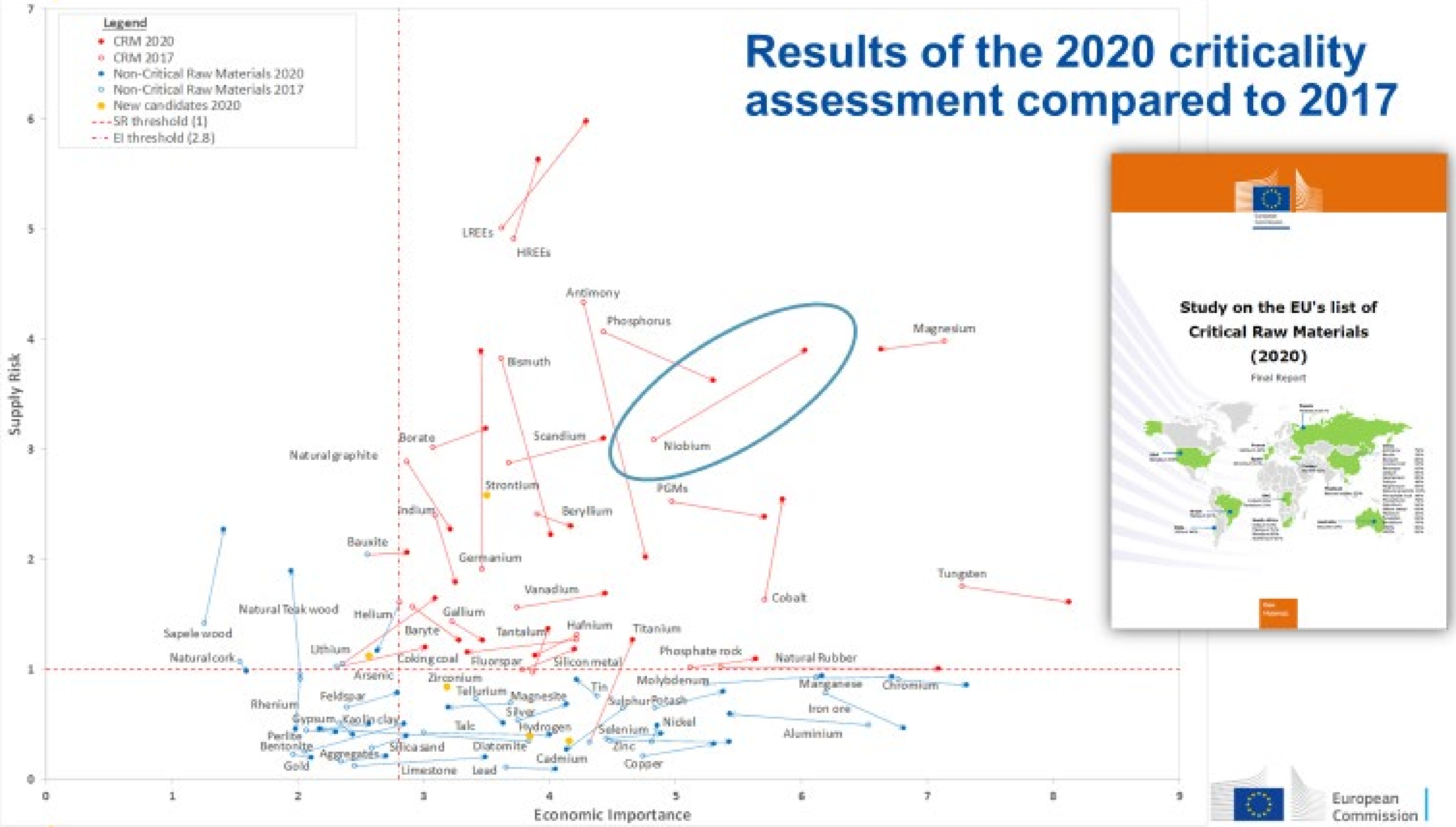


Percentage of Patents per application (2013 – 2018)



Source: Study of critical materials' production chains: opportunities and threats of the circular economy (2020)

Niobium is considered a CRM in all lists



Results of the 2020 criticality assessment compared to 2017

Study on the EU's list of Critical Raw Materials (2020)

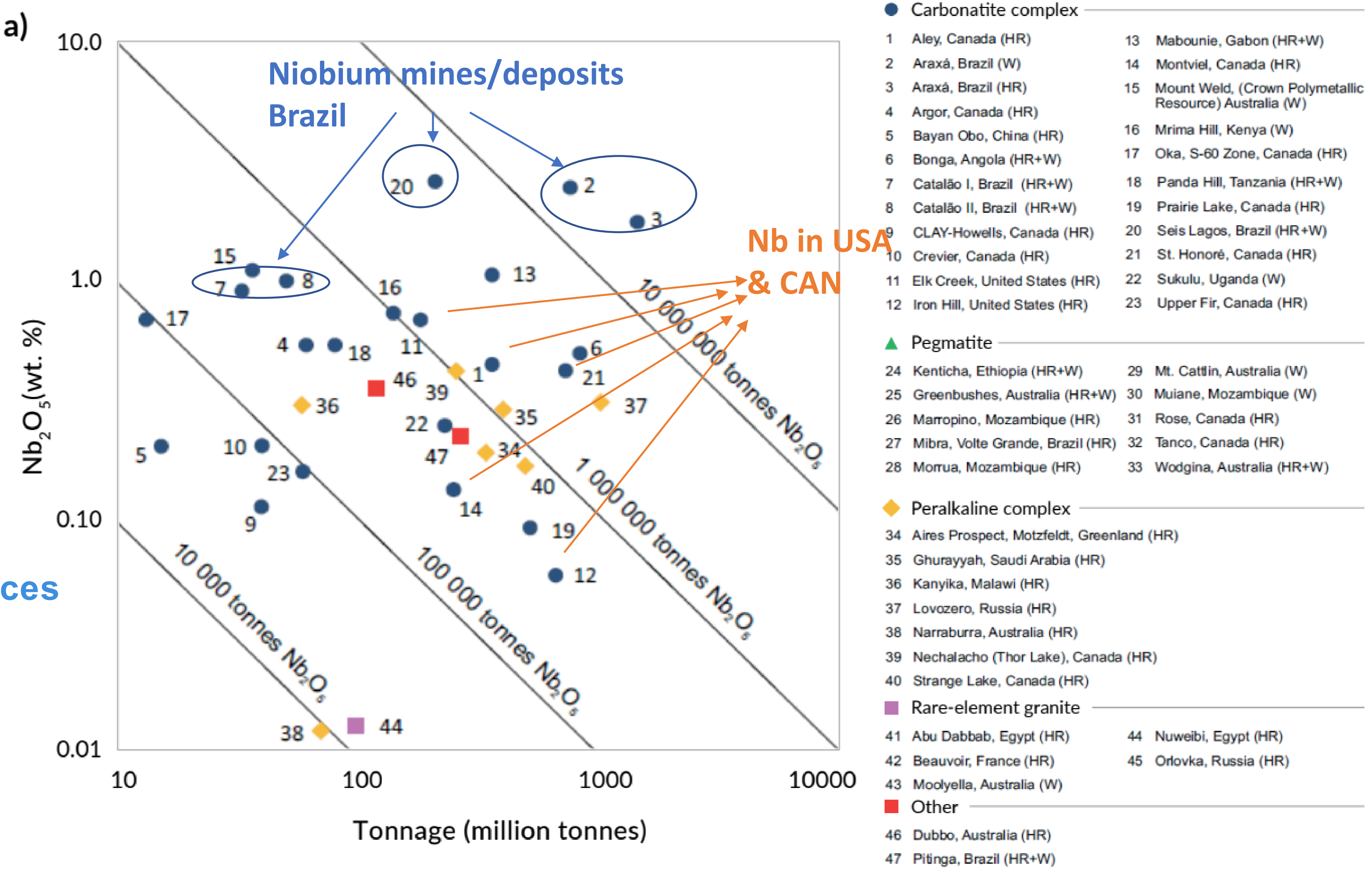
Final Report

European Commission

Sorce: Blengini, G.A. Presentation to the EU Brazil Dialogues final report. April, 2021.

Is Niobium a rare metal ?

Source: Simandl *et al* (2018)



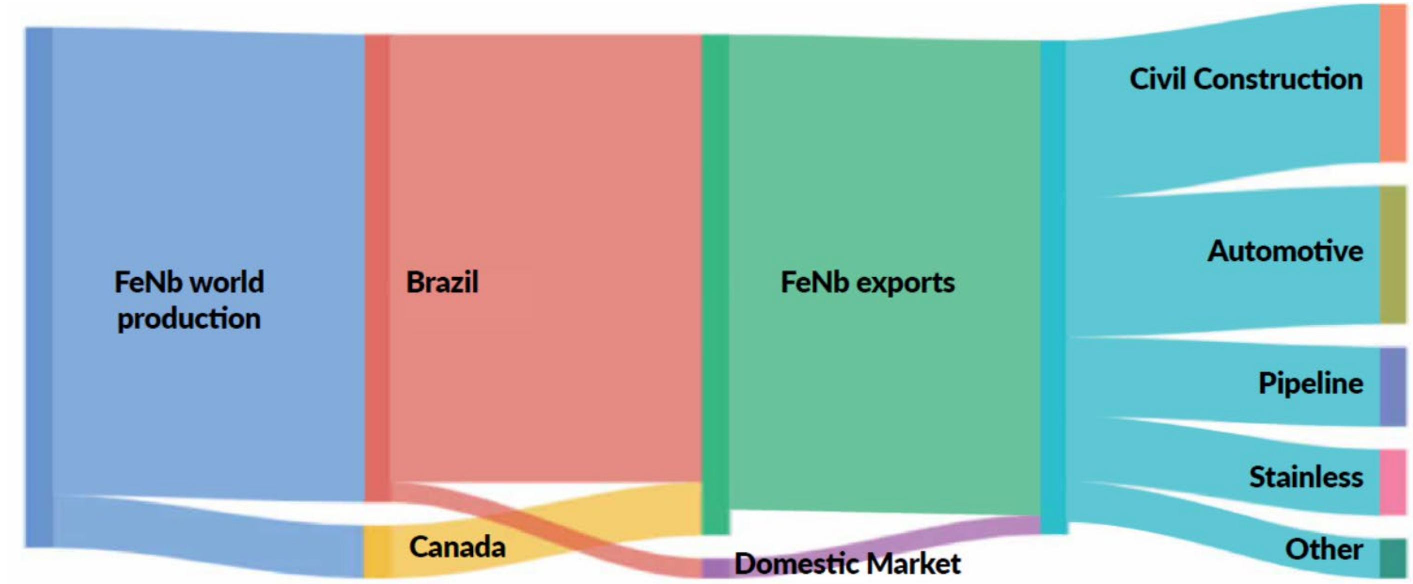
Niobium mines/deposits Brazil

Nb in USA & CAN

There are 48 Nb minerals mines/deposits/occurrences in all continents

Nb is strategic for Brazil that operates the higher Nb content mines

MFA for Ferroniobium and consumption diferences comparing USA and China



Source: Study of critical materials' production chains: opportunities and threats of the circular economy (2020)

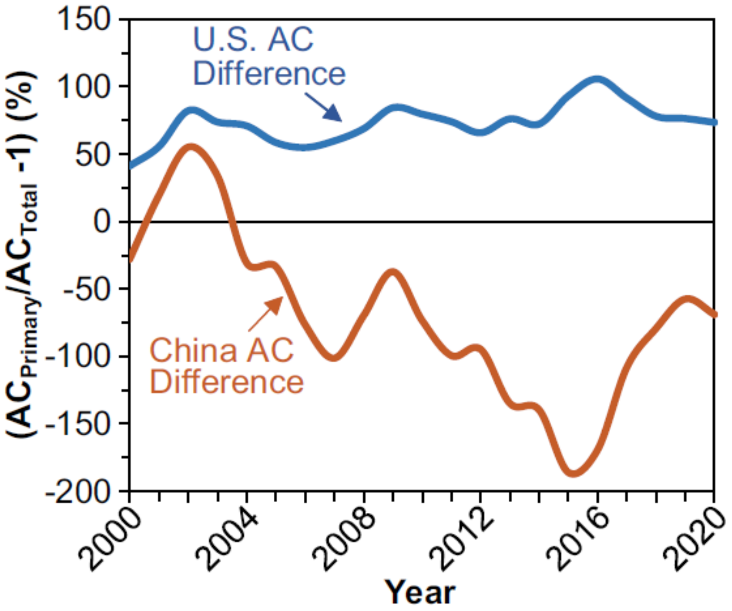


Fig. 3. Comparison of AC_{total} relative to $AC_{primary}$ [as relative rate of change in % = (($AC_{primary}/AC_{total}$) - 1) * 100] showing an increased apparent consumption of niobium for the United States when embedded niobium is included, and a general decreased niobium import reliance for China.

Source: D.McCaffrey et al., Resources, Conservation and Recycling (2023)

Main niobium producing companies

Table 9. Major companies producing niobium in the world (semi-manufactured.

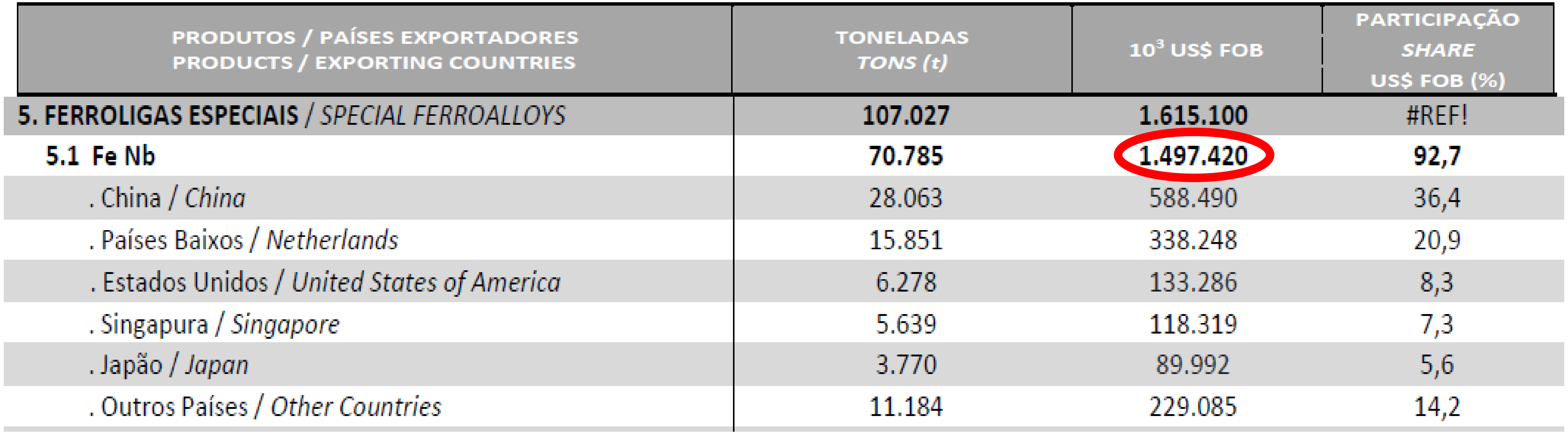
		FeNb production capacity (K t per year)	Prospects
CBMM Companhia Brasileira de Metalurgia e Mineração	Ferroniobium Vacuum Grade FeNb and NiNb Oxides: high purity, optical grade, niobic acid (HY-340) and ammonium niobium oxalate (ANO) Niobium metal: reactor-grade, commercial-grade, RRR superconductor grade, and niobium zirconium	150	CBMM 50% capacity expansion 2021. Is investing 40 million US$ in more than 300 R&D projects.
CMOC International Brasil NIOBRAS	Ferroniobium	9	CMOC Niobras improving Nb recovery from hard rock and from phosphate tailings. It is the 2nd phosphate minerals producer in BRA.
Niobec Nb UNE COMPAGNIE DE MAGRIS RESOURCES	Ferroniobium	?	Producing arounf 8% of the total Nb world output (*USGS, Minerals Yearbook,2023*)
TABOCA	Ferrotantalum & Ferroniobium	?	Larger Sn (tin) and Ta (tantalum) producer in Brazil

Source: Study of critical materials' production chains: opportunities and threats of the circular economy

Why is Niobium strategic for Brazil ?

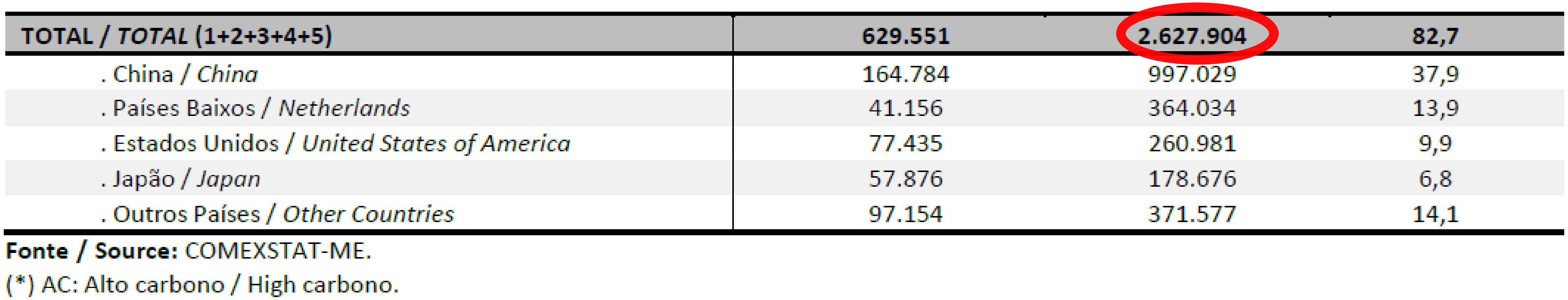
FERRONIOBIUM IS AROUND 60 % OF FERROALLOYS EXPORTS

(Brazillian metallurgical sector yearbook, 2021)



PRODUTOS / PAÍSES EXPORTADORES PRODUCTS / EXPORTING COUNTRIES	TONELADAS *TONS (t)*	10^3 US$ FOB	PARTICIPAÇÃO *SHARE* US$ FOB (%)
5. FERROLIGAS ESPECIAIS / *SPECIAL FERROALLOYS*	**107.027**	**1.615.100**	#REF!
5.1 Fe Nb	**70.785**	**1.497.420**	**92,7**
. China / *China*	28.063	588.490	36,4
. Países Baixos / *Netherlands*	15.851	338.248	20,9
. Estados Unidos / *United States of America*	6.278	133.286	8,3
. Singapura / *Singapore*	5.639	118.319	7,3
. Japão / *Japan*	3.770	89.992	5,6
. Outros Países / *Other Countries*	11.184	229.085	14,2

ALL FERROALLOYS :



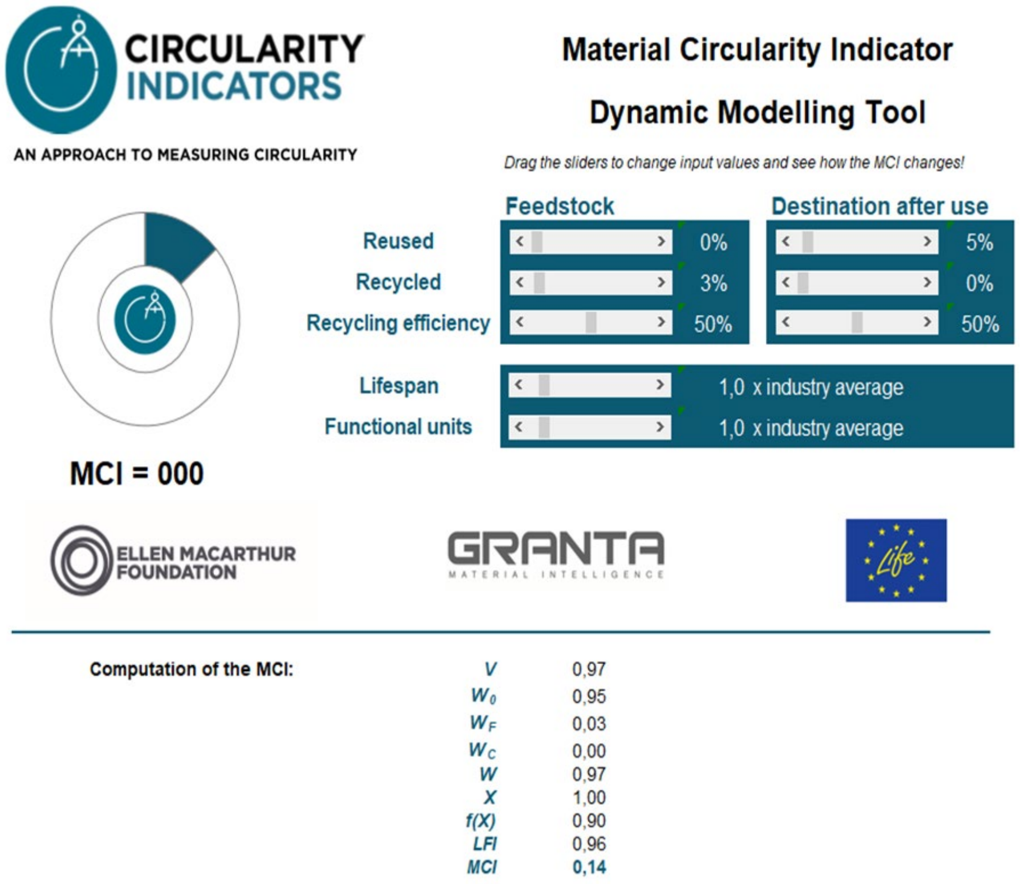
TOTAL / *TOTAL* (1+2+3+4+5)	**629.551**	**2.627.904**	**82,7**
. China / *China*	164.784	997.029	37,9
. Países Baixos / *Netherlands*	41.156	364.034	13,9
. Estados Unidos / *United States of America*	77.435	260.981	9,9
. Japão / *Japan*	57.876	178.676	6,8
. Outros Países / *Other Countries*	97.154	371.577	14,1

Fonte / Source: COMEXSTAT-ME.

(*) AC: Alto carbono / High carbono.

Niobium circularity is low

0.14 for generic Nb and 0.11 for Nb in steels for transportation based on EU mass flow analysis (Deloitte, 2015)



CIRCULARITY INDICATORS

AN APPROACH TO MEASURING CIRCULARITY

Material Circularity Indicator

Dynamic Modelling Tool

Drag the sliders to change input values and see how the MCI changes!

	Feedstock	Destination after use
Reused	0%	5%
Recycled	3%	0%
Recycling efficiency	50%	50%

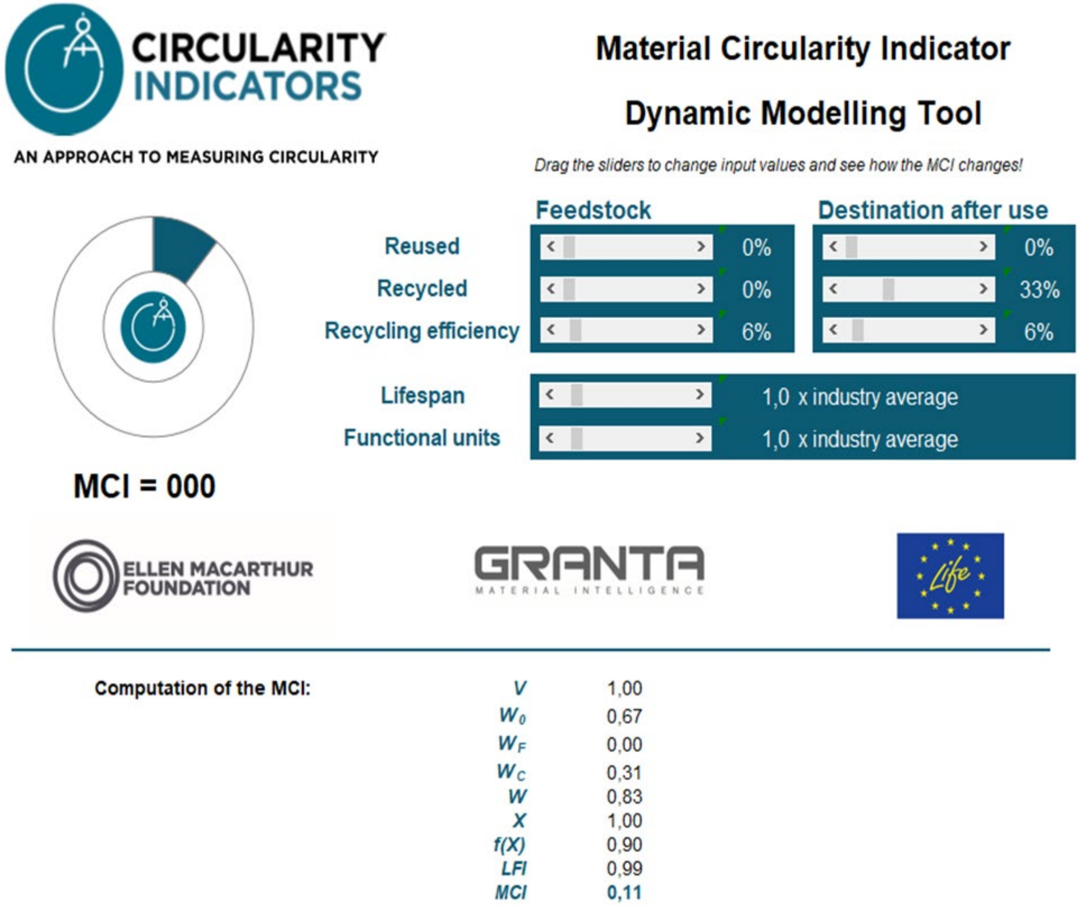
Lifespan: 1,0 x industry average

Functional units: 1,0 x industry average

MCI = 000

Computation of the MCI:

V	0,97
W_0	0,95
W_F	0,03
W_C	0,00
W	0,97
X	1,00
$f(X)$	0,90
LFI	0,96
MCI	**0,14**



CIRCULARITY INDICATORS

AN APPROACH TO MEASURING CIRCULARITY

Material Circularity Indicator

Dynamic Modelling Tool

Drag the sliders to change input values and see how the MCI changes!

	Feedstock	Destination after use
Reused	0%	0%
Recycled	0%	33%
Recycling efficiency	6%	6%

Lifespan: 1,0 x industry average

Functional units: 1,0 x industry average

MCI = 000

Computation of the MCI:

V	1,00
W_0	0,67
W_F	0,00
W_C	0,31
W	0,83
X	1,00
$f(X)$	0,90
LFI	0,99
MCI	**0,11**

Source: Study of critical materials' production chains: opportunities and threats of the circular economy

Evolution of Brazilian policy on strategic minerals

- **2011** National Mining Plan 2030 establishes the objective of Management of Strategic Minerals
- **2012** Creation of working groups and beginning of interministerial articulation
- **2016** Elaboration of the document National Science and Technology Strategy 2016/2020
- **2018** Establishment of the Science, Technology and Innovation Action Plan for Strategic Minerals
- **2020** Mining and Development Program 2020/2023
- **2020** Policy to speed up the environmental licensing of projects for strategic minerals
- **2021** Starting of the Interministerial Committee for the Analysis of Strategic Minerals Projects
- **2021** Definition of the list of Brazilian strategic minerals

Brazillian list of Strategic Minerals

Mineral resources that the country depends on its supply to important economic sectors			
Sulfur	Phosphate	Potassium	Molybdenum
Mineral resources intended for use in high-tech products and processes			
Cobalt	Copper	Tin	Graphite
Platinum group	Lithium	Niobium	Nickel
Silicon	Thallium	Tantalum	Rare Earths
Titanium	Tungsten	Uranium	Vanadium
Mineral resources that the country has competitive advantages and are essential for the economy			
Aluminum	Copper	Iron	Graphite
Gold	Manganese	Niobium	Uranium

Some final news and comments regarding critical minerals and niobium

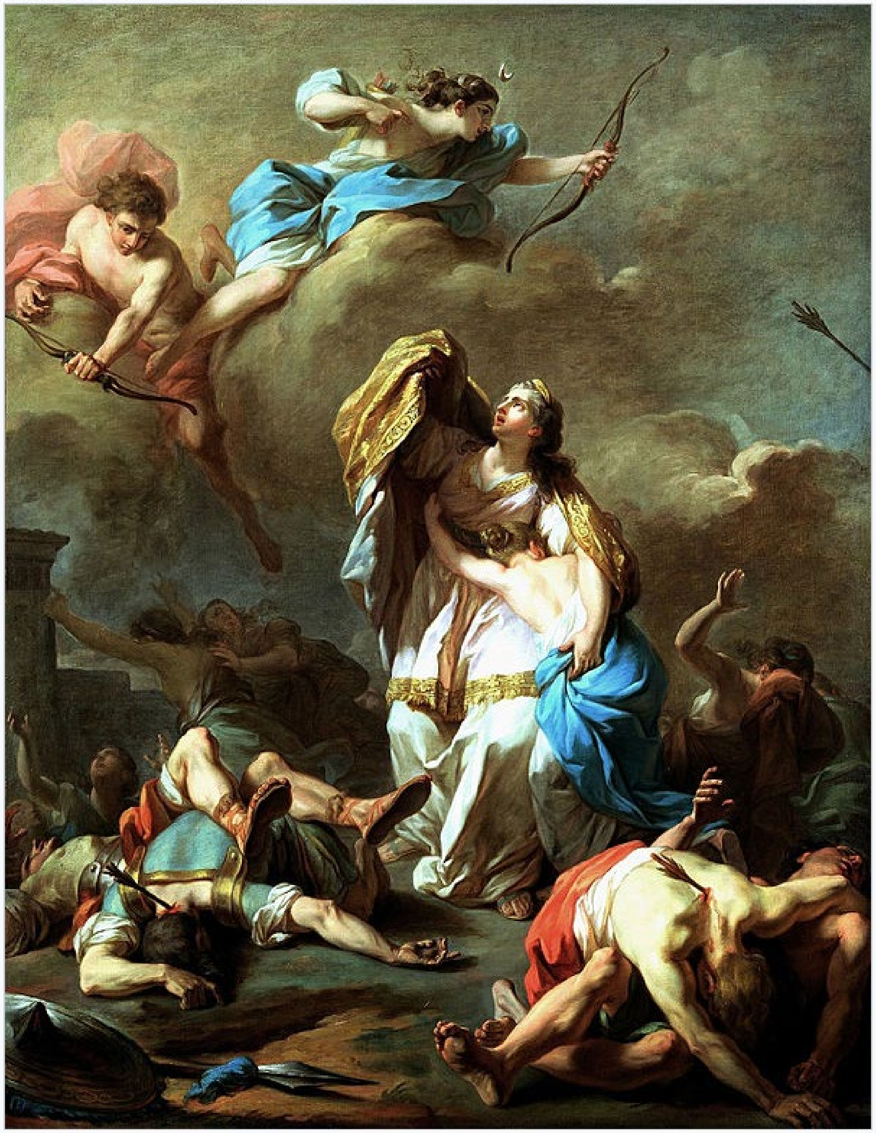
- ✓ Brazilian Ministry for Mines and Energy set an agreement with USGS to elaborate a national critical minerals list.

- ✓ Brazillian new industrial development plan will focus on reindustrialization : new materials and goods local production fostered by abundant renewable energies and raw materials domestic supply,

- ✓ Brazilian Ministry for Science, Technology and Innovations is investing US$ 6,6 million in a new laboratory devoted to graphene and niobium (GRANIOTEC)

- ✓ The upcoming signature of the EU Mercosur free trade agreement will offer much more opportunities for investing in new mining and processing projects in South America.

THANK YOU FOR THE KIND ATTENTION



A Punição da Arrogante Níobe por Diana e Apolo, por Pierre-Charles Jombert, École nationale supérieure des Beaux-Arts, 1772

Source: Wikipedia

Geography of Control? A Deep Dive Assessment on Criticality and Critical Materials Supply Chain

Lille, 16th February - IRTC Conference 2023

The opinions and views that follow are only **personal**.

ACADEMIC BACKGROUND

Executive Course in Strategic Affairs
LUISS School of Government
MA in Sustainable Development, Geopolitics of Resources and Arctic Studies
Italian Society for International Organization (SIOI)
PhD Summer School in Critical Raw Materials
EIT Raw Materials & Politecnico di Milano
Course in Risk Management (Energy & Metals) - *ongoing*
Politecnico di Milano - School of Management

CURRENT POSITIONS

Editorial Research Assistant at Fondazione Eni Enrico Mattei (FEEM)
Independent Analyst for Italian think tanks and journals

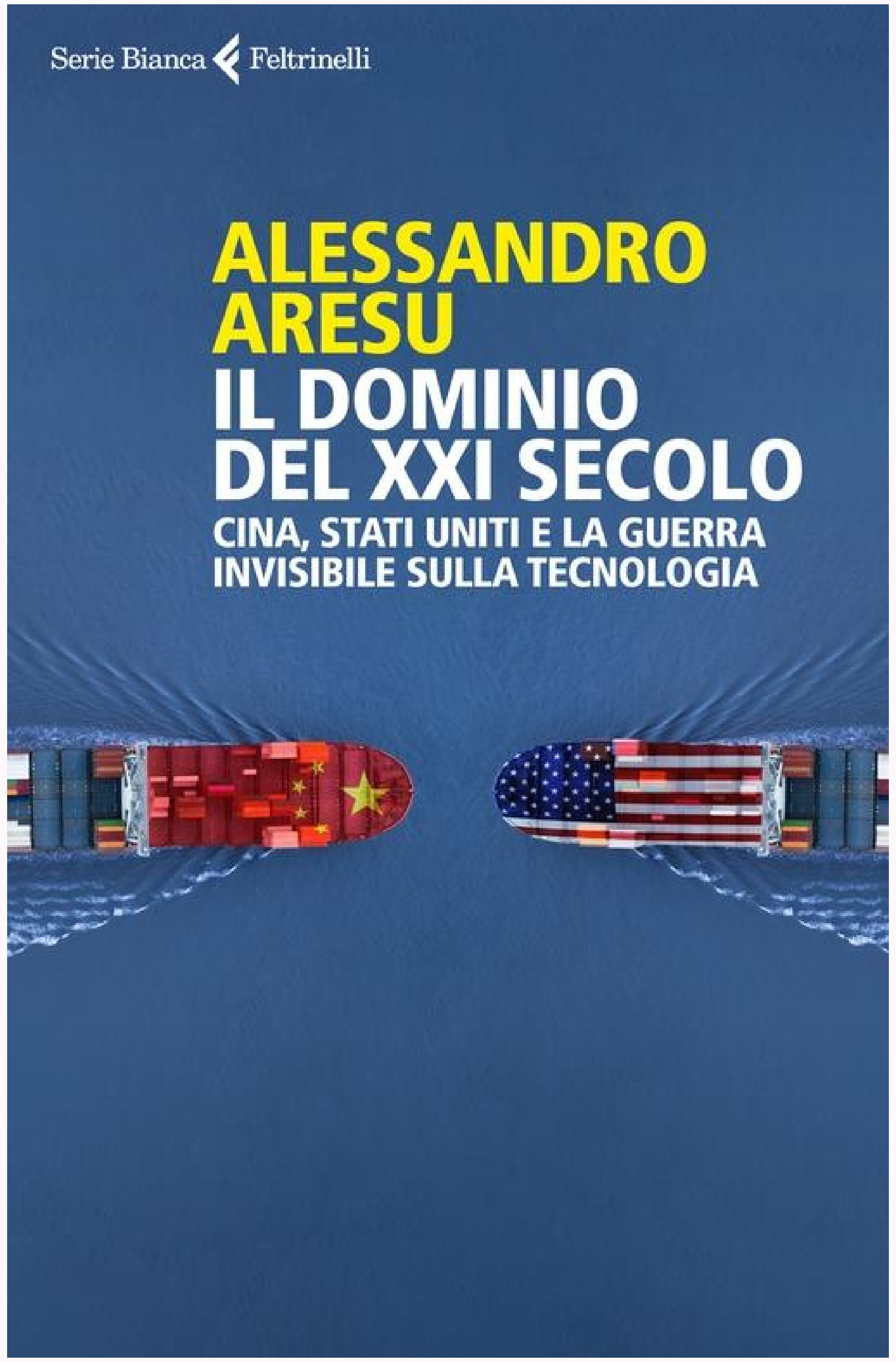
Introduction

1. **Methodology & Data**
2. **Case study: lithium**

Concluding remarks

Disclaimer: this study is currently an independent and not yet final assessment (*working paper* out in spring 2023)

- The new global context may require new or newly applied **indicators** for Criticality Assessment Methodology.
- The energy transition (as well as digitalization) highlight that CRMs are and will be increasingly economically important (DERA, 2021), but we need to better assess their **geopolitical weight**.
- The US-China tech competition show us that **interdependence** is perceived as a risk as much as opportunity to strike back (e.g. semiconductors/rare earths).
- If interdependence can be **weaponized** in the context of highly globalized networks, should criticality assessment be expanded on **supply chains**? How?



Serie Bianca Feltrinelli

ALESSANDRO ARESU

IL DOMINIO DEL XXI SECOLO

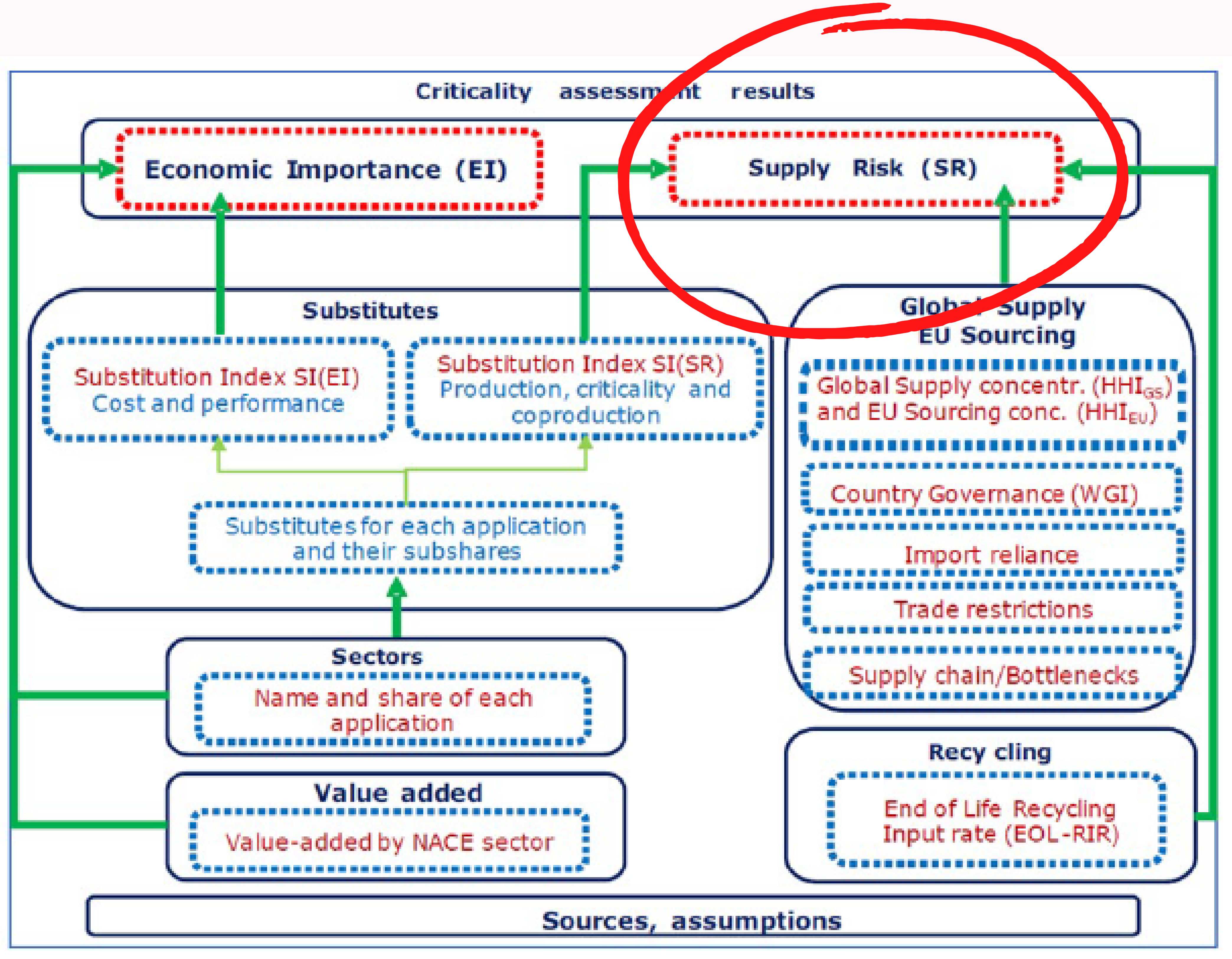
CINA, STATI UNITI E LA GUERRA INVISIBILE SULLA TECNOLOGIA

> *...a* ***deeper supply chain*** *than what we see on the surface...*

Alessandro Aresu in conversation with Paolo Cerruti
Northvolt COO & co-founder

My purpose: Looking for the *deep supply chain*...

My research question: How do we measure or track this "depth" in the context of criticality assessment methodology?



Source: European Commission, 2020

My assumption: "*Geography of extraction is not geography of production nor geography of control...*"

Why?

① "*...because "control" is not a linear continuous function of the percentage of extraction or production shares held*"

Leruth L., et. al., (2022) → **Source of Control (SOC)**

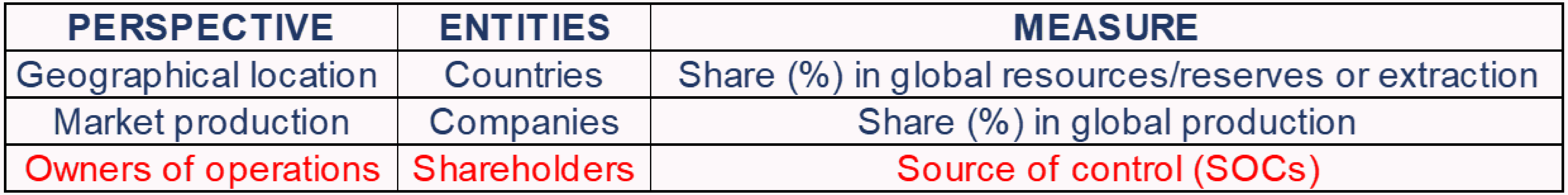
Source of Control (SOC)*

*"[...] it measures the ability of a **direct or indirect shareholder** to change the outcome of a vote by forming potential voting coalitions with other shareholders. It allows for the computation of a single index **measuring the level of control** that the shareholder could exercise over a company. [...] It discriminates between financial links that are associated only with portfolio investments and those that can translate into significant control. It also addresses the top weaknesses of the indices traditionally used by researchers to measure **concentration** (such as the **Herfindahl indices**, which sum squared proportions of shares held by shareholders). Those weaknesses include the (incorrect but widely held) notion that diluting the capital of a company necessarily reduces the level of control held by the top shareholder."*

*SOCs are assessed through data processed using **ZENO-Indices**, a proprietary software.

Why it is important?

It adds a potential ***indicator*** to assess *who* control production regardless *where* the extraction occur.



	PERSPECTIVE	ENTITIES	MEASURE
X	Geographical location	Countries	Share (%) in global resources/reserves or extraction
Y	Market production	Companies	Share (%) in global production
Z	Owners of operations	Shareholders	Source of control (SOCs)

SOCs are, thus, a **vertical assessment of control** (from shareholders to operating companies)...

Why it is insightful?

It stress that countries of **incorporation** of CRMs mining operations are not necessarily the countries *where* extraction geographically occur. This observation lead to revaluate the widespread notion that criticality is linked to a sort of “geological determinism”, that implies control as a function of fixed extraction.

In terms of **quantitative analysis**, this is a significant contribution to the degree of “production concentration” as traditionally assessed because it allows to de-territorialize HHI indicators while considering private held companies or SOEs (here referred *corporate entities*), not countries, the variables in the geography of extraction.

But there is a problem, a missing link...

Leruth L., et. al., (2022) *"Green Energy Depends on Critical Minerals: Who Control the* ***Supply Chains****?"*

My assumption: "*Geography of extraction is not geography of production nor geography of control...*"

Why?

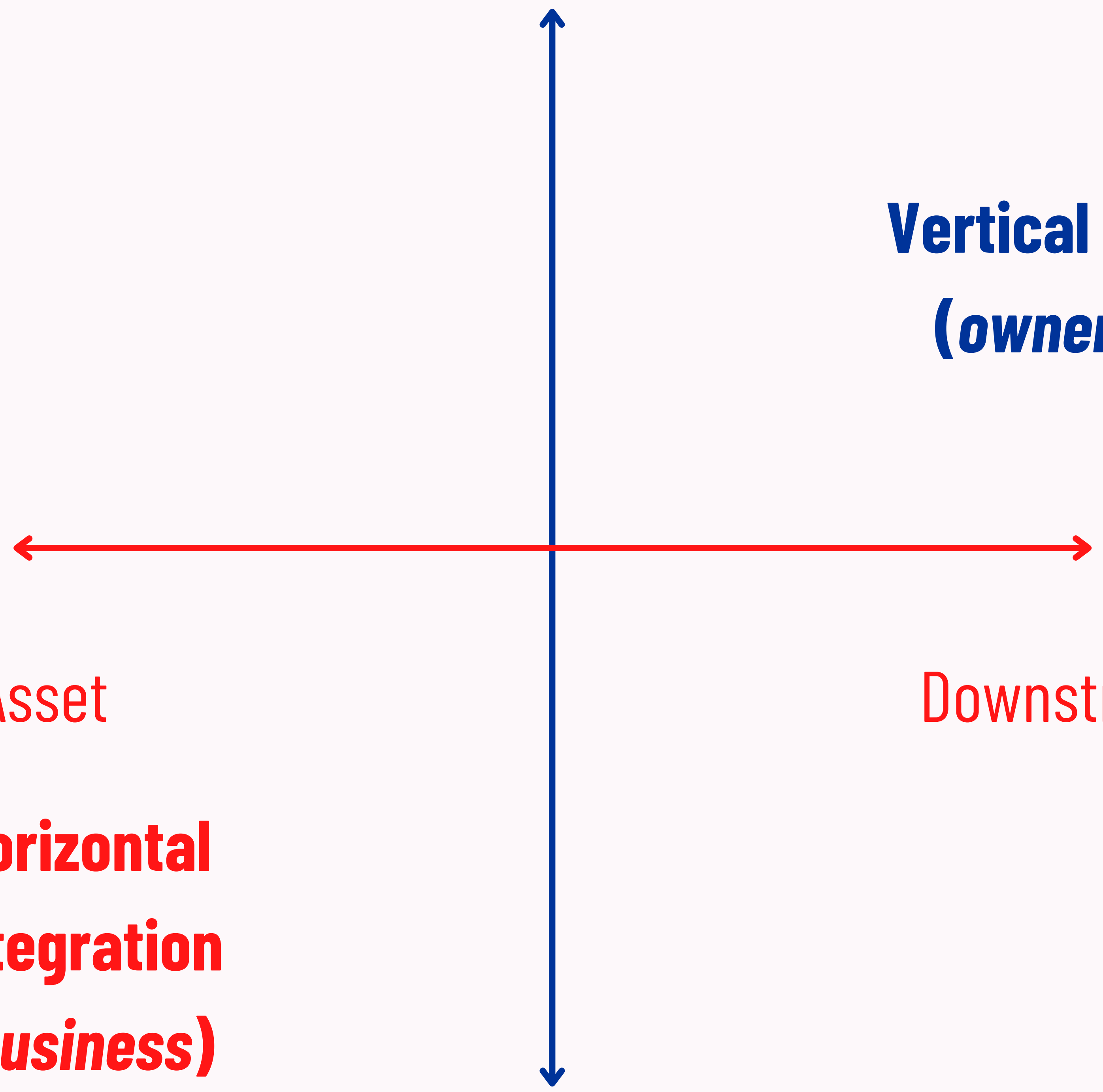
②

Because owners of operating companies are not only empowered by controlling mining assets. Their controlling shares are a premium if they can leverage them in terms of ***supply chain control***.

In terms of **qualitative analysis**, this refers to a ***horizontal assessment of control*** (from upstream to mid- and downstream) that is essential to understand current and future developments in the critical raw materials industry. Therefore, the obvious question is therefore: can we measure the company's degree of supply chain control? A potential indicator could be the level of **business integration** between mining and refining/processing activities.

We can say that owning mining assets (SOCs) is the **necessary but not sufficient condition** in the framework of this study. What is needed and missing is a long-term orientation toward supply chain dynamics.

FRAMEWORK: Deep Supply Chain Assessment



SOC X
(*shareholder*)

Vertical Control
(*ownership*)

Mining Asset

Downstream Tiers

Horizontal integration
(*business*)

Operating Company

Two preliminary and roughly assessment on *ownership** and *supply chain control*.

Quantative data

1. Extraction output (metric tonnes**)
2. Refining output (metric tonnes**)

Source: Company Reports, USGS, Wood Mackenzie (2021)

Qualitative data

1. Ownership
2. Offtake agreements

Source: Company Reports, Dow Jones (2021)

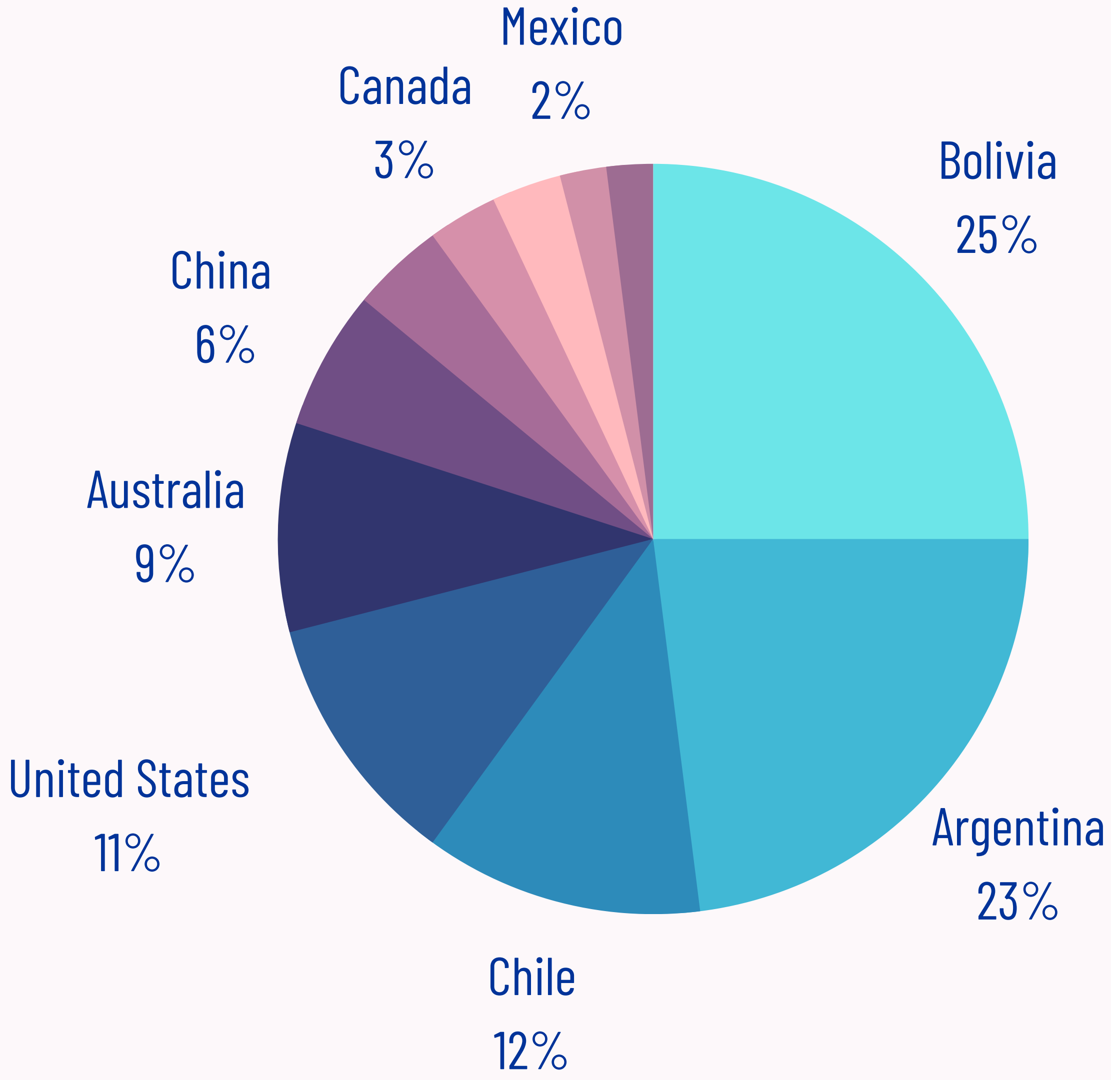
* No access to ZENO Indices (proprietary)

** If not otherwise specified

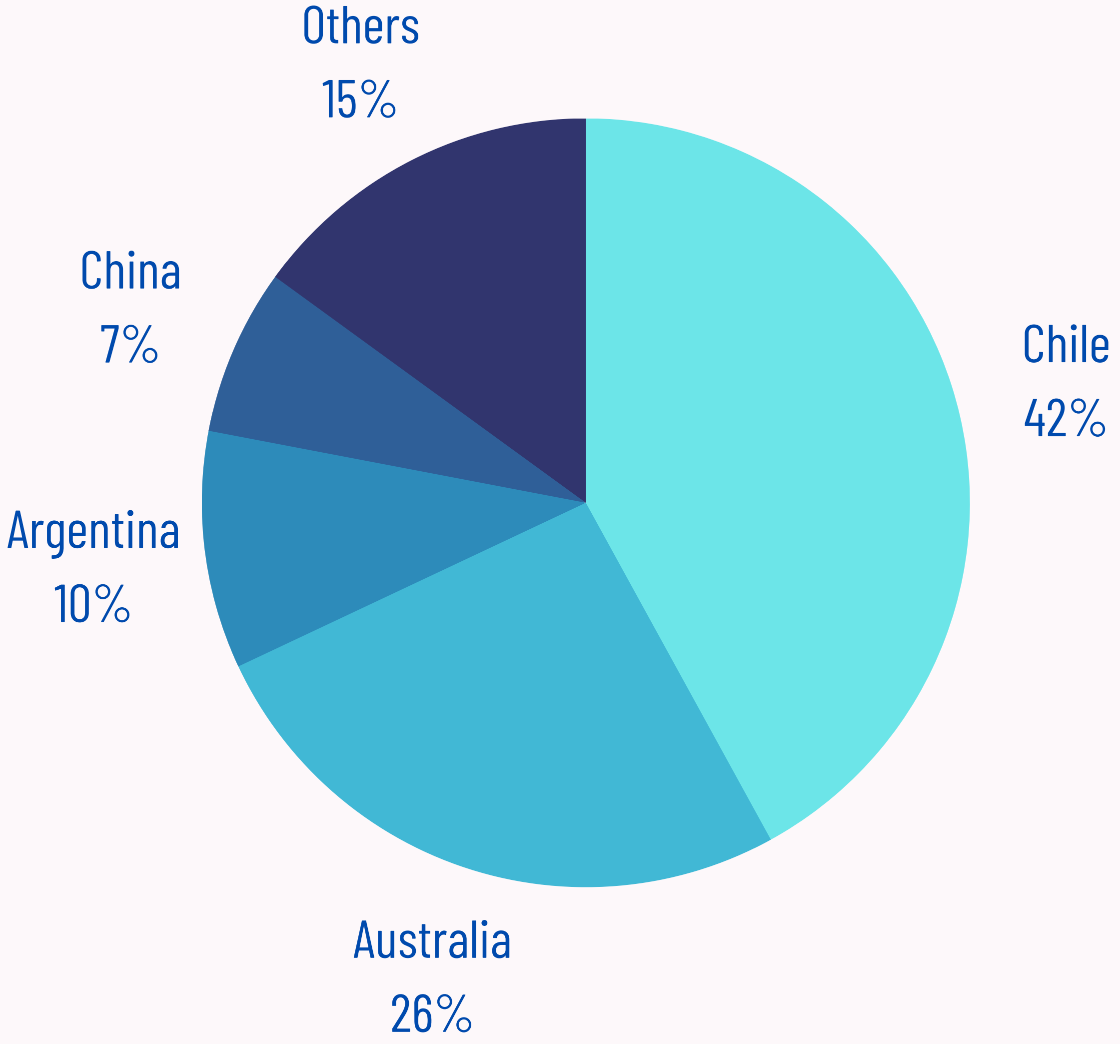
Lithium

Perspective X

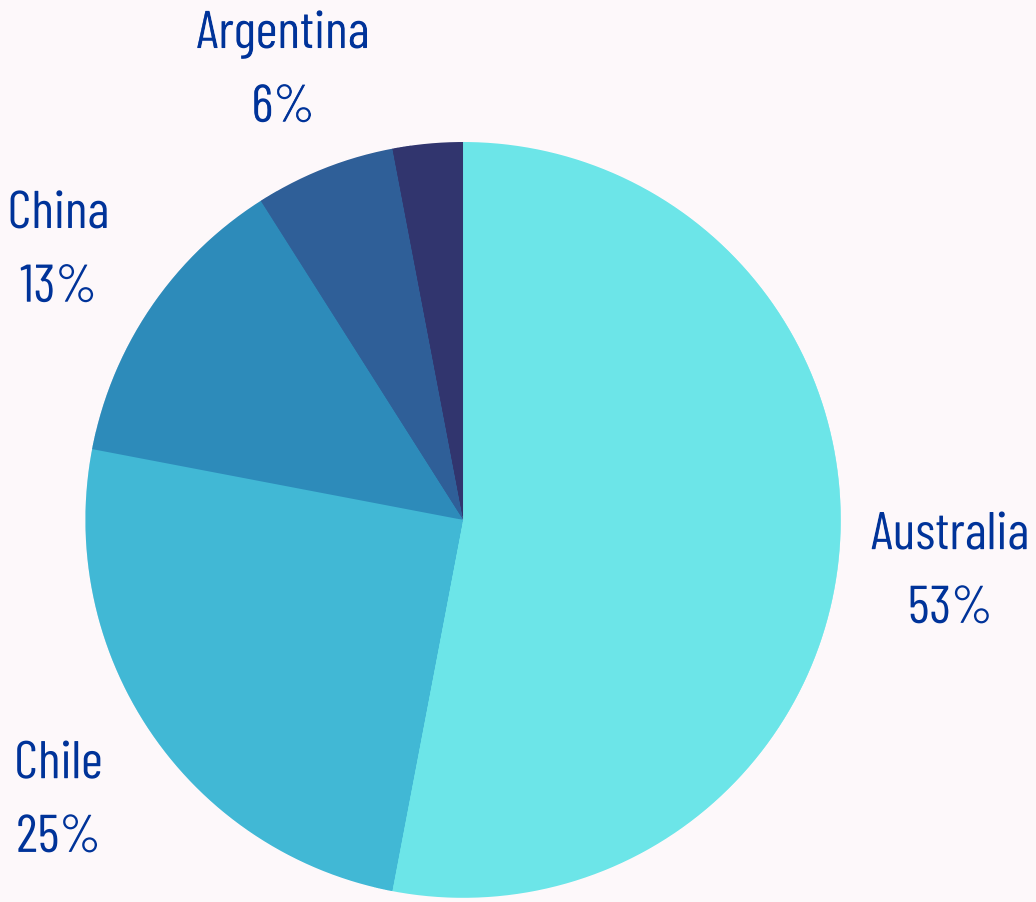
Resources



Reserves



Extraction

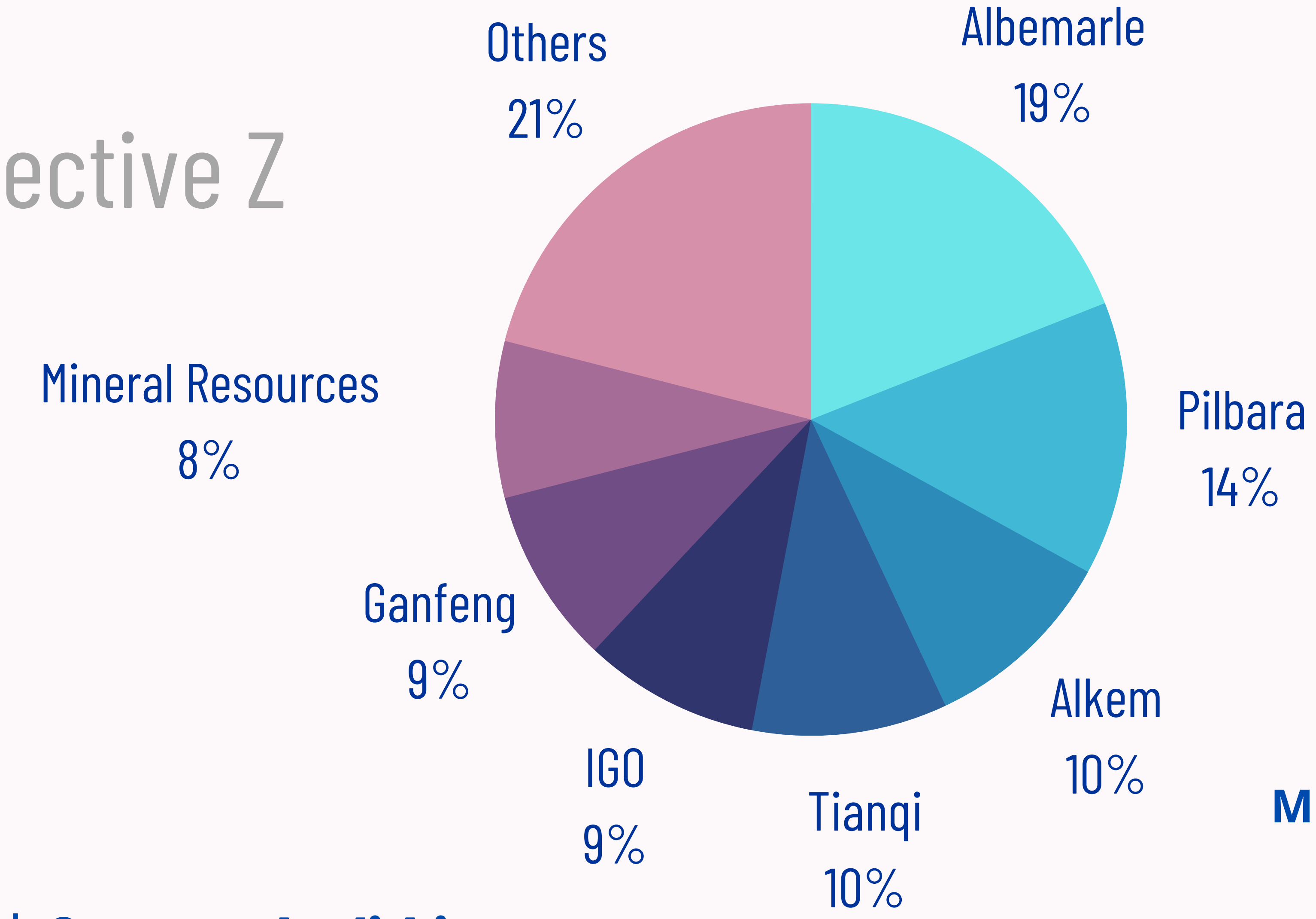


Total Australia's Operating Companies	55.000	100%
Total Australia Incorporated Companies with China's Stakes in the Projects	**37.950**	**69%**

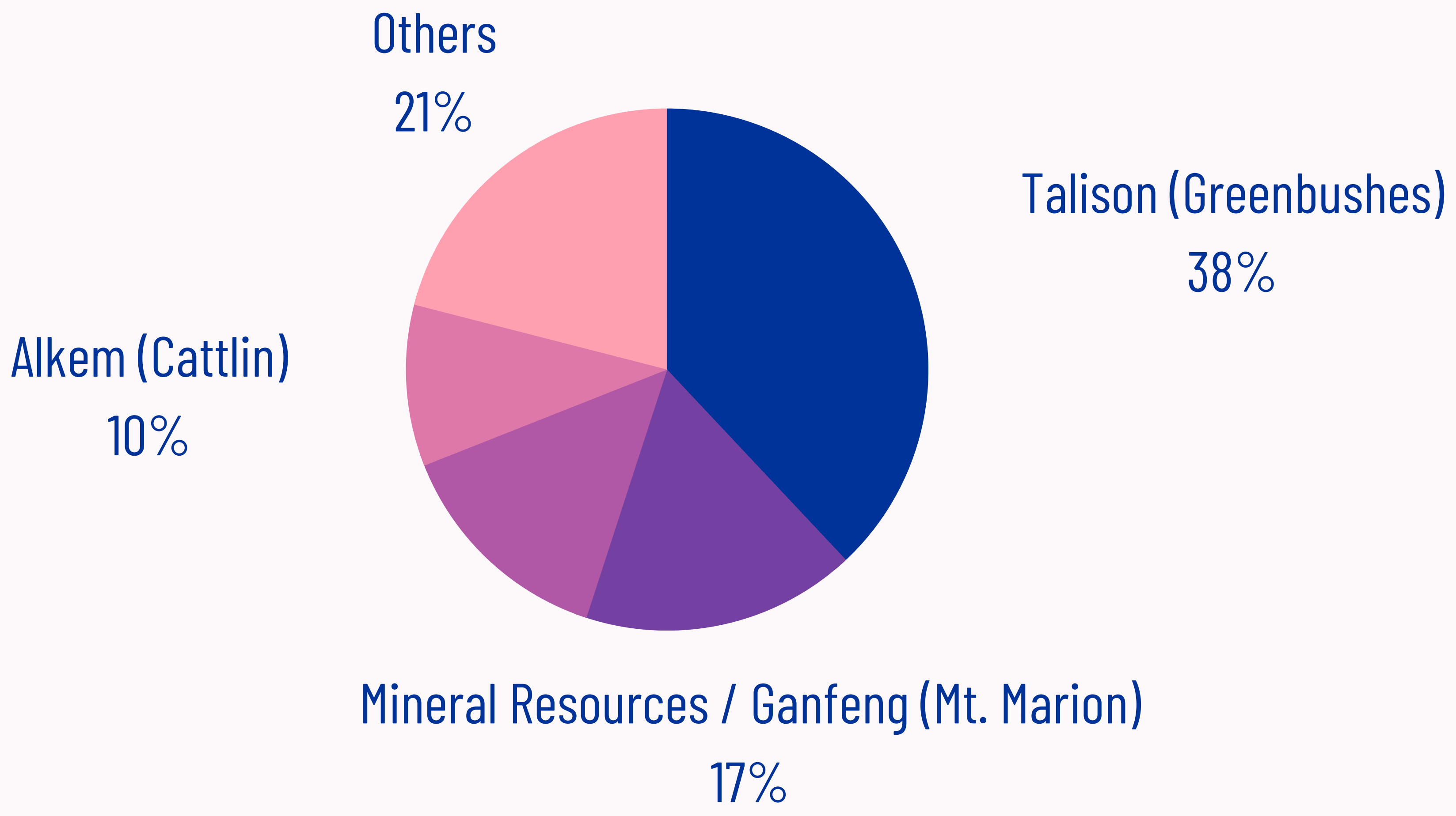
Total Chile's Operating Companies	28.287	100%
Total Chile's Incorporated Companies	**20.387**	**72%**

Total Argentina's Operating Companies	**5.970**	100%
Total Argentina's Incorporated Companies	0	0

Perspective Z



Mined lithium output market share by mine operator (2021)



Perspective Y

Mined lithium output market share by corporate control (2021)

GANFENG LITHIUM CO. OVERSEAS INVESTMENTS

PROJECT	TYPE	ACQUISITION YEAR	EQUITY OWNERSHIP	COUNTRY	AGREEMENT	LITHIUM RESOURCES (million tonnes, LCE)	COUNTRY SHARE*	GLOBAL SHARE*
Avalonia	Spodumene	2012	55% in the JV	Ireland	N/A	*Exploration*	n.c	USGS (2022)
Mariana	Brine	2014	86.25%	Argentina	Offtake of the lithium products based on proportion of equity interests in the project	8,12	8.1%	
Mt. Marion	Spodumene	2015	50%	Australia	Offtake of 49% of total lithium concentrate product (own consumption), while the rest (51%) processed and marketed by Ganfeng (selling to customers)	2,42	6.2%	
Pilgangoora	Spodumene	2017	6.9% in Pilbara	Australia	No more than 160kt of 6% lithium concentrate per annum from PP1; no more than 150kt from PP2 after completion	8,71	22.4%	
Cauchari Olaroz	Brine	2017	51% in the project and 16.7% in Lithium Americas	Argentina	Offtake rights to 76% of the lithium products from PP1 (40kt LCE)	24,58	24.3%	
Sonora	Lithium clay	2019	50% in the project and 25.8% in Bacanora	Mexico	Offtake of 50% lithium products in the PP1 and entitlement to increase the offtaking rights to 75% in the PP2	8,82	97.4%	
Goulamina	Spodumene	*in progress*	50% in the project	Mali	50% output offtaken by Ganfeng with option to increase ratio to 100%	3,89	100%	
				TOTAL		**56,54**		**~12%****

Source: Ganfeng Lithium, own research

*Data on resources refer to 2021, collected from USGS (2022) and roughly converted in lithium carbonate equivalent (LCE)

**This data is an estimated control of potential lithium resources. Whether these projects will become commercial viable while contributing to Ganfeng feedstocks it remain to be seen.

Concluding remarks

1. **How to include SOCs in the criticality assessment** through the SR Index (production concetration)?
2. **How to assess *supply chain control*?** A tentative integration of WGI, Import Dependence and trade restrictions indicators?

Proposal: using the *IEN Framework* tailored for raw materials criticality assessment

Ding, J., Dafoe, A., "The Logic of Strategic Assets: From Oil to AI", Security Studies, Vol. 30, No. 2 (2021), pp. 182-212

Thank you for your attention!

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Twitter - @aprinacerai

Lille, 16th February - IRTC Conference 2023

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ENGIE

Research & Innovation

Carbon neutral energy transition: "From Emissions to Resources"

Jan Mertens, Fanny Maigne, Olivier Sala, Peter Verwee, Luc Goossens and Elodie Lecadre

IRTC 2023 – Raw Materials for a Sustainable Future

15-17 February 2023 – Lille, France

Jan Mertens

Chief Science Officer @ ENGIE R&I

Visiting Professor @Ugent

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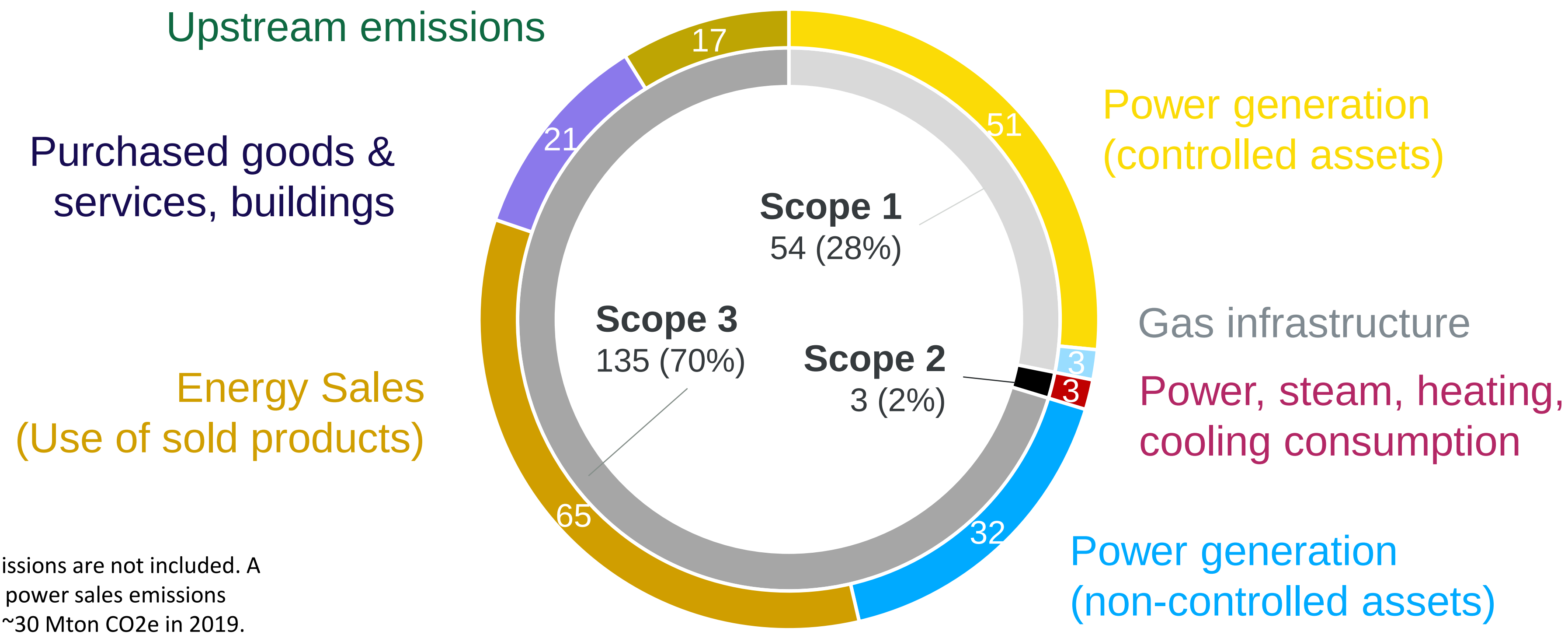
ENGIE &
ENGIE Research

LEADING THE ENERGY TRANSITION

ENGIE's ambition covers all 3 scopes, including direct emissions as well as all indirect emissions

ENGIE carbon footprint in 2019 (*)
192 Mton CO_{2eq}



(*) power sales emissions are not included. A first assessment of power sales emissions estimates these at ~30 Mton CO2e in 2019.

Proposed net zero ambition by 2045 covers all scopes including procurement and upstream emissions, but intermediate targets are limited to energy generation and sales, the two most important sources of emission

Pilot projects with academic, industrial and government partners are important to co-develop, test and demonstrate new solutions

Pilots are key for ENGIE and a large part of the research budget

Biomass gasification Gaya

+ =

gaya

France

Battery Storage

Belgium

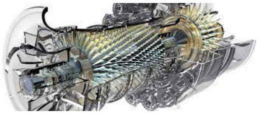
Bifacial Solar testing

Chile

Decentralized Energy System for Islands

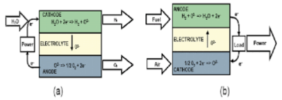
Singapore

H_2 co-combustion in gas turbine



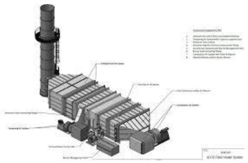
Belgium

High temperature SOEC/SOFC



France

Supercritical CO_2 cycle



US

Solar-H_2 panels

France

OPV for Buildings Heliatek

Heliatek

HeliaFilm®

Global

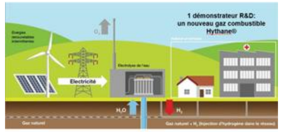
Floating Wind turbine

Portugal

High Altitude Airborne Wind

Germany

H_2 injection in natural gas grid



France

Power to methane

France

Solar cooling

France

2

From ‘emissions’ to ‘resources’

The energy transition will imply a booming need for critical raw materials: from emissions to resources

- Today’s dependance on fossil fuel will switch towards **dependance on minerals used in clean technologies.**

Technology demand trend :

167 GW
EU 2020
x 6 →
1,043 GW
EU 2050

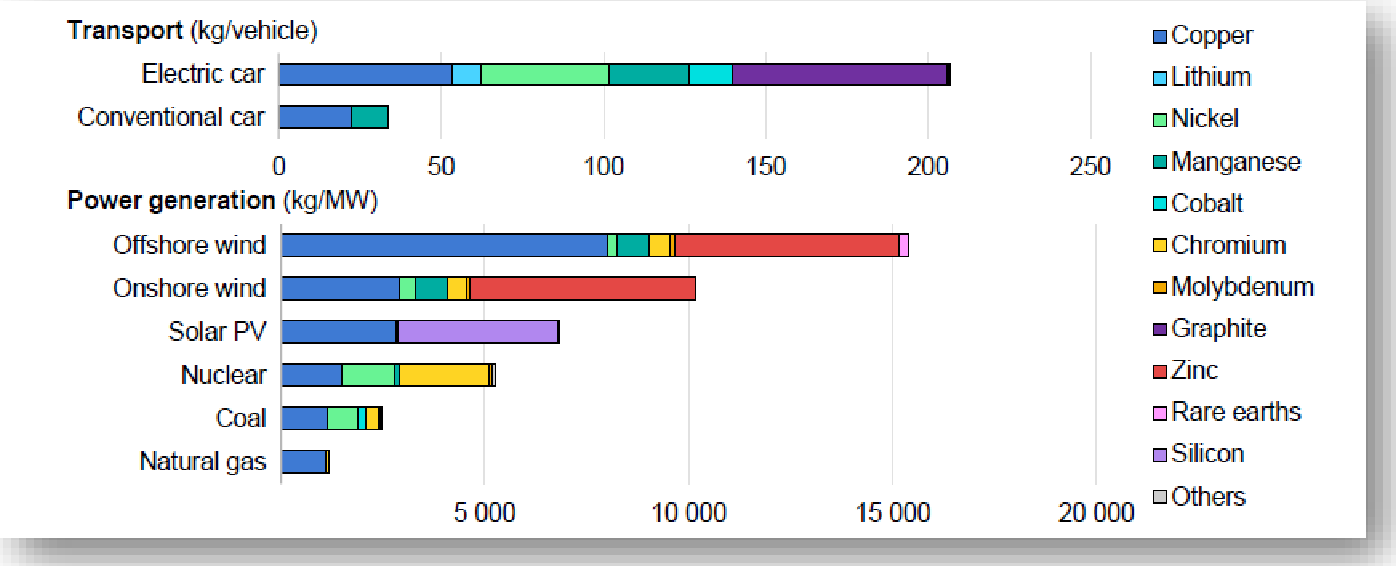
217 GW
EU 2020
x 6 →
1,210 GW
EU 2050
x 4 onshore
x 16 offshore

19 GWh
EU 2020
x 37 →
700 GWh
EU 2050

H_2

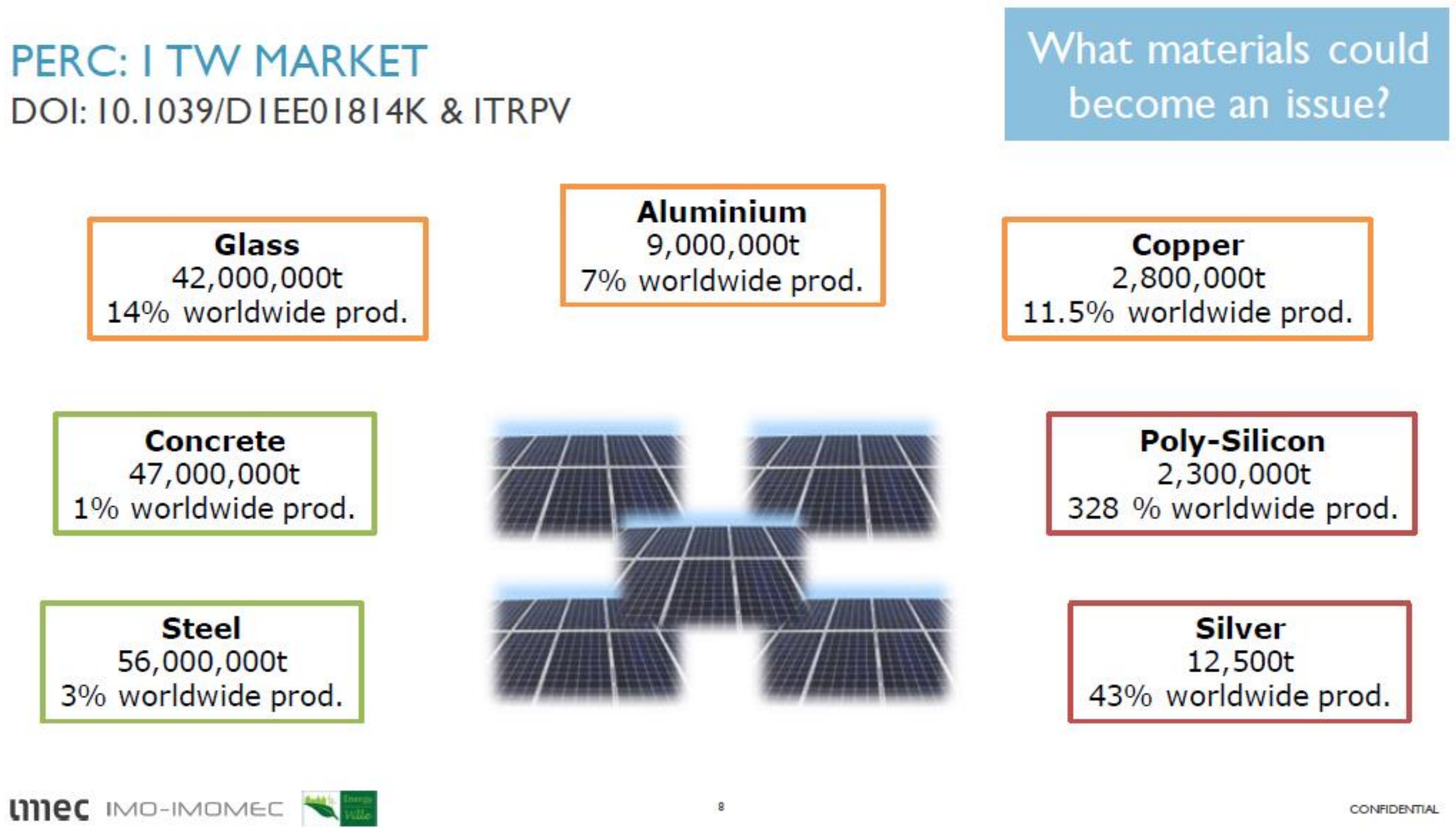
~0 GW
EU 2020
→
1,400 GW
EU 2050

Mineral intensity of selected clean and fossil energy technologies



Source : IEA, Securing Clean Energy Technology Supply Chains, 2022.
KU Leuven, Metals for Clean Energy, 2022.

Example: Amount of material needed for the expected 2030 TW_p yearly PV market will impact the worldwide production of many materials:



PERC: 1 TW MARKET

DOI: 10.1039/D1EE01814K & ITRPV

What materials could become an issue?

Glass
42,000,000t
14% worldwide prod.

Aluminium
9,000,000t
7% worldwide prod.

Copper
2,800,000t
11.5% worldwide prod.

Concrete
47,000,000t
1% worldwide prod.

Poly-Silicon
2,300,000t
328 % worldwide prod.

Steel
56,000,000t
3% worldwide prod.

Silver
12,500t
43% worldwide prod.

imec IMO-IMOMEC

8

CONFIDENTIAL

- PV reached the 1 TerraWatt peak cumulative installation in 2022! This is expected to increase to 1 TWp **yearly** installation by 2030.

- Although **Silver** is not considered a critical material by the EU it could be crucial for the PV supply chain since very important for the cost of manufacturing PV!

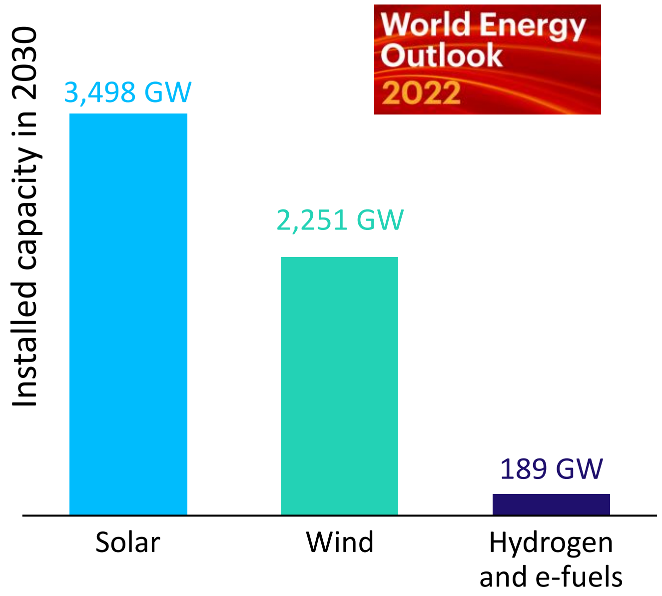
Engie's ambitions on solar, PV and hydrogen are very significant in a highly fragmented market: critical materials are an important topic of concern

2022

ENGIE has 100.3 GW installed power production capacity, all technos included (**1.2%** of world's total)

2030

IEA Announced Pledges Scenario - 2030



ENGIE

27 GW installed by **2030***

53 GW installed by **2030** (50% onshore, 50% offshore)*

H_2 **4 GW** of renewable hydrogen production capacity by **2030**

ENGIE's 2030 global market share
(vs IEA Announced Pledges Scenario)

0.8 %

2.4 %

H_2 **2.1 %**

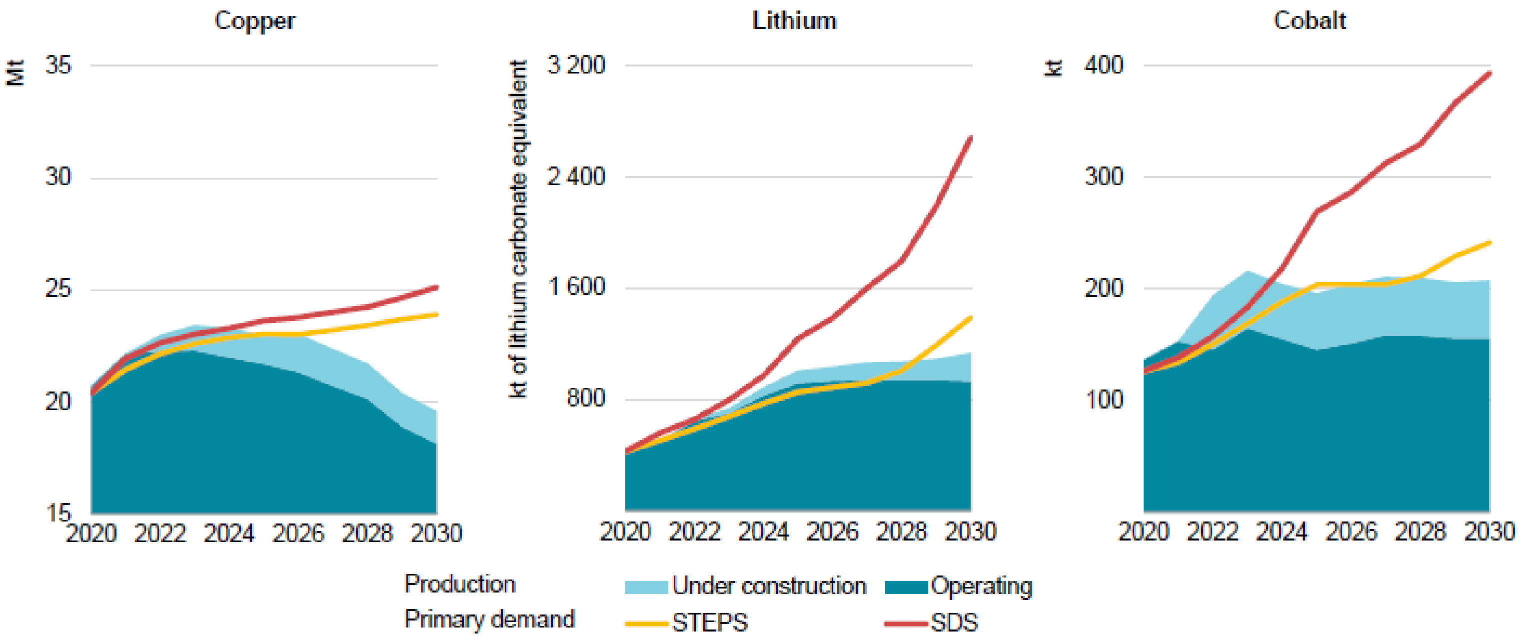
- Working assumptions

Source : IEA, World Energy Outlook 2022

IEA, 2021 alerts on a mismatch between the need of critical minerals to meet our climate ambitions and the predicted supply of some important critical metals

Meeting primary demand in the SDS requires strong growth in investment to bring forward new supply sources over the next decade

Committed mine production and primary demand for selected minerals



IEA. All rights reserved.

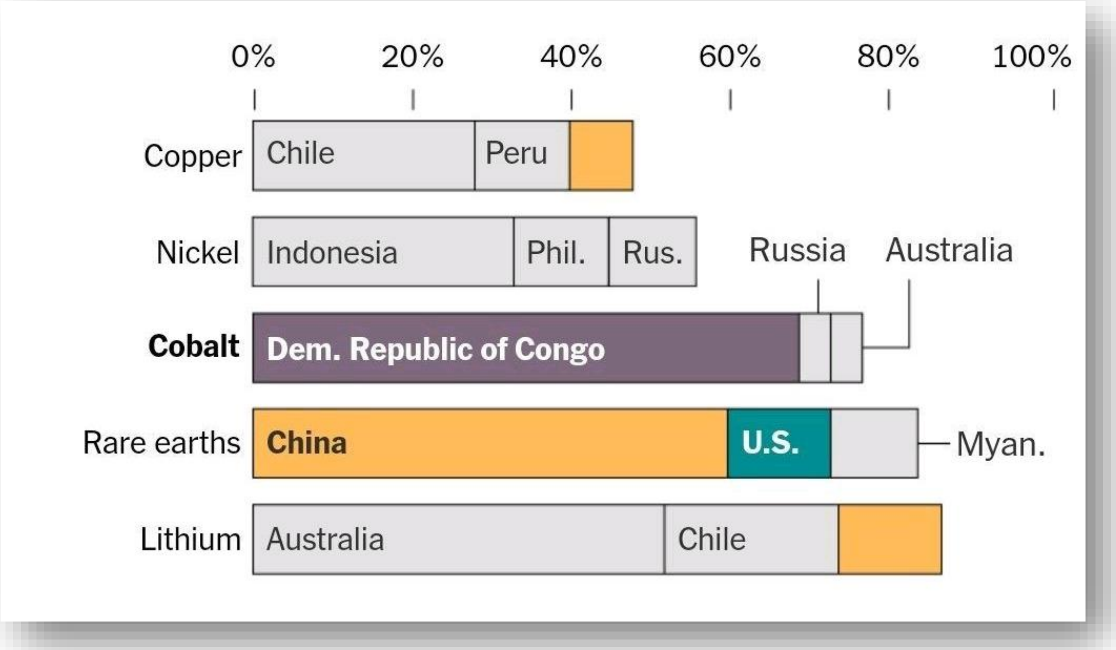
Notes: Primary demand is total demand net of recycled volume (also called primary supply requirements). Projected production profiles are sourced from the S&P Global Market Intelligence database with adjustments to unspecified volumes. Operating projects include the expansion of existing mines. Under-construction projects include those for which the development stage is indicated as commissioning, construction planned, construction started or preproduction. Mt = million tonnes.

Source: IEA analysis based on S&P Global (2021).

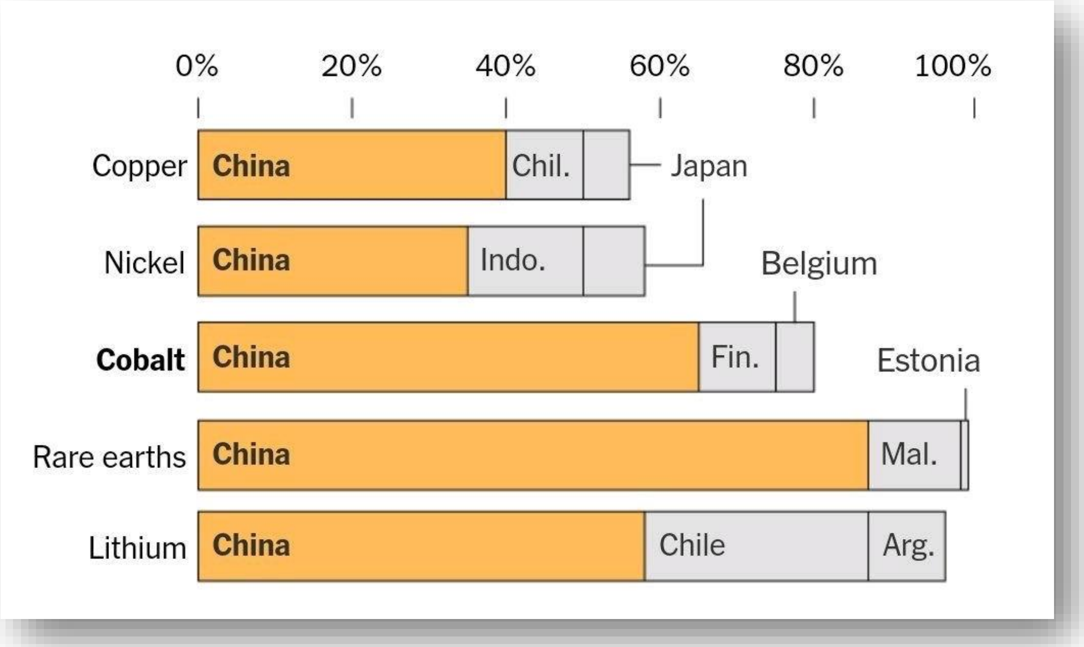
IEA, WEO special report, 2021. The Role of Critical Minerals in Clean Energy Transitions.

On top of the criticality, environmental and social impact of the raw materials themselves, the dependence on few countries in which the processing is located is even higher!

Clean energy metals mining location



Clean energy metals processing location



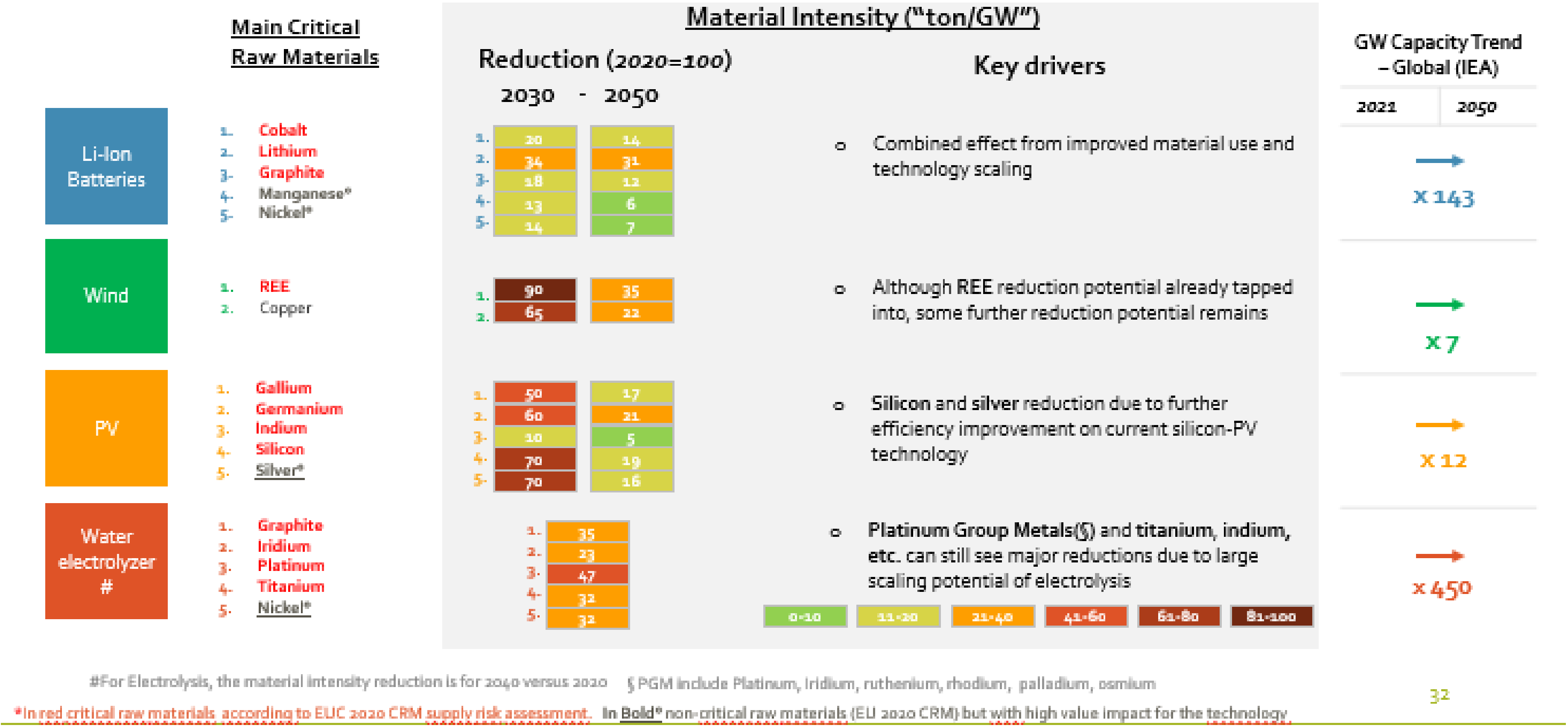
Source : IEA, Securing Clean Energy Technology Supply Chains, 2022

Now what can we do?

Material supply chain

1. Increase material efficiency

Do the same with less material



	Main Critical Raw Materials	Material Intensity ("ton/GW") Reduction (2020=100) 2030	2050	Key drivers	GW Capacity Trend – Global (IEA) 2021 → 2050
Li-Ion Batteries	1. Cobalt 2. Lithium 3. Graphite 4. Manganese* 5. Nickel*	20 34 18 13 14	14 31 12 6 7	○ Combined effect from improved material use and technology scaling	x 143
Wind	1. REE 2. Copper	90 65	35 22	○ Although REE reduction potential already tapped into, some further reduction potential remains	x 7
PV	1. Gallium 2. Germanium 3. Indium 4. Silicon 5. **Silver***	50 60 10 70 70	17 21 5 19 16	○ Silicon and silver reduction due to further efficiency improvement on current silicon-PV technology	x 12
Water electrolyzer #	1. Graphite 2. Iridium 3. Platinum 4. Titanium 5. **Nickel***		35 23 47 32 32	○ Platinum Group Metals(§) and titanium, indium, etc. can still see major reductions due to large scaling potential of electrolysis	x 450

🟩 0-10 🟨 11-20 🟧 21-40 🟥 41-60 🟫 61-80 🟫 81-100

#For Electrolysis, the material intensity reduction is for 2040 versus 2020 § PGM include Platinum, Iridium, ruthenium, rhodium, palladium, osmium

*In red critical raw materials according to EUC 2020 CRM supply risk assessment. In **Bold*** non-critical raw materials (EU 2020 CRM) but with high value impact for the technology

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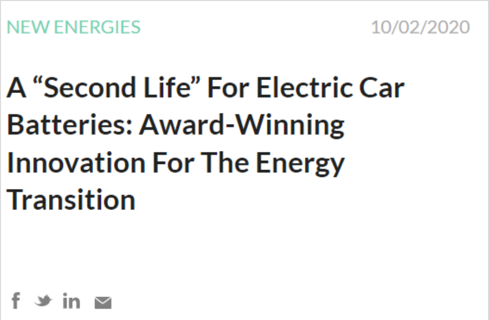
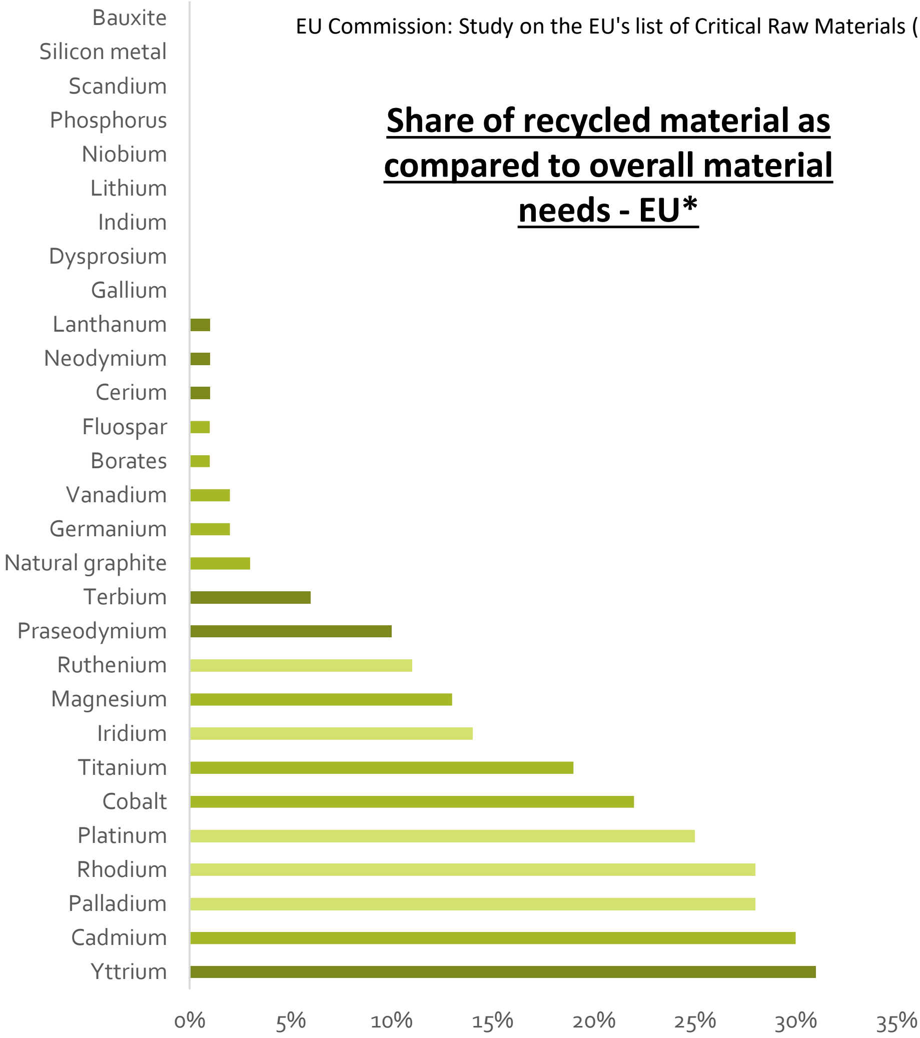
Sources : EUC, Critical raw materials for strategic technologies and sectors in the EU, 2020.
IEA, The role of critical minerals in clean energy transitions, 2021
"DERA, Mineralische Rohstoffe für die Wasserelektrolyse, 2022

Now what can we do?

Material supply chain	
1. Increase material efficiency	**2. Re-use and Recycle**
Do the same with less material	Second life where possible or else recycle
	 NEW ENERGIES 10/02/2020 **A "Second Life" For Electric Car Batteries: Award-Winning Innovation For The Energy Transition**



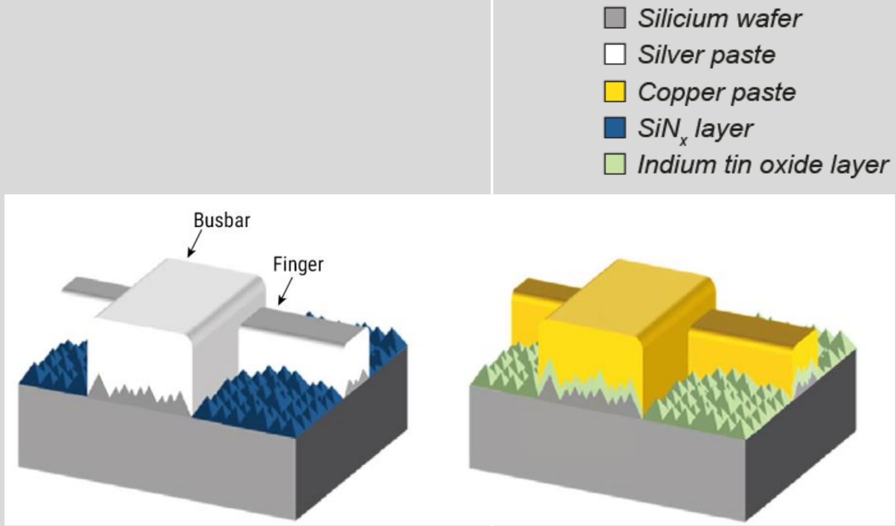
EU Commission: Study on the EU's list of Critical Raw Materials (2020)

Share of recycled material as compared to overall material needs - EU*

*Definition : Ratio of recycling of old scrap in the EU to the EU supply of raw material.

Now what can we do?

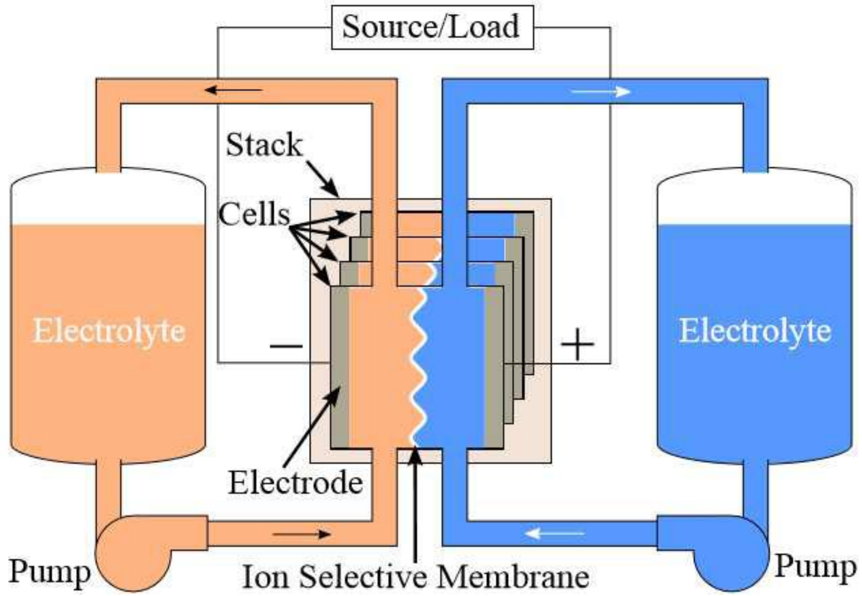
Material supply chain		
1. Increase material efficiency	**2. Re-use and Recycle**	**3. Substitution**
Do the same with less material	Second life where possible or else recycle	Replace with earth abundant material



Substitution of silver by copper in PV cells

Redox flow batteries

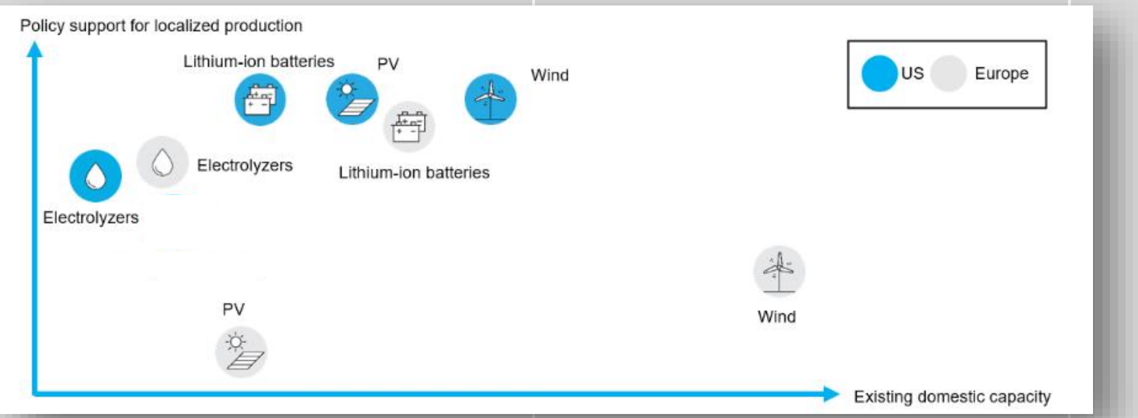
All iron-based and organic redox flow batteries have no critical material issue and are scalable for large-scale ESS.



Now what can we do?

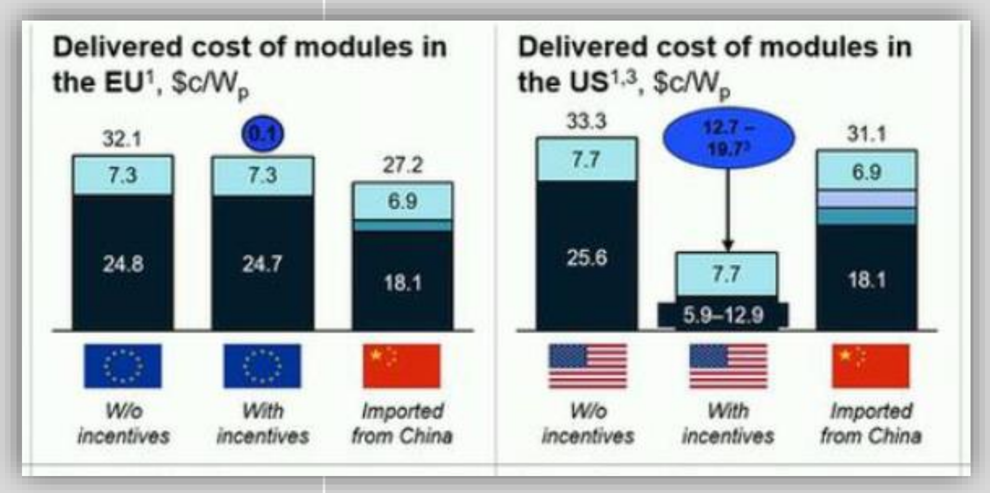
Material supply chain			Manufacturing supply chain
1. Increase material efficiency	**2. Re-use and Recycle**	**3. Substitution**	**4. Relocate processing and manufacturing chain**
Do the same with less material	Second life where possible or else recycle	Replace with earth abundant material	Bring refining and production to EU, US, …

Localizing clean energy manufacturing, US and Europe



Source : BNEF, Localizing clean energy supply chains comes at a cost, 2022.

Impact incentives for local PV manufacturing cost – US and Europe



Source : McKinsey, Building a competitive solar-PV supply chain in Europe, 2022.

4

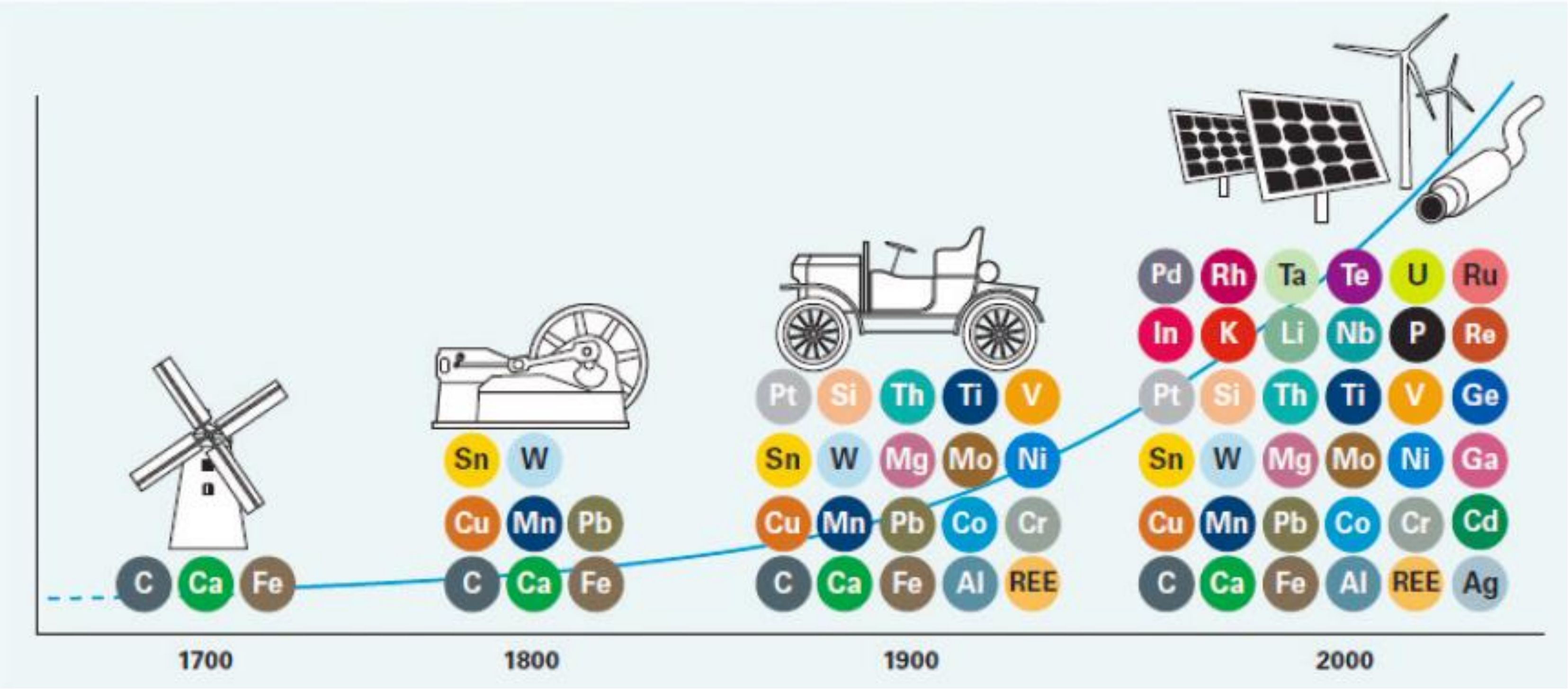
Conclusion

Critical Raw Material access is crucial for ENGIE's strategy since it may hinder the energy transition, but technical and political solutions exist to mitigate the risks

Technical and political solutions exist and are kicking-in:

1. Increase material efficiency
2. Re-use and recycle
3. Substitution
4. Relocate processing and manufacturing chain

Materials widely used in energy technologies (Volker et al., 2015)



RMG Consulting

IRTC Conference, Lille, February 16 2023
Raw materials for a sustainable future

Ukraine, Russia, Belarus and global mineral supply

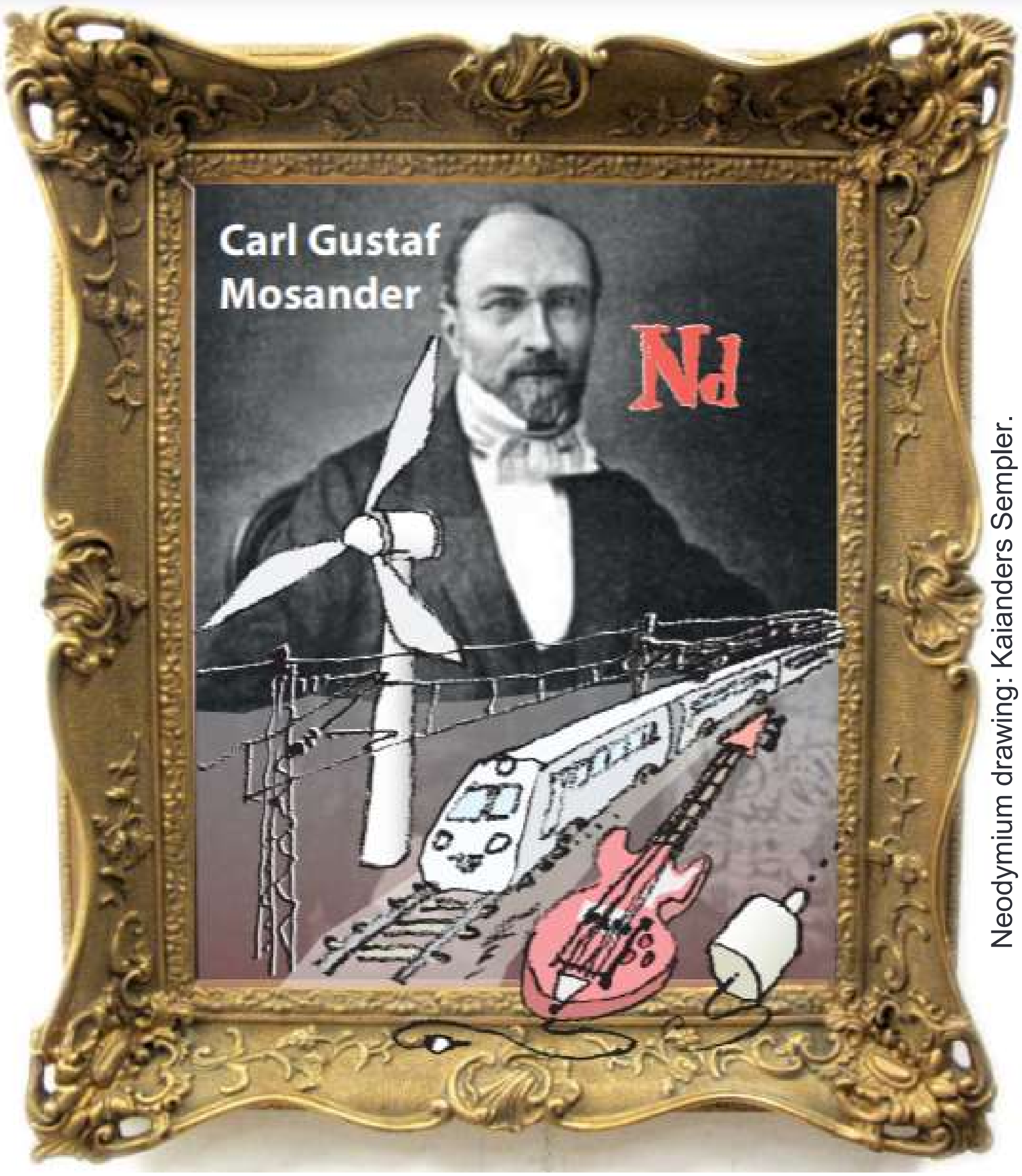
Magnus Ericsson and Olof Löf

Agenda

- ○ Russian, Ukrainian and Belarussian production of metals and minerals
- ○ Russian exports of metals and minerals
- ○ EU’s import dependence on Russia and Ukraine
- ○ Results of sanctions against Russia and effects of destruction in Ukraine
- ○ Conclusions

- ○ The most important Russian and Ukrainian mining companies

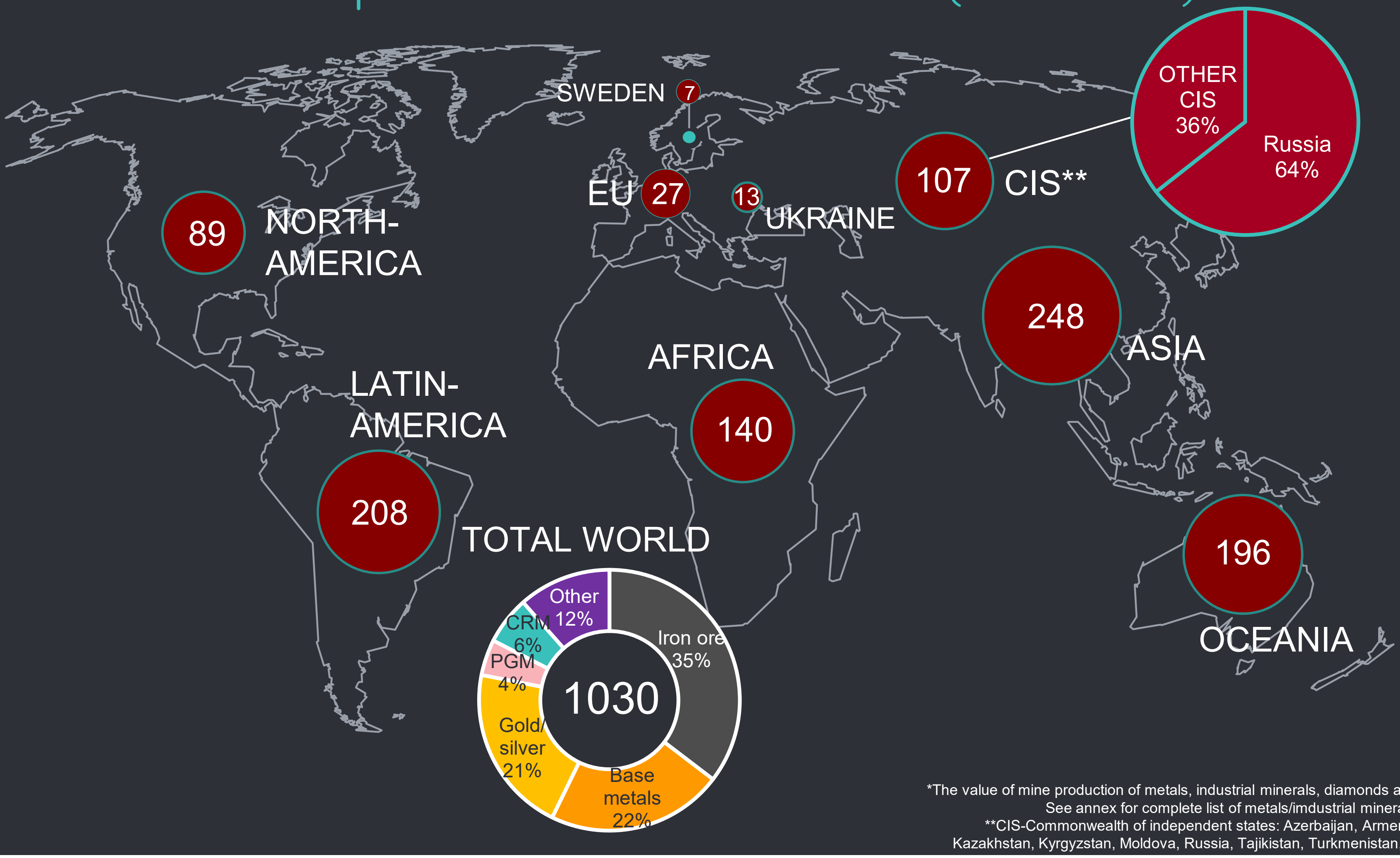
Russian, Ukrainian, Belarussian production of metals, minerals



Neodymium drawing: Kaianders Sempler.

RMG Consulting

Value of mine production* 2021 (billion USD)



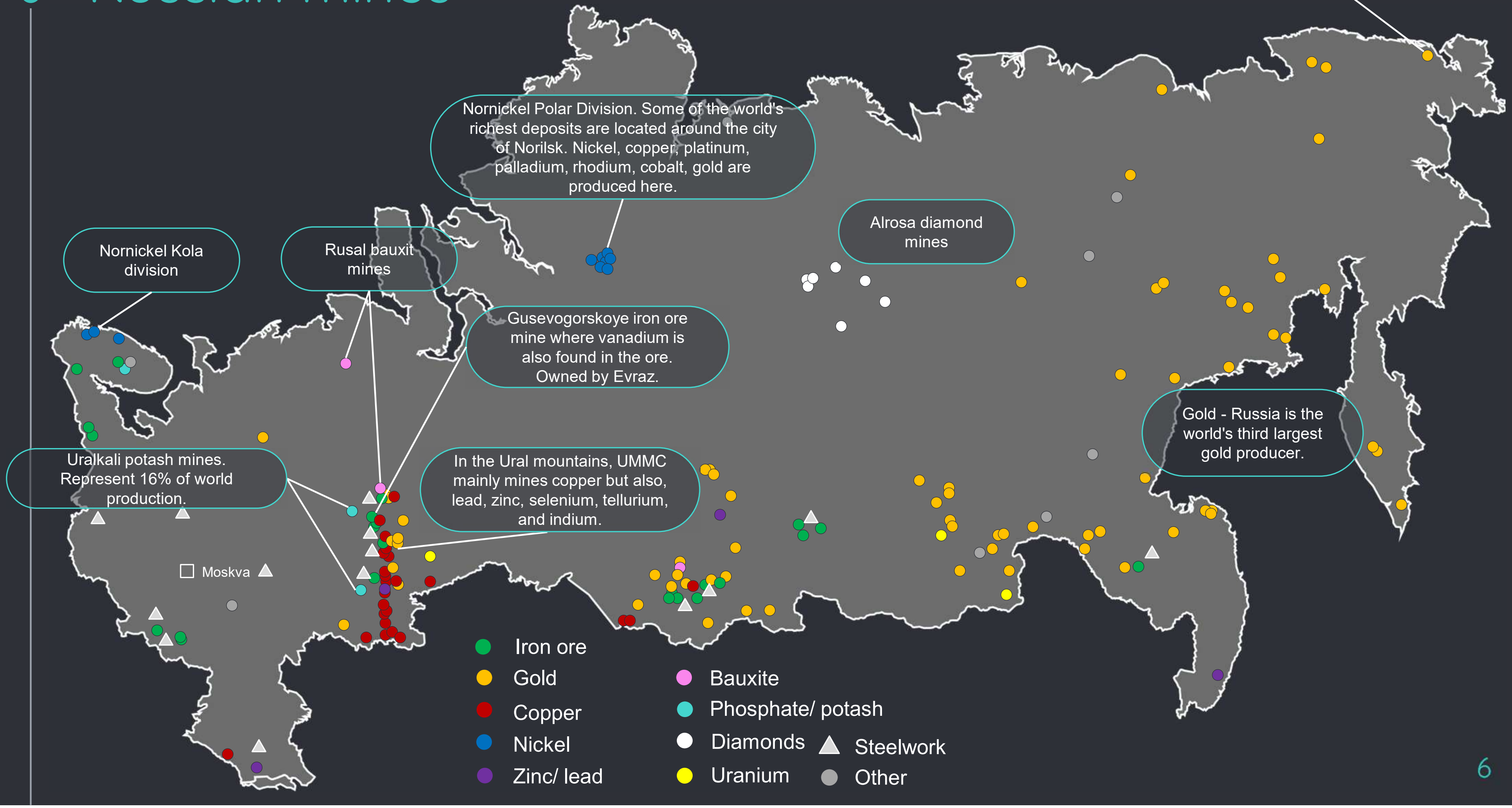
*The value of mine production of metals, industrial minerals, diamonds and uranium. See annex for complete list of metals/imdustrial minerals included.

**CIS-Commonwealth of independent states: Azerbaijan, Armenia, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan

Russia and the green transition

Russia's share of world production

Russian mines



Kupol gold mine. One of the world's largest gold mines, owned by Canadian gold miner Kinross. Agreement of sale to Highland Gold in place. Production was stopped on March 22.

Nornickel Polar Division. Some of the world's richest deposits are located around the city of Norilsk. Nickel, copper, platinum, palladium, rhodium, cobalt, gold are produced here.

Alrosa diamond mines

Nornickel Kola division

Rusal bauxit mines

Gusevogorskoye iron ore mine where vanadium is also found in the ore. Owned by Evraz.

Uralkali potash mines. Represent 16% of world production.

In the Ural mountains, UMMC mainly mines copper but also, lead, zinc, selenium, tellurium, and indium.

Gold - Russia is the world's third largest gold producer.

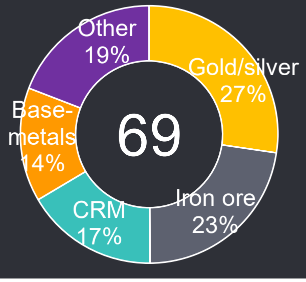
- ● Iron ore
- ● Gold
- ● Copper
- ● Nickel
- ● Zinc/ lead
- ● Bauxite
- ● Phosphate/ potash
- ● Diamonds
- ▲ Steelwork
- ● Uranium
- ● Other

Russian mine production

Metal/ mineral	Value $” 2021	Russian share of world total	CRM
Coal	56.6	5.4%	
Gold	17.65	9.1%	
Iron ore	15.50	4.3%	
Palladium	7.21	40.9%	x
Potash	6.64	16.3%	
Copper	5.84	3.9%	
Diamonds	4.12	30.4%	
Nickel	2.92	8.4%	
Asbest	1.58	64.4%	
Rhodium	1.42	7.7%	x
Silver	1.10	5.2%	
Phosphate rock	1.04	6.1%	x
Platinum	0.75	11.6%	x
Zinc	0.58	2.5%	
Lead	0.48	4.7%	
Vanadium	0.28	22.7%	x
Kaolin	0.24	6.2%	
Antimony	0.19	16.9%	x
Bauxite	0.18	1.6%	x
Chrome	0.15	1.8%	
Uranium	0.14	5.3%	
Magnesium	0.13	1.4%	x
Cobalt	0.09	4.5%	x
Molybden	0.07	0.7%	
Tin	0.07	0.8%	

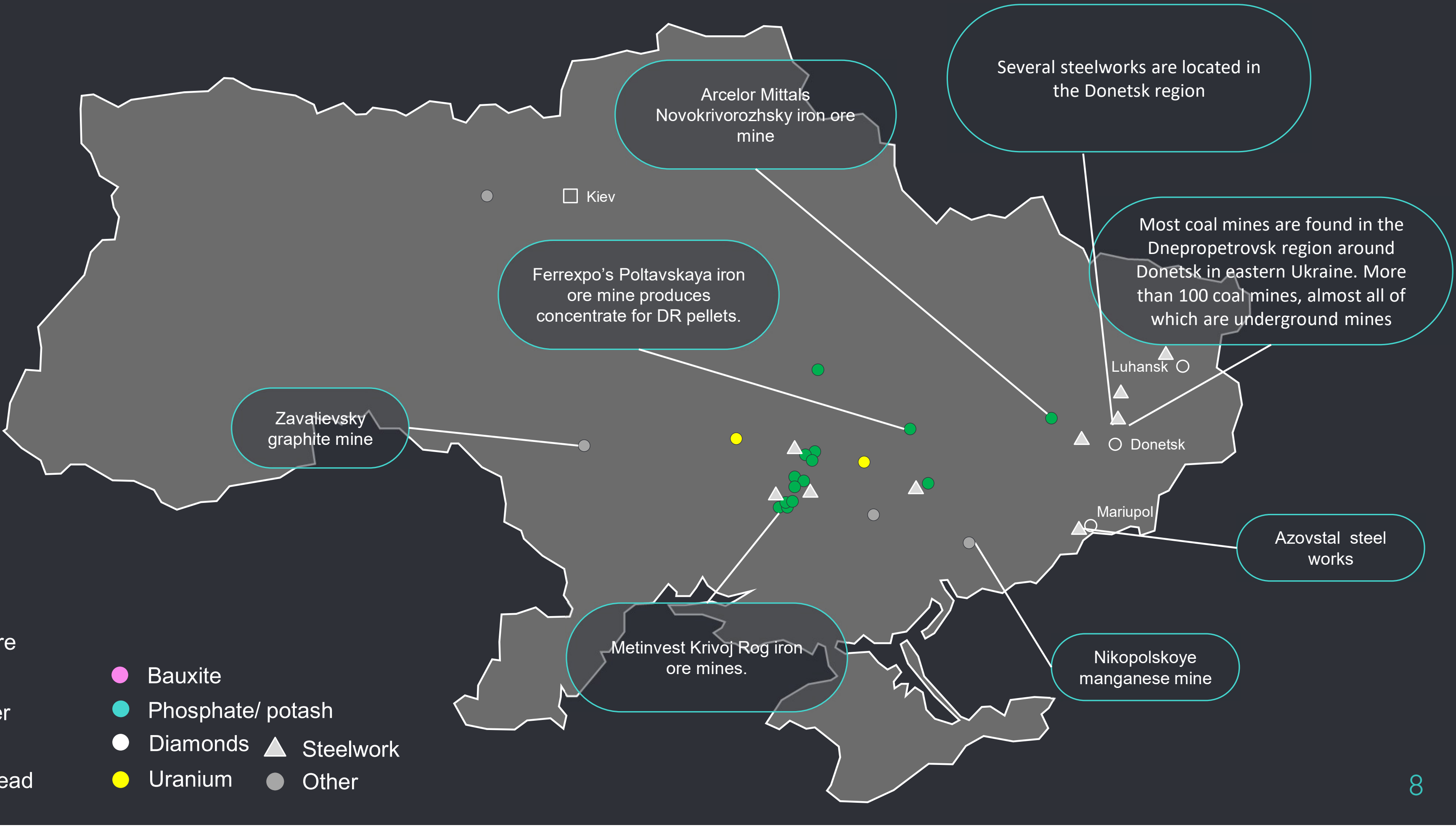
Metal/ Mineral	Value $” 2021	Russian share of world total	CRM
REE	0.06	1.2%	x
Tungsten	0.05	3.1%	x
Salt	0.04	0.3%	
Talk	0.04	2.0%	
Gips	0.03	2.3%	
Fältspat	0.03	0.9%	
Bor	0.03	3.8%	x
Graphite	0.03	1.5%	x
Tantalum	0.01	1.4%	x
Zircon	0.01	0.5%	
Mercury	0.00	1.8%	
Tellurium	0.00	8.0%	
Svavel	0.00	1.0%	
Flourspar	0.00	0.1%	x
Mica	0.00	1.6%	
Bismuth	0.00	1.4%	x
Aluminium	*	5.8%	
Gallium	*	6.3%	x
Germanium	*	6.3%	x
Baryte	*	0.0%	x
Hafnium	*	0.5%	x
Silicon	*	8.6%	x
Niobium	*	1.2%	x
Indium	*	0.5%	x
Titanium (sponge)	*	13%	x

*Biproduct and/or extracted from steel production
”Billion USD



Billion USD

Ukrainian mines



Arcelor Mittals Novokrivorozhsky iron ore mine

Several steelworks are located in the Donetsk region

Most coal mines are found in the Dnepropetrovsk region around Donetsk in eastern Ukraine. More than 100 coal mines, almost all of which are underground mines

Ferrexpo's Poltavskaya iron ore mine produces concentrate for DR pellets.

Zavalievsky graphite mine

Azovstal steel works

Metinvest Krivoj Rog iron ore mines.

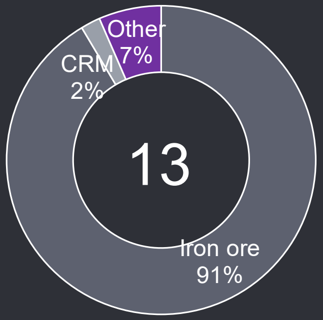
Nikopolskoye manganese mine

- ● Iron ore
- ● Gold
- ● Copper
- ● Nickel
- ● Zinc/ lead
- ● Bauxite
- ● Phosphate/ potash
- ● Diamonds
- ● Uranium
- ▲ Steelwork
- ● Other

Ukrainian mine production

Metal/ mineral	Vale $" 2021	Ukraine share of world total	CRM
Iron ore	11.97	3.3%	
Coal	3.3	0.3%	
Manganese ore	0.36	3.3%	
Kaolin (clay)	0.29	7.5%	
Titanium	0.24	7.7%	x
Salt	0.12	0.7%	
Uranium	0.04	1.5%	
Zirkonium	0.03	1.6%	
Graphite	0.02	1.3%	x
Gipsum	0.01	0.8%	
Feldspar	0.00	0.1%	
Hafnium	*	1.6%	x
Silicon	*	0.7%	

*Biproduct and/or extracted in smelters/refineries
"Billion USD

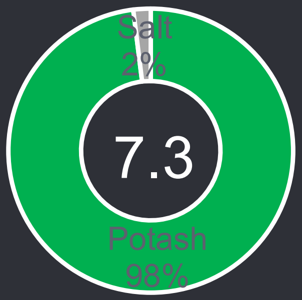


Billion USD

Belarussian mine production

Metal/ mineral	Value $" 2021	Belarus' share of world total	CRM
Potash	7,20	18%	
Salt	0,14	0,9%	

"Billion USD

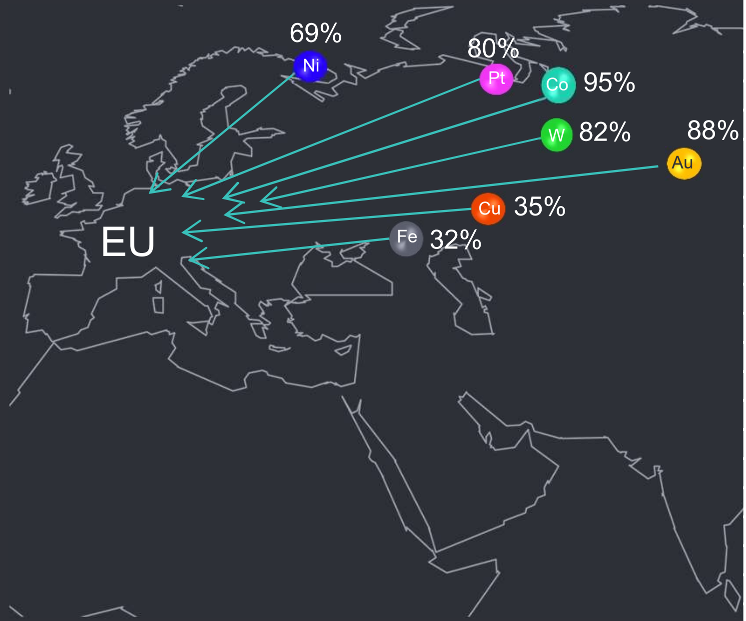


Billion USD

Russian exports

Nickel drawing: Kaianders Sempler.

Russia’s metal and mineral exports



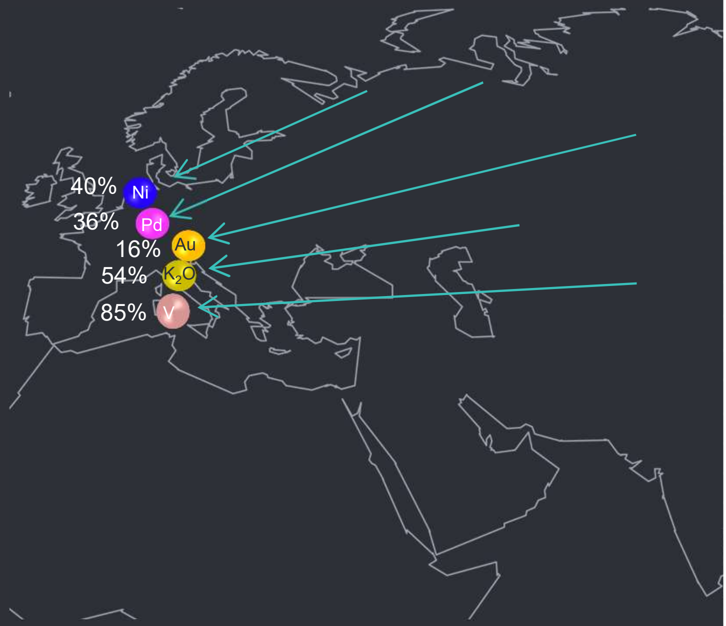
Metal/ mineral	Value of export (MUSD)	Share of EU in Russia’s exports
Cobalt	83	95%
Beryllium	22	91%
Gold	19292	88%
Tungsten	22	82%
Platinum	688	80%
Nickel	3077	69%
Vanadium	89	66%
REE	17	65%
Phosphate	439	57%
Silver	428	57%
Chrome	135	54%
Titanium	414	52%
Silicon	73	51%
PGM other	707	45%
Diamonds	3189	45%
Palladium	6449	38%
Aluminium	5224	36%
Copper	6337	35%
Iron ore	1980	32%
Met. Coal	10743	22%
Potash	1776	20%
Pig iron	1325	19%
Zinc	234	16%

Source: OECD

EU imports

Vanadium drawing: Kaianders Sempler.

EU's imports of metals from Russia



Metal/mineral	Value of import from Russia (MUSD)	Russia's share of EU's import
Vanadium	56	85%
Potash*	461	54%
Nickel	1693	40%
Palladium	2600	36%
Met. Coal	2213	36%
Titanium	465	18%
Chrome	38	17%
Diamonds	1393	16%
Gold	17099	16%
Platinum	578	16%
Phosphate	282	15%
Aluminium	2279	14%
REE	11	13%
PGM other	385	13%
Iron ore	1098	12%
Copper	1200	9%
Silver	241	8%
Cobalt	17	4%
Zircon**	3	4%
Indium	2	3%
Silicon	31	2%
Beryllium	1	1%
Borate	3	1%

*Russia & Belarus

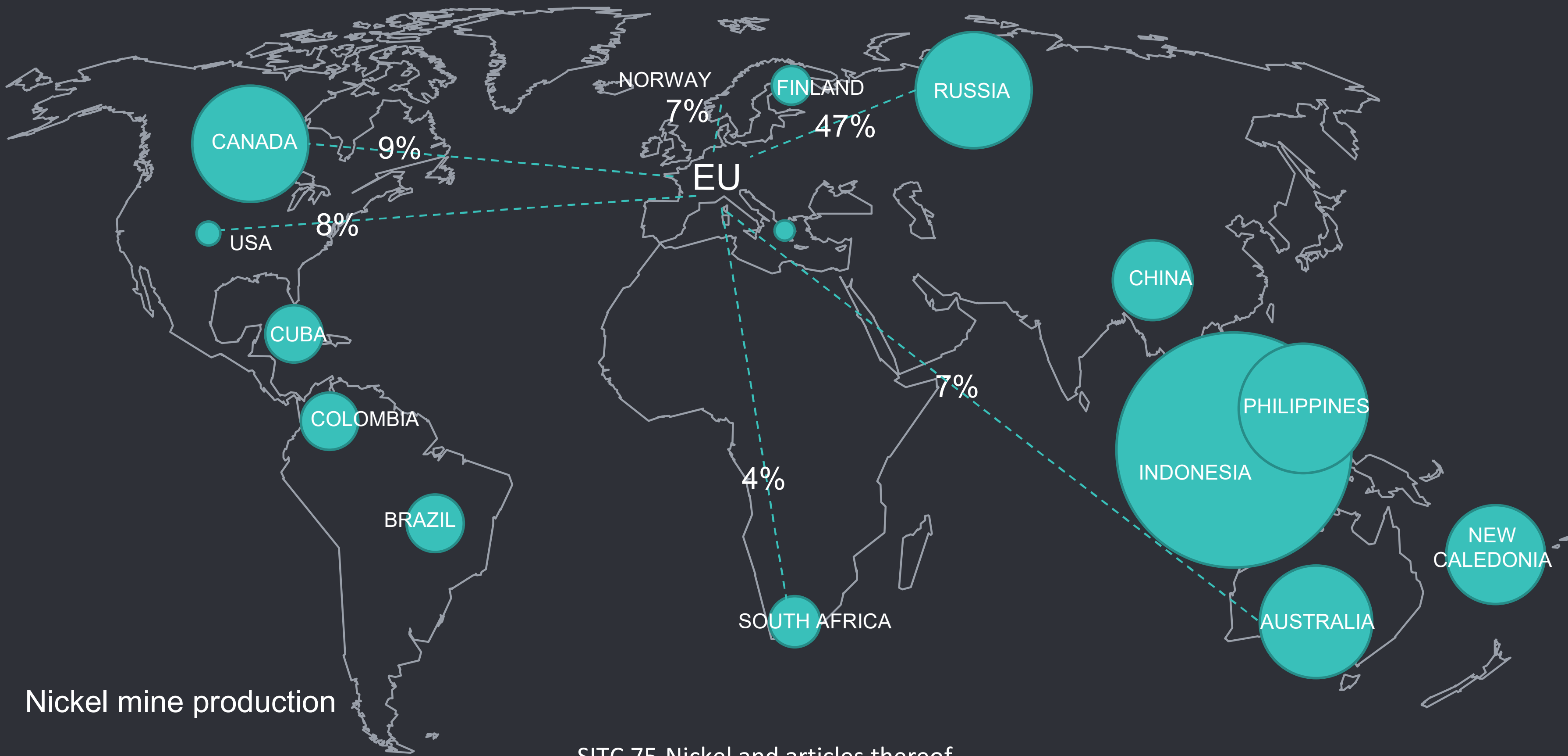
**Imported from Ukraine

Source: OECD

EU imports from Russia

EU-import	2021	10 months-2022	Weight 2021	Weight 2022
Aluminium MUSD	2658	2680	N.A.	N.A.
Aluminium %	8.3	7.5		
Palladium MUSD	1732	1128	21.6 t	14.7 t
Palladium %	34.2	31.1		
Nickel MUSD	2509	2758	N.A.	N.A.
Nickel %	42.3	44.4		
Gold MUSD	672	598	11.5 t	10.0 t
Gold %	3.3	3.8		
Iron ore MUSD	2069	400	10.5 Mt	2.4 Mt
Iron ore %	12.6	4.0		

Nickel EU import 2021: 4573 MUSD



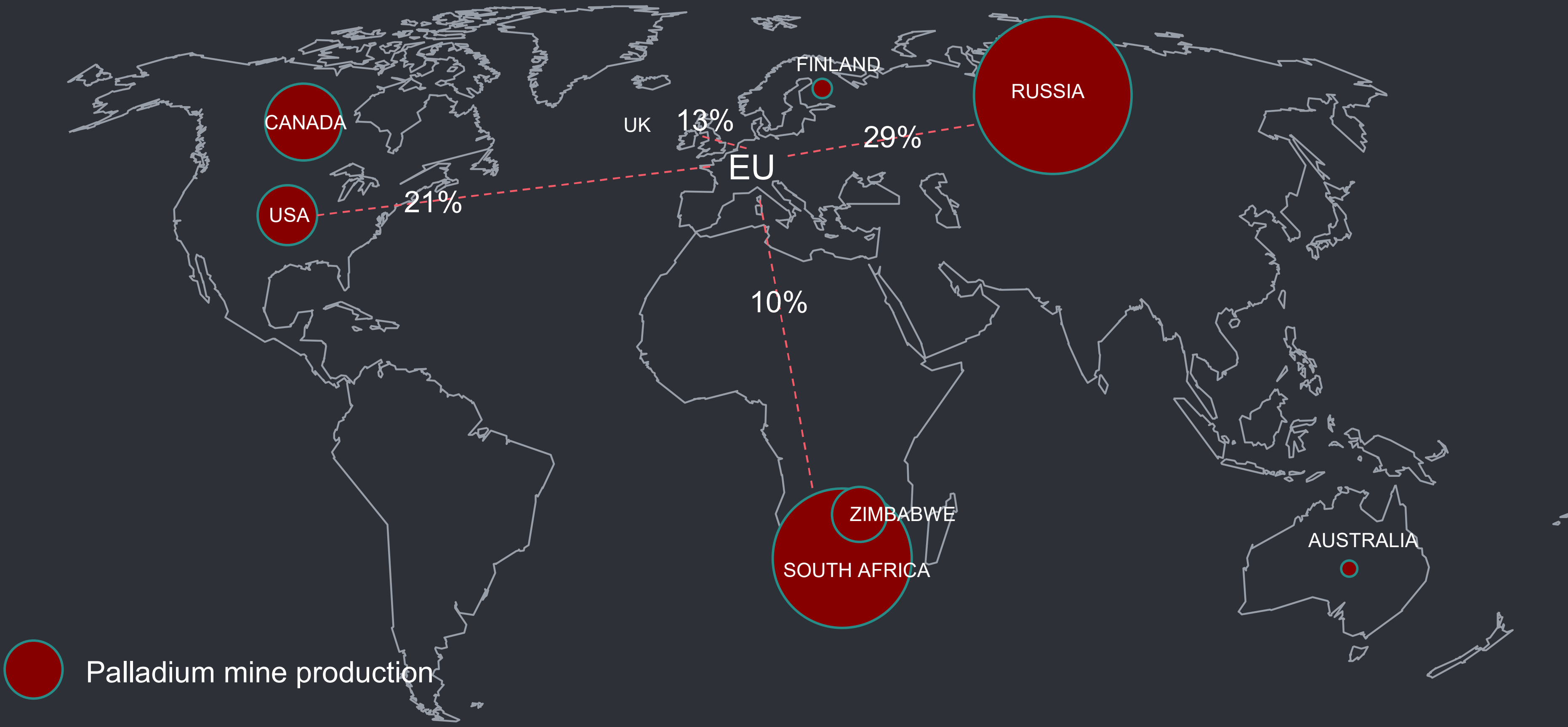
● Nickel mine production

% EU import nickel (refined)

SITC 75 Nickel and articles thereof
Ni conc. import value 280 MUSD

Circles are proportonal to national prpduction

Palladium EU import 2021: 5925 MUSD



● Palladium mine production

% EU import palladium (refined)

Circles are proportonal to national prpduction

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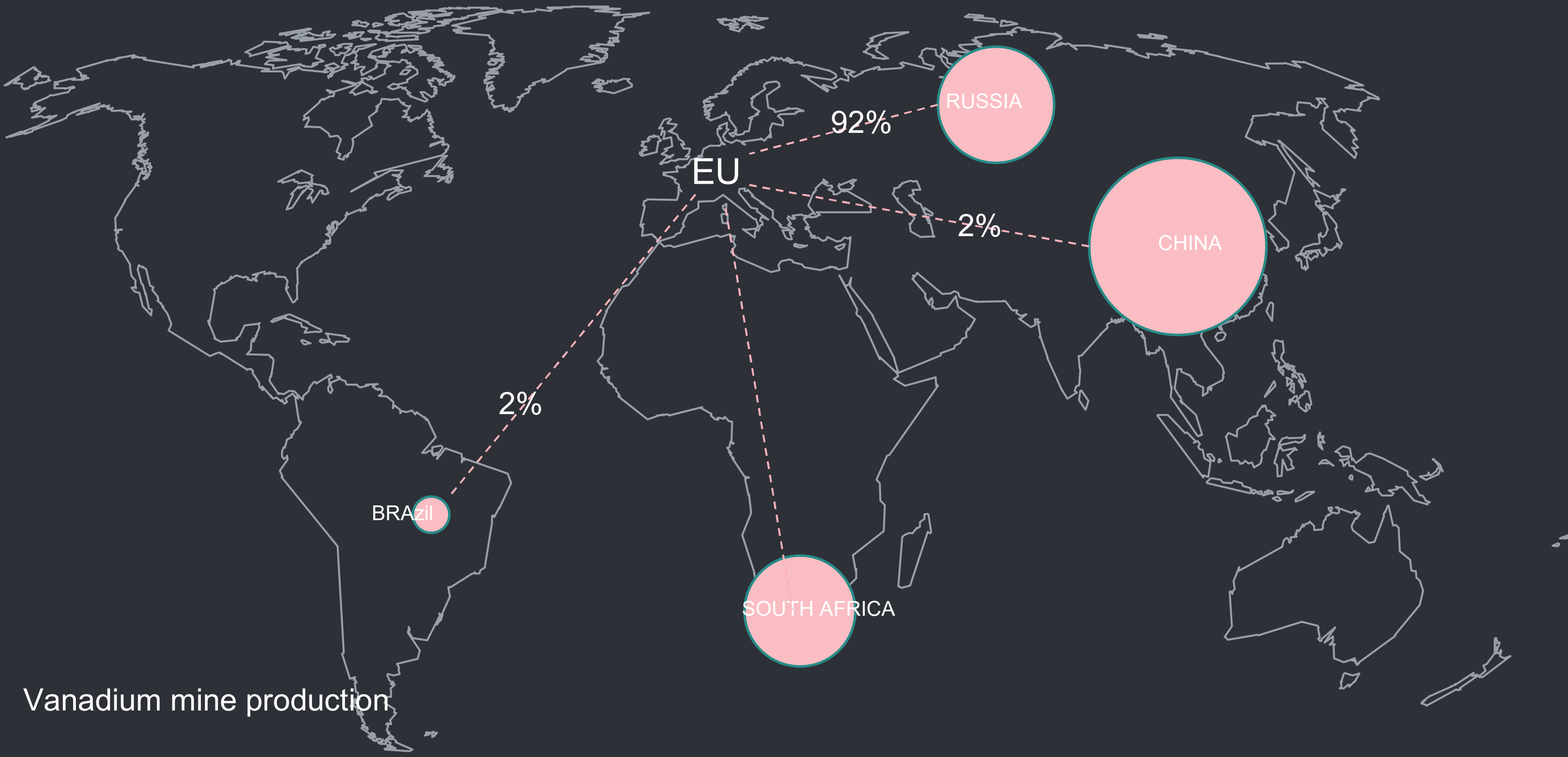
Vanadium EU import 2021: 132 MUSD

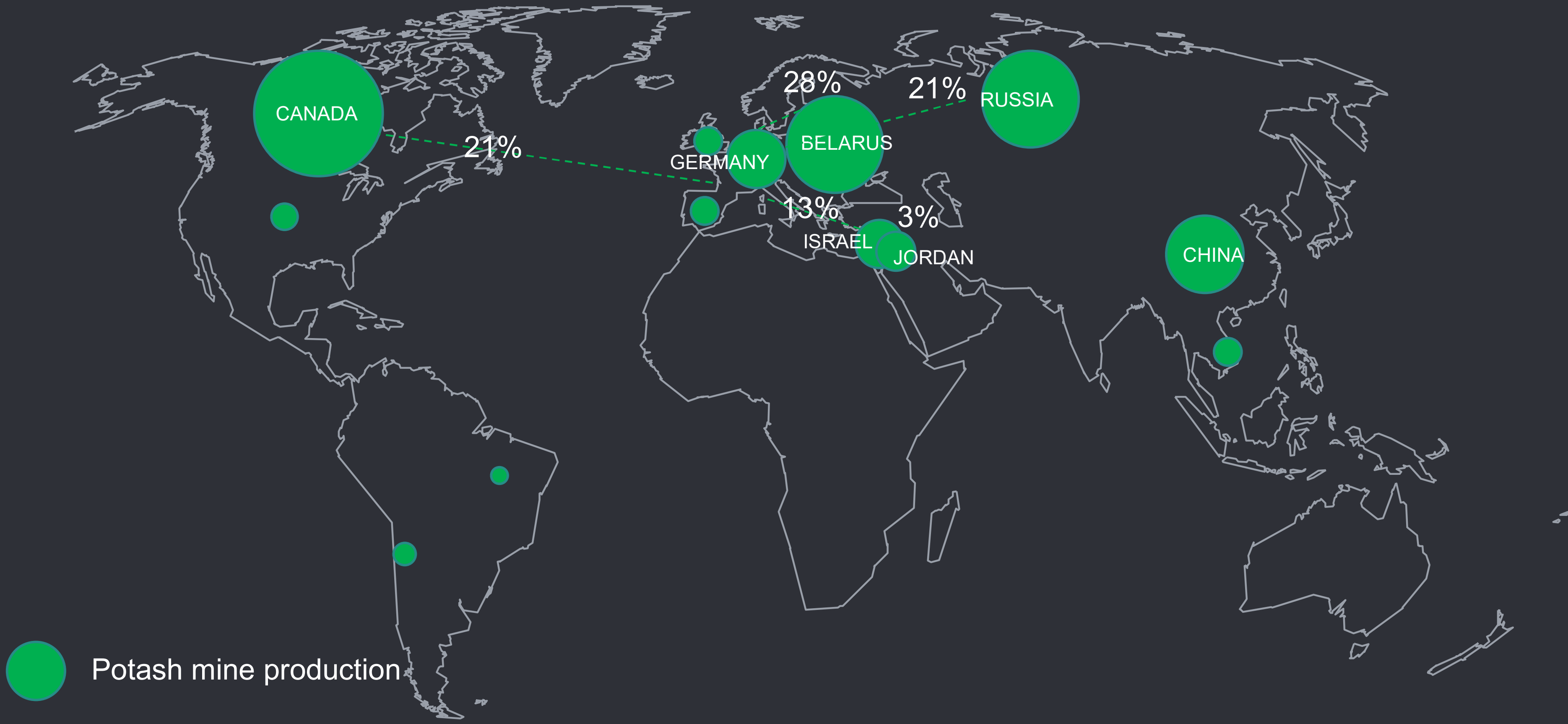


● Vanadium mine production

% EU import vanadium (refined)

Circles are proportonal to national prpduction

Potash EU import 2021: 1077 MUSD

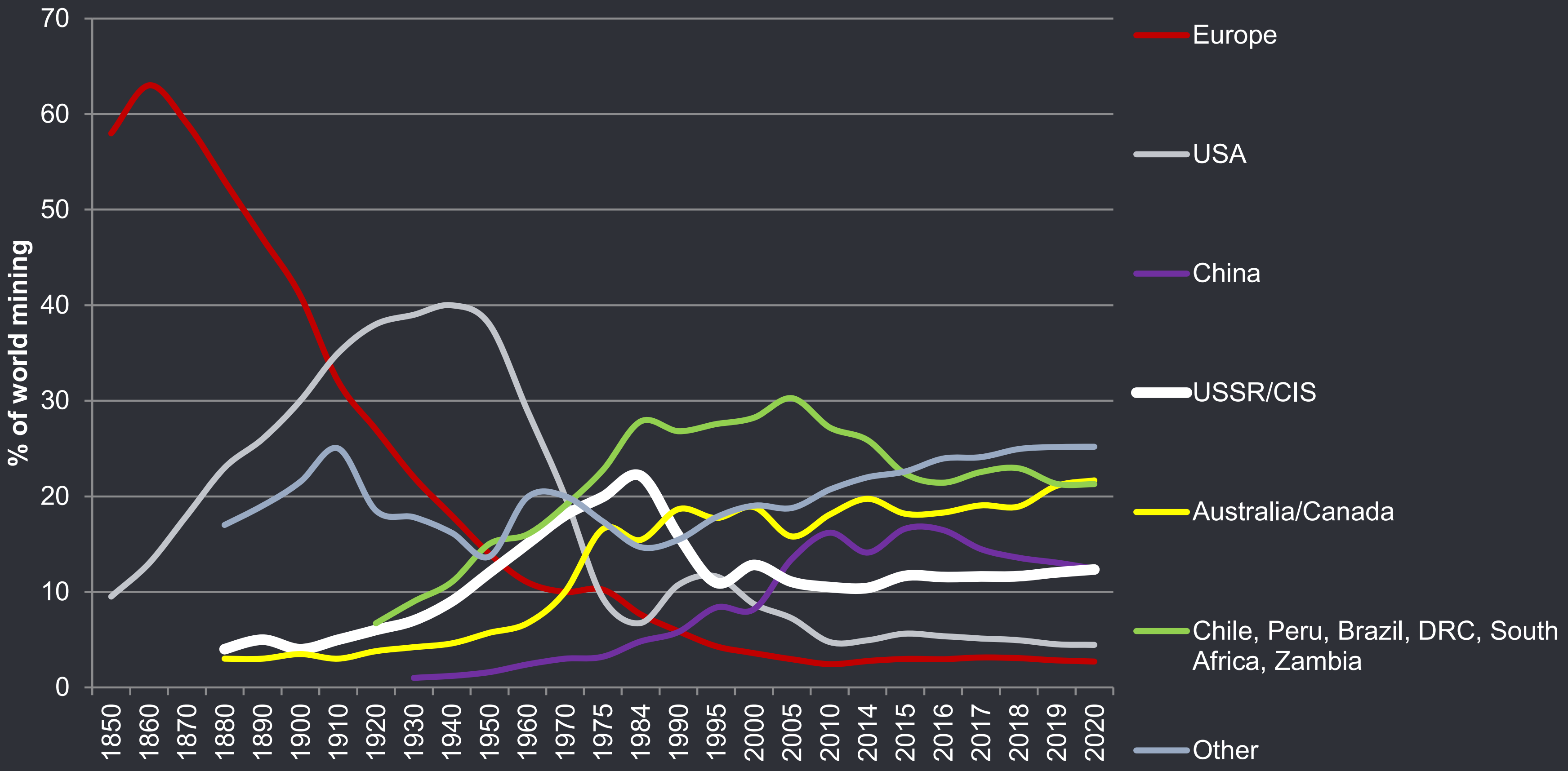


● Potash mine production

% EU import potash

Circles are proportonal to national prpduction

Locus of mine production historically



Consequences

REE drawing: Kaianders Sempler.

Consequences: short term

European energy crisis is affecting smelters and refineries in Europe, suspensions, closures

So far limited effects on trade. LME still trading with Russian metals

Legally binding long term contracts make it difficult to stop imports from Russia.

The Russian nickel production is important for the EU.
Nornickel operates a nickel refinery in Finland where nickel from Russia is refined.

Palladium is used mainly in auto catalysts. This is probably a use where it is most difficult to replace Russian metal.

Ukraine is an important producer of high quality iron ore products suitable for the production of green steel. Ukrainian company Ferrexpo's production has been reduceed and its future is uncertain.

There are pellet producers also in Russia for example Severstal's mine and plant in Kostamus Karelia. Their export via a Finnish port has been stopped.

Gold imports have been reduced into EU/UK. Switzerland gold imports increased with 50% in 2022.

Consequences: long term

European smelting/refining industry

A serious threat of close down of an important industry in the EU. Opportunities in Nordic countries.

Prices

Increased freight costs when ores have to be shipped longer distances than from Russia.

Direct investments into mining

Possibly large user of metals might get interested in investing directly into mines in countries with low sovereign and economic risks. So far few such deals but they might come.
All new mines, wherever they are located, must be competitive at present world market prices.

Environment

If production by Nornickel is replaced by mines in other parts of the world CO_2 emissions would increase.

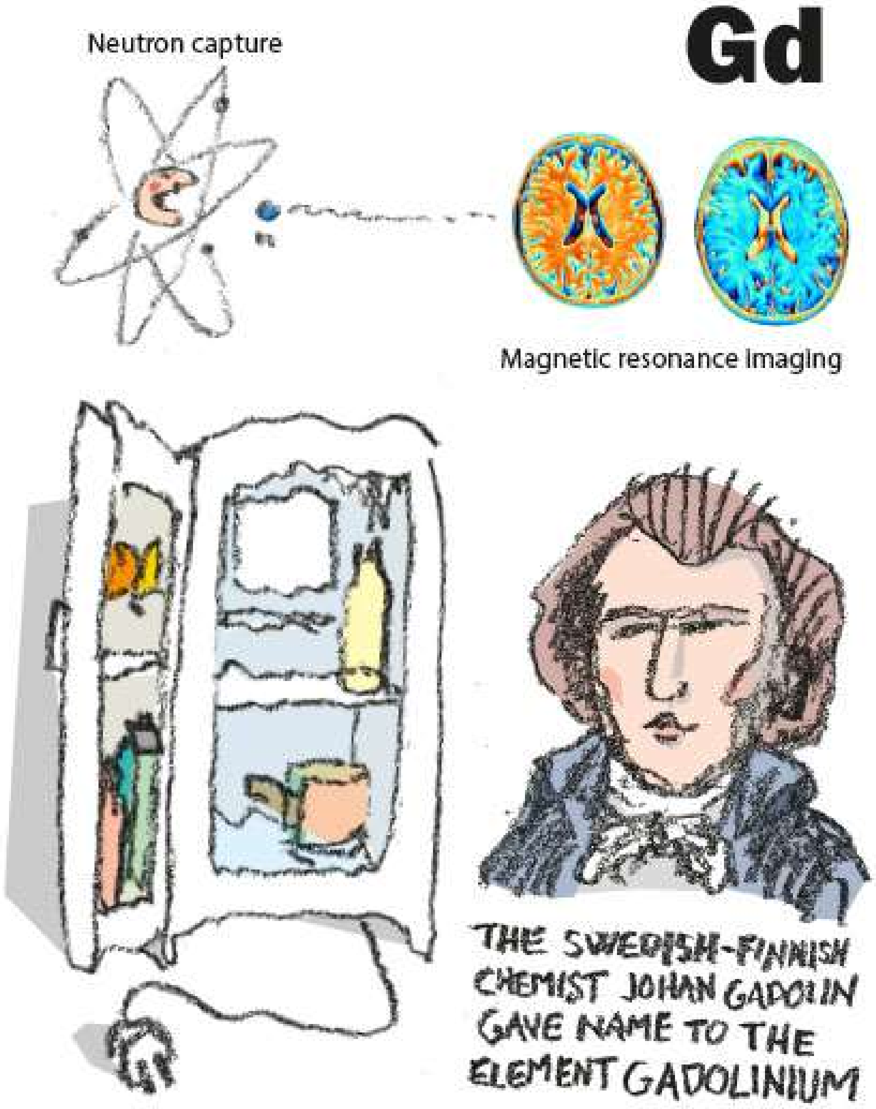
Equipment suppliers

Equipment suppliers will lose an important market in Russia which is a major underground market.
The effectiveness of Russian mines could gradually decrease if cut off from top class equipment.

Opportunities for developing countries

High quality deposits in emerging economies might be developed to replace Russian exports.

Conclusions



Gadolinium drawing: Kaianders Sempler.

Conclusions 1

Russian metal production

Russia's importance as a mining country and exporter might slowly decline.

The role of the oligarchs

Oligarchs are major owners of Russian mining and smelting companies. How would a decrease in profits form these companies influence the oligarchs and their relation to the Russian regime?

Russian companies

The major Russian mining companies started to modernise after the collapse of the Soviet Union. This process has to a large extent ground to a halt undeer Putin. India and China might become the only major countries willing to do business as usual with Russia.

International experts to Russian listed companies are withdrawing and they will lose competences.

Investments into Russia

Chinese investors might be willing to spread their investment and target also Russia. But Chinese investments into mining outside China is slowing down and interest is focused on SE Asia, Africa, Latin America.

Aluminium

Russia is however highly import dependent on alumina imports. Rio Tinto has stated they will stop bauxite deliveries also to Rusal's alumina plant in Ireland, which could affect also delveries to Russia.

Conclusions 2

Sanctions on Russian metals and minerals exports and imports should be feasible and would affect Russia more seriously than the EU.

There are alternative sources of imports for most metals Russia produces.

The role of China should be monitored closely.

The war in Urkaine puts a pan-European mineral intelligence centre high on EUs agenda.

RMG Consulting

Thank you/Merci/Danke/Tack/Kiitos

This study was originally prepared for Svemin - the Swedish Association of Mines, Mineral and Metal Producers in April 2022. We have up-dated it for this presentation.
The original full report is available on
www.rmgconsulting.org

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Russian, Belarussian and Ukrainian companies

Manganese drawing: Kaianders Sempler.

RMG Consulting

Companies in a global comparison (billion USD)

Company	Country	Main metal	Value mine production* 2020
BHP	UK/Australia	Iron ore	44
Vale SA	Brazil	Iron ore	38
Rio Tinto Group	UK	Iron ore	37
…			
Nornickel	Russia	Nickel/PGM	12
Belaruskali	Belarus	Potash	7.2
Uralkali	Russia	Potash	5.5
Polyus Gold	Russia	Gold	5.2
Evraz Group SA	Russia	Iron ore	4.4
Metalloinvest	Russia	Iron ore	4.4
Alrosa	Russia	Diamant	4.1
Metinvest	Ukraine	Iron ore	3.3
Polymetal International Plc	Russia	Gold	2.8
NLMK	Russia	Iron ore	2.0
Ural Mining and Metallurgical Company	Russia	Base metals	2.0
Severstal	Russia	Iron ore	1.9
Nord Gold	Russia	Gold	1.9
United Company Rusal Plc	Russia	Aluminium	1.8
Ferrexpo	Ukraine	Iron ore	1.2
Phosagro	Russia	Phosphate	0.9
Atomenergoprom (Rosatom)	Russia	Uranium	0.1
…			
KGHM Polish Copper	Poland	Copper	3.5
LKAB	Sweden	Iron ore	2.9
Boliden	Sweden	Base metals	1.9

Russian mining companies

Nornickel is the world's second largest producer of nickel (both concentrates and refined metal). The world's largest producer of palladium. Also produces copper, platinum and cobalt. The mines are located in Siberia and on the Kola Peninsula. Controlled by Vladmir Potanin and Oleg Deripaska. Listed in Moscow.

POLYUS Gold is the world's third largest gold producer with 81 tonnes of gold 2020. All mines are located in Russia. Controlled by Said Kerimov. Listed in Moscow and London. The company was spun off from Nornickel just over 10 years ago.

Evraz is Russia's largest steel and iron ore company. Its largest individual owner is the oligarch Roman Abramovich. Produced 14 Mt of iron ore in 2020. The company is listed on the London Stock Exchange.

Metalloinvest is a steel and iron ore company and is Russia's largest iron ore producer with about 40 million tonnes annually, including pellets and so-called HBI (hot briquetted iron) a steel raw material. The company is not listed on the stock exchange.

Polymetal is one of the world's top 10 largest gold companies. They control 8 gold mines in Russia and 1 in Kazakhstan. The production amounts to 44 t gold and 6 300 t silver. Listed on the London Stock Exchange. One of the largest owners is Alexander Nesis.

Ural Mining and Metallurgical Company (UMMC) is one of the largest Russian mining producers of copper, zinc, coal, gold and silver. UMMC also produces lead, selenium, tellurium, cadmium and indium. Listed in Russia. The largest owner is Iskander Makumodov.

Severstal is primarily a steel company but also a large producer of iron ore and iron ore pellets. All mines are located in Russia. Severstal is listed on the London Stock Exchange where the majority of the shares belong to the oligarch Alexei Mordashov.

United Company RUSAL is the world's second largest aluminum producer. A fully integrated company with bauxite mines in Russia, Guinea, Guyana and Jamaica. Listed in Moscow and Hong Kong with Oleg Deripaska as major owner. Owner of Swedish Kubikenborg Aluminum (KUBAL) with aluminum smelter in Sundsvall.

Russian and Belarussian mining companies

Uralkali is one of the world's largest producers of potassium salts for fertilizer production. The company is listed on the Moscow Stock Exchange and has Dmitry Mazepin as a major shareholder.

Nordgold is a gold company with operations in West Africa, Kazakhstan and Russia. Produced more than 31 tonnes of gold in 2020. Marina Mordashova is the largest shareholder with more than 50%. The company is based and registered in the United Kingdom.

Phosagro mines phosphates (phosphate rock) and produced 12 million tonnes by 2020. The company is one of the world's largest integrated fertilizer producers. Has an international board. Is listed on the Moscow Stock Exchange.

Belarussian companies

Belaruskali is one of the world's largest potash companies. 100% state controlled. 7.4 million tonnes were produced 2020 to a value of about 7 billion USD. Belaruskali accounts for 18% of global production.

Ukrainian mining companies

Ukrainian companies

METINVEST

Metinvest is Ukraine's largest iron ore company with a production of 30 million tonnes 2020. The company is not listed on the stock exchange. It is controlled by Rinat Akhmetov.

FERREXPO

Ferrexpo is Ukraine's largest producer of iron ore pellets and also produces DR pellets needed to produce the so-called “green steel” with hydrogen as a reducing agent. Production about 11 Mt iron ore products. The company is the third largest pellet exporter in the world. Konstantin Zhevago controls the company, which is listed on the London Stock Exchange but is headquartered in Switzerland.

IRTC 2023 – Raw Materials for a Sustainable Future
15-17 February 2023, Lille, France

Paradoxes in material criticality: revealing the multifaceted nature of the phenomenon

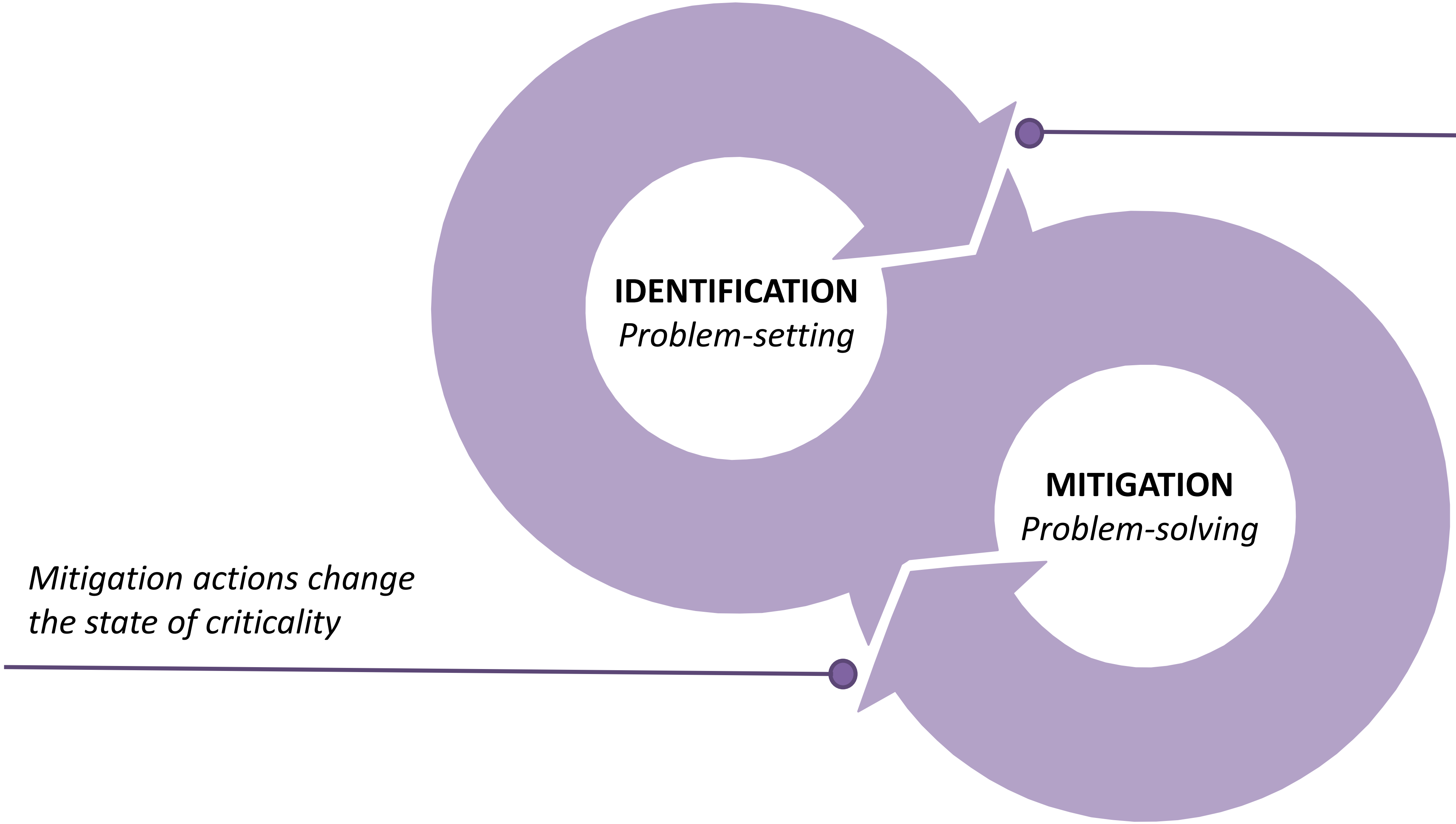
Yulia Lapko, Politecnico di Milano (IT)
David Peck, TU Delft (NL)

Co-funded by the European Union

Funded by the European Union

CiRCLETECH 101079354 Funded by the European Union - Twinning partnership to deliver enhanced networking for circular technological and socio-economic impact, raising research excellence and strengthening management capacity.

How we think it is:
Identification and Mitigation of material criticality as a dynamic interdependent system



Our understanding of the problem guides the scope and effectiveness of mitigation (or maybe even preventative?) actions

Mitigation actions change the state of criticality

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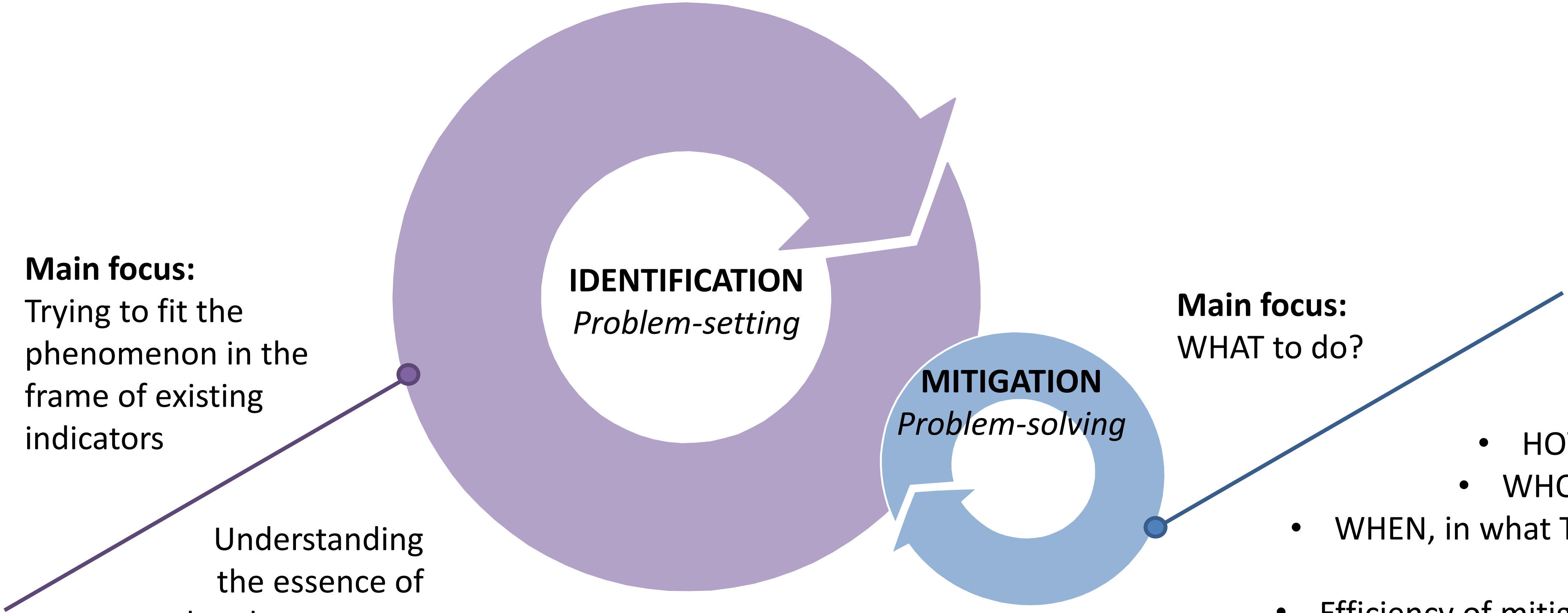
Where we really are:



Main focus:
Trying to fit the phenomenon in the frame of existing indicators

Understanding the essence of the phenomenon (what is material criticality)?

IDENTIFICATION
Problem-setting

MITIGATION
Problem-solving

Main focus:
WHAT to do?

- HOW to do that?
- WHO will do that?
- WHEN, in what TIME horizon?

- Efficiency of mitigation efforts?
- Unintended consequences?

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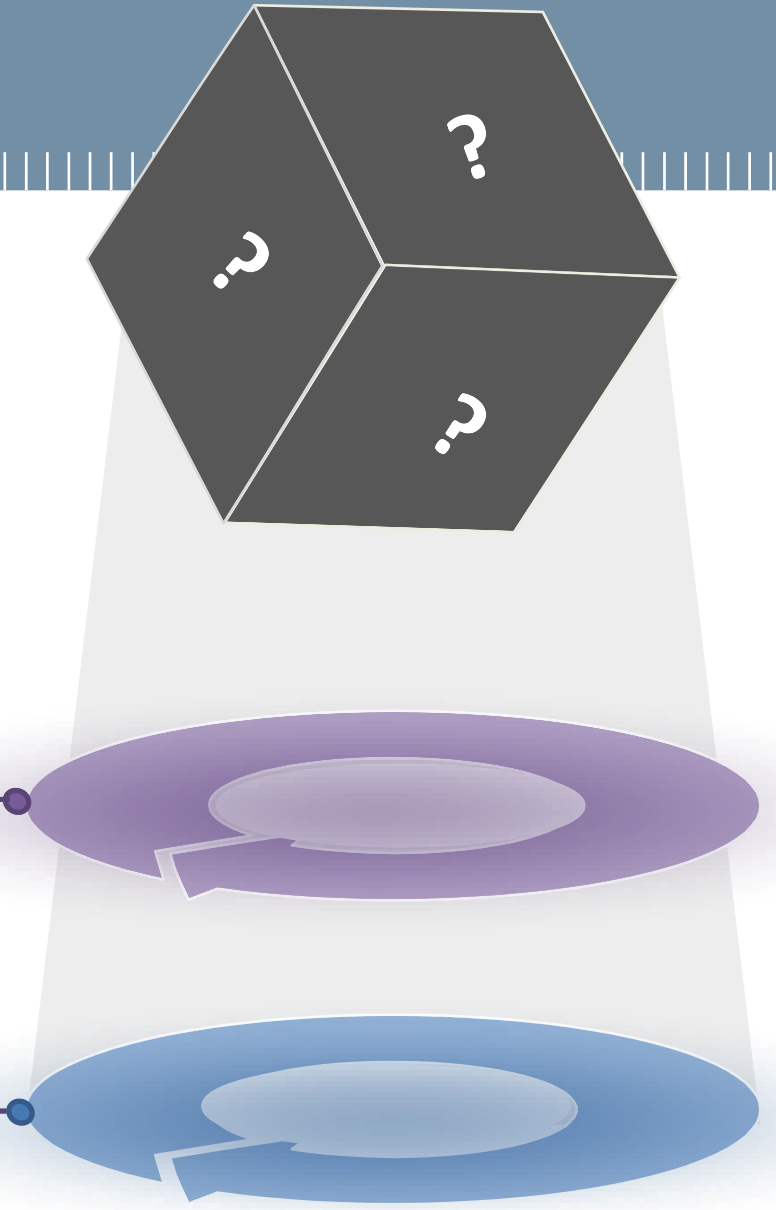
Identification and Mitigation: critical appraisal



*Regardless of prominent progress in the field, it is possible to say that material criticality remains a **dynamic black box**.*

***Urgency and importance** of criticality push the investigation towards solving the problems before the phenomenon is fully understood, thus putting under question the efficiency and effectiveness of taken actions*

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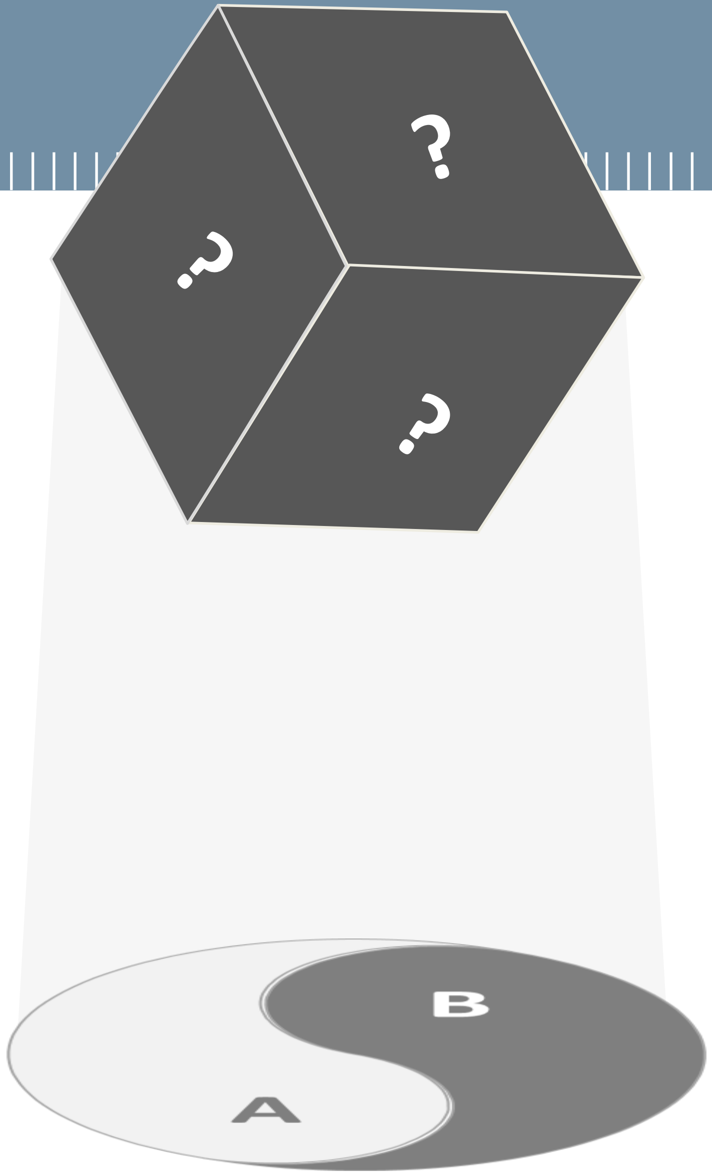
Paradox perspective



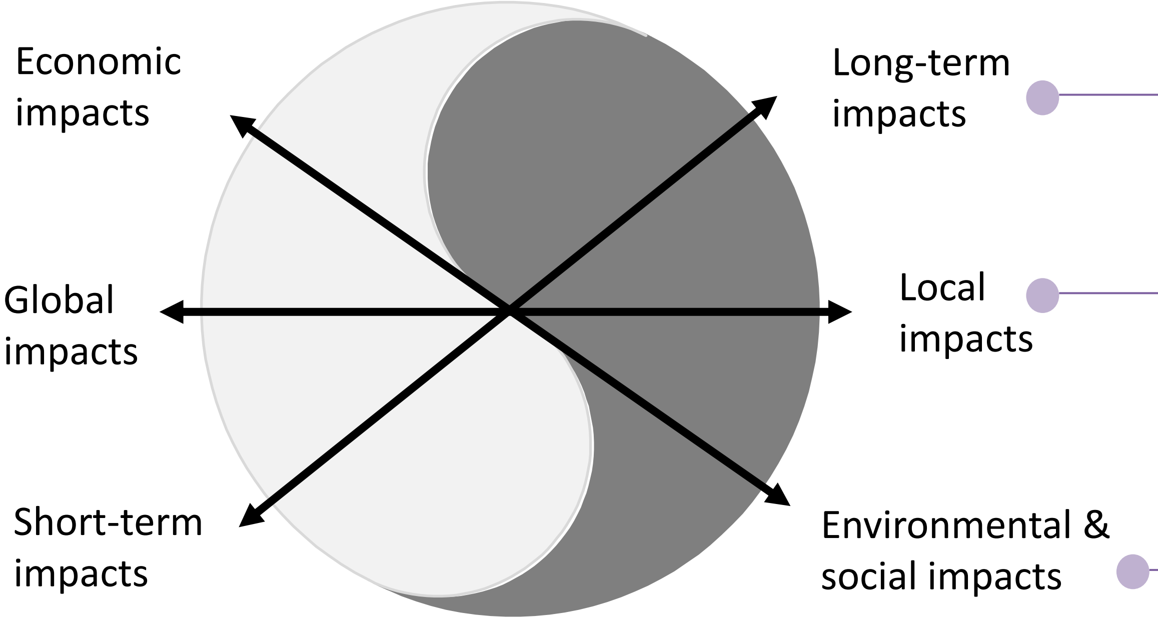
Paradox: contradictory yet interrelated elements (dualities) that exist simultaneously and persist over time

Dualities (A and B) – Opposites that exist within a unified whole

- Internal boundary creates distinction and highlights opposition
- External boundary encourages synergies by constructing the unified whole

(Smith and Lewis, 2011)

Paradoxes of Identification: significance of impacts

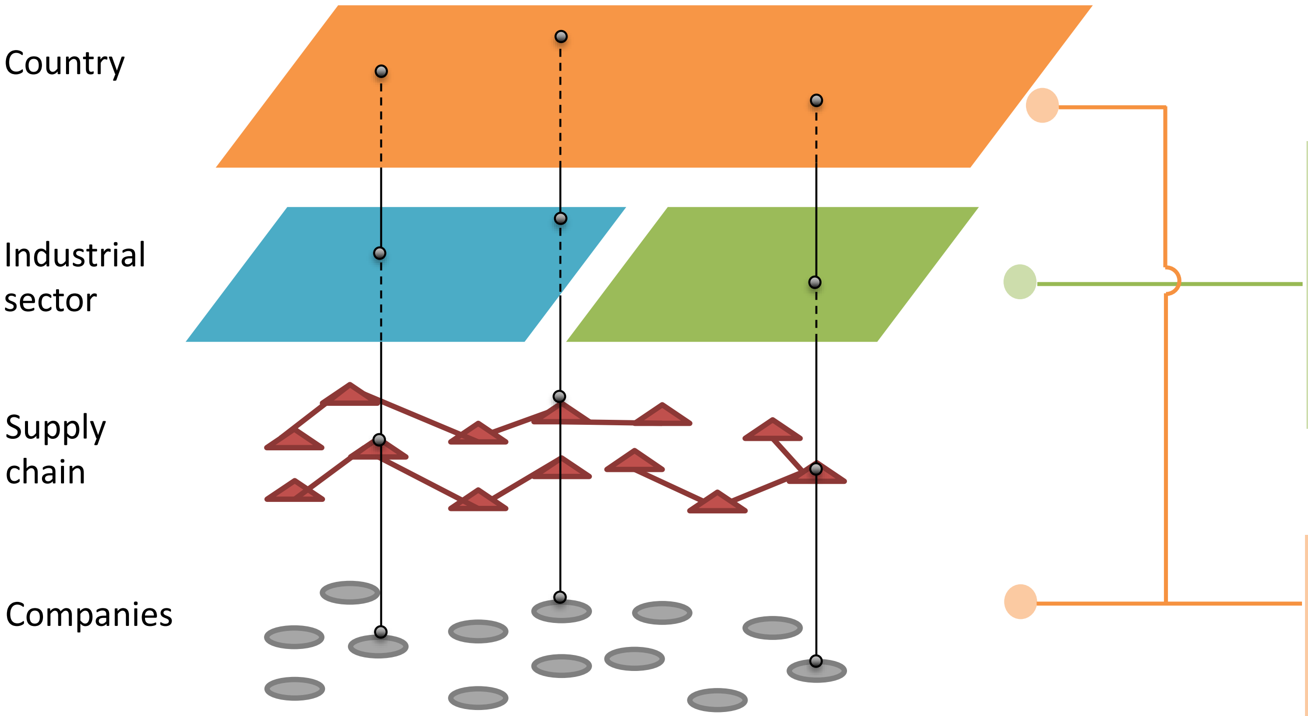


Conflicting prioritisation of short-term vs long-term impacts

Conflicting prioritisation of global impacts (e.g. climate change) vs local impacts (e.g. human rights, pollution)

Conflicting prioritisation of economic impacts and environmental & social impacts

Paradoxes of Identification: multiple organisational levels



Conflicting perception/assessment of criticality of a certain material within an organisational layer, e.g. company in Industrial Sector A (technology A) vs company in Industrial Sector B (technology B)

Conflicting perception/assessment of criticality of a certain material across organisational layers, e.g.: Company vs Country

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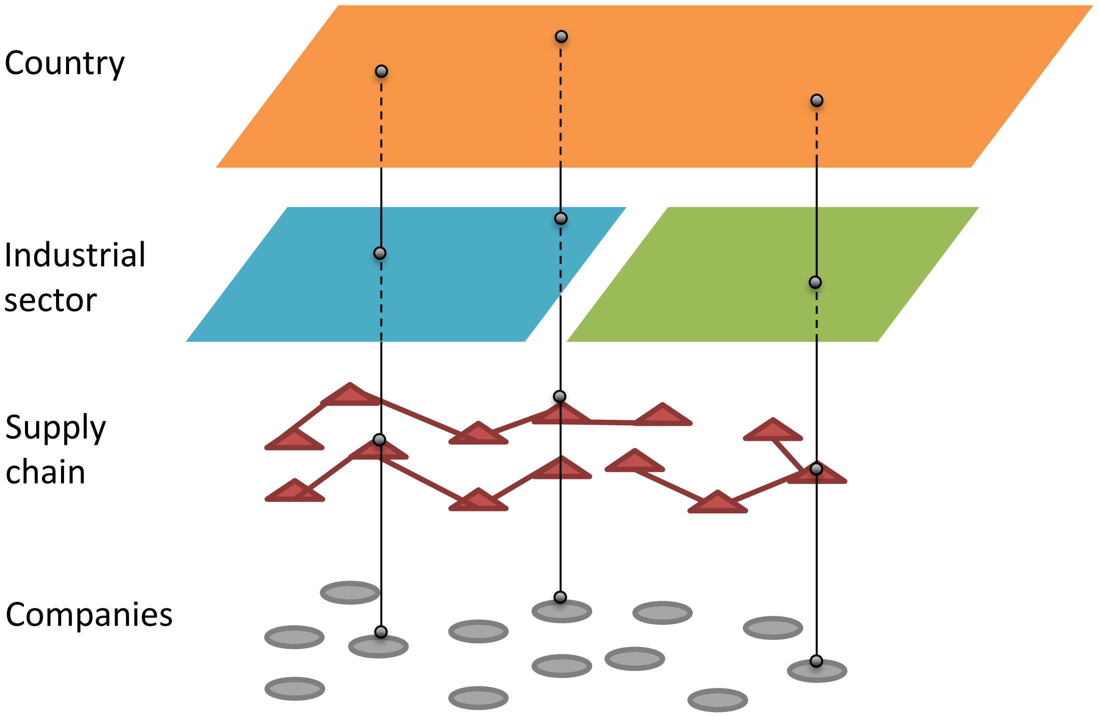
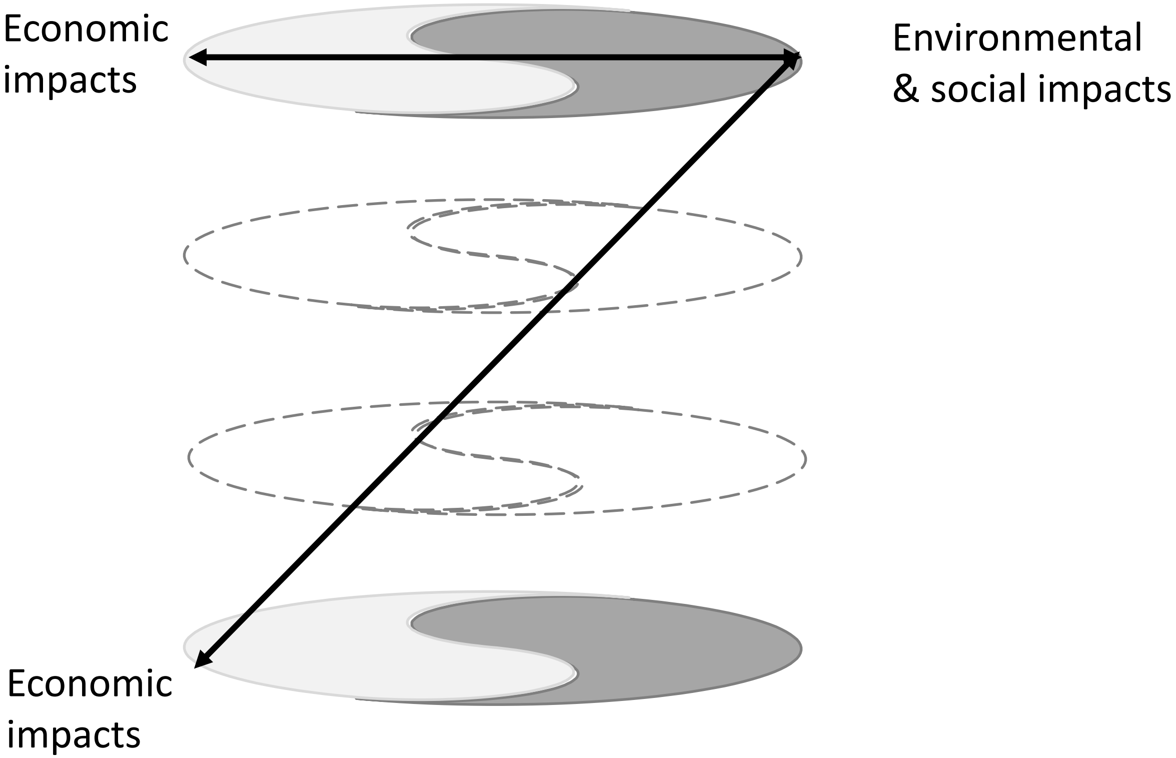
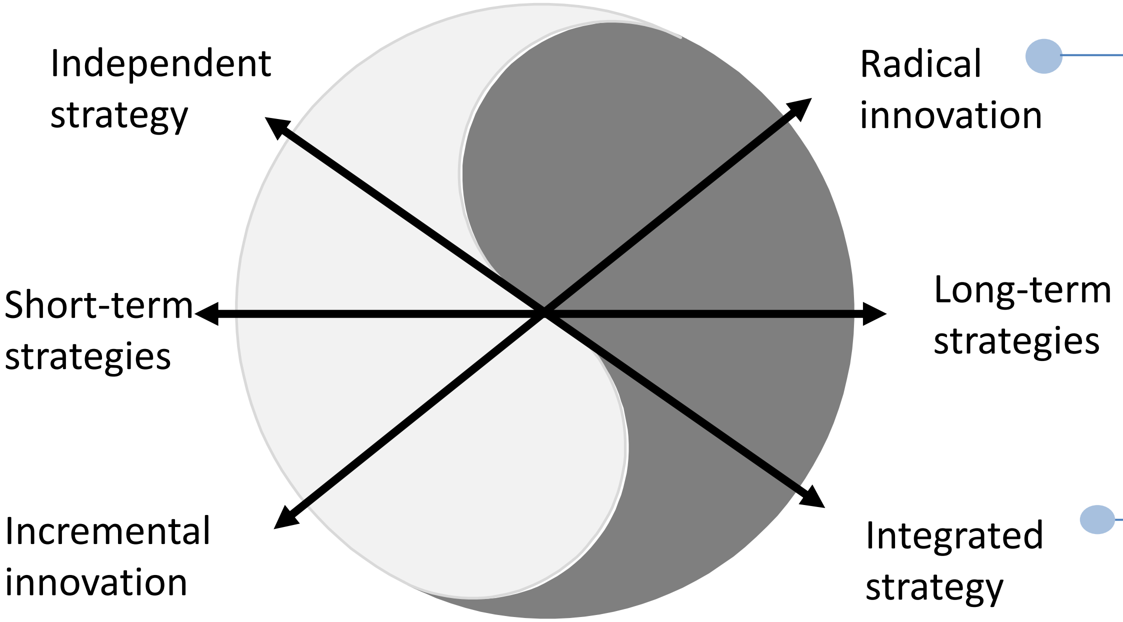
Paradoxes of Identification: multiple organisational levels





Paradoxes of Mitigation



Incremental innovations (e.g. material efficiency) VS Radical innovations (e.g. new technology that enables substitution)

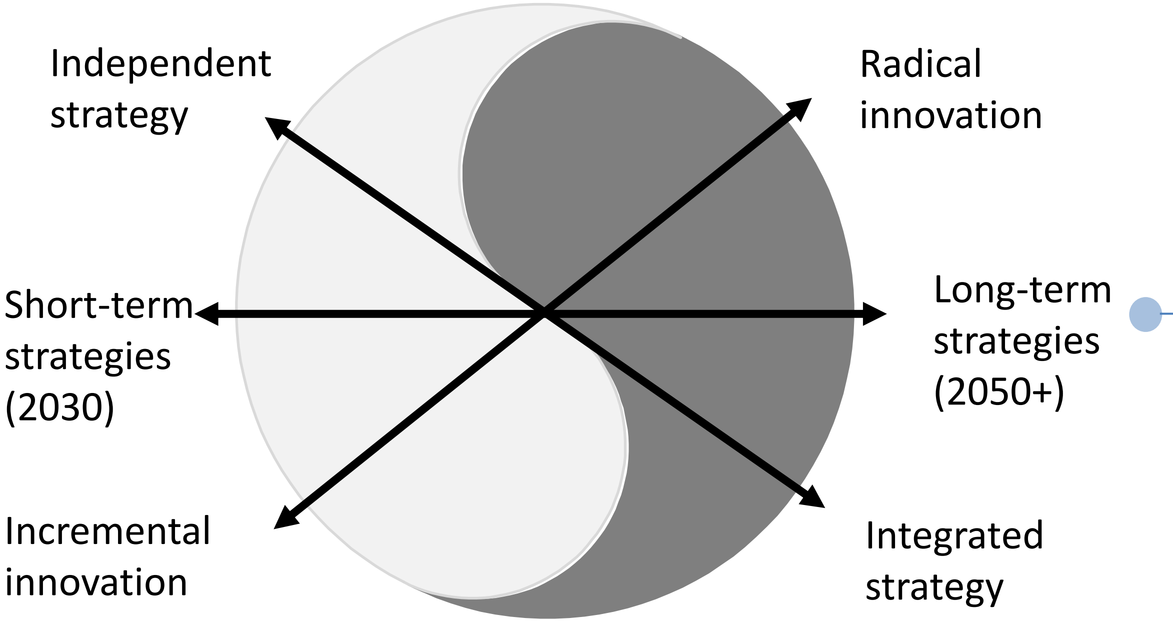
Feasibility (speed) of implementation VS impact on criticality state

Independent (e.g. material efficiency) VS integrated, systemic efforts (e.g. Circular Economy)

Individual VS collective (aligned) efforts*

**** No one is responsible for criticality today***

Paradoxes of Mitigation



Independent strategy

Radical innovation

Short-term strategies (2030)

Long-term strategies (2050+)

Incremental innovation

Integrated strategy

Conflicting short-term and long-term mitigation strategies

Deployment of strategies that favour short-term conditions may have detrimental impact in long-term (and vice versa).

Other relevant considerations:

- Time for a strategy to be developed and deployed
- Path dependence
- Proactive vs reactive action
- Problem shifting to the 'future'

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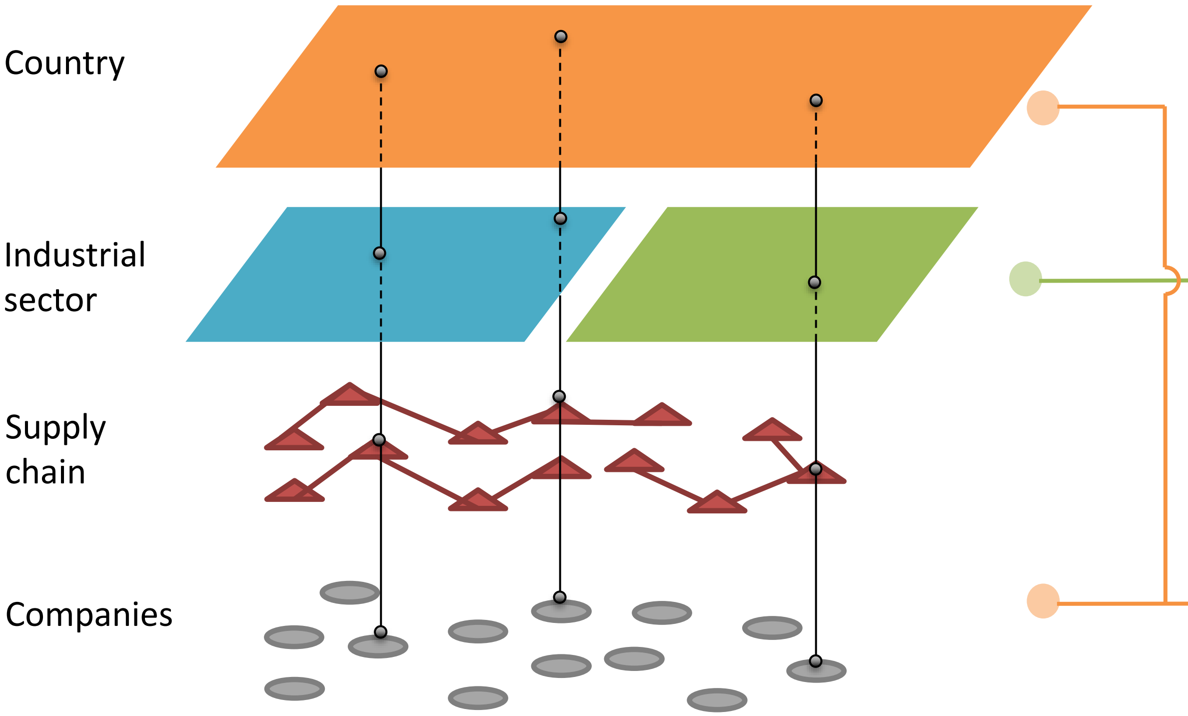
Paradoxes of Mitigation: multiple organisational levels



Misalignment of strategies is problematic because it diminishes overall efficiency and effectiveness of mitigation efforts (and thus resilience of an industrial system), leads to problem shifting (e.g. to another SC position, industrial system, country)

Conflicting mitigation strategies within an organisational layer, e.g.
company in Industrial Sector A (technology A) vs company in Industrial Sector B (technology B)

Conflicting mitigation strategies across organisational layers, e.g.: Company vs Country

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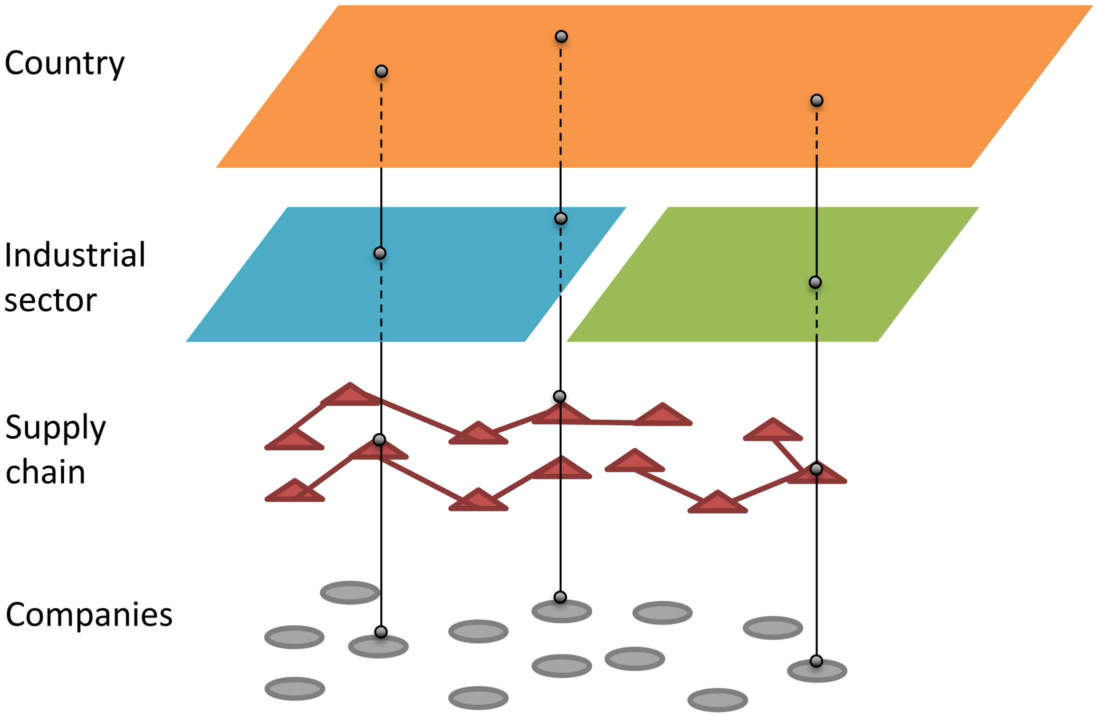
Paradoxes of Mitigation: multiple organisational levels

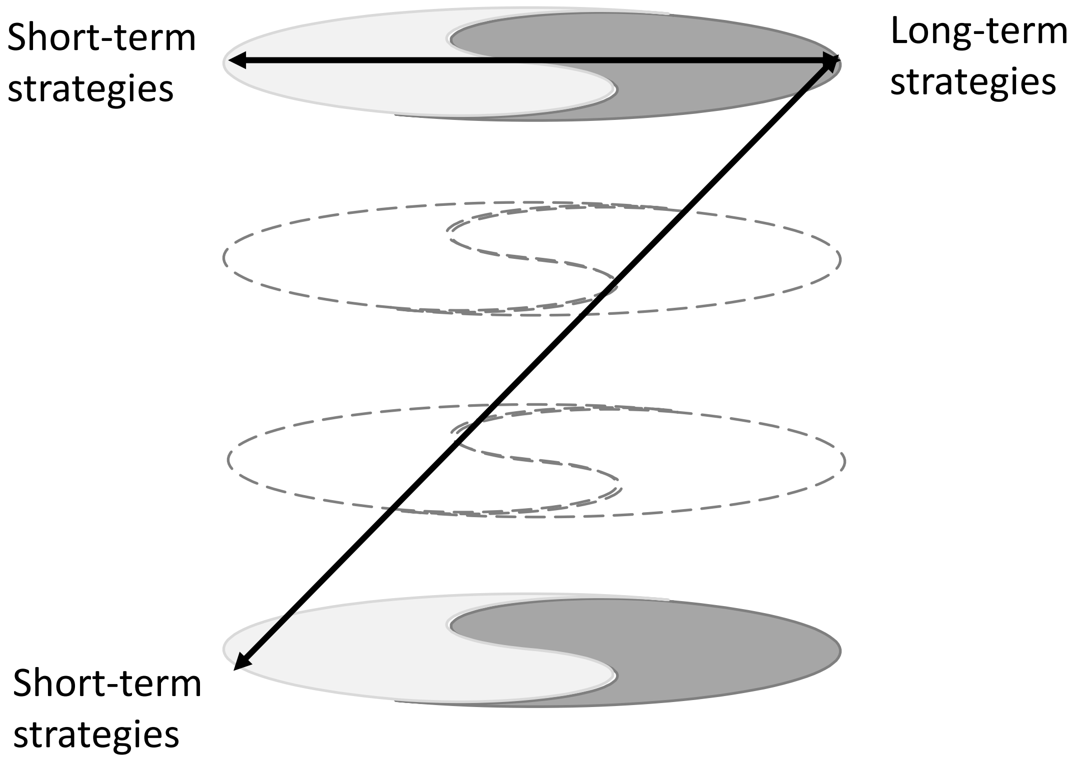


Country

Industrial sector

Supply chain

Companies



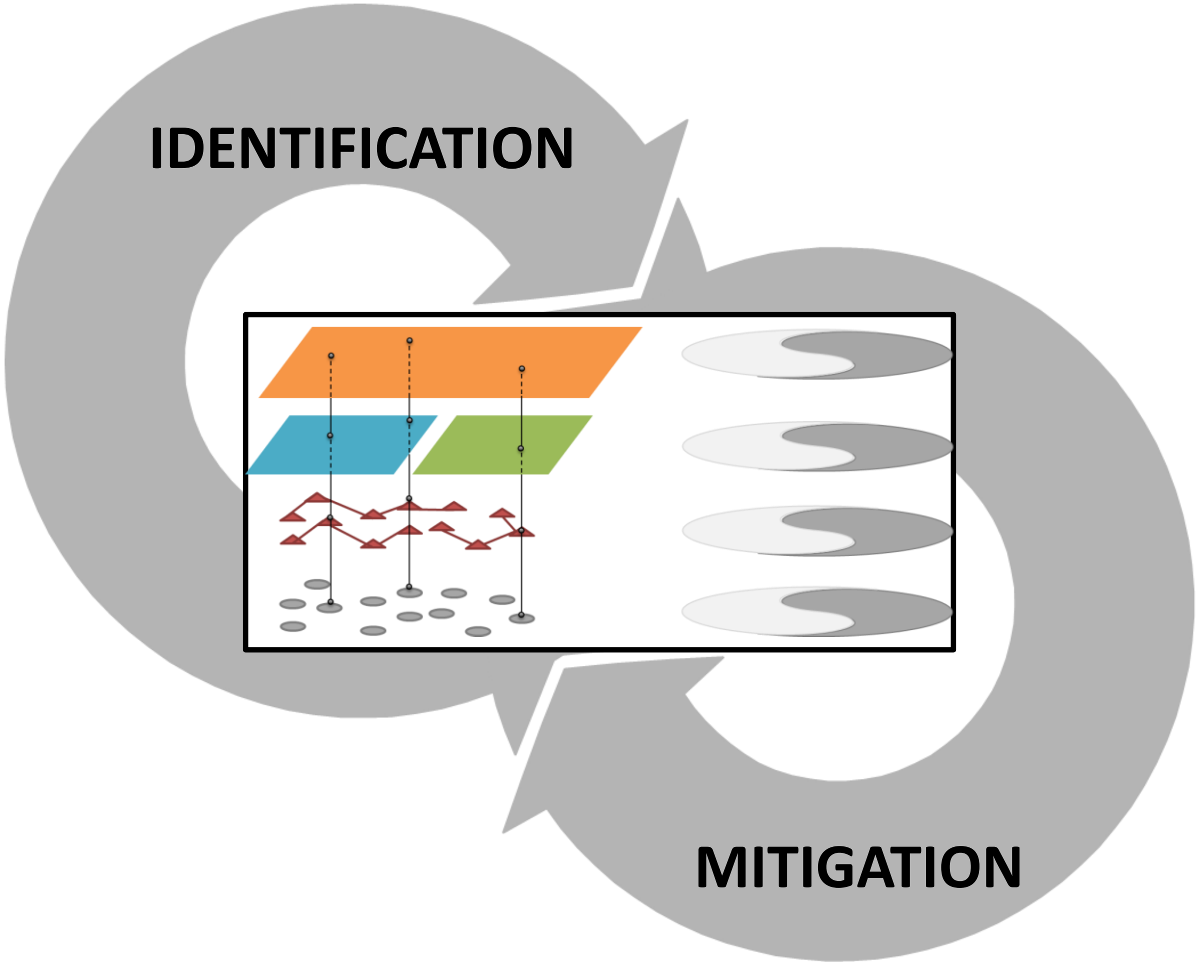
Short-term strategies

Long-term strategies

Short-term strategies

Conclusion

If we are to open the black box of material criticality, we need to embrace the phenomenon in its full complexity, and paradox perspective can assist with that



Thank you

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Please, reach us out if you would like to discuss paradoxes of material criticality and their management!

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