ENERGIAS RENOVÁVEIS

SPRING 2025

RENEWABLE ENERGY AND MINERAL RESOURCES

Bernardo Teixeira

Ciências ULisboa

INSTITUTO DOM LUIZ

TOPICS FOR TODAY

Raw Materials

Renewable Energy

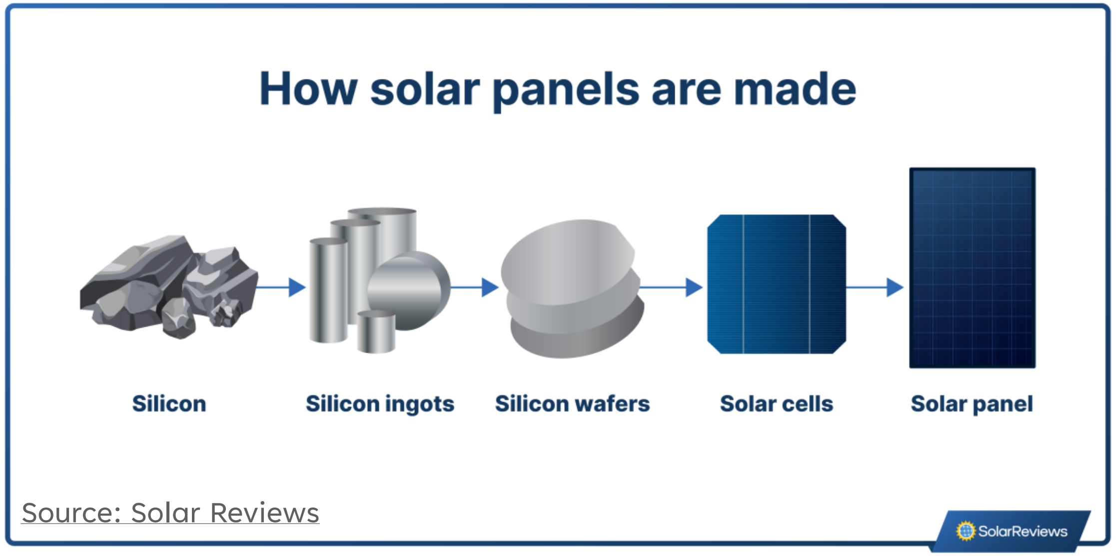
Economics

Policy

WHAT ARE RAW MATERIALS?

Basic material used to produce goods, finished goods, energy, or intermediate materials that feedstock for future finished products.

Source: NRC



Source: Solar Reviews

CRITICAL RAW MATERIALS (CRM)

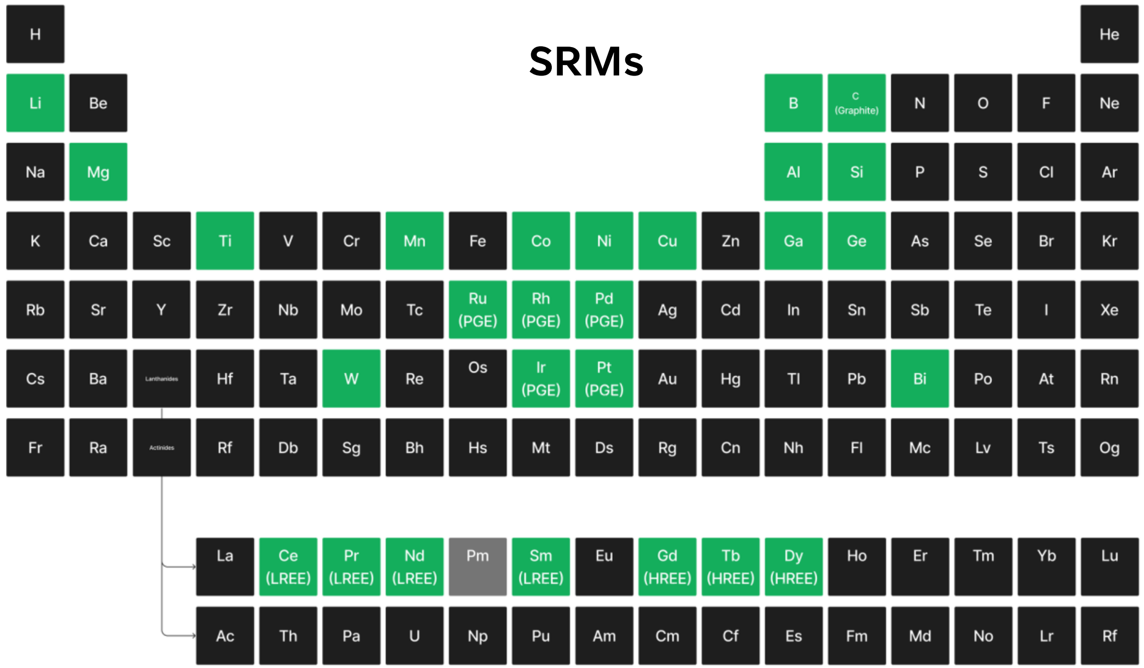
High economic importance

Highly vulnerable to supply disruptions

STRATEGIC RAW MATERIALS (SRM)

Sub-set of CRM

High strategic importance due to use in advanced technologies



Source: SLR Consulting

RESOURCES ≠ RESERVES

Concentration of naturally occurring material in or on the Earths crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially feasible.

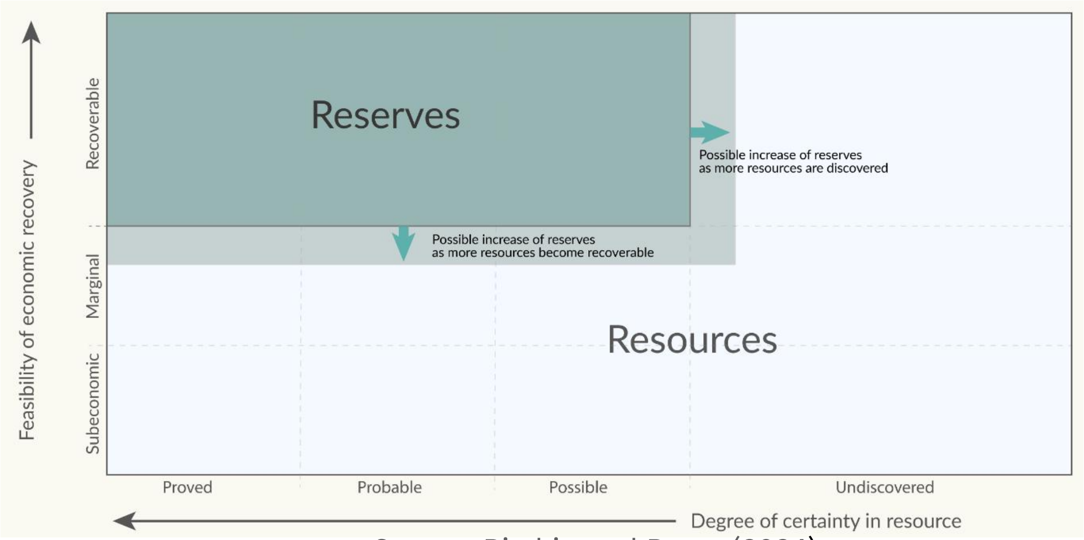
Source: USGS

Sub-set of Resources

Could be economically extracted or produced at the time of determination.

Need not signify that extractions facilities are in place and operative.

Includes only recoverable materials



Source: Ritchie and Roser (2024)

COPPER EXAMPLE

Estimated Resources – 1.6 Bt

Reserves – 280 Mt

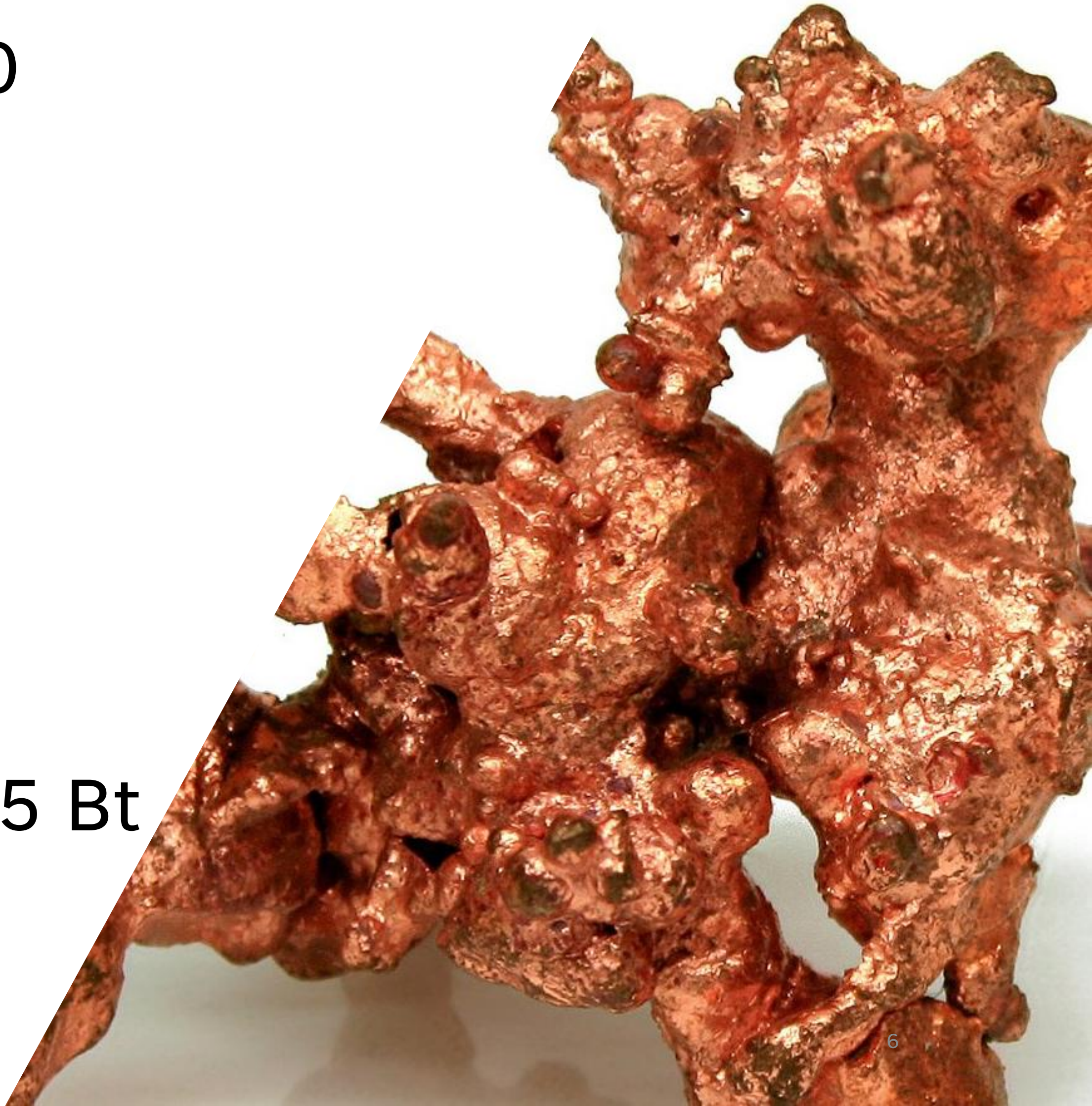
1970

Produced until today – 670 Mt

Reserves – 880 Mt

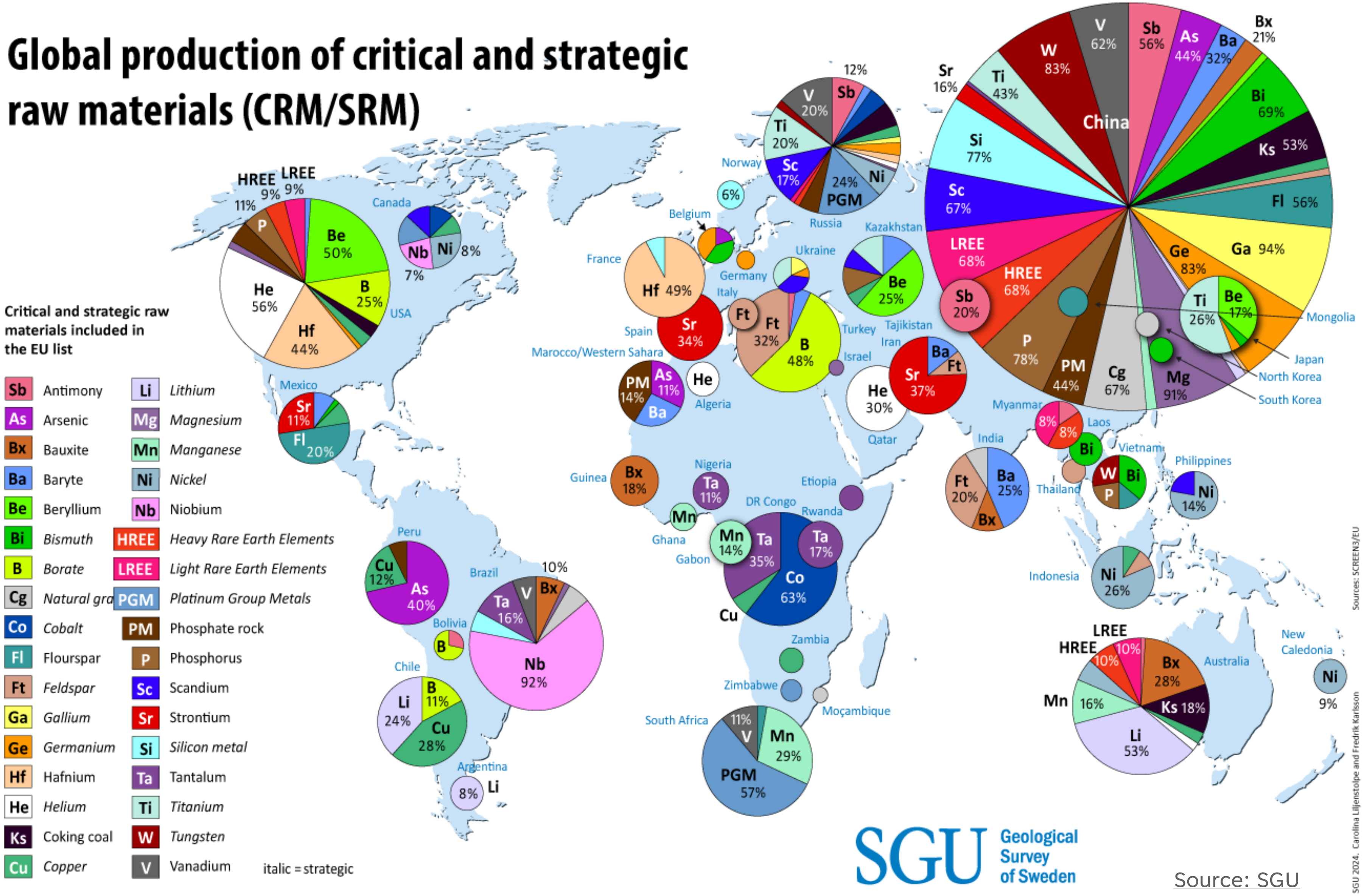
Identified Resources – 2.1 Bt

Estimated undiscovered Resources – 3.5 Bt



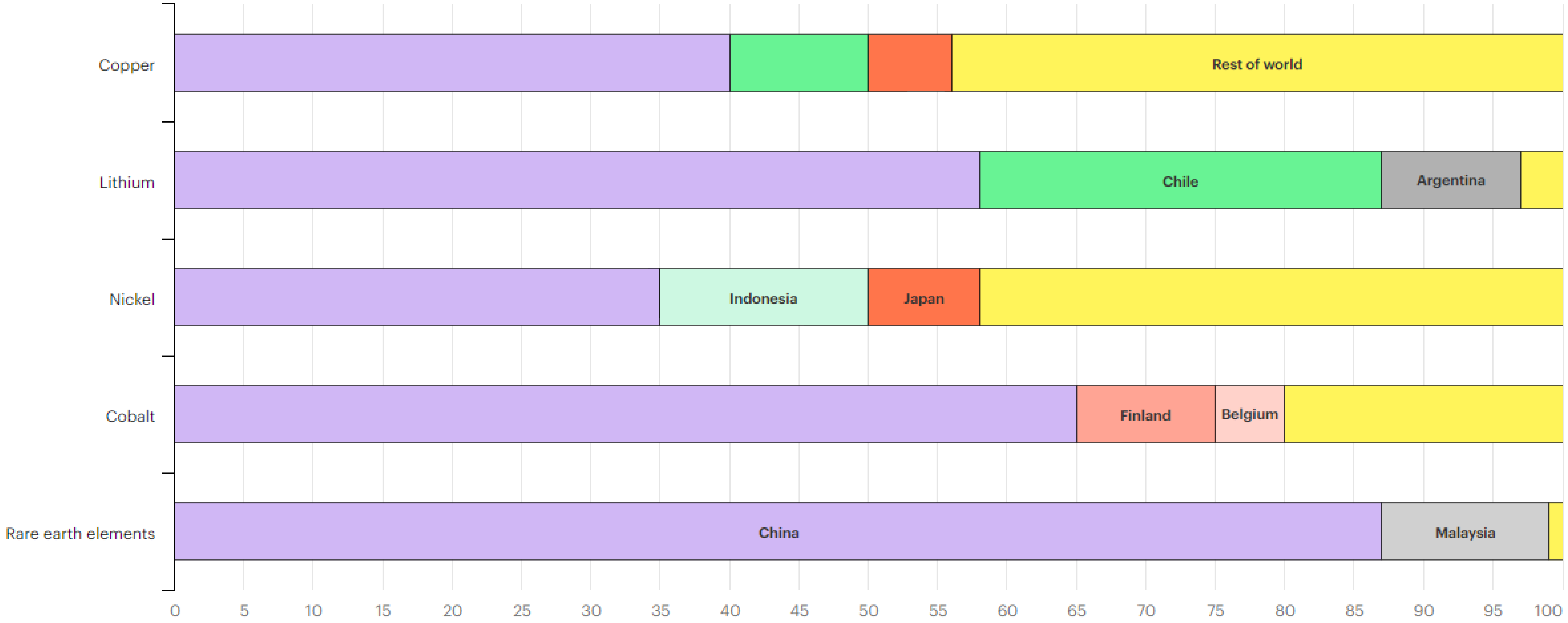
Source: USGS

CRM/SRM GLOBAL PRODUCTION



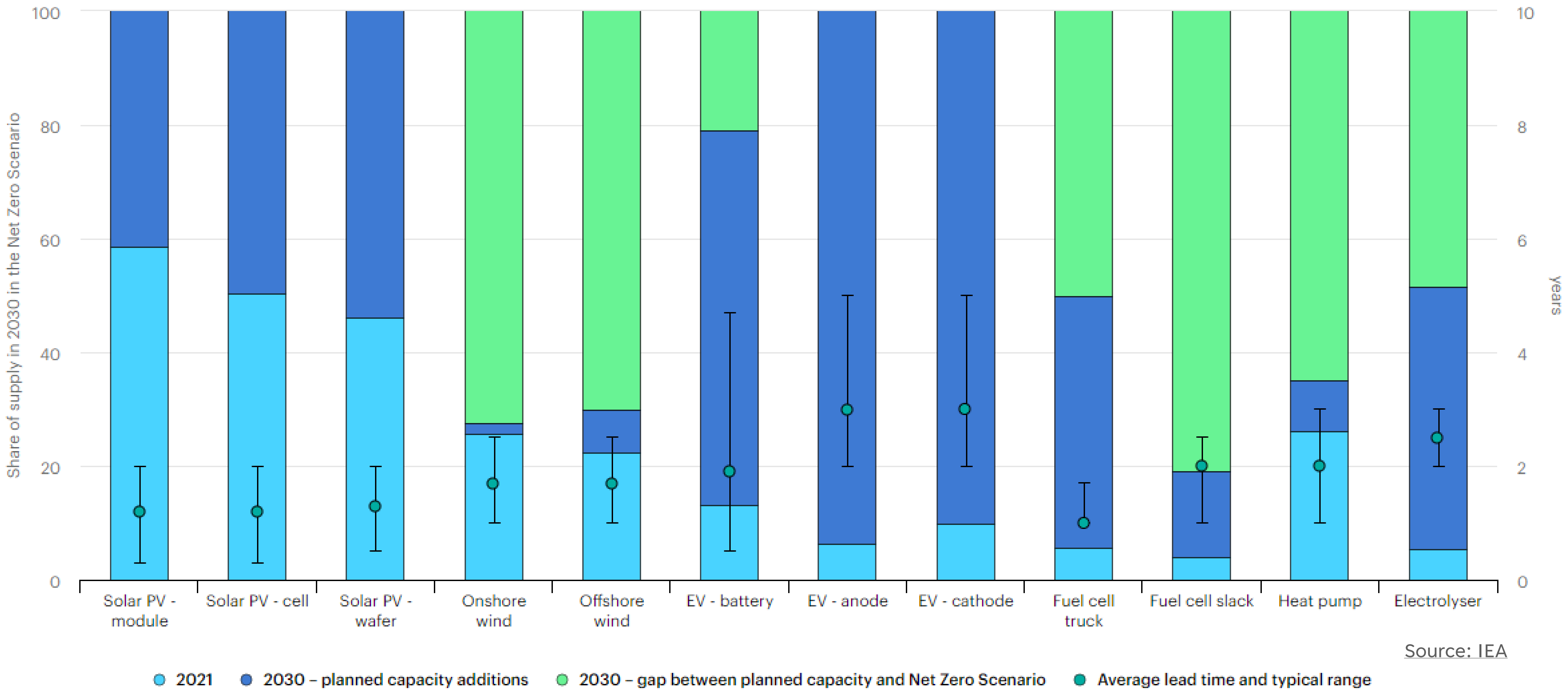
Source: SGU

CRM/SRM PROCESSING



Source: IEA

GREEN TECHNOLOGIES MANUFACTURING



Source: IEA

MARKET CONCENTRATION – HERFINDAHL-HIRSCHMAN INDEX

Market concentration measure

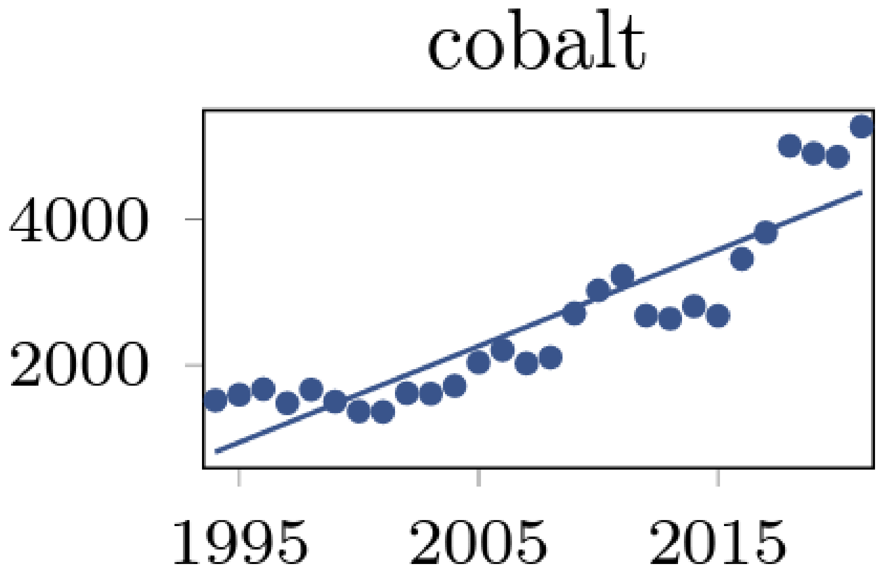
$$HHI = s_1^2 + s_2^2 + s_3^2 + \dots s_n^2 = \sum_{i=1}^{n} s_i^2$$

Larger firms have a proportionately greater impact in market dynamics

The HHI index	Market concentration
<0.01 (or 100)	Highly competitive market
<0.15 (or 1500)	Unconcentrated market
0.15<the HHI index<0.25 (or 1500 to 2500)	Moderate concentration
>0.25 (or 2500)	High concentration

Source: Merger Assessment Guidelines, 2010

Amplification of weight larger firms



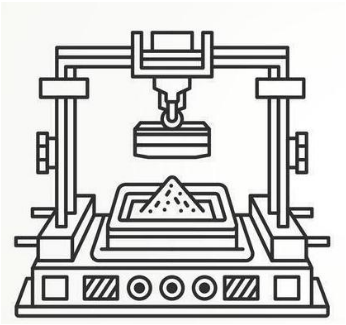
Source: Bucciarelli *et al.* (2024)

CRITICAL RAW MATERIALS ACT (CRMA)

2030 Benchmark

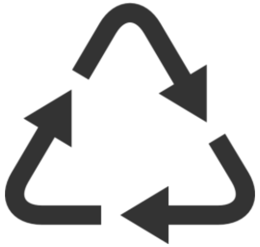
EU Extraction

- 10 % annual consumption



EU Processing

- 40 % annual consumption



EU Recycling

- 15 % annual consumption

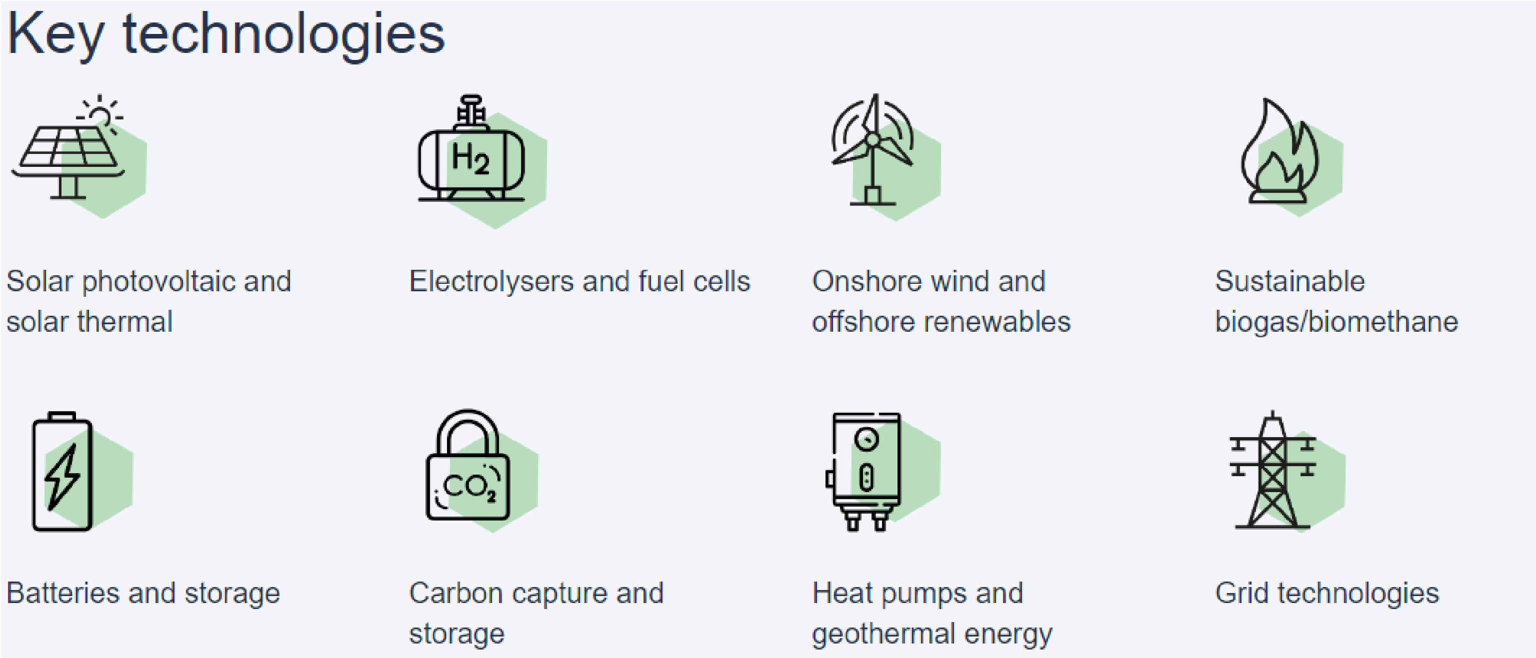
External Sources

- Not more than 65% of annual consumption of each SRM at any relevant stage of processing from a single third country

NET ZERO INDUSTRY ACT (NZIA)

Scale up manufacturing of clean technologies in the EU

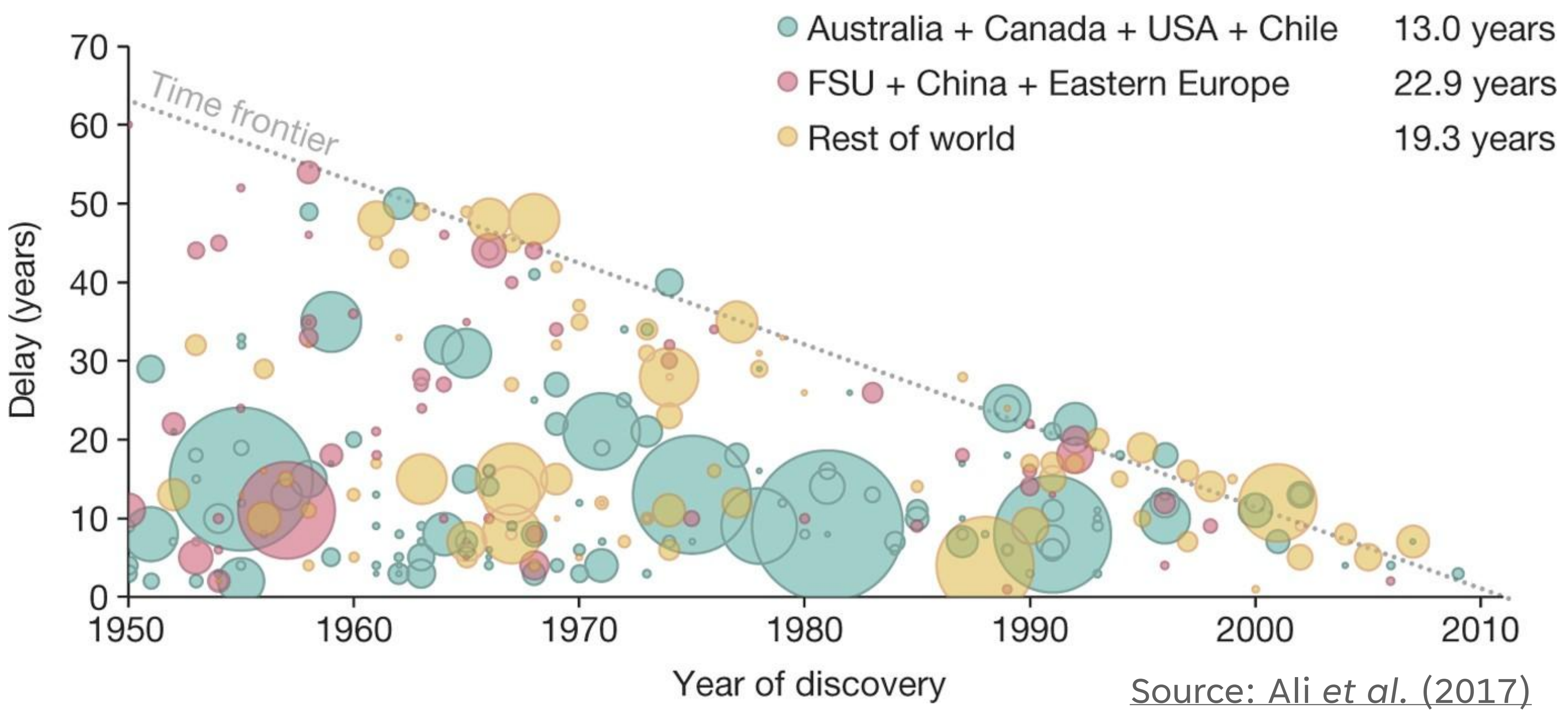
Increase manufacturing capacity of technologies that support the clean energy transition and release extremely low, zero, or negative GHG emissions



Goal?

40 % manufacturing capacity of the annual deployment needs in 2030

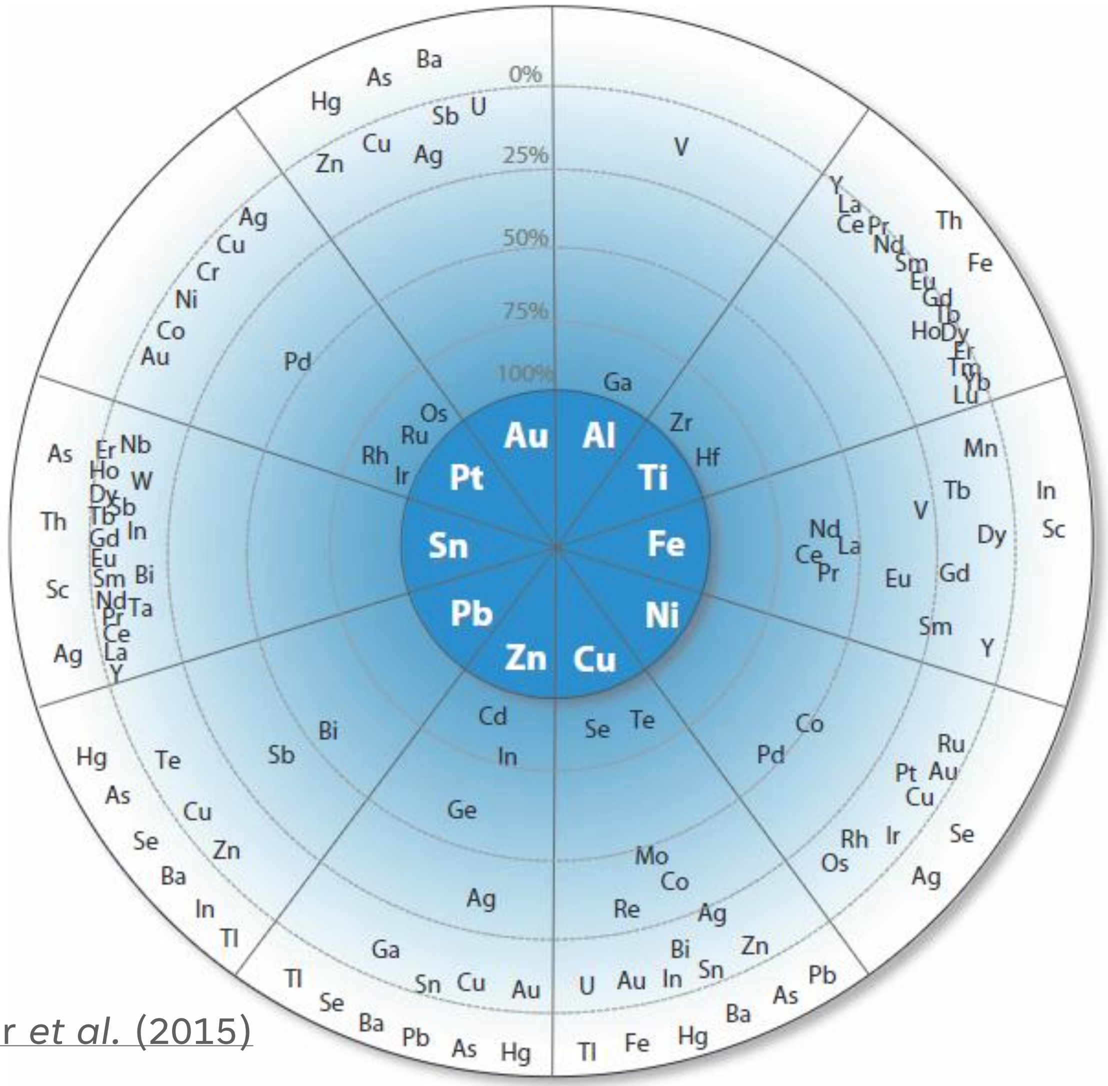
DELAYS IN APPROVED COPPER PROJECTS



Source: Ali *et al.* (2017)

Mining industry is not in a strong position to quickly find and bring on stream new capacity to meet a shortfall in production.

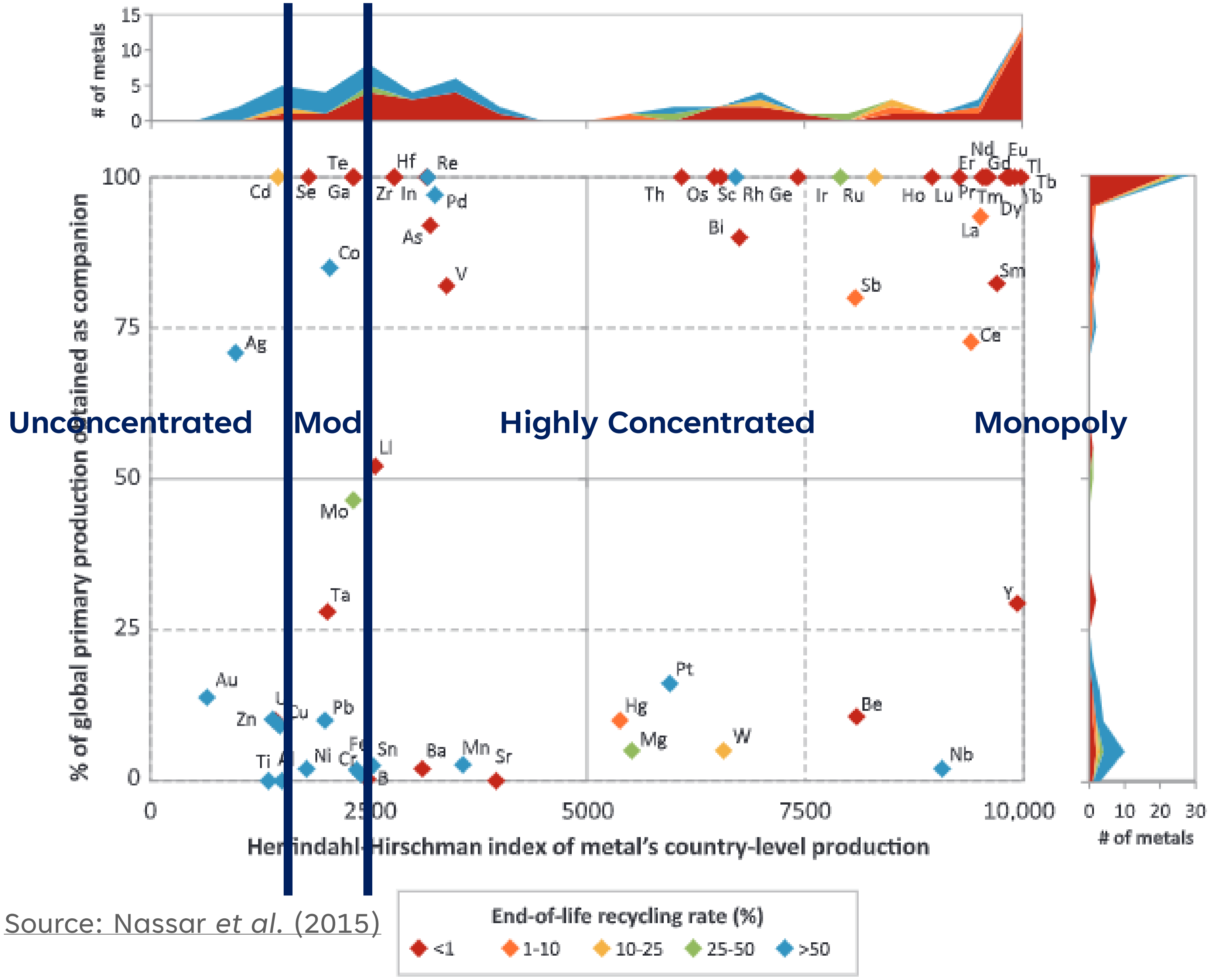
HOST, COPRODUCT, BYPRODUCTS, COMPANIONS



Source: Nassar *et al.* (2015)

The principal host metals form the inner circle. Companion elements appear in the outer circle at distances proportional to the percentage of their primary production (from 100 to 0%) that originates with the host metal indicated.

The companion elements in the white region of the outer circle are elements for which the percentage of their production that originates with the host metal indicated has not been determined.



HHI & COMPANIONALITY

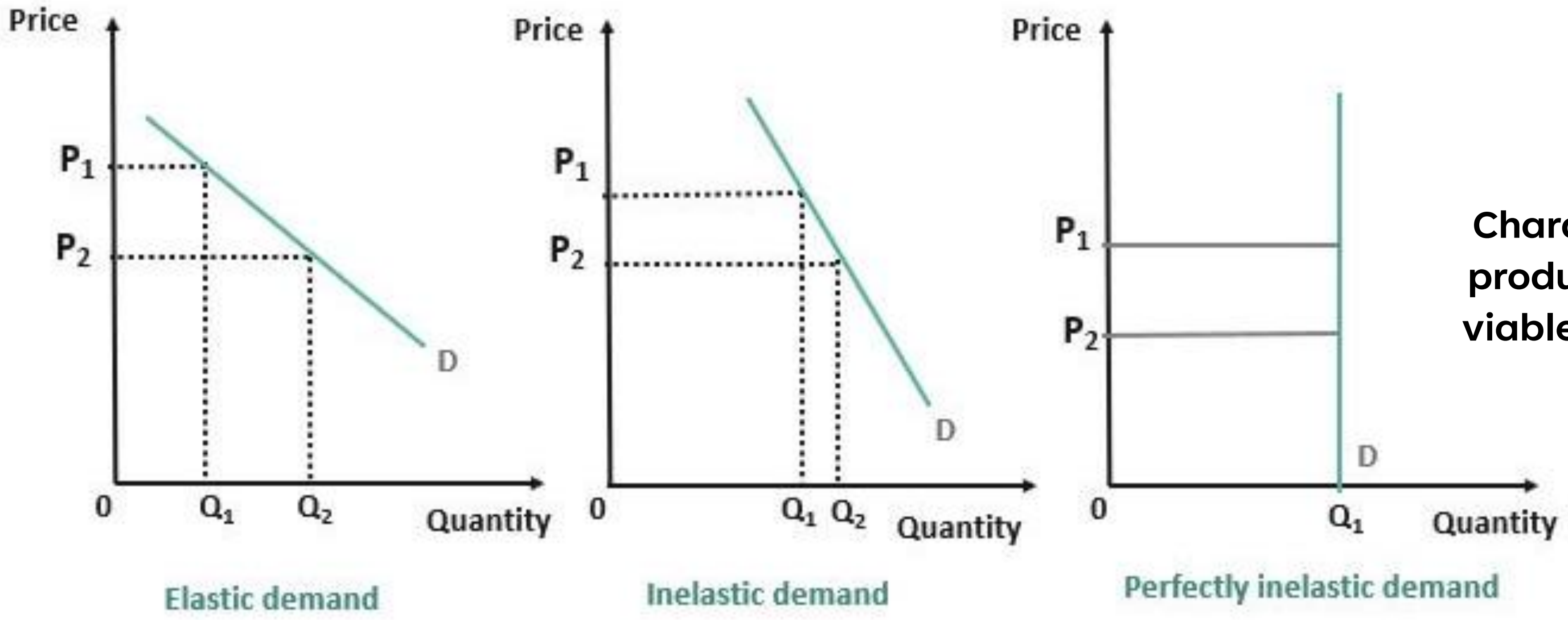
Source: Nassar *et al.* (2015)

DEMAND ELASTICITY

Elasticity measures the "sensitivity" of one variable with respect to another.

$$\varepsilon_{x,y} = \frac{\%\Delta x}{\%\Delta y}.$$

Many different applications (e.g., own-price elasticity of demand).

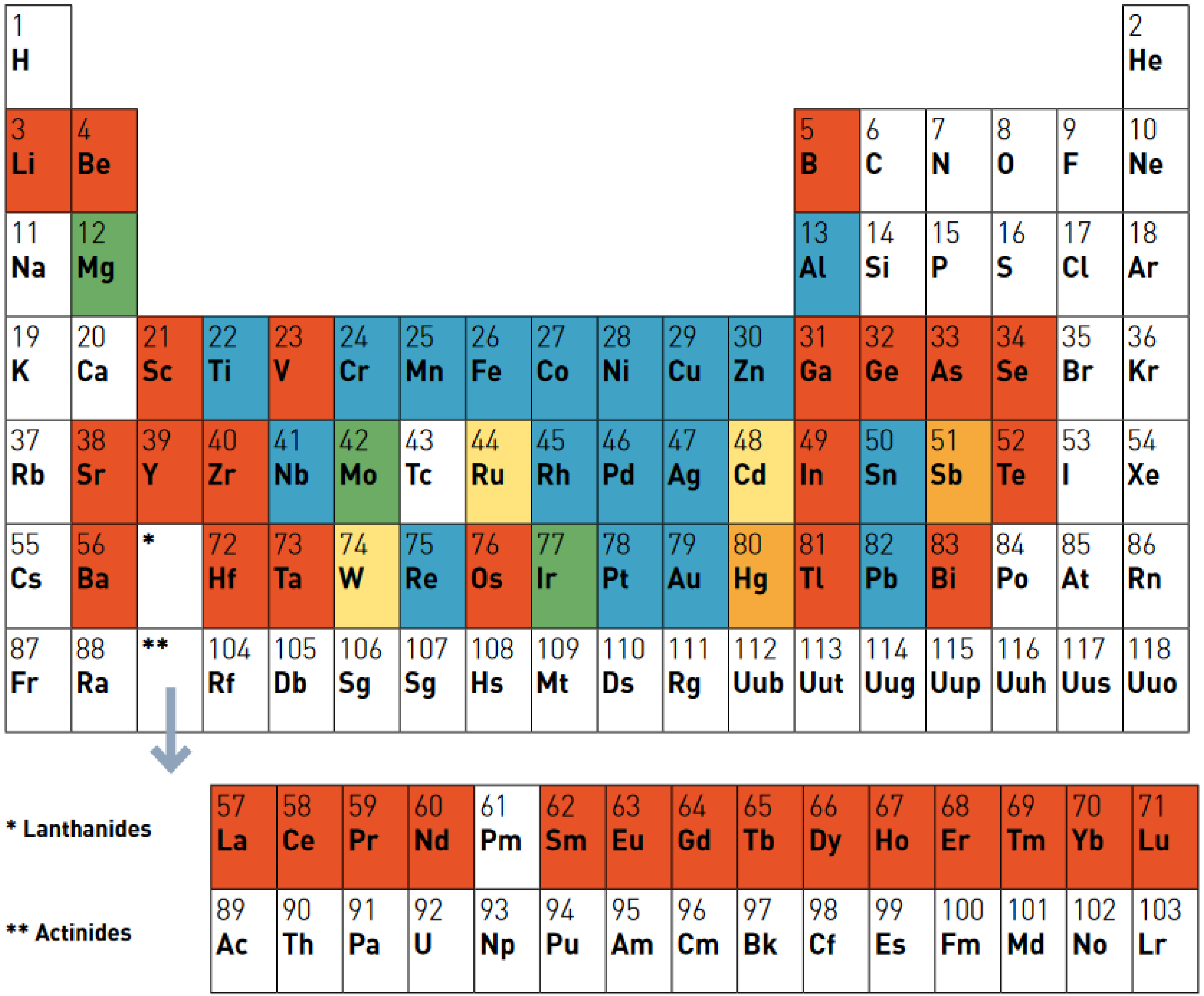


Characteristic of products without viable substitutes

RECYCLING RATE

EOL – RR

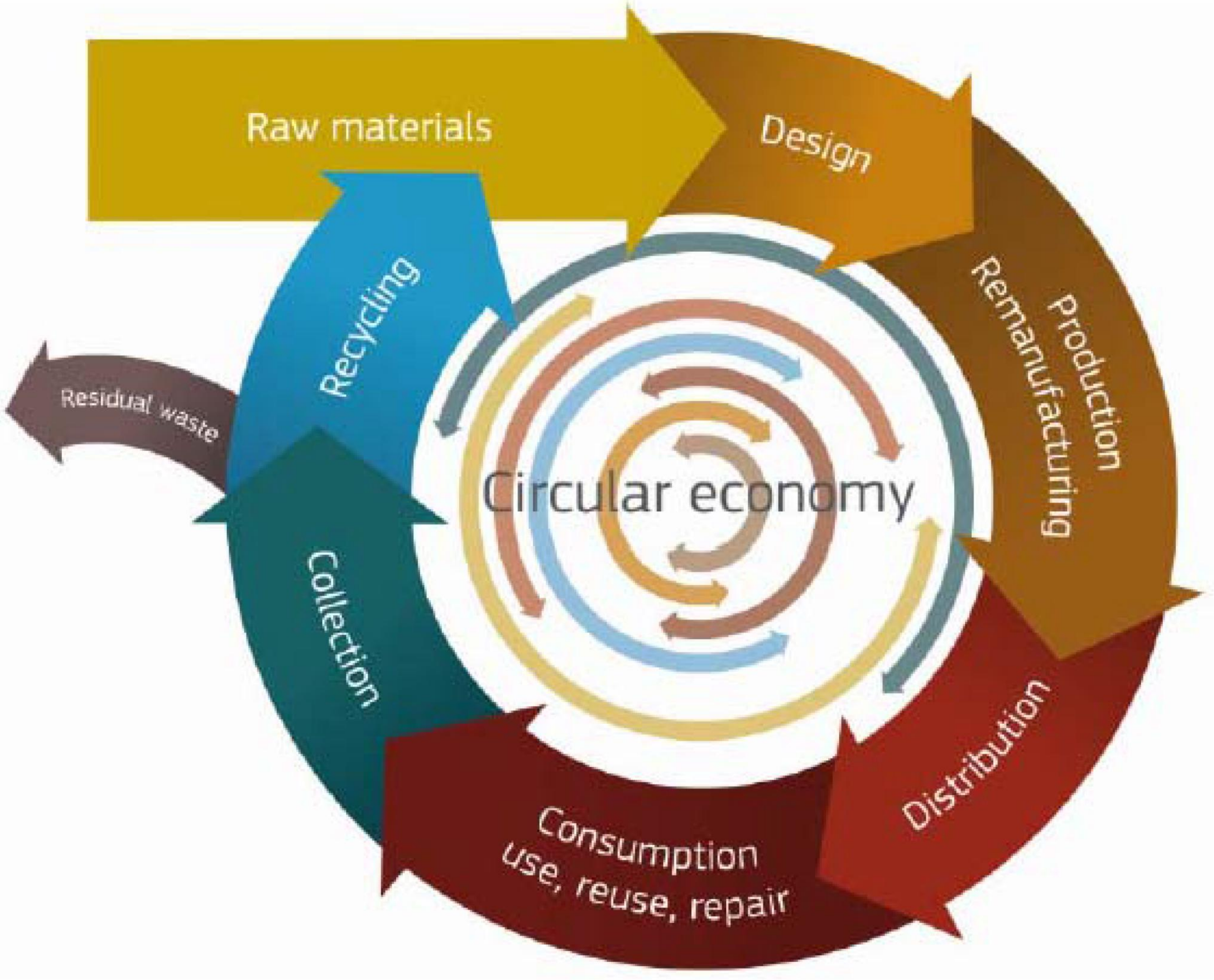
Strongly influenced by the least efficient link in the recycling chain, typically initial collection activity



- > 50 %
- > 25–50 %
- > 10–25 %
- 1–10 %
- < 1 %

Source: UNEP (2011)

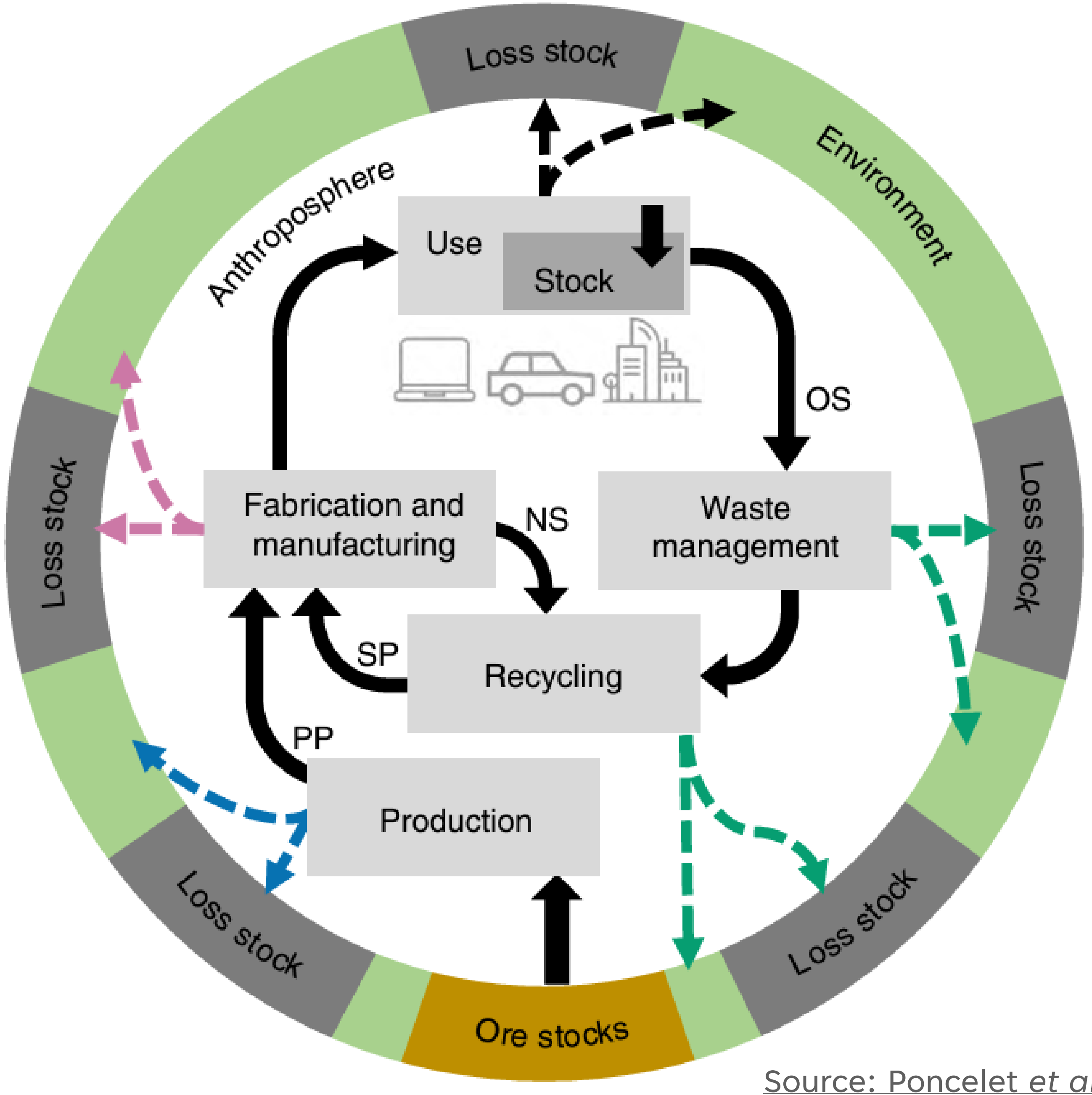
LIFE CYCLE



Source: Hageluken *et al.* (2016)

"metals are the perfect material for a circular economy, as they can be recycled again and again without losing their properties."

LIFE CYCLE



Source: Poncelet *et al.* (2022)

CASE STUDY

LITHIUM RESOURCES AND ELECTRIC MOBILITY IN PORTUGAL WITHIN THE EU CONTEXT

TEIXEIRA, CENTENO BRITO AND MATEUS (2025)

CASE STUDY - OBJECTIVE

Quantify Li required for Portugal electric mobility roadmaps

Can local resources realistically meet the demand?

Lepidolite-dominant pegmatite (Gonçalo-Seixo Amarelo)

CASE STUDY - METHODOLOGY

BEV Implementation
(n vehicles; low/high demand)

Battery Size
(kWh, min/max)

Total kWh
(low/high, min/max)

Lithium Material Intensity
(kg/kWh, min/max)

Technology Market Share
Scenarios (%)

Lithium Demand
(min/max; low/high)

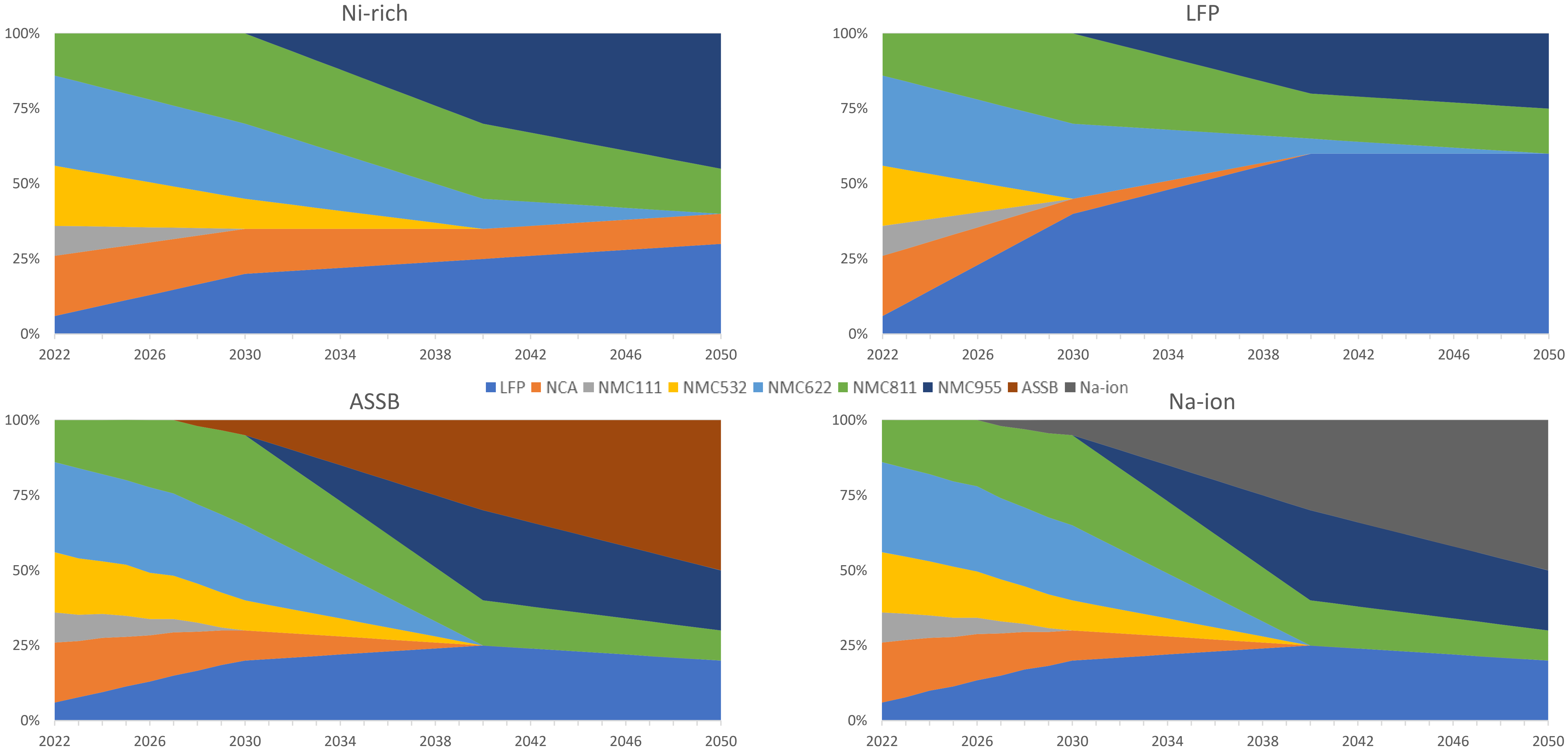
Recycling Scenarios
(%)

Lithium Demand

VS

Lithium in Portugal

CASE STUDY – MARKET SHARE

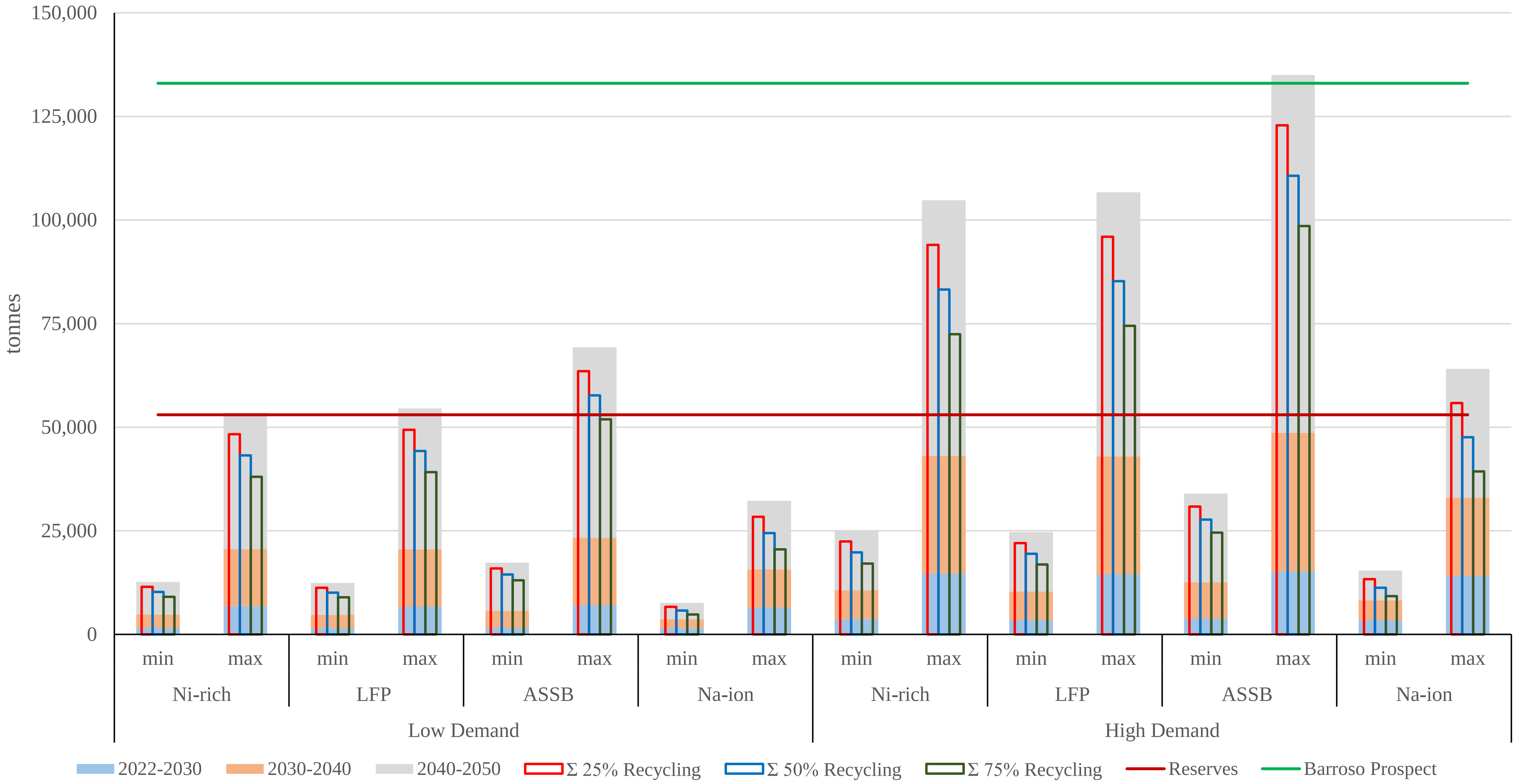


CASE STUDY – LITHIUM IN PORTUGAL

	Official		Mining Prospects				
	Reserves	Resources	Ore body (tonnes)	Dominant Li mineral phase	Li_2O in ore body	Li_2O (tonnes)	Li (tonnes)
USGS	60,000	270,000					
DGEG	53,000	306,000					
Alvarrões			3,900,000	Lepidolite	1.16%	45,240	20,991
Argemela			11,100,000	Amblygonite-Montebrasite	0.45%	49,950	23,177
Barroso			27,000,000	Spodumene	1.06%	286,200	132,797
Romano			10,300,000	Petalite	1.00%	103,000	47,792
Σ						484,390	224,757


Spodumene-dominant pegmatite (Adagói)

CASE STUDY – WHAT HAVE WE FOUND?



CASE STUDY – TAKE AWAYS

Li demand to increase 15-fold by 2030 and doubling every following decade.

Technology diversification may reduce primary Li demand by 40 %.

Secondary production from recycling will not be able to keep up with BEV implementation; may reduce Li demand by 40 %.

There is enough Li for our electric mobility transition if we choose to explore it.

UNANSWERED QUESTIONS

Slower market uptake form BEVs will allow a better match of supply and demand. At what cost?

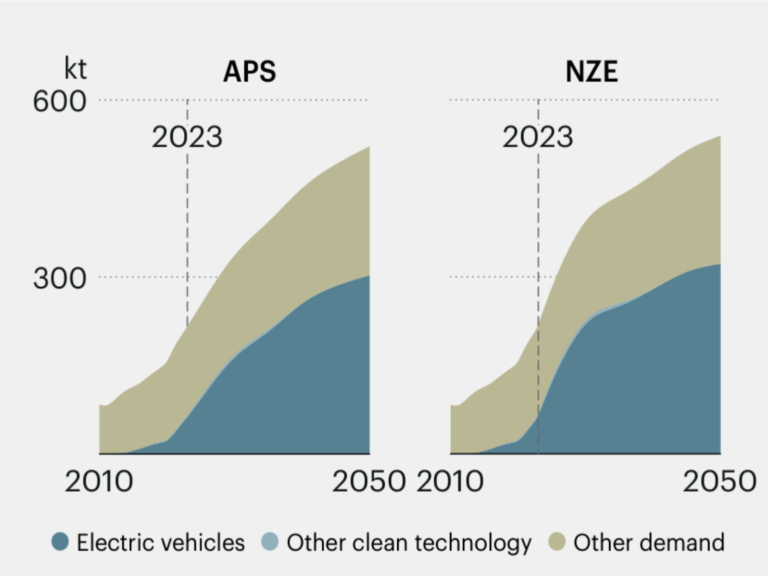
Slower transition might alleviate supply chains but will jeopardize several climate targets. Trade-offs need to be carefully investigated.

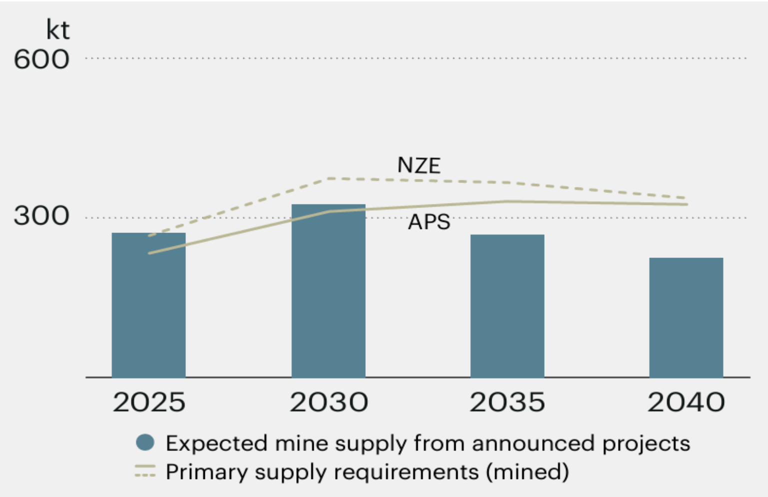
FINAL MESSAGES

RAW MATERIAL DEMAND

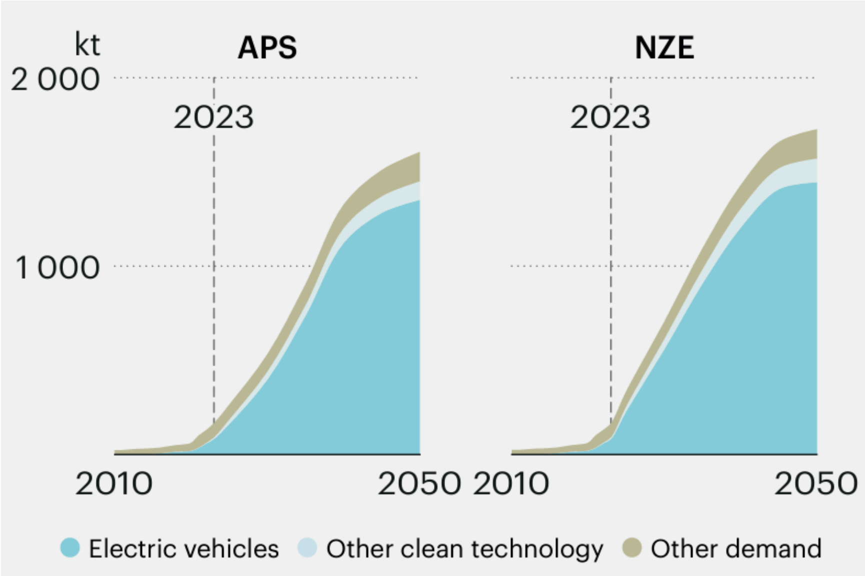
Source: IEA (2024)

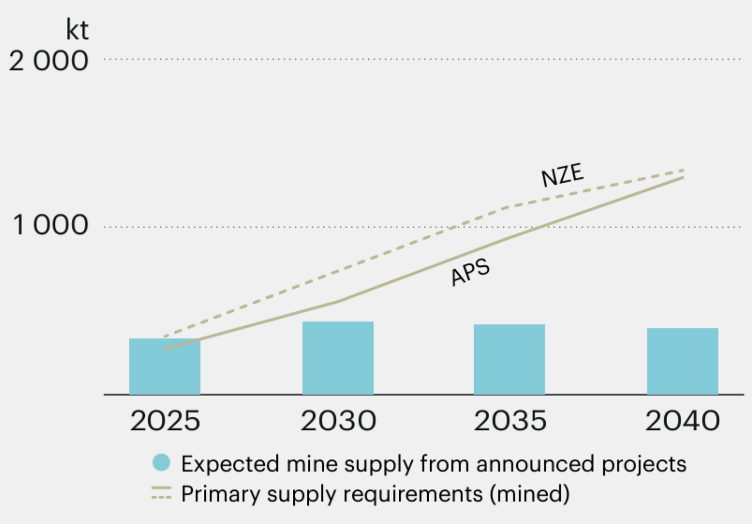
COBALT



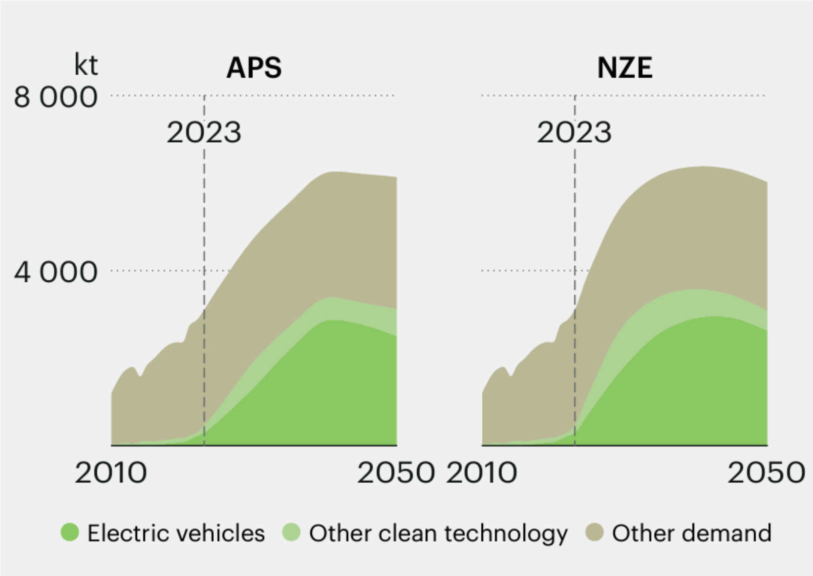


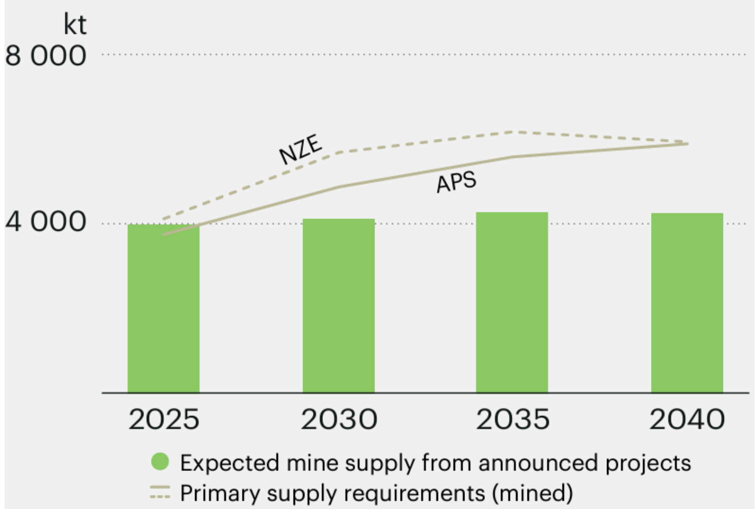
LITHIUM





NICKEL





MINERAL GRIEVANCE

Conde (2017)
Araujo et al. (2022)
Silva and Sareen (2023)
Arce and Nieto-Matiz (2024)

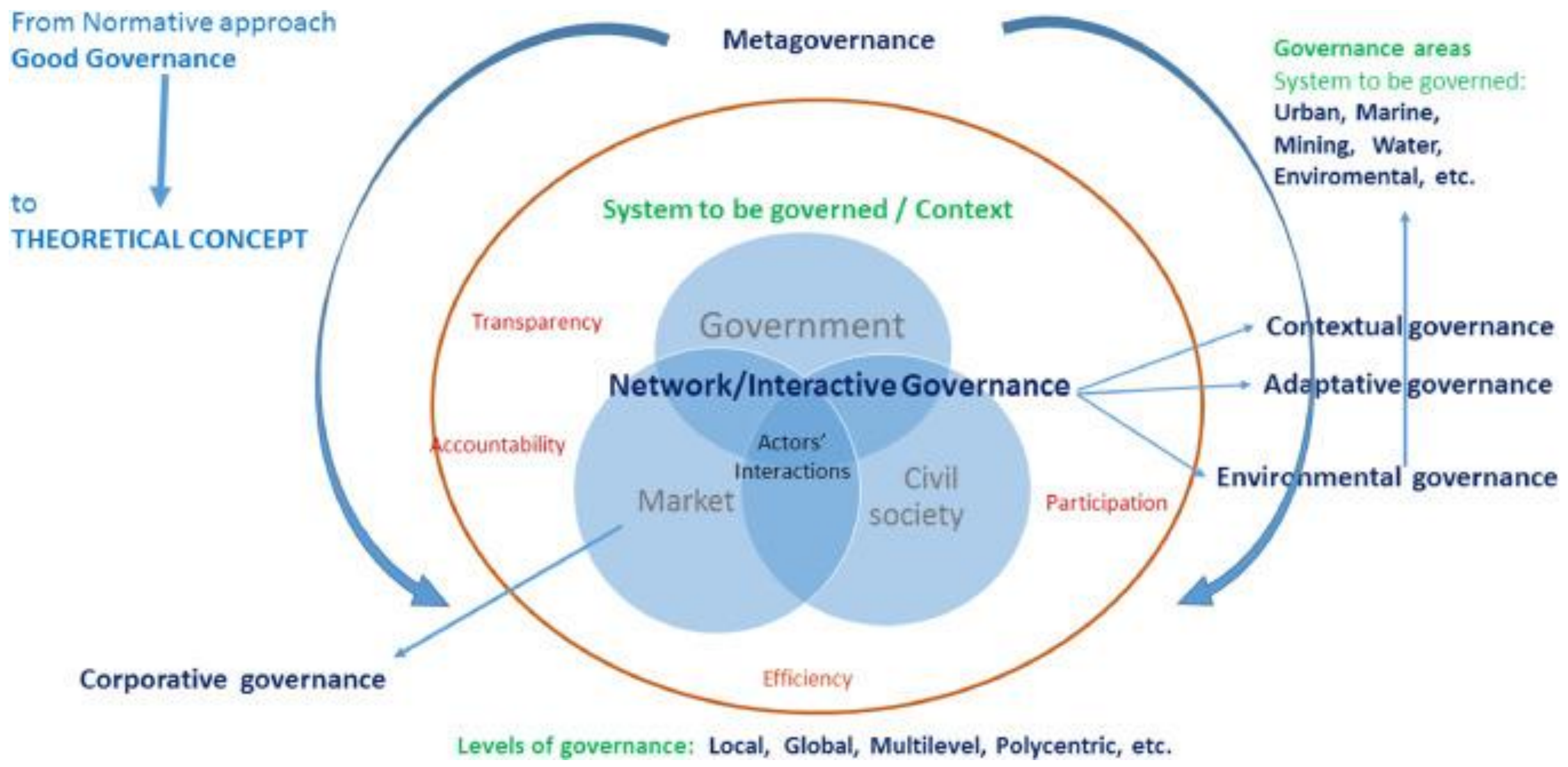
GOVERNANCE

Complex system or framework of processes, functions, structures, rules, laws and norms born out of the relationships, interactions, power dynamics and communication, which sets boundaries of acceptable conduct and practices, controls decision-making process, manages, allocates and mobilizes resources to effectively address specific needs, problems or challenges.

May be applied to anything...

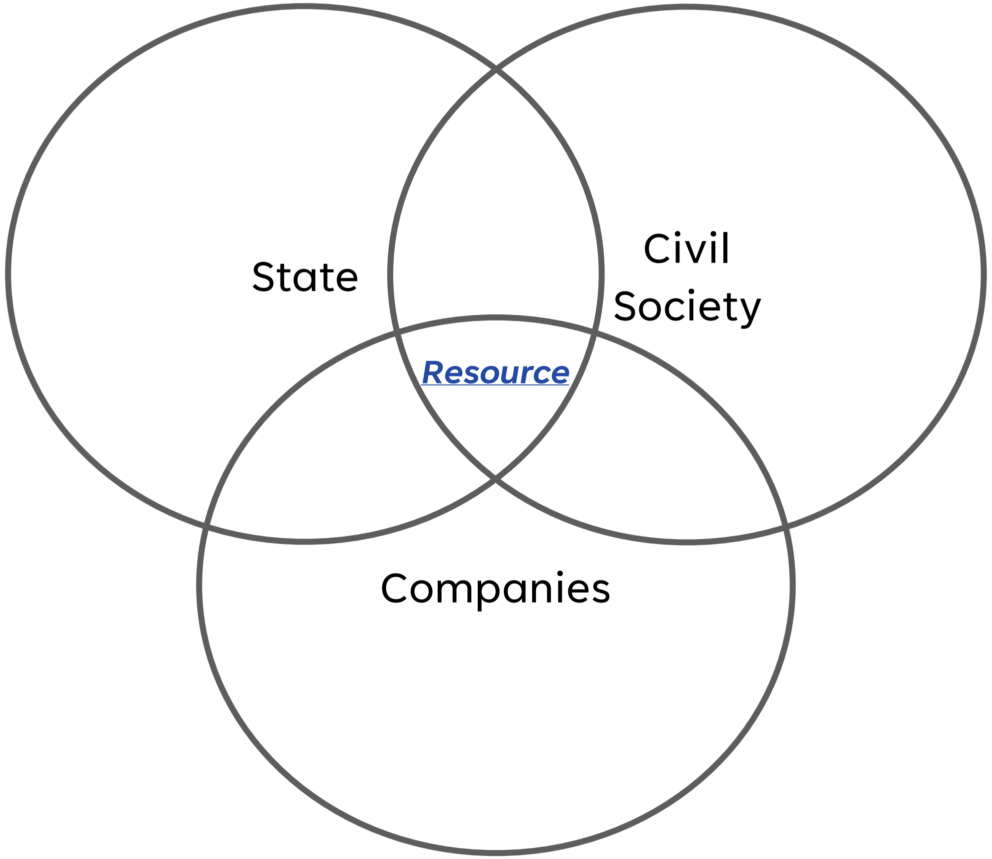
The act or process of governing or overseeing the control and direction of something

MINERAL GOVERNANCE



Source: Dominguez-Gomez & Gonzalez-Gomez

MINERAL GOVERNANCE



Externalities compensation?

Local management of resources ?

State as a referee?

LOW CARBON FUTURE

=

METAL INTENSIVE FUTURE

THANK YOU

Bernardo Teixeira

bdteixeira@fc.ul.pt

Acknowledgments: This work is supported by the Portuguese Fundação para a Ciência e Tecnologia, FCT, I.P./MCTES through national funds (PIDDAC): UID/50019/2025 and LA/P/0068/2020 (https://doi.org/10.54499/LA/P/0068/2020), and the IDL research grant UI/BD/151496/2021.