

# Material resources for the energy transition

Dr. Herena Torio



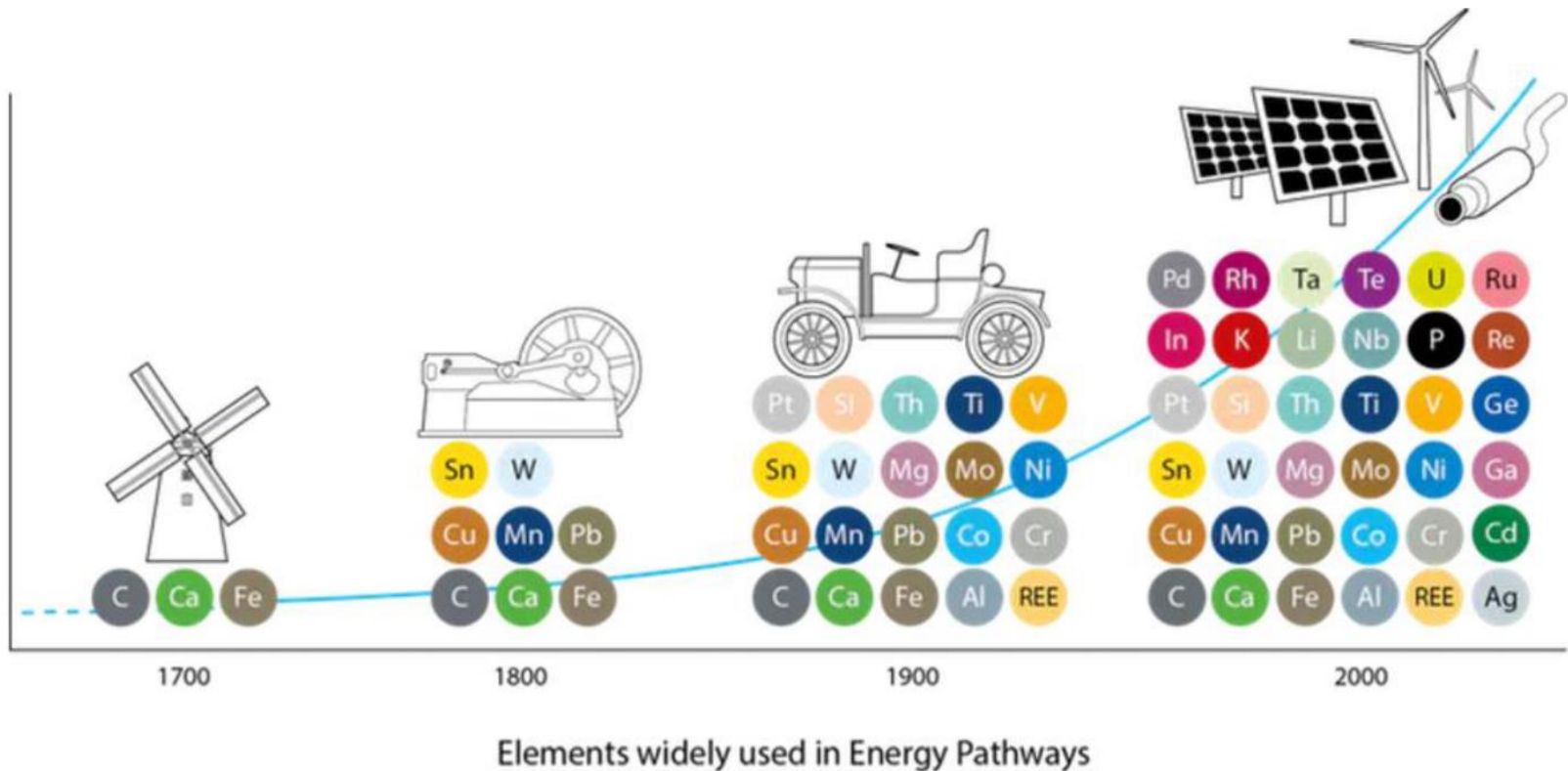
# Agenda

- **Materials demands for energy transition**
- Critical materials
- Ways out
- Example: electric vehicles

# Materials for the energy transition

## Ages of energy

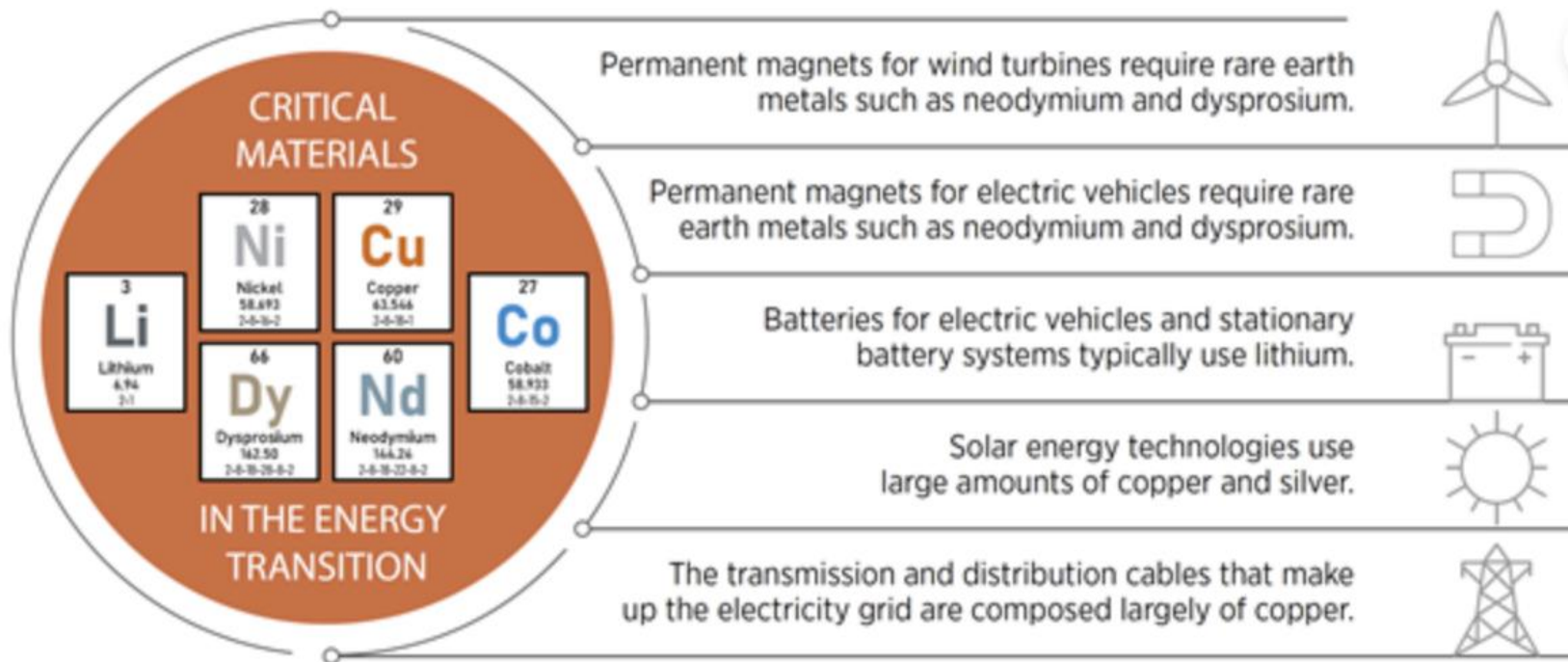
Higher amount and complexity of required materials



# Materials for the energy transition

## Critical materials in the energy transition

**Definition (IRENA, 2024):** Critical materials are the resources needed to produce numerous key technologies for the energy transition, including wind turbines, solar panels, batteries for EVs and electrolyzers.



# Agenda

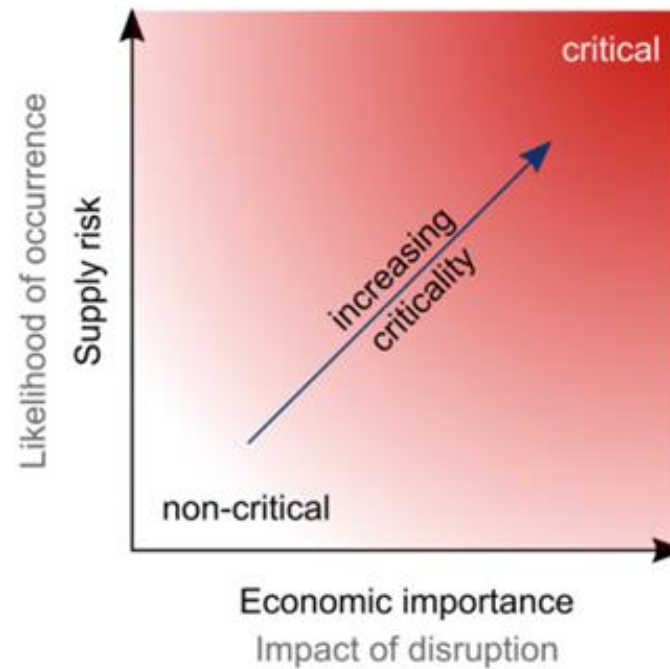
- Materials demands for energy transition
- **Critical materials**
- Ways out
- Example: electric vehicles

# Critical materials

## Supply risk:

Trying not to rely on a single provider (source)

- Includes aspects as governance, trade restrictions, degree of import...
- Availability of substitutes and recycling reduce it



## Economic importance

Economic damages of disruption in the supply, specially important the more strategic the field of use is.

Again: Availability of substitutes and recycling reduce it

# Critical materials

## Definition (IRENA, 2022)

### Materials which...

- require a significant extraction effort
  - a massive ramp-up of supply will be needed
- Demand**
- the production is concentrated in a few countries
  - the quality of natural resources is declining
  - prices have shown large fluctuations that reflect supply-demand imbalances.
- Supply risk**

## Examples of non-critical materials

**steel and concrete or aluminium:** not considered to be critical, despite a need for a massive ramp-up of supply: the resource is in place and widely distributed

# Critical Materials

## Top of important materials for Energy transition

By categories

1. Lithium plays a crucial role in renewable energy technologies
2. four REEs (neodymium, praseodymium, terbium and cerium)
3. borates,
4. Gallium
5. natural graphite
6. cobalt.

The **critical raw materials** most in demand are:

1. feldspar,
2. Strontium
3. lanthanum
4. phosphorus.

Gypsum, selenium and silica are the most required **non-critical raw materials**.

# Critical Materials

## Goals from the EU Critical material Act (2019)

- At least 10% of the EU's annual consumption for extraction
- At least 40% of the EU's annual consumption for processing
- At least 15% of the EU's annual consumption for recycling
- Not more than 65% of the Union's annual consumption of each strategic raw material at any relevant stage of processing from a single third country.
- Defines **critical** AND **strategic** raw materials

# Critical materials

## Definition (IRENA, 2022)

### Critical materials are those which...

- require a significant extraction effort
- a massive ramp-up of supply will be needed
- the production is concentrated in a few countries
- the quality of natural resources is declining
- prices have shown large fluctuations that reflect supply-demand imbalances.

Demand

Supply risk

### Strategic raw materials are...

Critical materials of strategic importance for the EU strategic objectives (i.e. military defense, green transition, digitalization). Characterized by:

- (1) high expected demand growth
- (2) a difficulty to significantly increase production
- (3) comparatively low level of identified economically extractable geological resources (reserves) compared to current production

# Critical materials

## Definition (IRENA, 2022)

### Critical Raw Materials

Broad “important + risky” category

Focus: supply risk monitoring

34 materials

Identifies vulnerabilities

### Strategic Raw Materials

Smaller priority subset of critical materials

Focus: active industrial and security policy

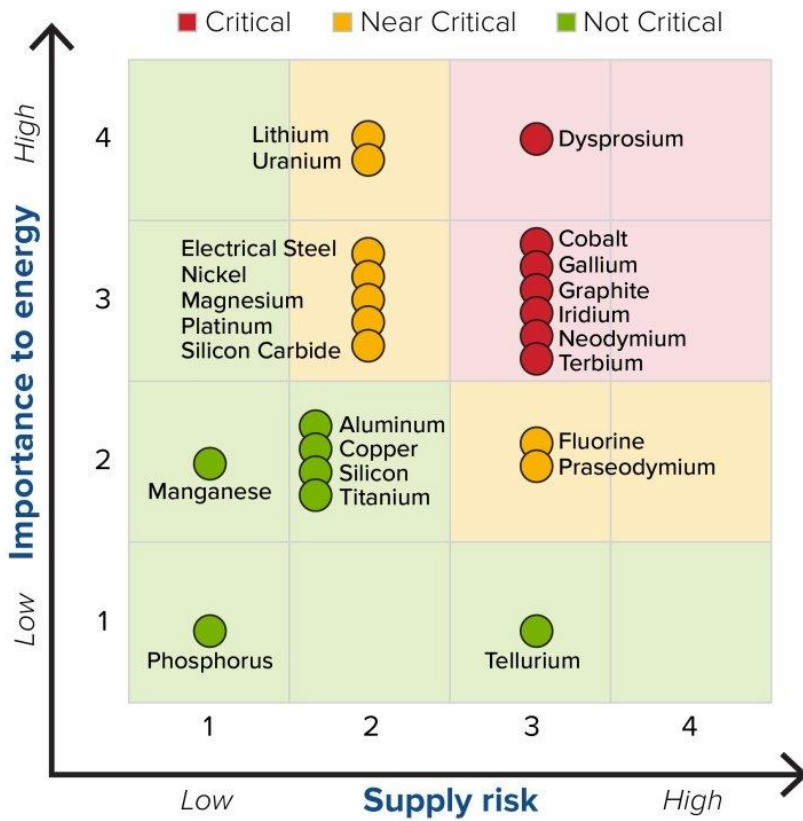
17 materials

Triggers stronger EU action

# Critical materials

## Overview of critical materials

**SHORT TERM** 2020-2025



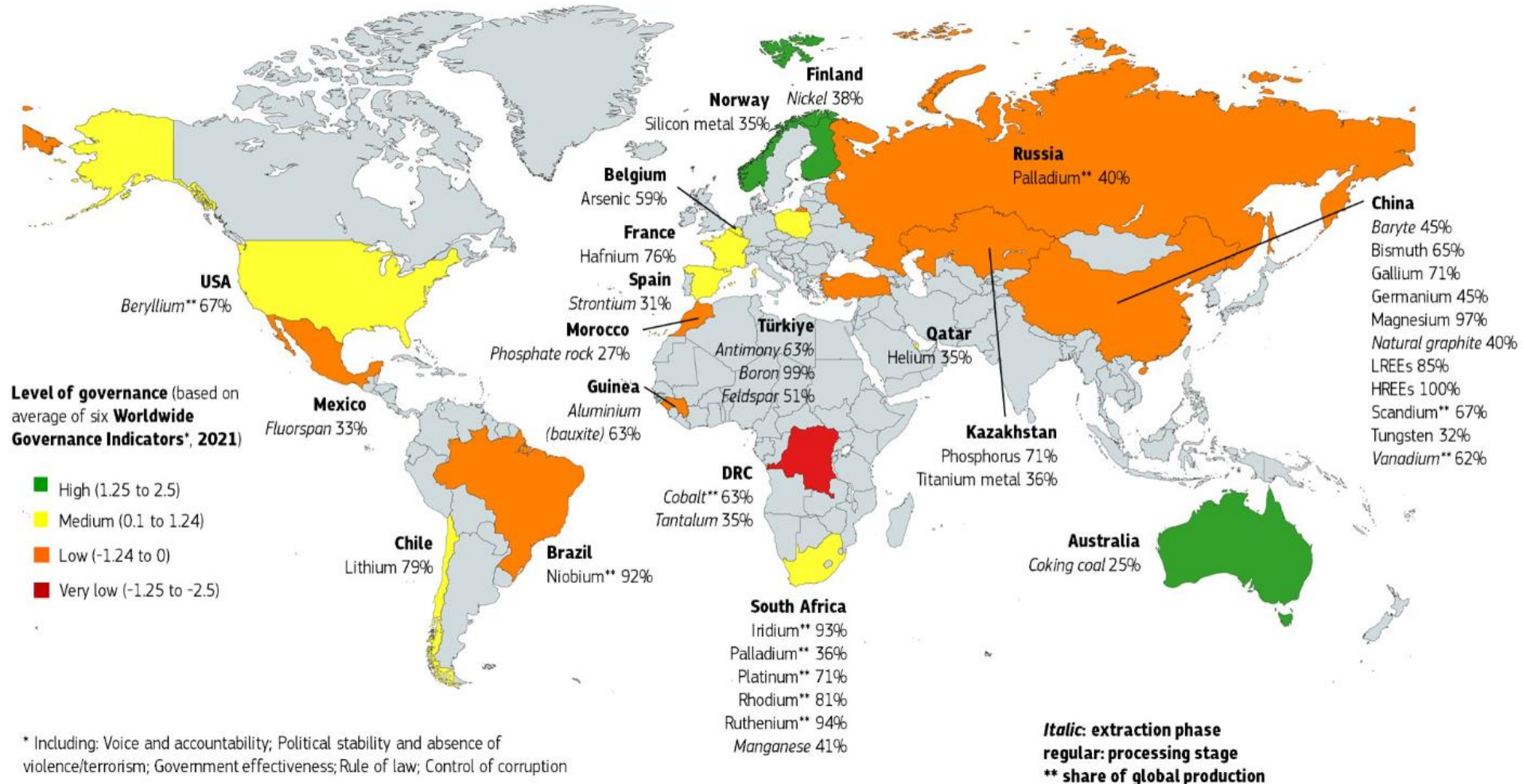
**MEDIUM TERM** 2025-2035



# Critical materials

## By countries and their „governance“

Major EU suppliers of CRMs (2023) and their level of governance

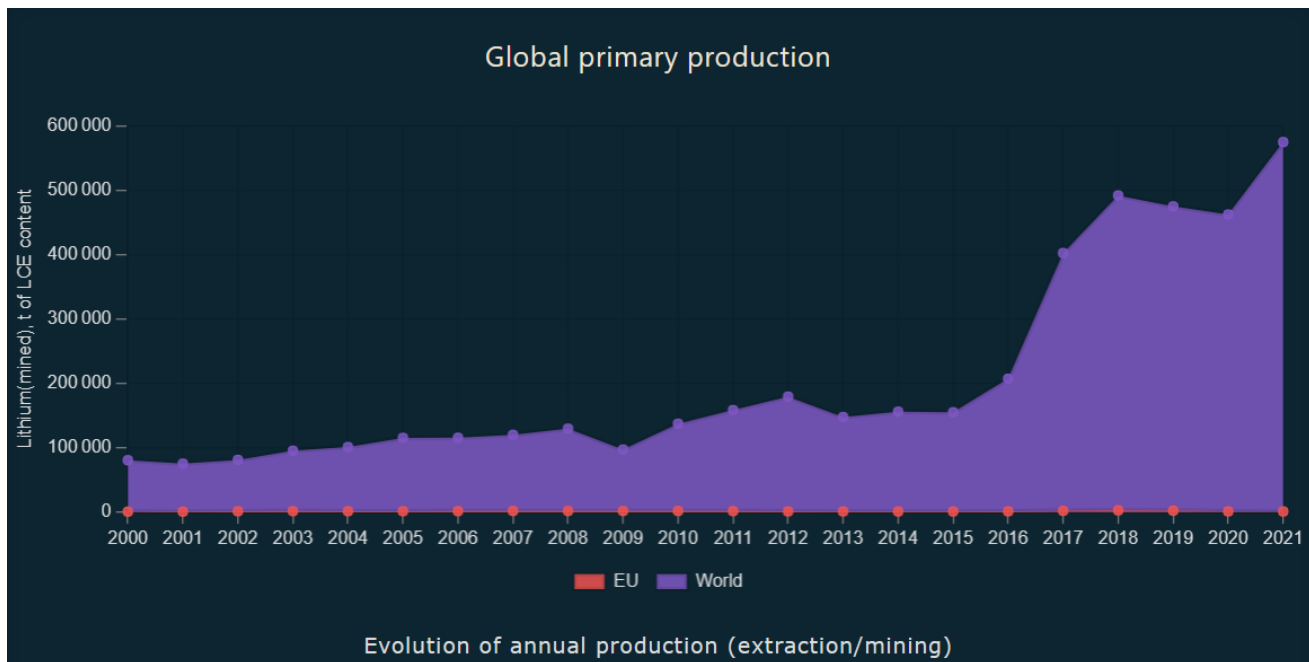


# Critical materials

## Production rates, historic data

### Lithium

Currently, about 600 kt/a (per year!)

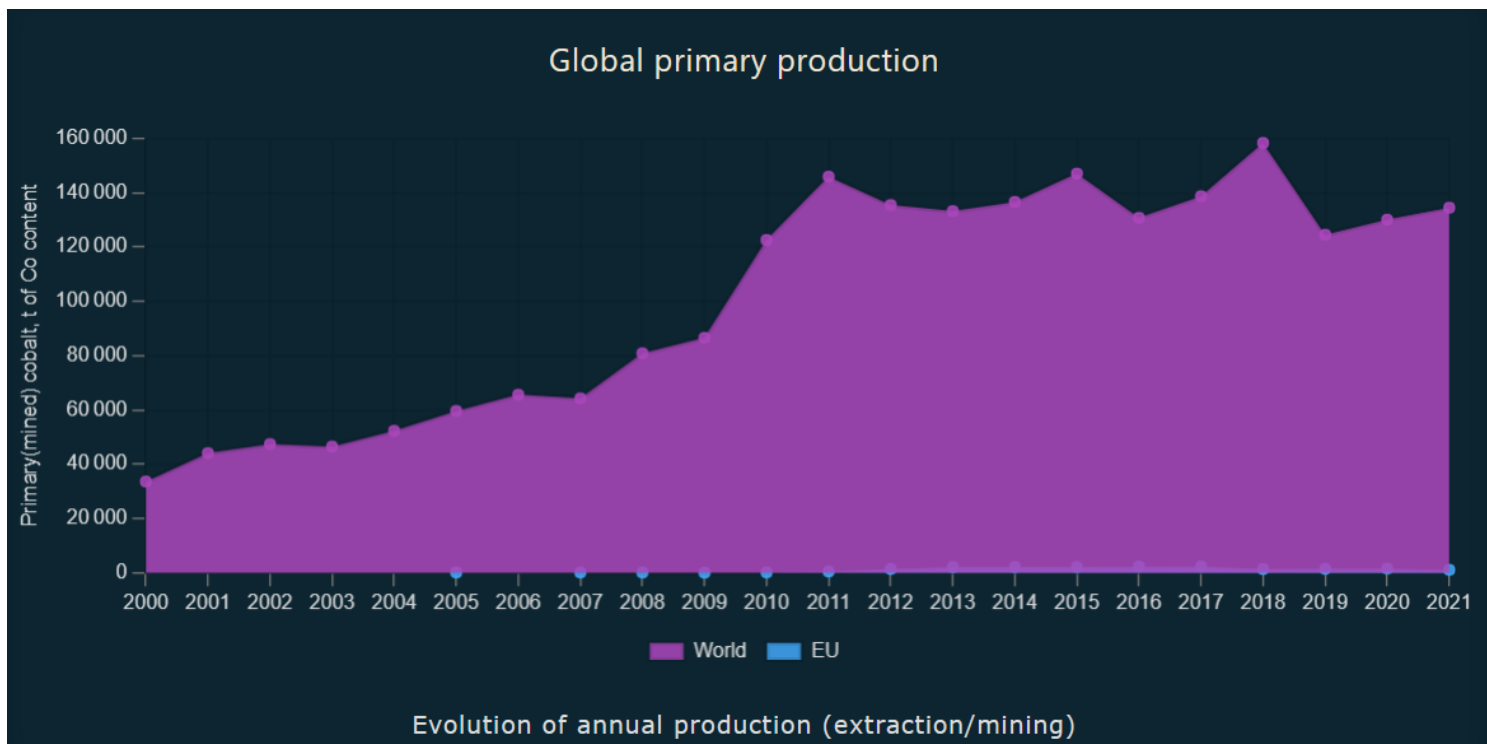


# Critical materials

## Production rates, historic data

### Cobalt

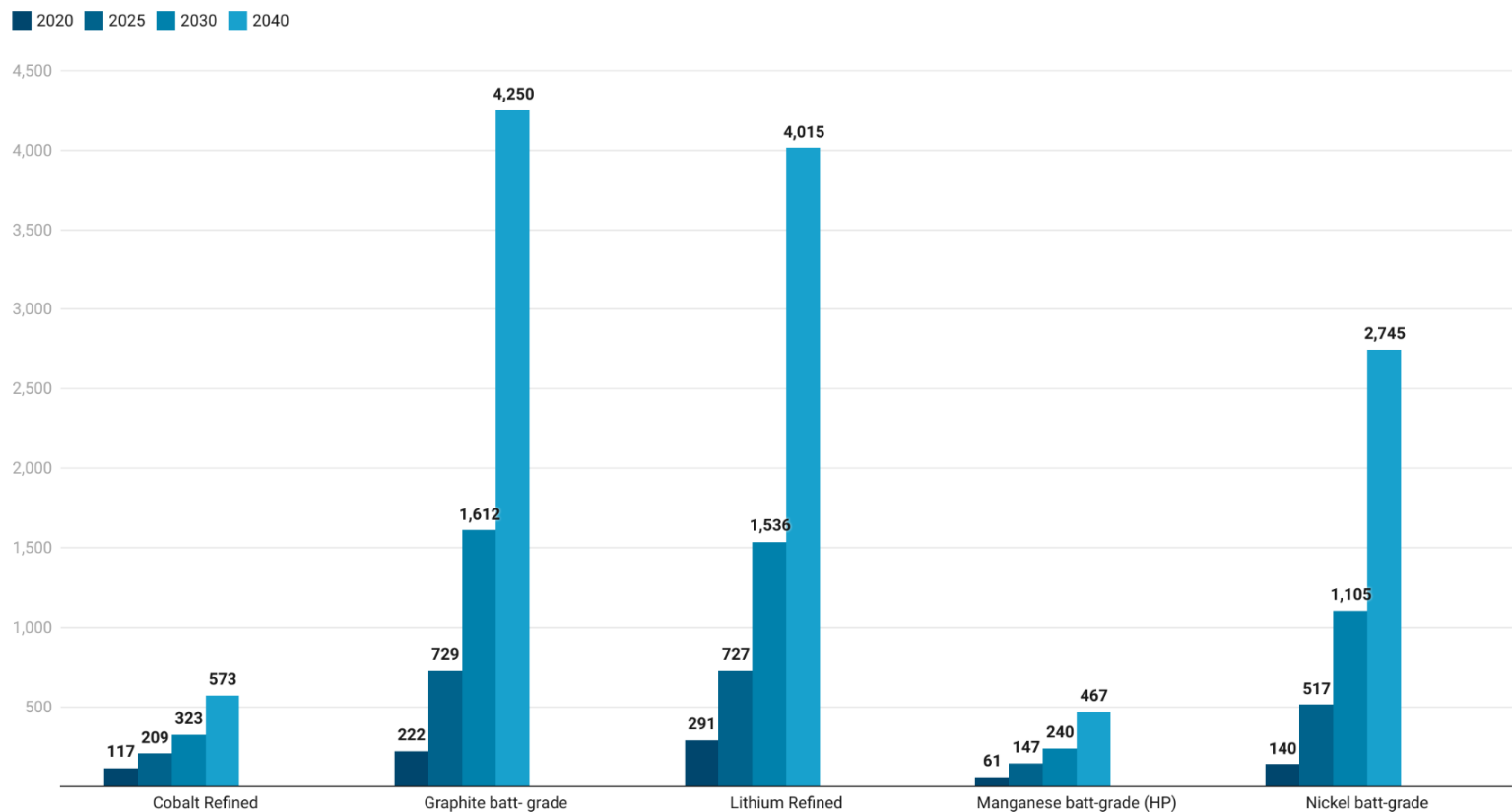
Currently, about 160 kt/a (per year!)



# Critical materials

## Projected global demands for E-batteries 2020 - 2040

Figure 1 – Forecast of battery demand globally from processed raw materials [kt]



Source: JRC analysis.

Source: [RMIS - Battery supply chain challenges \(europa.eu\)](https://www.europa.eu)

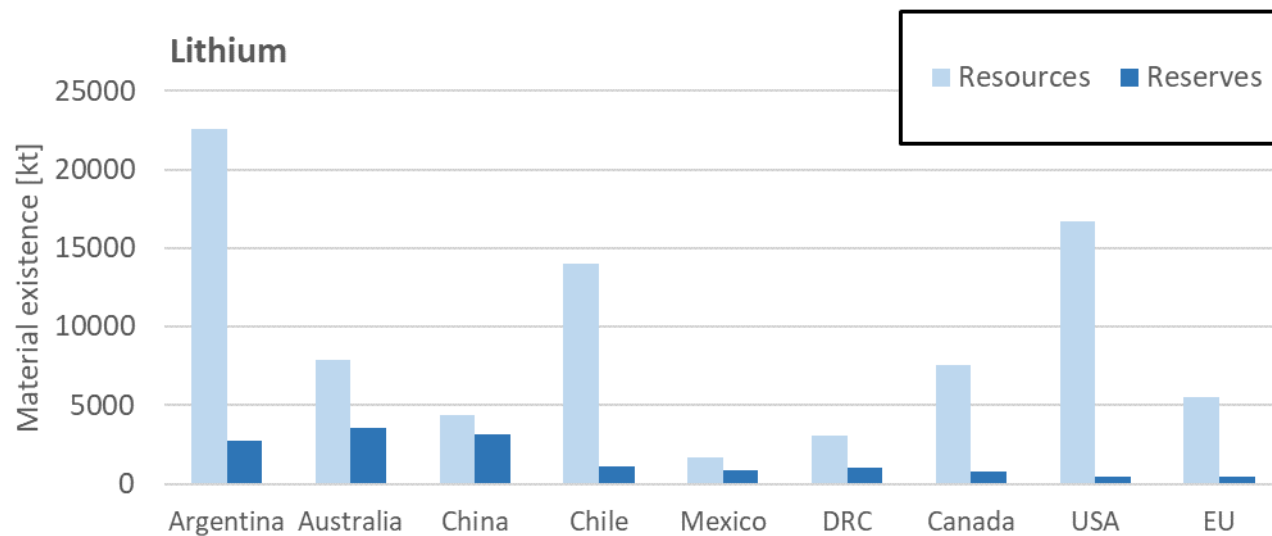
# Critical materials

## Resources and reserves

### Lithium

Currently, about 600 kt/a (per year!), with current reserves: **ca. 25 years!**

- Projected demand 2030 for E-batteries! → 9 years!
- Projected demand 2040 for E-batteries! → 3 years!



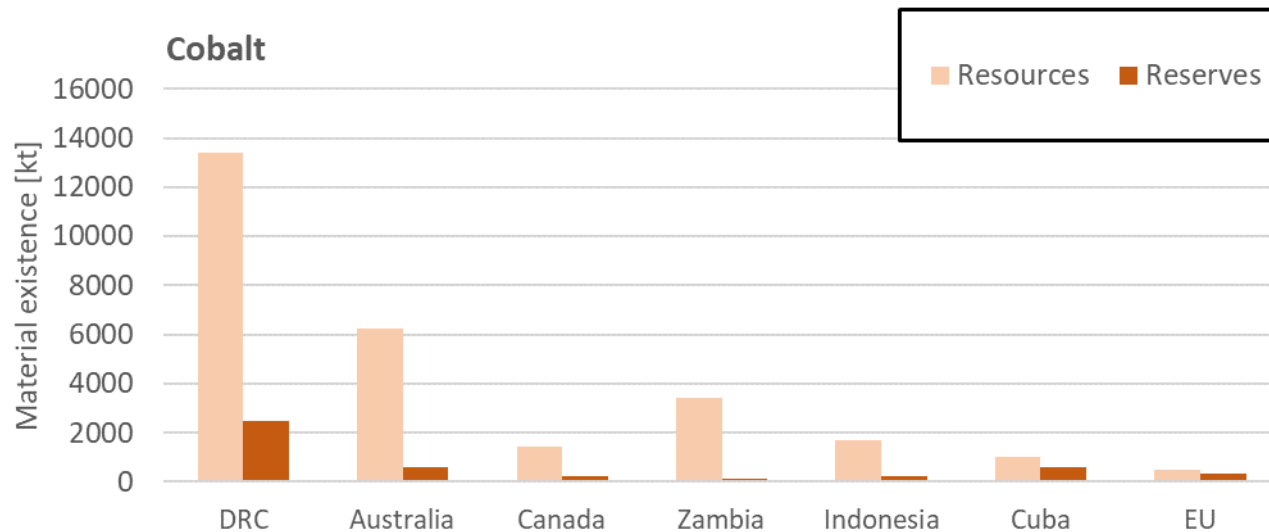
# Critical materials

## Resources and reserves

### Cobalt

Currently, about 160 kt/a (per year!), with current reserves: **ca. 28 years!**

- Projected demand 2030 for E-batteries! → 14 years!
- Projected demand 2040 for E-batteries! → 8 years!


















# Critical materials

## Regional supply

### Dependencies and fragilities

- Oligopolies concentrated in China
- Despite of diversification: expected to remain for **Co, Ni, Graphite & Manganese**)

Country	Cobalt (Refined Co)	Graphite (Anode precursors from natural graphite+synthetic graphite)	Lithium (Refined Li)	Manganese (HP EMM+HP MSM)	Nickel (NiSO <sub>4</sub> )	Cells
	51%	87%	34%	56%	59%	65%
	7%	3%	4%	14%	8%	14%
	10%	1%	11%	7%	6%	0%
	3%	1%	0%	0%	6%	1%
	0%	6%	10%	0%	1%	14%
	6%	1%	5%	0%	1%	0%
	1%	0%	0%	10%	1%	0%
	0%	0%	2%	0%	2%	1%
	2%	1%	0%	0%	0%	2%
	1%	0%	0%	0%	9%	0%
	2%	0%	0%	0%	0%	0%
	1%	0%	2%	0%	0%	0%
	0%	0%	16%	0%	0%	0%
	0%	0%	0%	8%	0%	0%
	0%	0%	11%	0%	0%	0%

Source: [RMIS - Battery supply chain challenges \(europa.eu\)](https://www.europa.eu)

# Agenda

- Materials demands for energy transition
- **Critical materials**
  - **Methodologies**
- Ways out
- Example: electric vehicles

# Critical materials

## EU methodology

### Supply risk

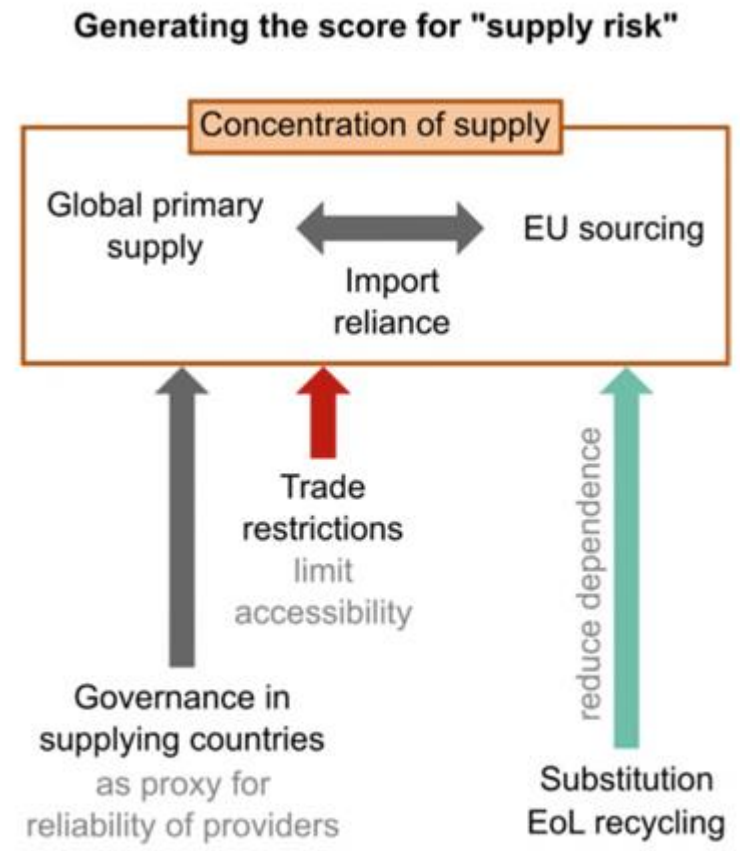
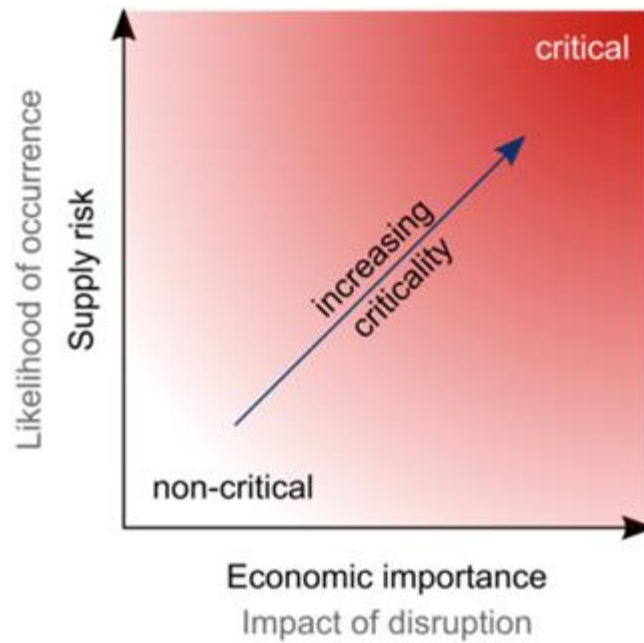


Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

# Critical materials

## EU methodology

### Supply risk

Developed in 2017, revised and more complex now

Uses two main indicators **as basis**:

### 1. Herfindahl-Hirschman-Index

Measures the concentration of a market into one single actor, or the diversity of actors in a given market segment (proxy for monopolies)

$$H := \sum_{i=1}^N a_i^2$$

mit

$$a_i := \frac{x_i}{\sum_{j=1}^N x_j}$$

X is the share of a given actor (in % or normalized)

H has values between 1 (or 10000) = monopoly or

1/N (or 10000/N) = highly diverse market

**Example:** 20% shares for 5 actors corresponds to a (not normalized value) H of: 400+400+400+400+400=2000

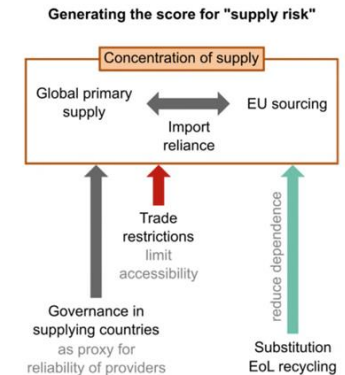


Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

# Critical materials

## EU methodology



Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

## Supply risk

Developed in 2017, revised and more complex now

Uses two main indicators as basis:

## 2. World-Governance-Index

Measures governance of (right now over 200 countries) based on the following dimensions:

- Peace / Security
- Democracy / Rule of Law
- Human Rights / Participation
- Sustainable Development
- Human Development

Factors constituting the World Governance Index

Indicator	Sub-indicator	Index
Peace / Security	National Security	Conflicts
		Refugees / Asylum Seekers
		Displaced Persons
	Public Security	Political climate
		Degree of trust
		Violent Crime
Rule of Law	Body of Laws	Homicides / 100,000 inhabitants
		Ratification of International Treaties
	Legal System	Protection of Property Rights
		Independence
	Corruption	Effectiveness
		Settlement of Contractual Disputes
Human Rights / Participation	Civil and Political Rights	Corruption Perceptions Index
		Respect of Civil Rights
		Respect of Physical Integrity Rights
		Freedom of the Press
	Participation	Violence against the Press
		Participation in Political Life
		Electoral Process and Pluralism
		Political Culture
	Discrimination / Gender Inequalities	Women's Political Rights
		Women's Social Rights
		Women's Economic Rights
		Female Parliamentary Rate
Sustainable Development	Economic Sector	Gross Domestic Product (GDP) per capita
		GDP Growth Rate
		Inflation Rate
		Ease in starting a business
	Social Dimension	Poverty Rate / Inequalities (Gini Coefficient)
		Unemployment Rate
		Ratification of International Labor Law Treaties
	Environmental Dimension	Ecological Footprint / Biocapacity
		Environmental Sustainability
		Environmental Performance Index
Human Development	Development	Human Development
		Subjective Well-being
	Well-being / Happiness	Happiness

# Critical materials

## EU methodology



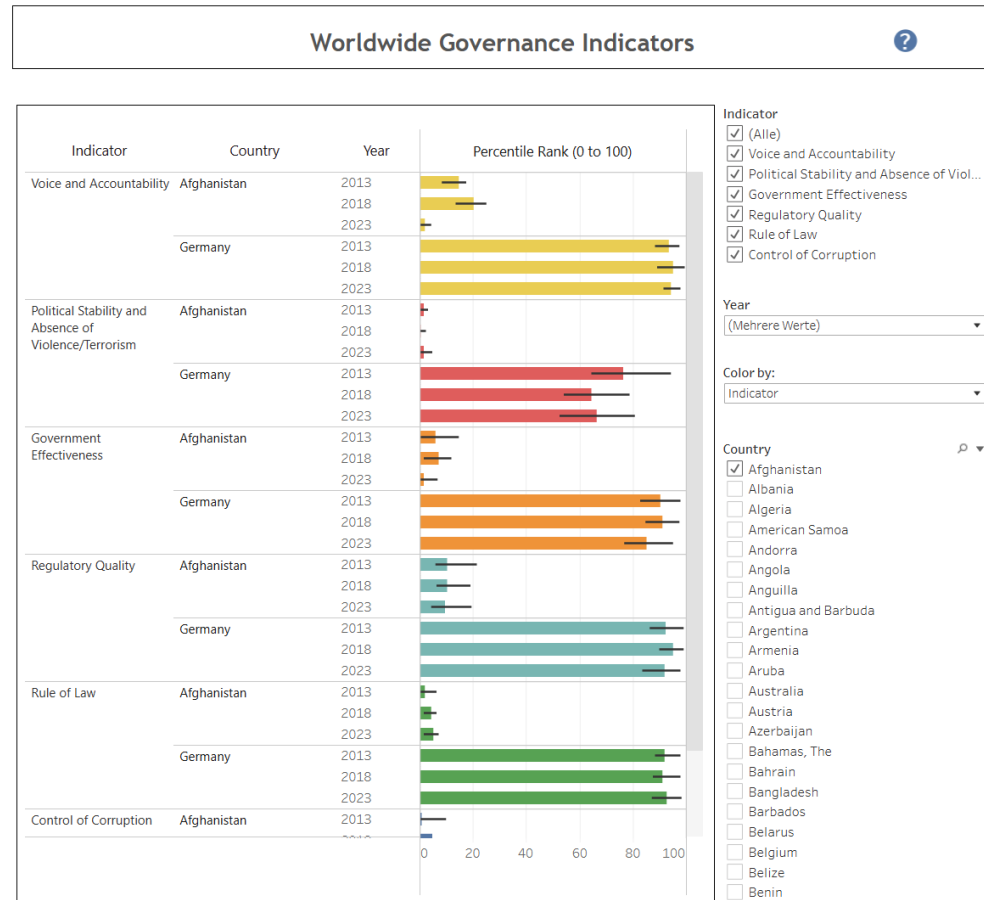
### Supply risk

Developed in 2017, revised and more complex now

Uses two main indicators as basis:

## 2. World-Governance-Index (WGI)

Database with extensive interactive data available (World Bank)



Source: Worldwide Governance Indicators ([www.govindicators.org](http://www.govindicators.org))

# Critical materials

## EU methodology

### Supply risk



Developed in 2017, revised and more complex now

Uses two main indicators **as basis**:

### Weighting the two indicators

Low supply risk given both in:

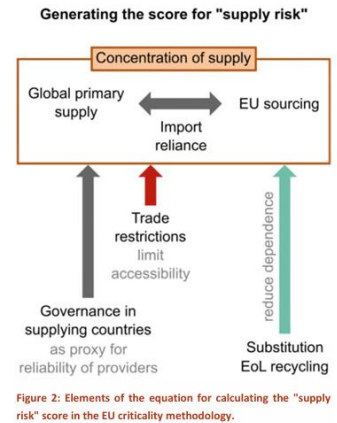
- Monopoly with perfect governance
- a very diverse market supply with very low governance

# Critical materials

## EU methodology

### Supply risk

Developed in 2017, revised and more complex now



**Original**

$$SR = HHI_{WGI} \cdot (1 - EoLRIR) \cdot SI$$

$$HHI_{WGI} = \sum_{countries} [(share\ in\ production)_{country} \times 100]^2 \times WGI_{country}$$

$$Subst_{mat} = \sum_{end\ uses} share\ of\ material_{end\ use} \times substitutability_{end\ use}$$


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**Revised**

$$SR = \left[ \frac{(HHI_{WGI-t})_{GS} \cdot \frac{IR}{2} + (HHI_{WGI-t})_{EUsourcing} \left(1 - \frac{IR}{2}\right) \right] \cdot (1 - EoLRIR) \cdot SI_{SR}$$

Import Reliance (IR) =  $\frac{Import - Export}{Domestic\ production + Import - Export}$

contribution of recycling to supply (but interpreted differently!)

$$(HHI_{WGI-t})_{GS\ or\ EUsourcing} = \sum_c (S_c)^2 WGI_c \cdot t_c$$

$$t_c = (ET-TA_c\ or\ EQ_c\ or\ EP_c\ or\ EU_c)$$

$$SI_{SR} = \sum_i [(SP_i \cdot SCr_i \cdot SCo_i)^{1/3} \cdot \sum_a (Sub - share_{i,a} \cdot Share_a)]$$

Figure 5: Calculation of the supply risk score in the original and revised EU methodologies (Blengini et al. 2017a; Blengini et al. 2017b; European Commission 2010, 2017b). *SR* = supply risk; *HHI<sub>WGI</sub>* = Herfindahl-Hirschmann-Index weighted with the *WGI* = World Governance Indicators; *EoLRIR* = end-of-life recycling input rate; *SI* = substitutability index; *GS* = global supply; *IR* = import reliance; *HHI<sub>WGI-t</sub>* = *HHI<sub>WGI</sub>* but also including trade restrictions (*t<sub>c</sub>*) as a weighting factor; *t<sub>c</sub>* accounts for export taxes and trade agreements (*ET-TA<sub>c</sub>*), export quotas (*EQ<sub>c</sub>*), export prohibitions (*EP<sub>c</sub>*) in non-EU countries while EU countries receive the scoring of 0.8 (*EU<sub>c</sub>*); *SI<sub>SR</sub>* = substitutability index for the supply side considering substitute production (*SP*), substitute criticality (*SCr*), substitute co-production (*SCo*) as well as the share of the raw material in a given application and the sub-share that the substitute may achieve.

# Critical materials

## EU methodology

### Supply risk

Developed in 2017, revised and more complex now

**Original**

$$SR = HHI_{WGI} \cdot (1 - EoLRIR) \cdot SI$$

$$HHI_{WGI} = \sum_{countries} [(share\ in\ production)_{country} \times 100]^2 \times WGI$$

$$Subst_{mat} = \sum_{end\ uses} share\ of\ material_{end\ use} \times substitutability,$$

contribution of recycling to supply (but interpreted differently!)

$$Import\ Reliance\ (IR) = \frac{Import - Export}{Domestic\ production + Import - Export}$$


---

**Revised**

$$SR = \left[ \frac{(HHI_{WGI})_{GS}}{2} + \frac{(HHI_{WGI})_{EU\ sourcing}}{2} \left( 1 - \frac{IR}{2} \right) \right] \cdot (1 - EoLRIR) \cdot SI_{SR}$$

$$(HHI_{WGI})_{GS\ or\ EU\ sourcing} = \sum_c (S_c)^2 WGI_c \cdot t_c$$

$$SI_{SR} = \sum_i [(SP_i + SCr_i + SCo_i)^{1/3} + \sum_u (Sub - share_{i,u} + Sha$$

$$t_c = (ET - TA_{or\ EQ_{or\ EP_{or\ EU}})$$

### New features:

- EU vs RoW focus

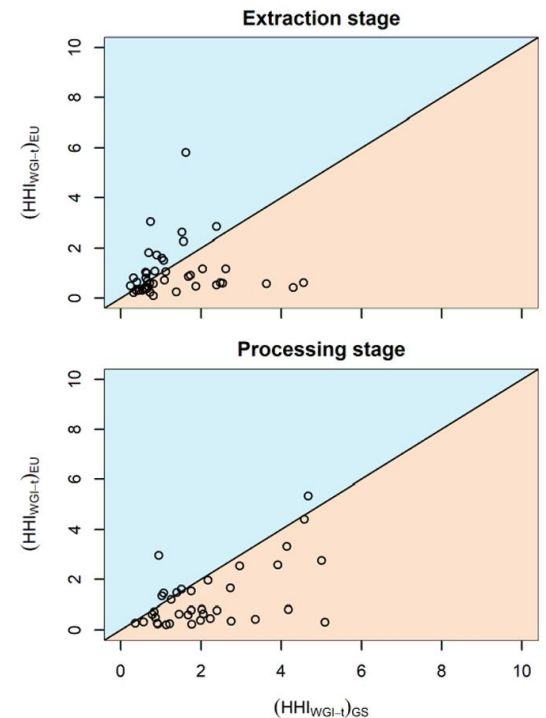
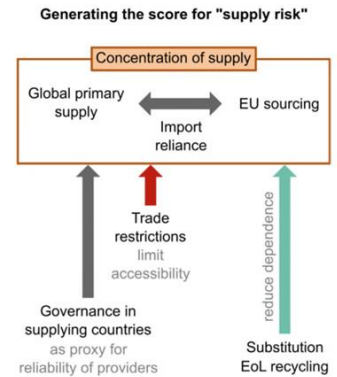


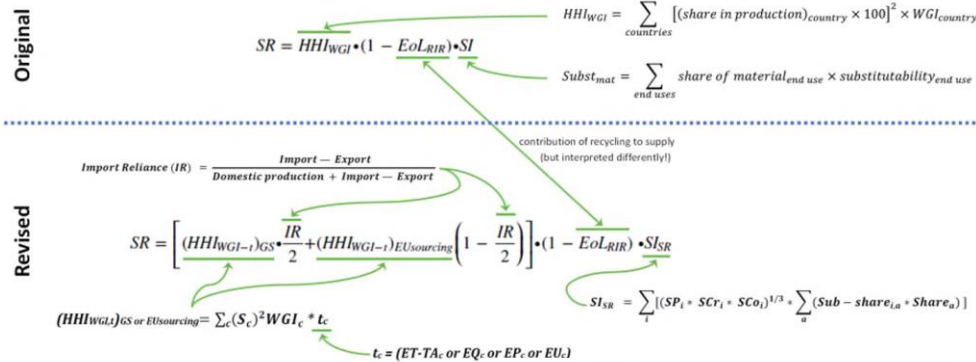
Figure 11: Global vs. EU sourcing at the mining (top) and processing stage (bottom). A dot in the orange half shows a higher risk of global sourcing vs. EU sourcing. A dot in the blue half shows higher EU sourcing risk compared to global. Data from European Commission (2023a).

# Critical materials

## EU methodology

### Supply risk

Developed in 2017, revised and more complex now



### New features:

- EU vs RoW focus
- Recycling

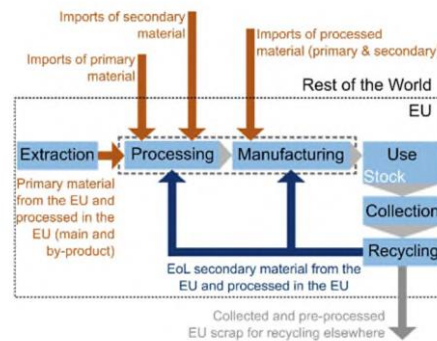
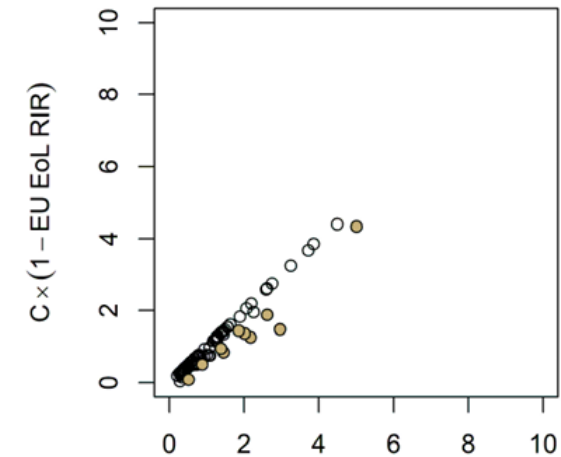
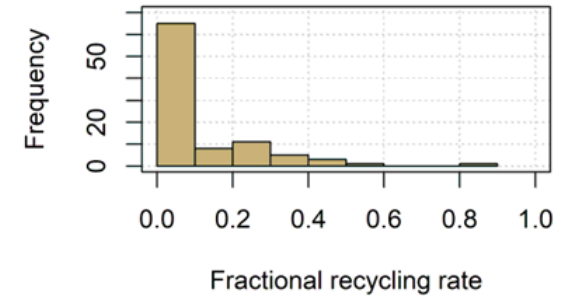


Figure 15: Flow data necessary for calculating the recycling rate (EU EoL RIR) used in the EU criticality methodology. Flows in blue go into the numerator and denominator, while flows in dark orange go into the denominator only (Talens Peiró et al. 2018; Tercero Espinoza 2021). The flow in gray is not included in the calculation.



$$C = (HHI_{WGI-t})_{GS} \times \frac{IR}{2} + (HHI_{WGI-t})_{EU} \times \left( 1 - \frac{IR}{2} \right)$$

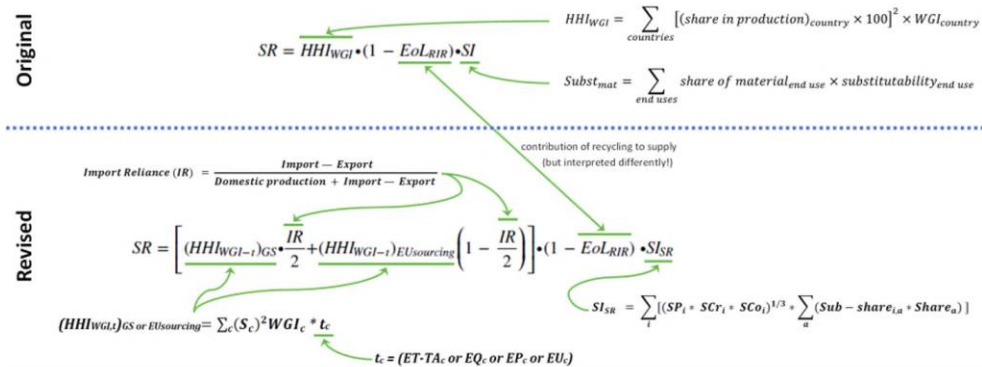
Figure 16: (top) Distribution of recycling rates used in the latest EU criticality exercise (cf. European Commission 2023a), and (bottom) the indicator for concentration of supply (denoted by "C" in the legend for convenience, cf. Figure 14) before (horizontal axis) and after accounting for recycling (vertical axis). Data from European Commission (2023a). Raw materials for which the risk score is significantly reduced are highlighted in light brown.

# Critical materials

## EU methodology

### Supply risk

Developed in 2017, revised and more complex now



### New features:

- EU vs RoW focus
- Recycling
- Taxes and trading barriers
- Substitutability

# Critical materials

## EU methodology

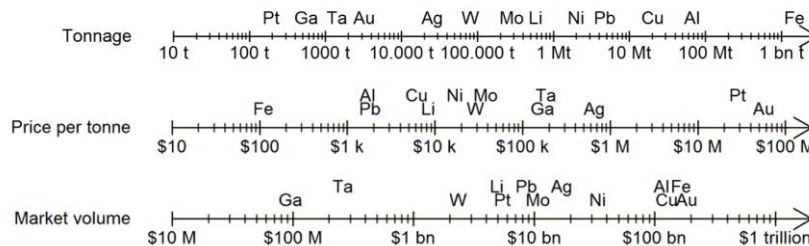
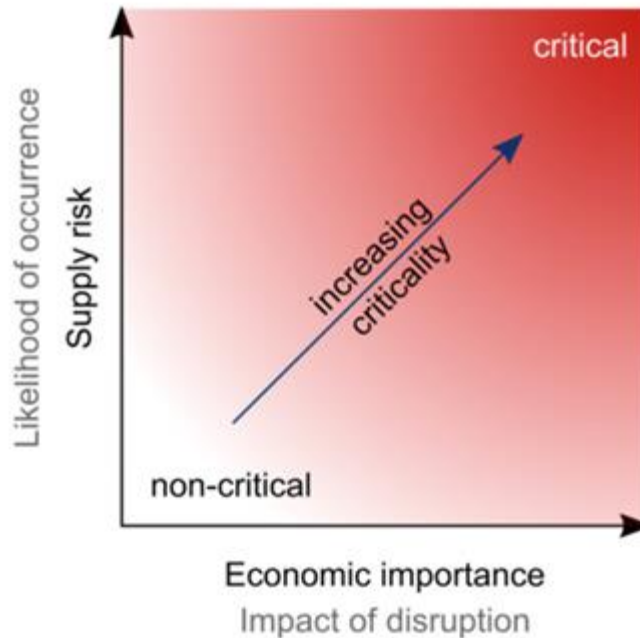


Figure 3: Ranking raw materials by tonnage (global primary production), price (average for 2020) and market volume (tonnage × price per tonne) (DERA 2020; Tercero Espinoza & Erdmann 2018). Pt = platinum, Ga = gallium, Ta = tantalum, Au = gold, Ag = silver, W = tungsten, Mo = molybdenum, Li = lithium, Ni = nickel, Pb = lead, Cu = copper, Al = aluminium, Fe = iron.

## Economic importance

Generating the score for "economic importance"

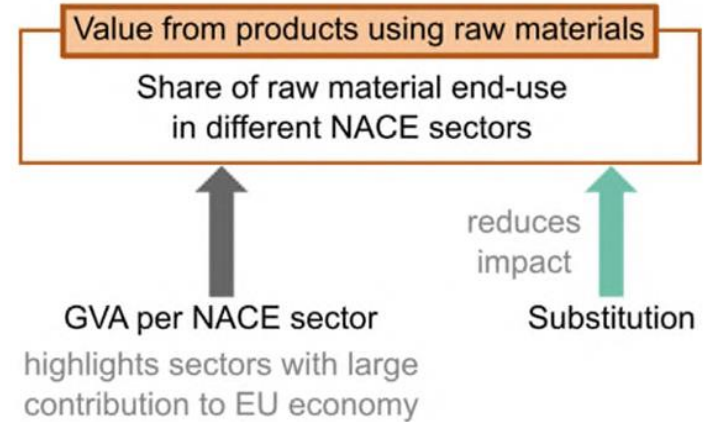


Figure 4: Elements of the scoring equation for economic importance. GVA = gross value added; NACE (*nomenclature statistique des activités économiques dans la Communauté européenne*) is the industry standard classification system used in the European Union.



Typical economic indicators do not give the picture

# Critical materials

## EU methodology

## Economic importance

Developed in 2017, revised 2020.  
Now includes substitution as a reduction of the importance

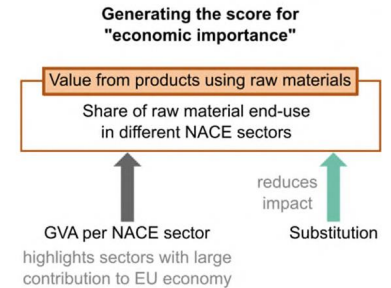


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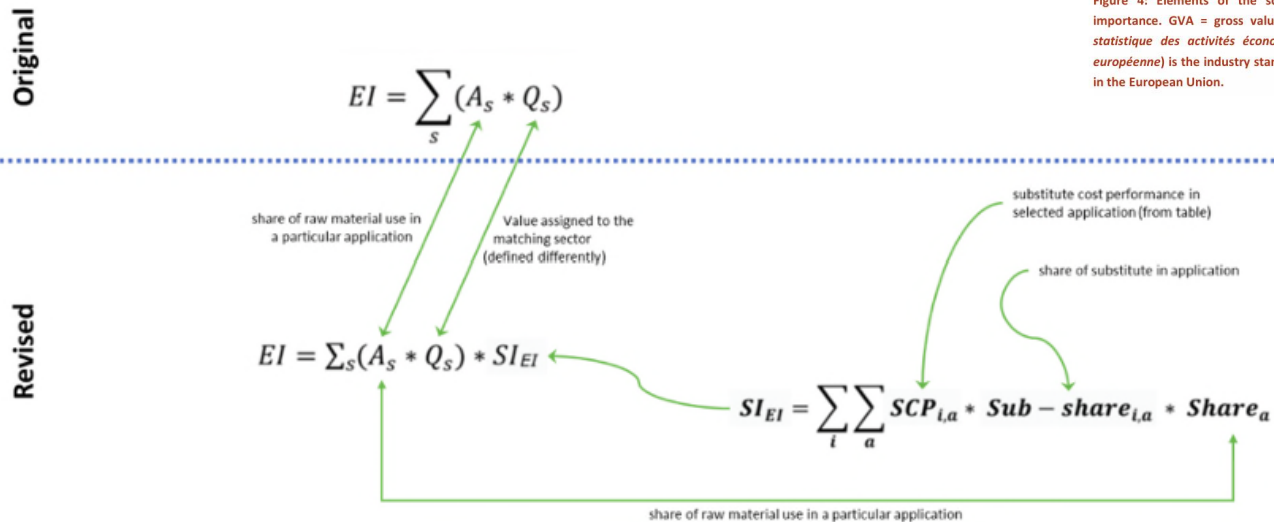


Figure 18: Calculation of the economic importance score in the original and revised EU methodologies (Blengini et al. 2017a; Blengini et al. 2017b; European Commission 2010, 2017b). *EI* = economic importance; *A<sub>s</sub>* = share of raw material use in a particular sector; *Q<sub>s</sub>* = gross value added of the sector using the raw material; *SI<sub>EI</sub>* = substitutability index for the economic importance dimension, based on the substitute cost performance in each application (*SCP<sub>i,a</sub>*) as well as the share of the raw material in a given application and the sub-share that the substitute may achieve.

# Critical materials

## EU methodology

Developed in 2017, revised 2020.  
Now includes substitution as a reduction of the importance

## Economic importance

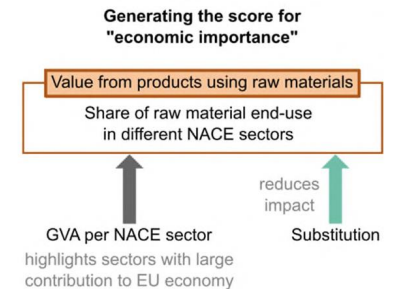


Figure 4: Elements of the scoring equation for economic importance. GVA = gross value added; NACE (*nomenclature statistique des activités économiques dans la Communauté européenne*) is the industry standard classification system used in the European Union.

Difficult to estimate the added value of a sector as a result of the use of a particular material  
 → very detailed and extensive I/O analysis required for this  
 → Instead: NACE indices

Table 1: Substitute cost performance (SCP) evaluation matrix from Blengini et al. (2017a).



		Performance		
		Better	Similar	No substitute
Costs	Much higher	0.9	1.0	1.0
	Slightly higher	0.8	0.9	1.0
	Similar or lower	0.7	0.8	1.0

Figure 19: Value added of 2-digit NACE sectors used in the calculation of the economic importance axis in the last criticality exercise. Data from European Commission (2023a) and Eurostat (2023).

# Critical materials

## EU methodology

## Economic importance

Developed in 2017, revised 2020.  
Now includes substitution as a reduction of the importance

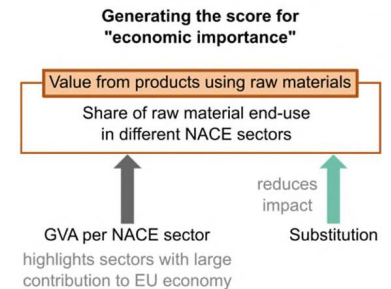


Figure 4: Elements of the scoring equation for economic importance. GVA = gross value added; NACE (*nomenclature statistique des activités économiques dans la Communauté européenne*) is the industry standard classification system used in the European Union.

Difficult to estimate the added value of a sector as a result of the use of a particular material

- very detailed and extensive I/O analysis required for this
- Instead: NACE indices
- Substitute cost performance MATRIX

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Revised

$$EI = \sum_s (A_s * Q_s) * SI_{EI}$$

$$SI_{EI} = \sum_l \sum_a SCP_{l,a} * Sub - share_{l,a} * Share_a$$

# Critical materials

## EU methodology

### Results and analysis

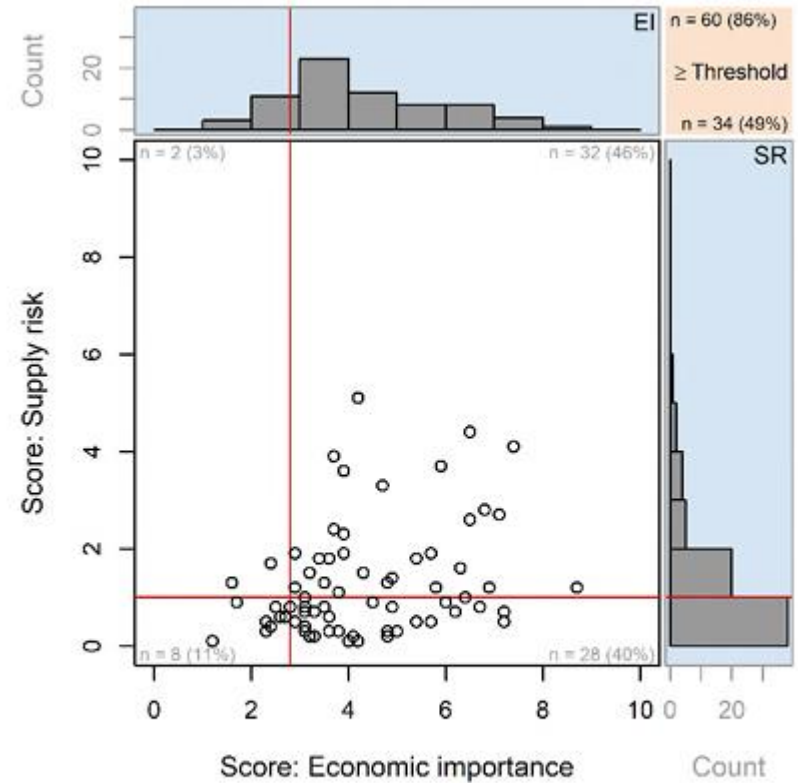


Figure 21: Results of the 2023 criticality study, with some diagnostic additions (data from European Commission 2023a).

# Critical materials

## Methodologies and indicators

Highly dynamic and not uniform field → 10 pages with different methods!!

### 3.2 Organisations developing their own methodologies

Organisations	EU only?	Objective of the organisation	Relation to EC methodology	Methodology
ADELPHI (DE)		To identify raw minerals of economic interest, from the perspective of German companies, whose supply situation could become critical	References EC methodology	See Institute for Futures Studies and Technology Assessment (Erdmann_2011b) for further details.
AEA Technology plc (UK)		To assess future resource risks faced by UK business through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	AEA_2010: The two dimensions of criticality are consumption/production and scarcity/availability, based on the following indicators: <ul style="list-style-type: none"> <li>• Availability of alternatives</li> <li>• Supply distribution</li> <li>• Supply domination</li> <li>• Extent of Geopolitical Influences</li> <li>• Press Coverage</li> <li>• Price Fluctuations</li> </ul> See Scotland & Northern Ireland Forum for Environmental Research (SEPA_2011) for follow-up and further details.
Alpen-Adria University (AT)		To monitor potential disruption in supply of critical materials which could endanger a transition to low-carbon infrastructure	References EC methodology	See university of Leeds (Roelich_2014) for further details.
American Physical Society (APS, US)	No	To identify potential constraints on the availability of energy-critical elements and to identify five specific areas of potential action by the United States to insure their availability		From Peck_2015: The term 'energy-critical element' is used to describe a class of chemical elements that currently appears critical to one or more new energy-related technologies. More specifically: <ol style="list-style-type: none"> <li>1. Elements that have not been widely extracted, traded, or utilised in the past</li> <li>2. Elements that could significantly inhibit large-scale deployment of the new energy-related technologies</li> </ol> See BGS_2011 for original methodology.
British Geological Survey (BGS, UK)		To assess elements needed to maintain UK economy and lifestyle through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	BGS_2012: An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on seven criteria scored between 1 and 3. <ul style="list-style-type: none"> <li>• Scarcity</li> <li>• Production concentration</li> <li>• Reserve distribution</li> <li>• Recycling Rate</li> <li>• Substitutability</li> <li>• Governance (top producing nation)</li> <li>• Governance (top reserve-hosting nation)</li> </ul>
British Petroleum (BP, UK)		To improve understanding of the risk to the sustainability of each existing energy pathways induced by restricted supply of materials through the development of a criticality methodology and its use in the definition of a list of critical materials	References EC methodology	BP_2014: Criticality is defined as the degree to which a material is necessary as a contributor to an energy pathway, based on: <ul style="list-style-type: none"> <li>• Reserves,</li> <li>• Trades,</li> <li>• Ecological impact,</li> <li>• Processing,</li> <li>• Substitutability,</li> <li>• Recyclability</li> </ul>

# Critical materials

## Methodologies and indicators

Highly dynamic and not uniform field → 10 pages with different methods!!

**Table 3.** Overview of different criticality indicators applied to the considered Elements and their specific special focus, where red indicates a high, yellow a moderate, and green a low "criticality". Corresponding minimum and maximum values are provided at the very bottom of the table.

Element	EU Supply Risk (SR <sup>EU</sup> )	Nassar et al. Supply Risk	Hayes et al. – USGS Review	Static range [y]	Three main suppliers (int. Country codes) by global share	Level
Scope	Europe	US	Global	Global	Global	
Al	0.6	0.6	33	153	CN 55%, RU 5.7%, IND 4.6%	Processing
Co	2.5	0.6	73	49	CD 72.4%, AU 3.7%, RU 3.5%	Mining
F	1.2	0.3	57	44	CN 52.7%, MX 29.5%, VN 3.6%	Mining
Fe	0.5	0.1	25	64	AU 36.8%, BR 19.3%, CN 13.8%	Mining
Li	1.6	0.35	40	240	AU 60.9%, CL 19%, CN 7.5%	Mining
Mg	3.9	0.4	75	954	CN 90.9%, USA 3.2%, IL 2.2%	Processing
Mn	0.9	0.35	40	68	ZA 28%, AU 16.9%, GA 13.6%	Mining
Na	0	0	0	1000	N/A	N/A
Ni	0.5	0.4	19	38	CN 31.3%, ID 13.2%, JP 8.5%	Processing
P	1.1	0.25	40	282	CN 41.1%, MA 15.6%, USA 10.3%	Processing
S	0.3	0	0	1000	N/A	N/A
Si	1.2	0	20	1000	CN 61.9%, USA 14.8%, BR 6.5%	Processing
Ti	1.3	0.4	25	50	ZA 14.8%, MZ 12.8%, AU 11.6%	Mining
V	1.7	0.45	67	271	CN 58.7%, RU 18.8%, ZA 16.4%	Mining
Zr	0.8	0.2	57	45	AU 32.3%, ZA 29.5%, USA 8.0%	Mining
Min	0	0	0	12		
Max	7	1	100	1000		
Threshold	1	N/A	N/A	N/A		

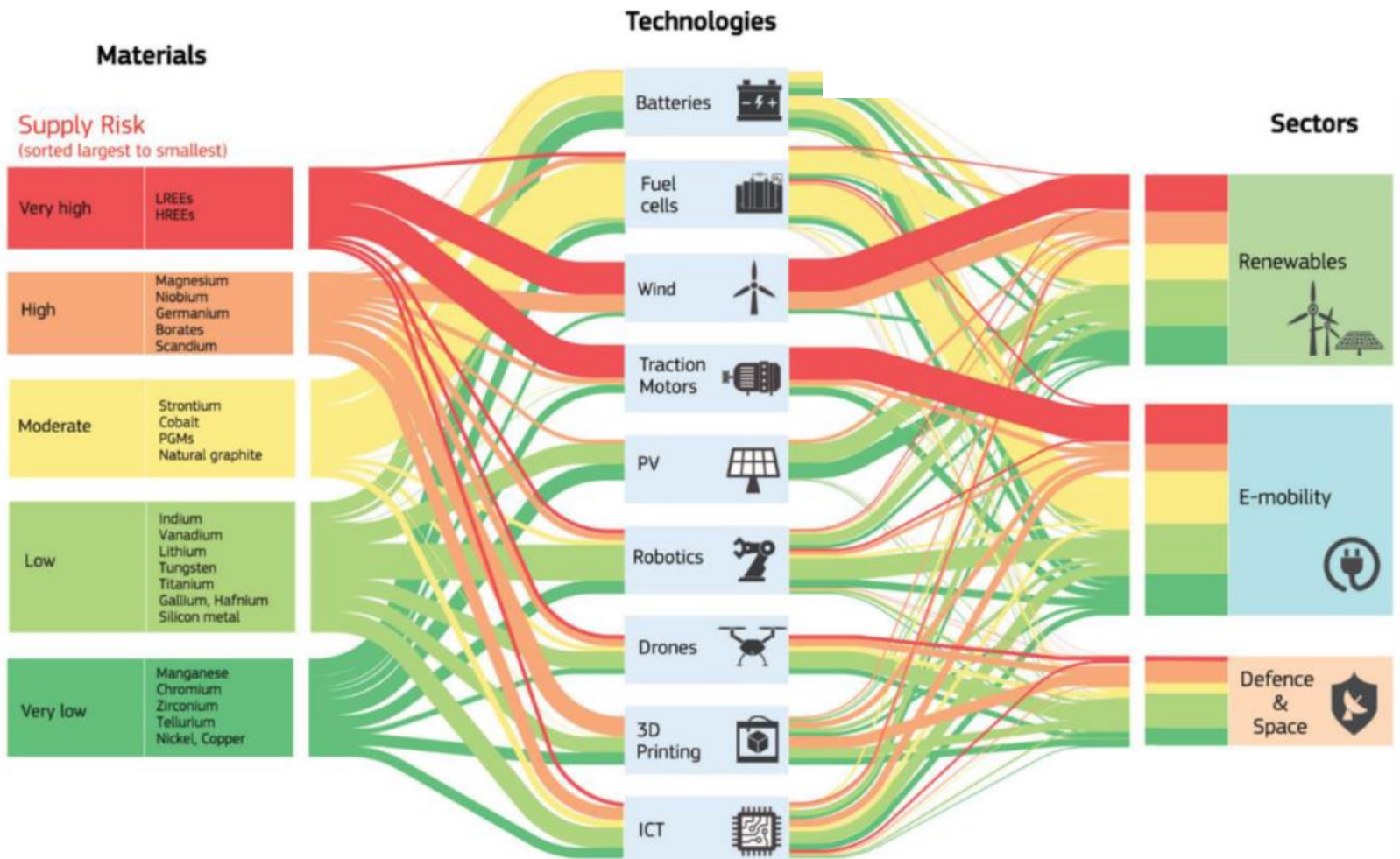
# Agenda

- Materials demands for energy transition
- **Critical materials**
  - Methodologies
  - **Examples**
- Ways out
- Example: electric vehicles

# Critical materials

## Supply required for different sectors

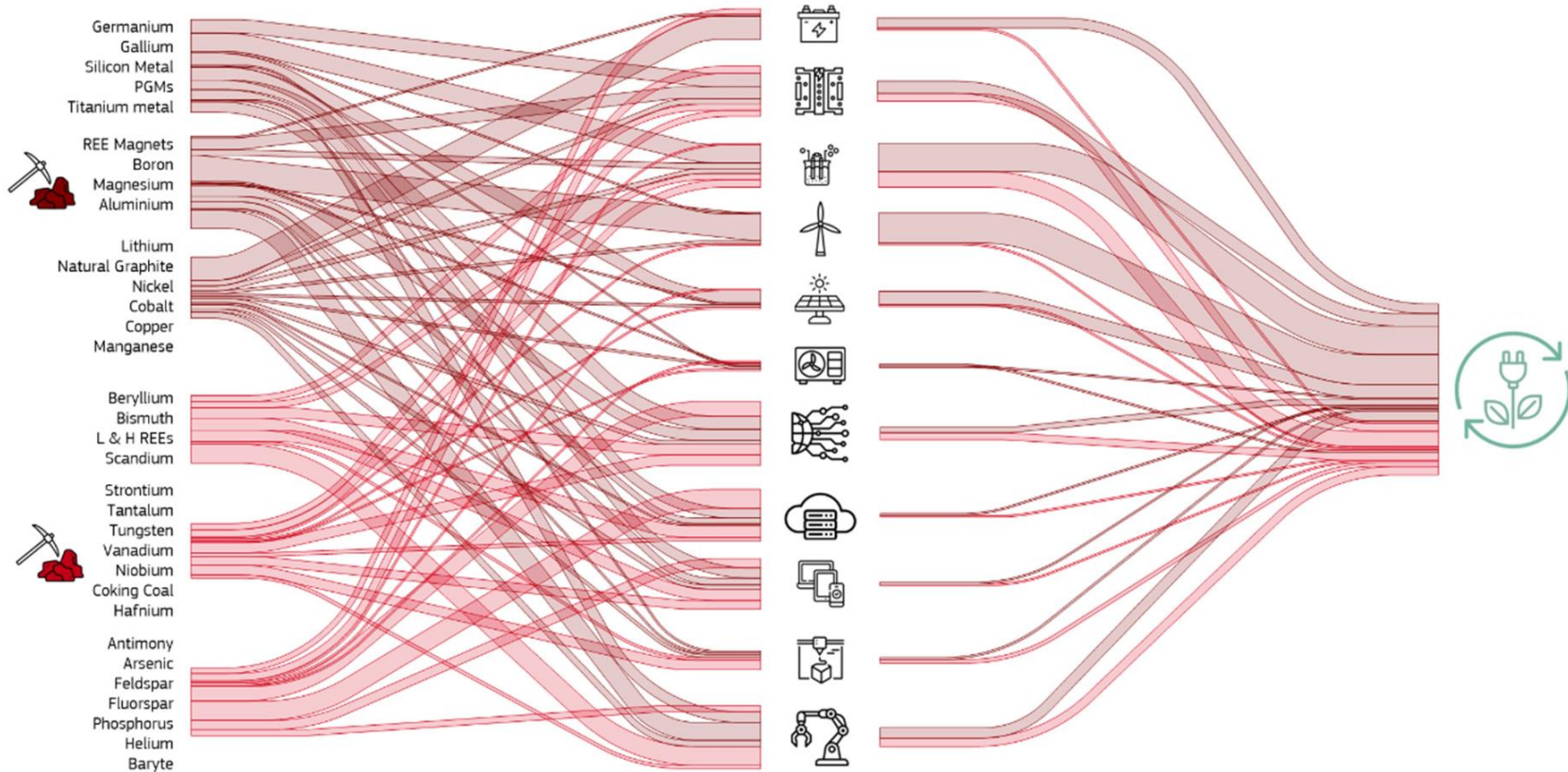
### Dependencies and fragilities



# Critical materials

## Supply required for different sectors

### Dependencies and fragilities



Sankey diagram of the raw materials present in each technology of the renewable energy sector (critical = bright red; strategic = dark red)

Source: JRC, 2023.

Source: [RIMS - Raw Materials Information System \(europa.eu\)](https://www.europa.eu)

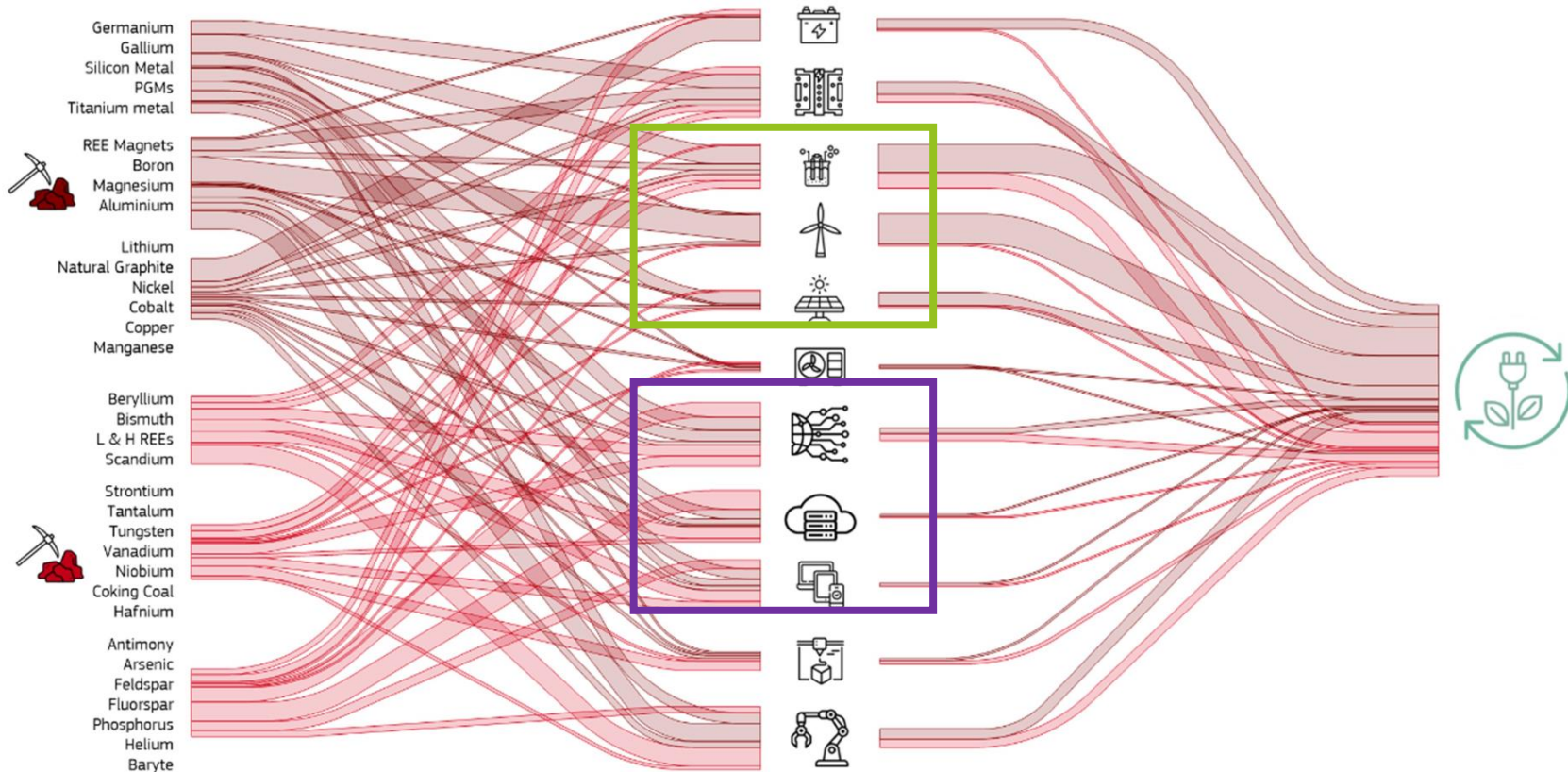
# Critical materials

## Supply required for different sectors

Dependencies and fragilities

Renewables

ICT, smart-grids



Sankey diagram of the raw materials present in each technology of the renewable energy sector (critical = bright red; strategic = dark red)

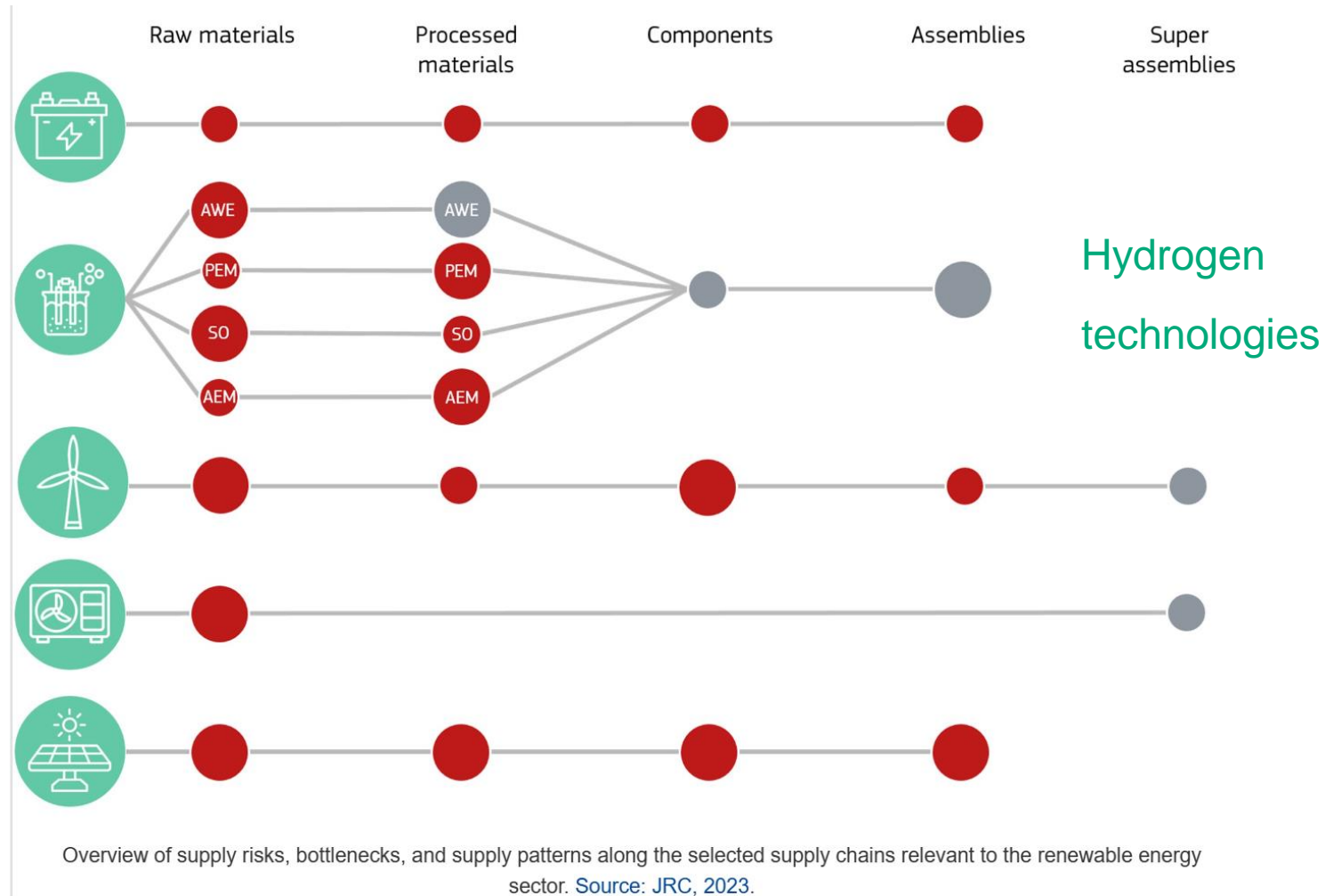
Source: JRC, 2023.

Source: <https://www.ec.europa.eu/euro-observatory/>

# Critical materials

## Supply risks for RE

### Supply chain bottlenecks



# Critical materials

## Technology profiles

### Photovoltaics

**Aluminium:** in panel frames and inverters or in alloys for construction and support

**Iron:** in steel alloys for different parts and in fixing systems

**Lead:** in alloys with tin as solder for electric circuits and interconnectors

**Nickel:** in electroplating or in stainless steel frames, fasteners and connectors

**Zinc:** as transparent conductive oxide in the front contact of solar cells

Al

Fe

Pb

Ni

Zn



Cu

Se

In

Mo

Ga

**Copper:** highly used for wires, cables, inverters, also in thin-film copper indium gallium selenide (CIGS) technology

**Selenium:** in thin-film CIGS solar cell

**Indium:** as indium-tin-oxide (ITO) conductive layer or in CIGS technology

**Molybdenum:** as back contact for CIGS or in stainless steel frames

**Gallium:** as dopant in semiconductors or in CIGS technology

**Tin:** in combination with lead for soldering or with indium in ITO conductive layers

**Tellurium and Cadmium:** in thin-film cadmium telluride (CdTe) PV technology

B

**Boron:** as dopant in crystal lattice of the silicon-based wafers

Ge

**Germanium:** as semiconductor materials for multi-junction solar cells for space applications

Si

**Silicon:** as semiconductor materials in crystalline solar cells

Ag

**Silver:** as conductive paste on front and back side of the crystalline solar cells

Sn

Te

Cd

● Strategic Raw Material

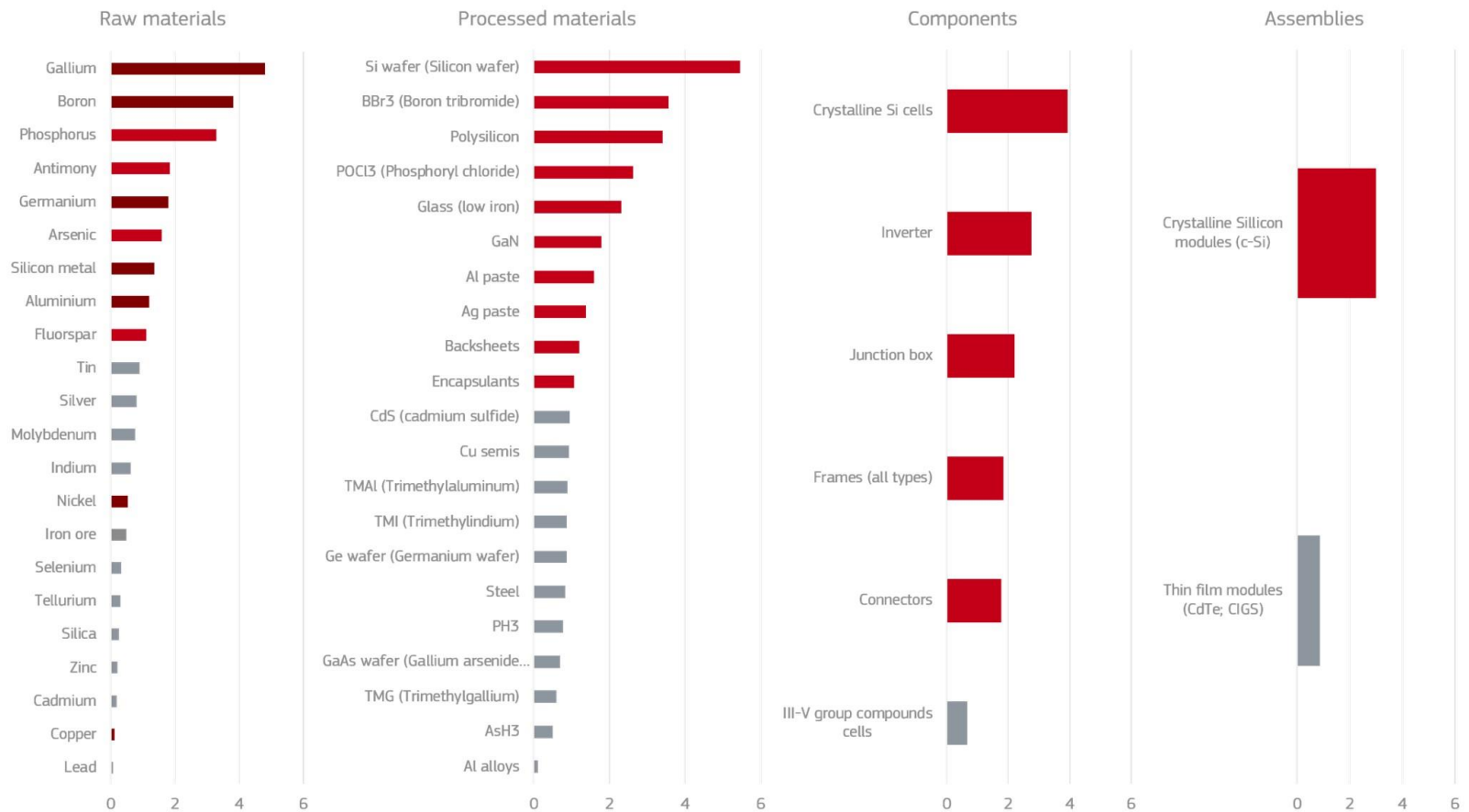
● Critical Raw Material

# Critical materials

## Technology profiles



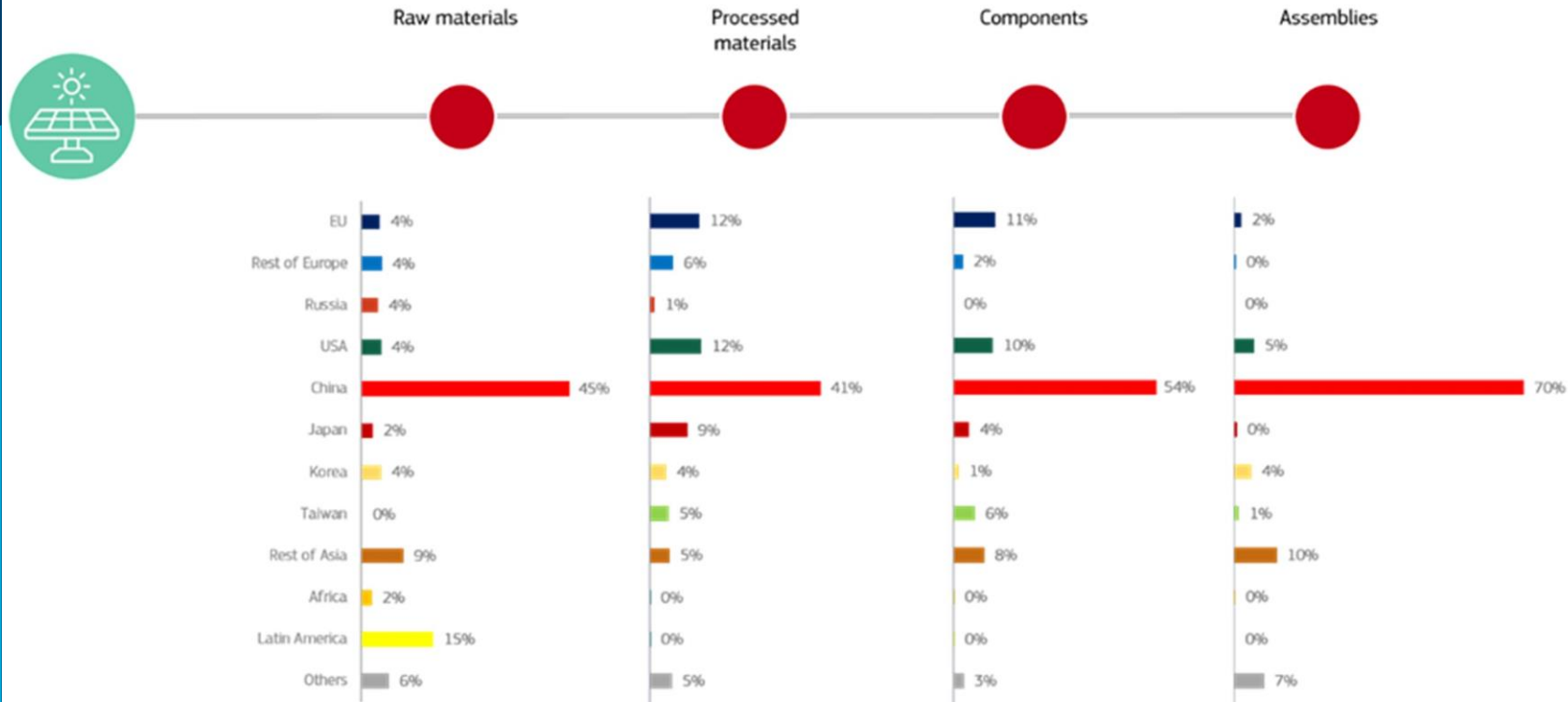
### Photovoltaics- Supply risk for different materials



# Critical materials

## Technology profiles

### Photovoltaics



# Critical materials

## Technology profiles

### Wind turbines

**Iron:** as cast iron or in steel composition for tower, nacelle, rotor and foundation; in neodymium-iron-boron (NdFeB) permanent magnets

**Chromium:** essential for stainless steel and other alloys in rotor and blades

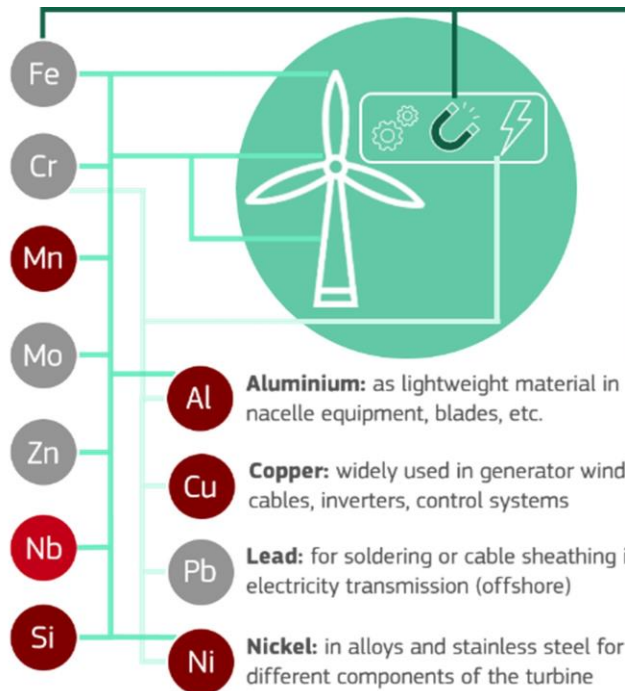
**Manganese:** essential for steel production used for many parts of a turbine

**Molybdenum:** in stainless steel composition for many components of the turbine

**Zinc:** in protective coatings against corrosion

**Niobium:** a microalloying element in high strength structural steel for towers of a turbine

**Silicon:** as alloying element in high-performance steels and as silicone in polymers (sealants, adhesives, lubricants)



**Boron:** in composition of NdFeB permanent magnets or as lubricant

**Dysprosium:** important additive of NdFeB permanent magnets

**Neodymium:** in NdFeB permanent magnets for electricity generation

**Praseodymium:** together with neodymium in permanent magnets

**Aluminium:** as lightweight material in nacelle equipment, blades, etc.

**Copper:** widely used in generator windings, cables, inverters, control systems

**Lead:** for soldering or cable sheathing in electricity transmission (offshore)

**Nickel:** in alloys and stainless steel for different components of the turbine

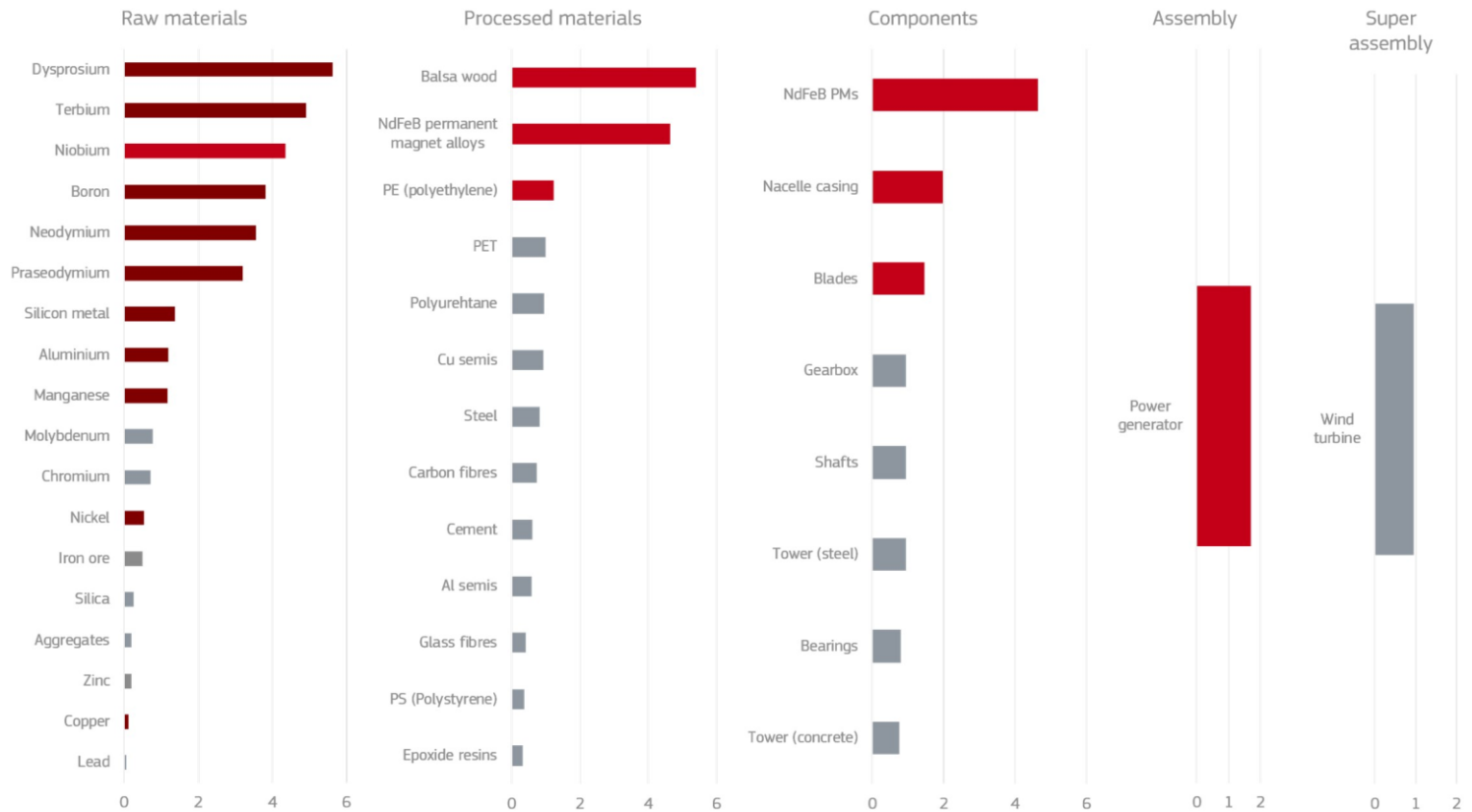
● Strategic Raw Material

● Critical Raw Material

# Critical materials

## Technology profiles

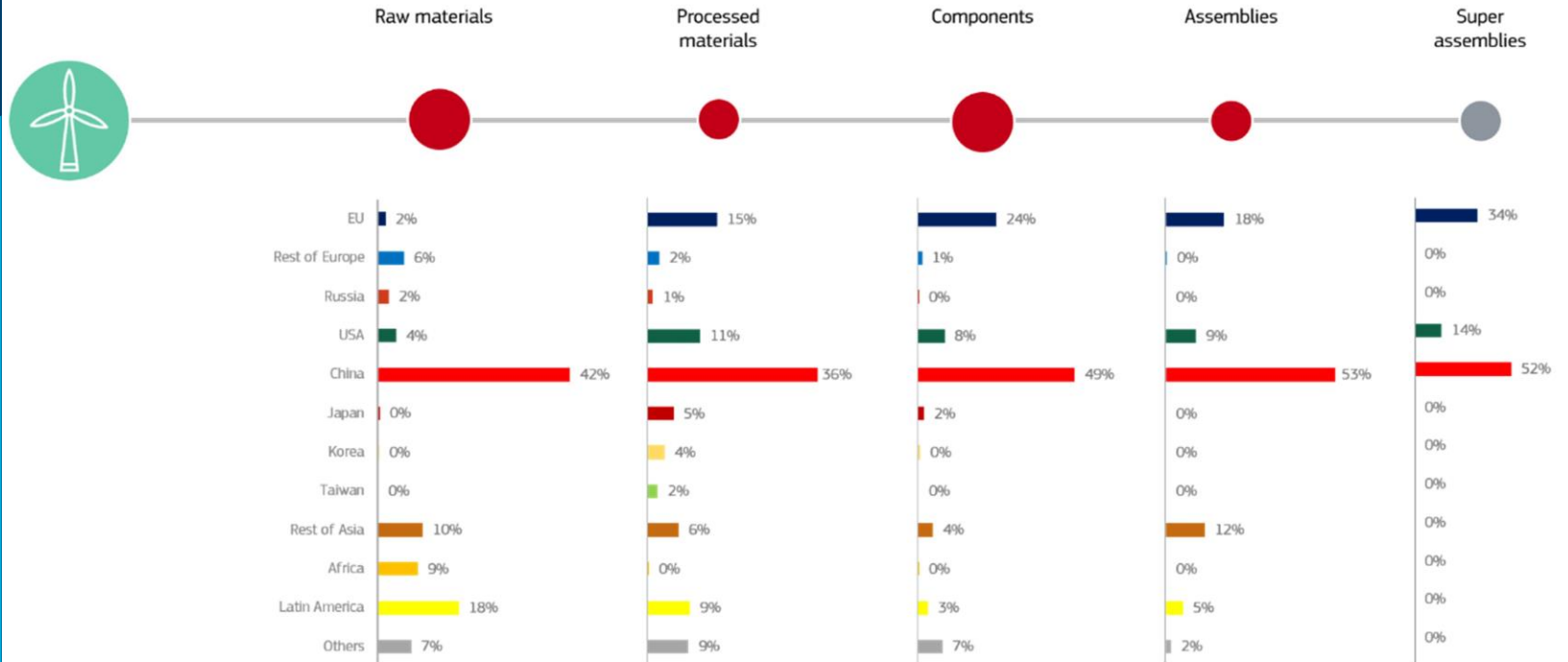
### Wind turbines – Supply risk



# Critical materials

## Technology profiles

### Wind turbines



# Critical materials

## Technology profiles

### Li-Batteries

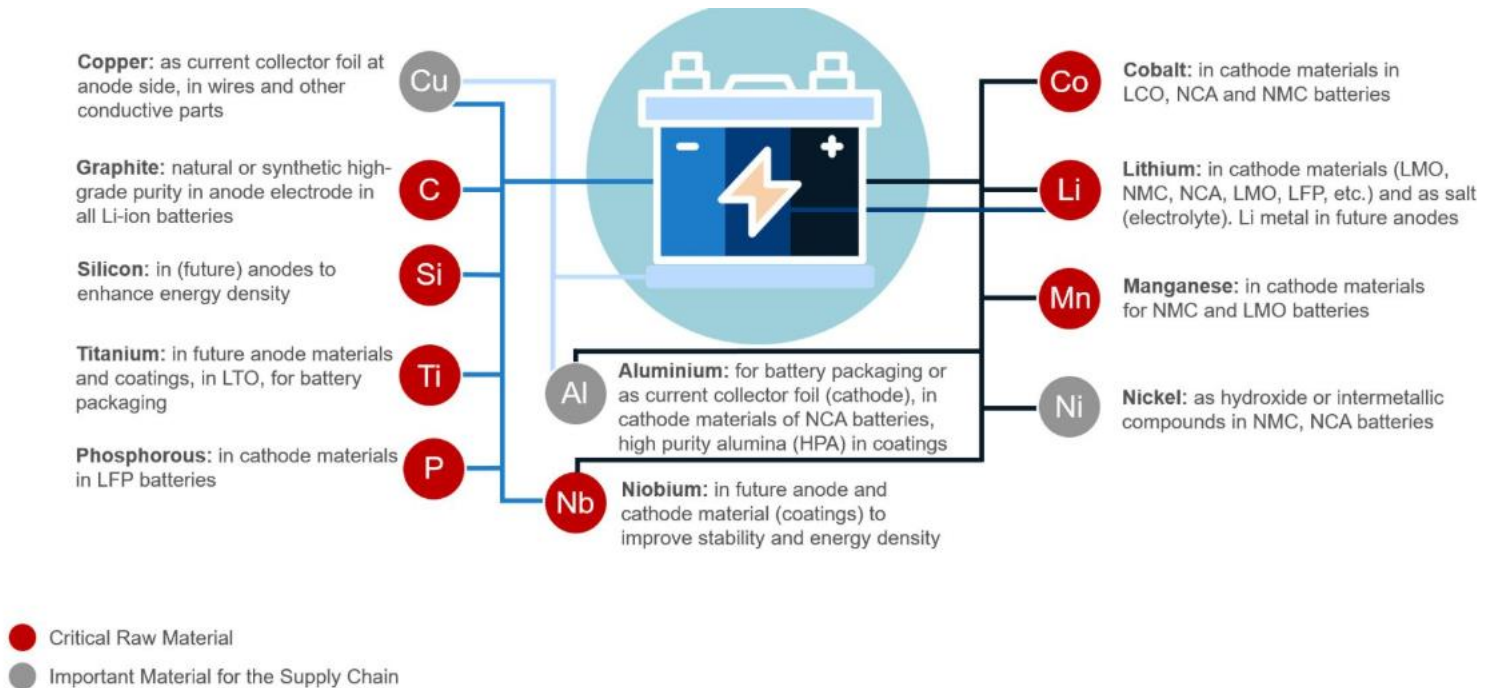


Figure 1: Selection of raw materials used in Li-ion batteries and their function. Source: JRC, 2023

# Critical materials

## Technology profiles

### Li-Batteries– Supply risk

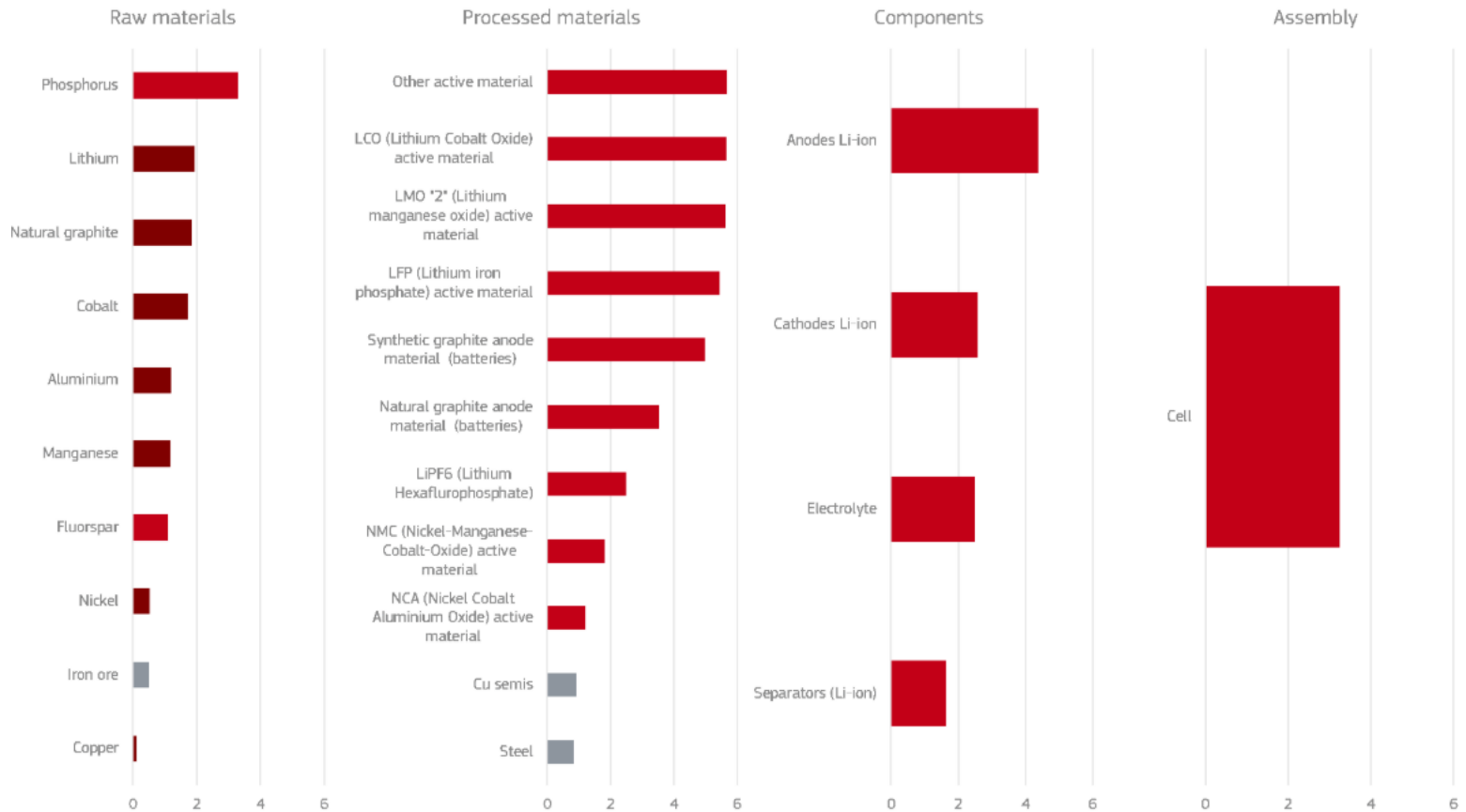


Figure 2 : Detailed Supply Risk of all elements in the Li-ion battery supply chain. Source: JRC, 2023.

Source: [RMIS - Technologies and sector profiles](#)

# Critical materials

## Technology profiles

### Li-Batteries

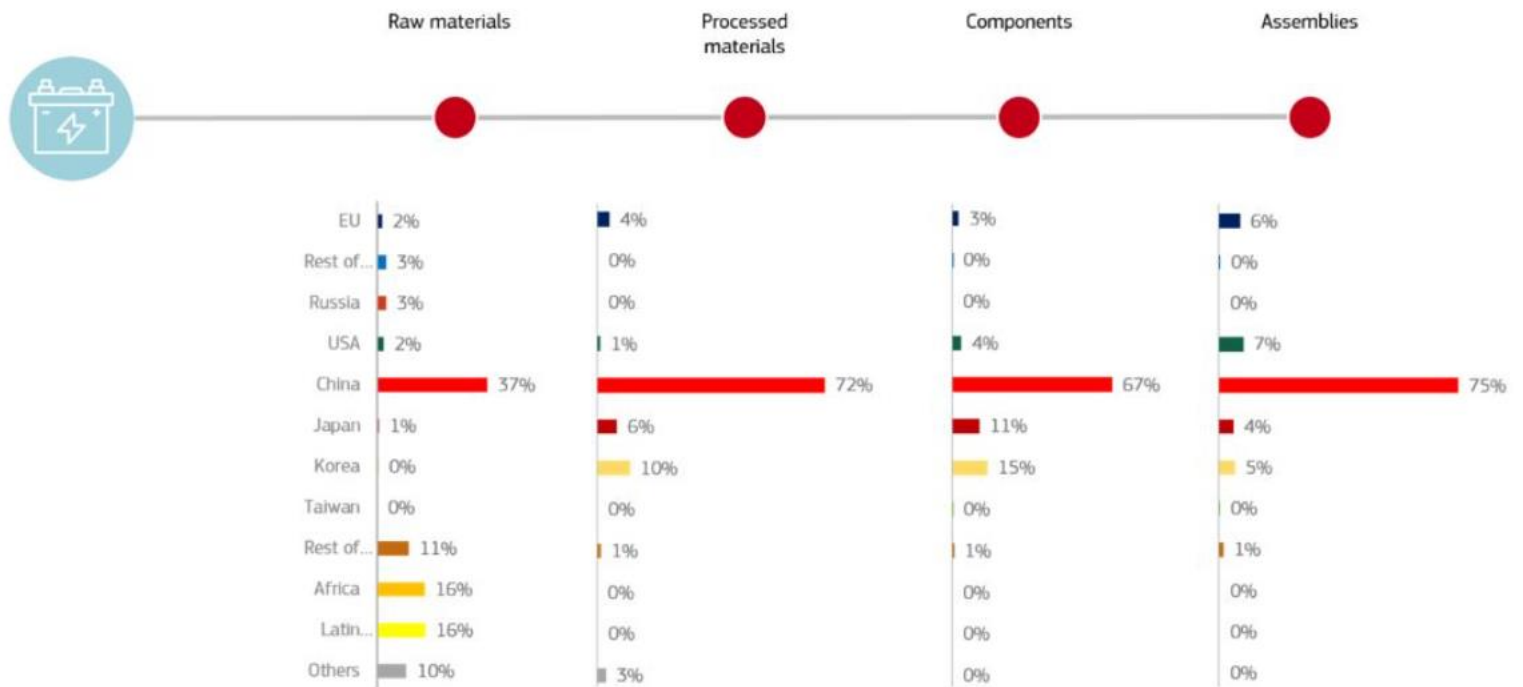


Figure 3: An overview of supply risks, bottlenecks, and key players along the supply chain of Li-ion batteries Source: JRC, 2023.

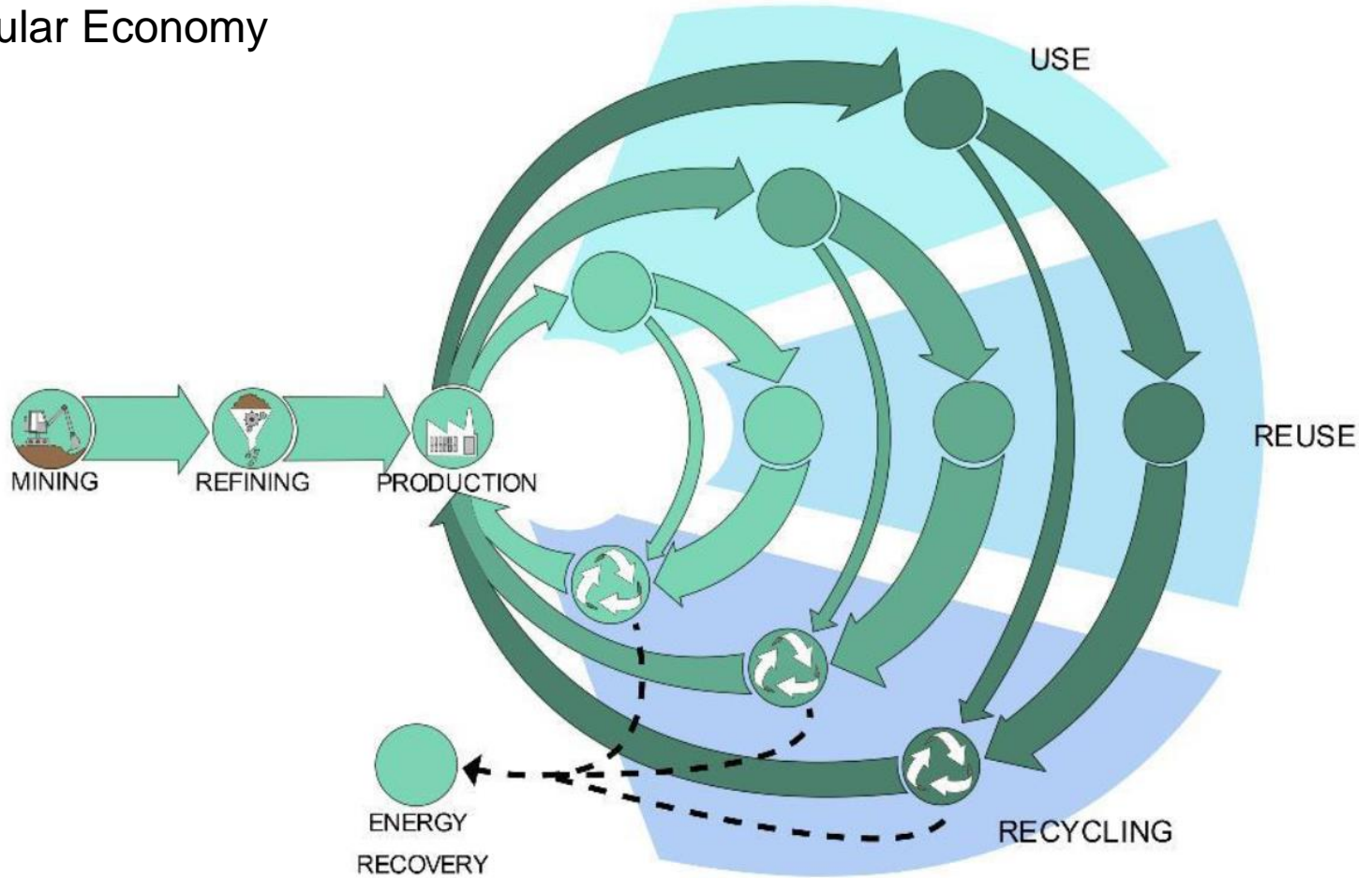
# Agenda

- Materials demands for energy transition
- Critical materials
- **Ways out**
- Example: electric vehicles

# Critical materials

## Ways out

### Circular Economy



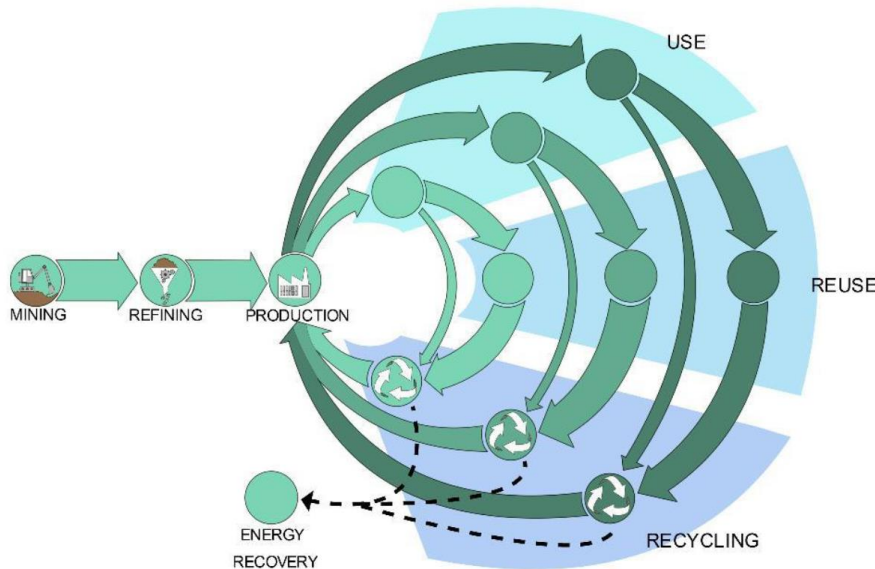
# Critical materials

## Ways out

### Circular Economy

## Methods

- **Life-cycle Assessment (LCA)**
- **Material Flow Analysis (MFA):** a great data base for MFA can be found in the link here: [RMIS - Material system analysis \(MSA\) \(europa.eu\)](#)

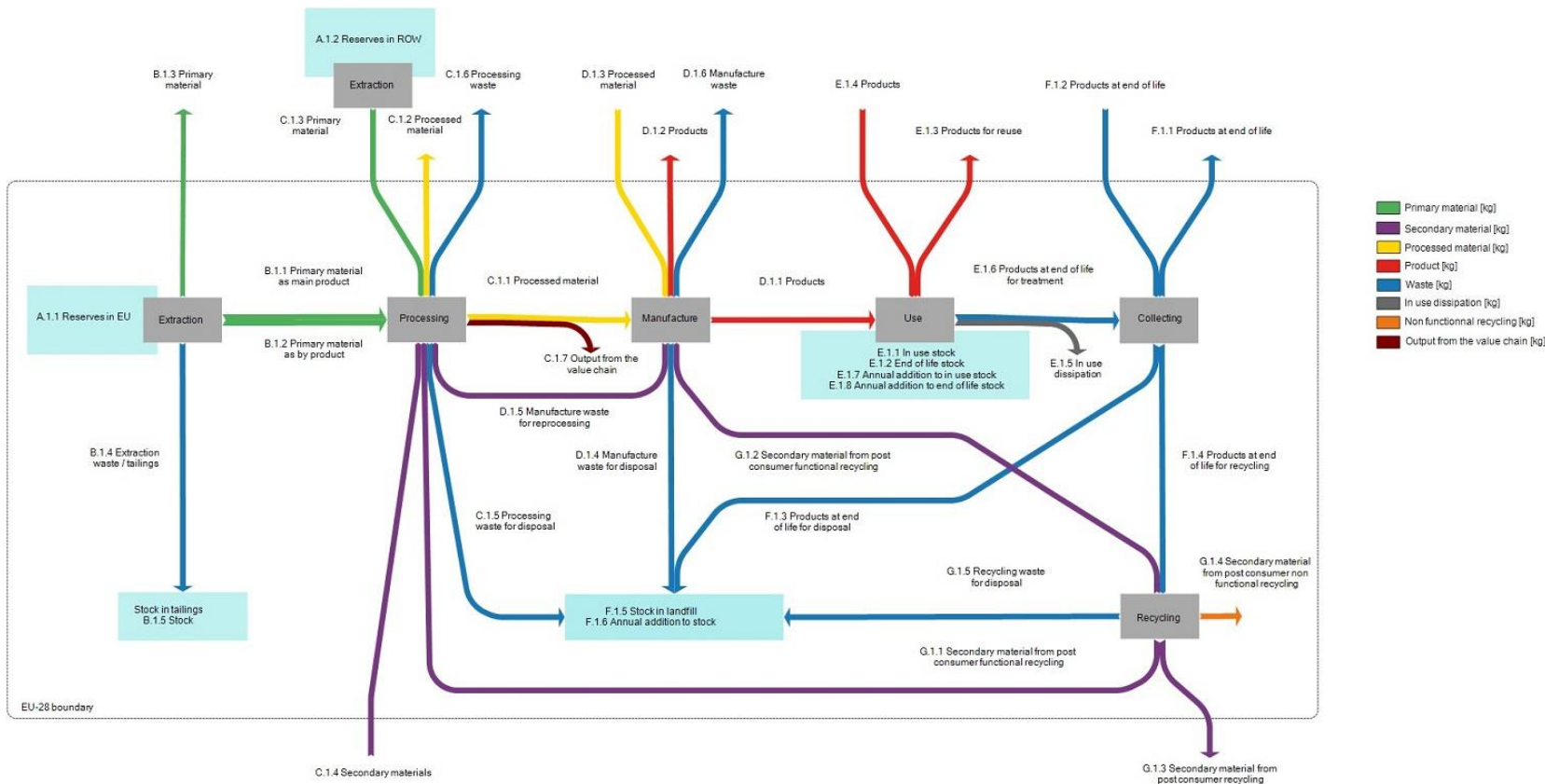


# Critical materials

## Global demand and supply

**Primary sources** → directly obtained from nature, raw materials

**Secondary sources** → are any processed materials at any stage of the subsequent material use

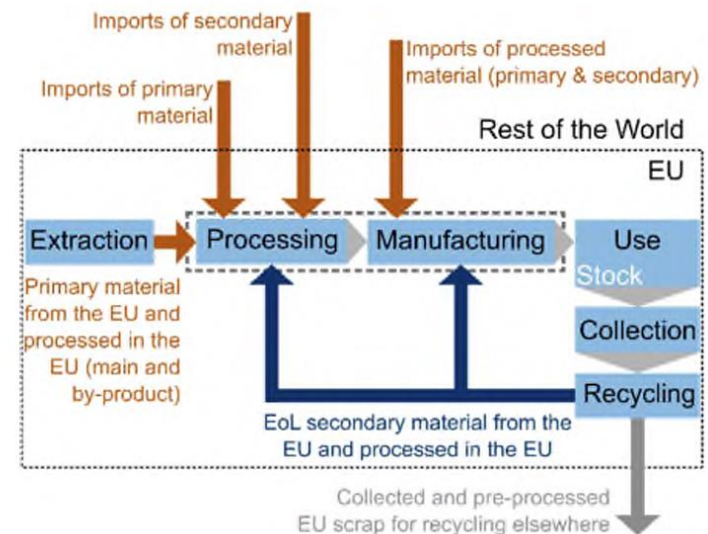
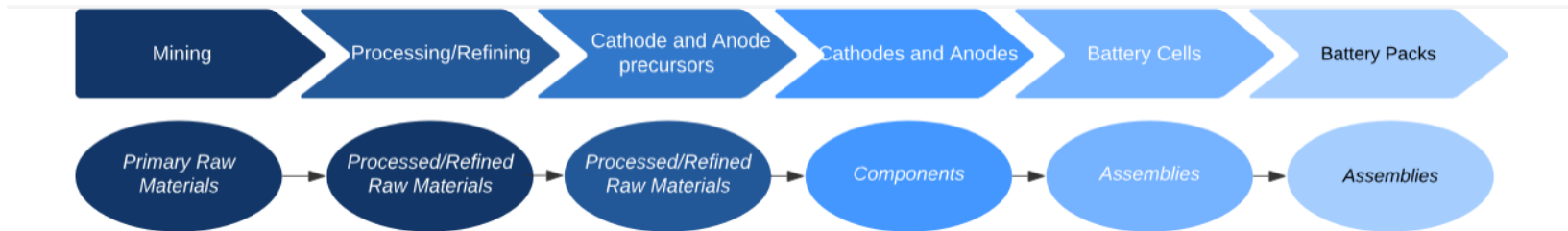


# Critical materials

## Global demand and supply

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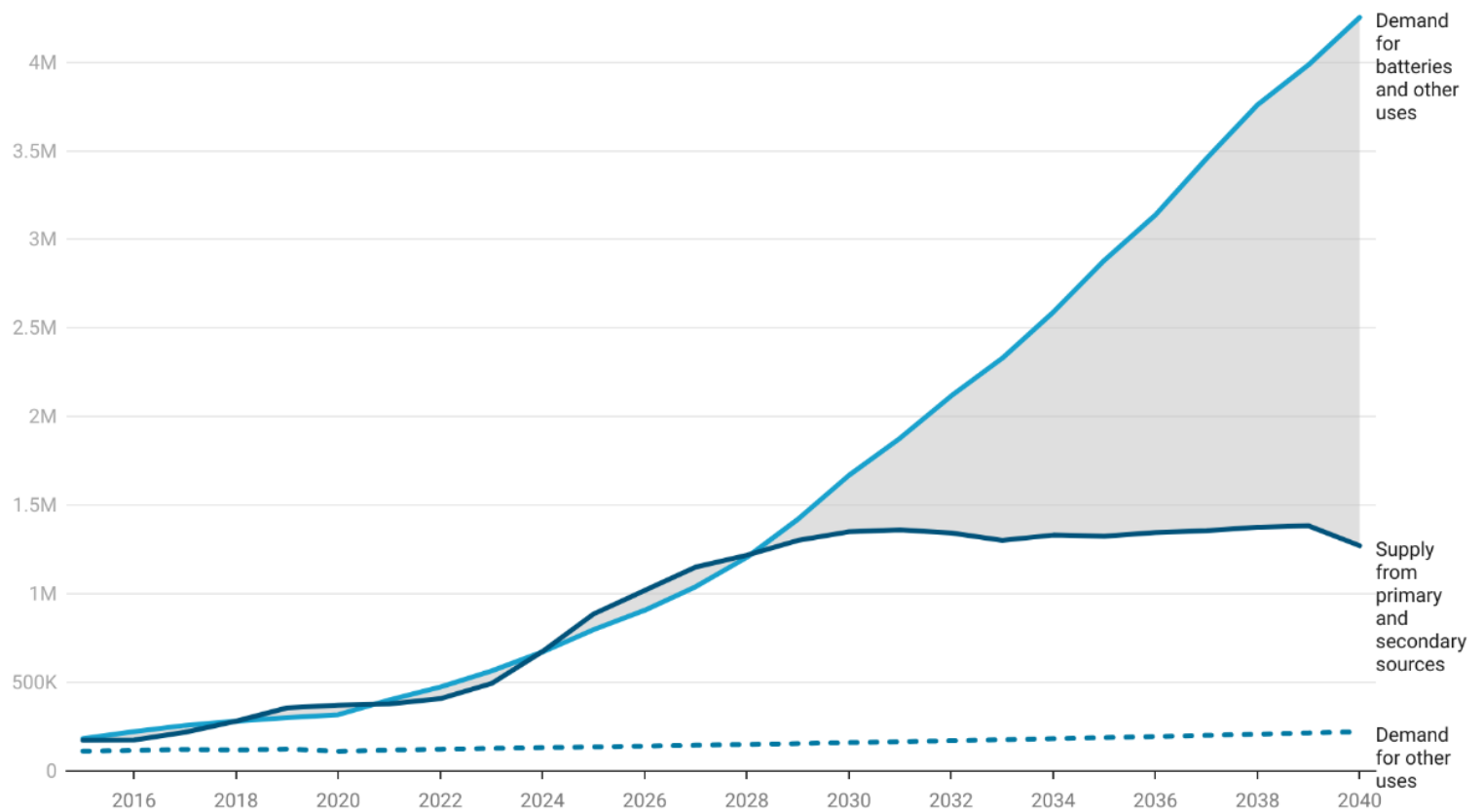


# Critical materials

## Global demand and supply

### Primary and secondary sources

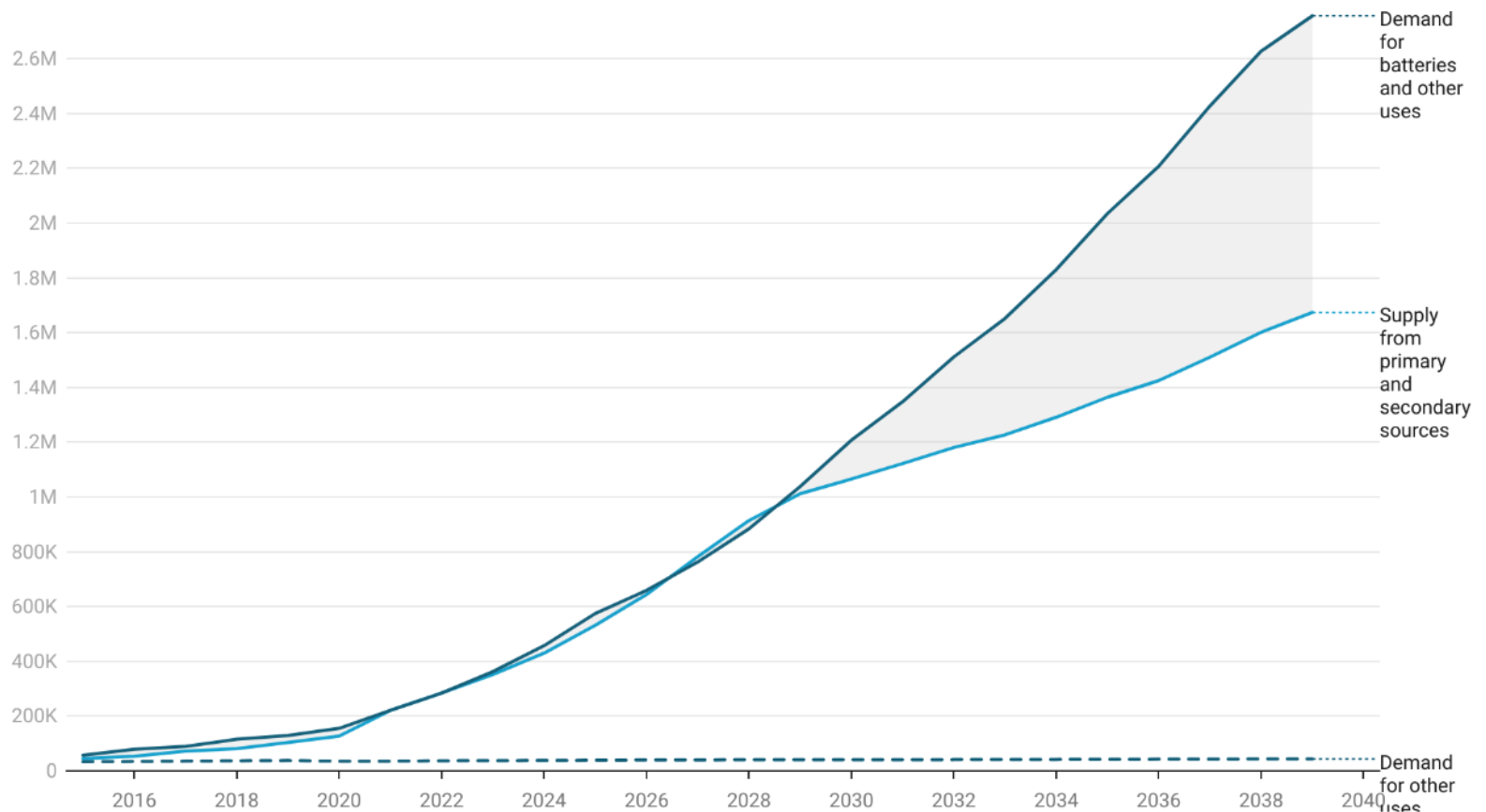
Forecast of global Supply-Demand balance for **lithium** [t LCE]



# Critical materials

## Global demand and supply Primary and secondary sources

Forecast of global Supply-Demand balance for **nickel** [t]

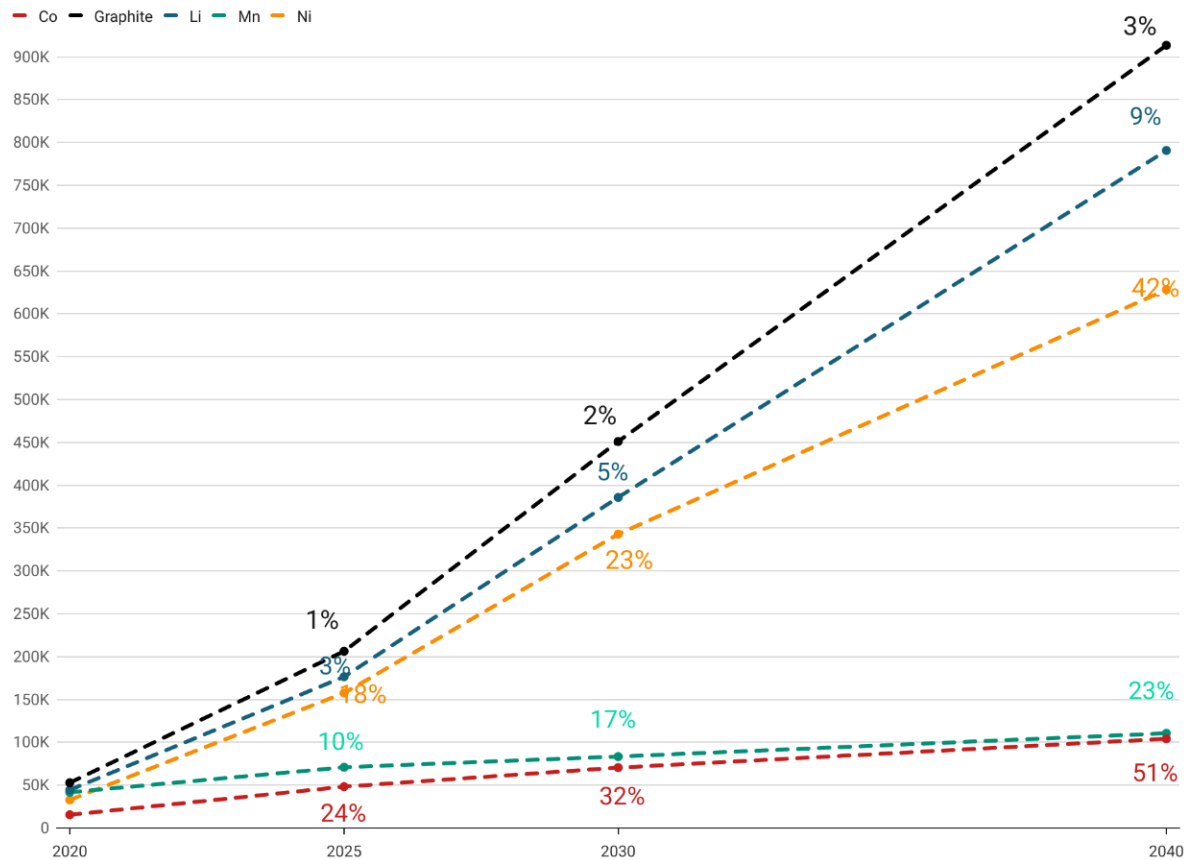


# Critical materials

## Potential secondary sources

### Forecast of global Supply-Demand balance for nickel [t]

**Figure 4** – Estimated consumption of battery raw materials [t] and supply potential from secondary raw materials (old+new scrap) [%] in the EU (2020-2040)



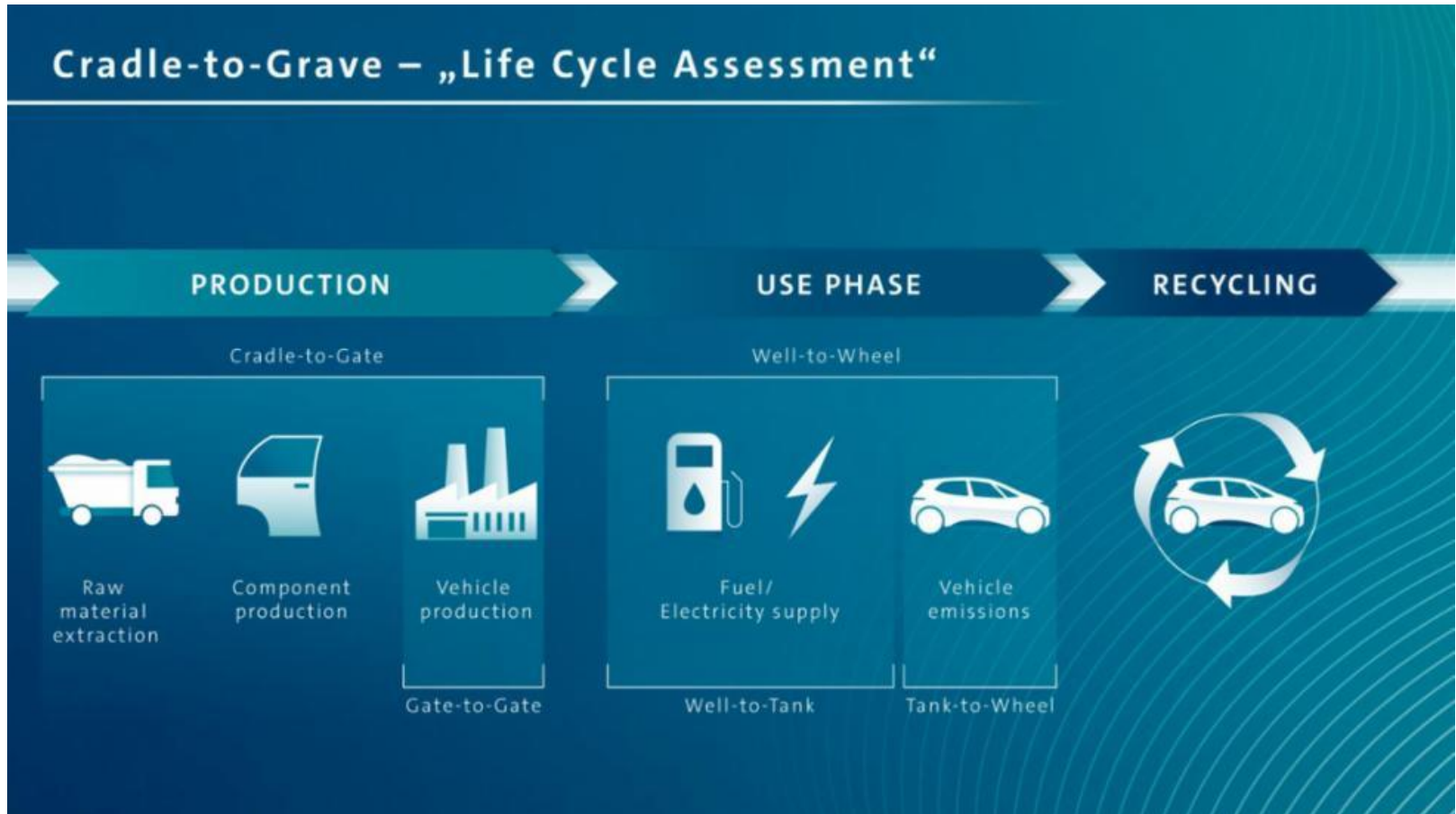
# Agenda

- Materials demands for energy transition
- Critical materials
- Ways out
- **Example: electric vehicles**

# Critical materials

## Example: E-vehicles

### Circular Economy

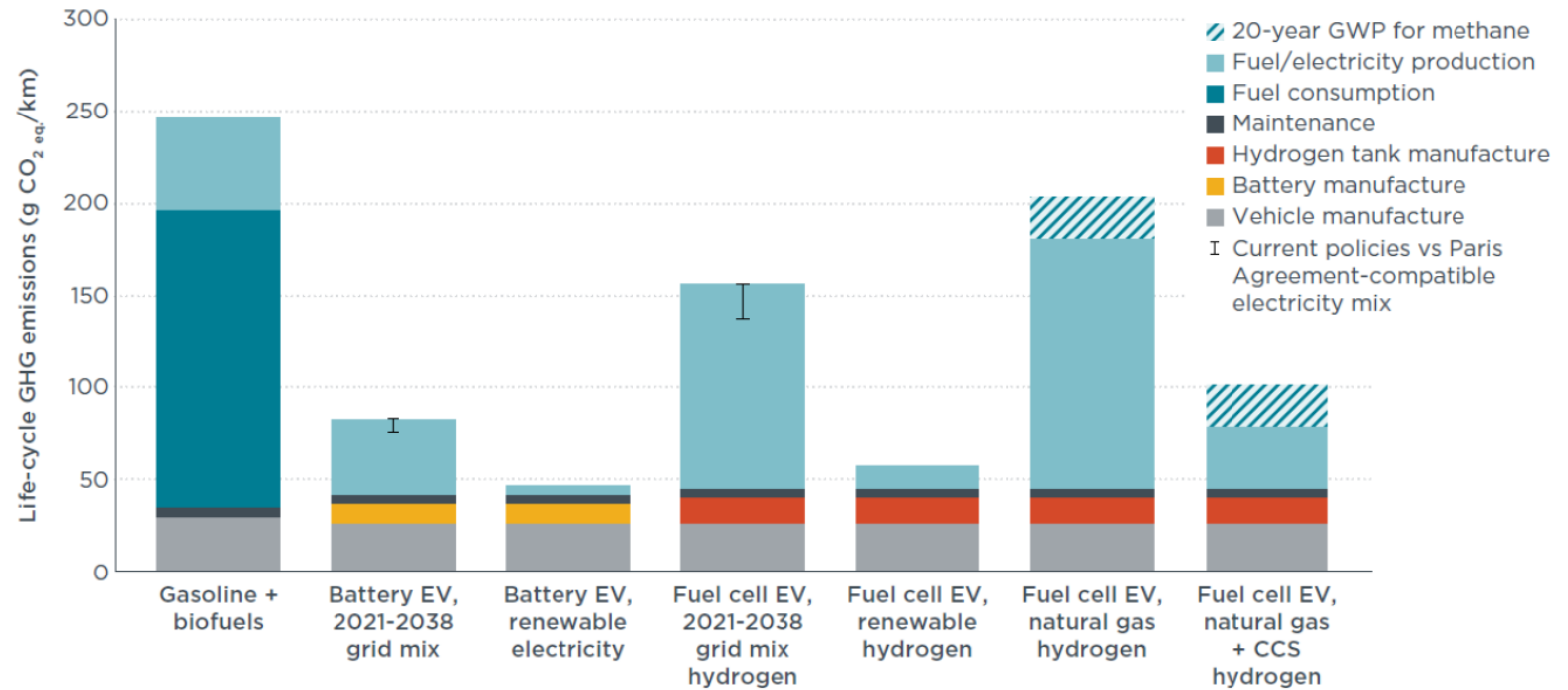


# Critical materials

→ Tank-to-wheel analysis

## Example: E-vehicles

### Circular Economy



Reference: ICCT WHITE PAPER, GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF PASSENGER CARS, 2021

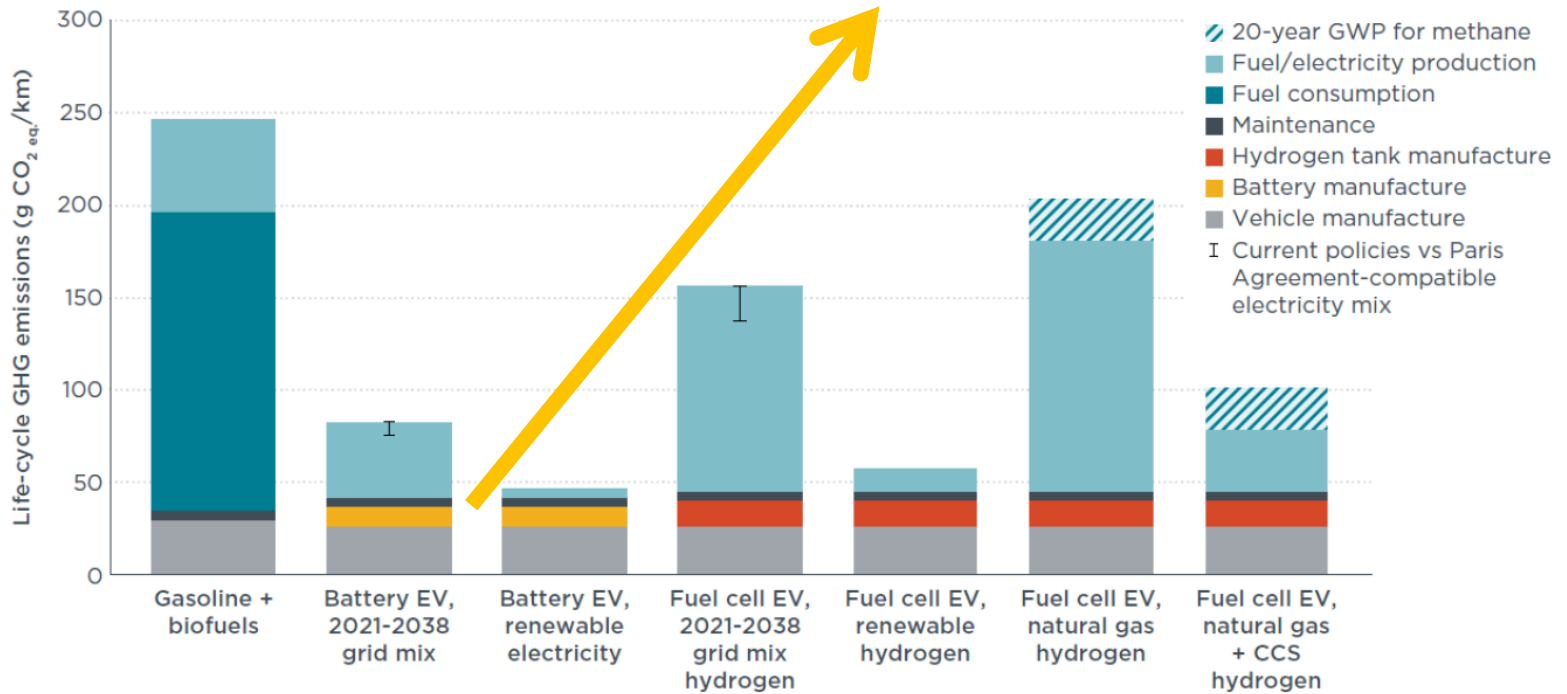
# Critical materials

→ Tank-to-wheel analysis

## Example: E-vehicles

→ CO2 is not the only relevant indicator!

### Circular Economy

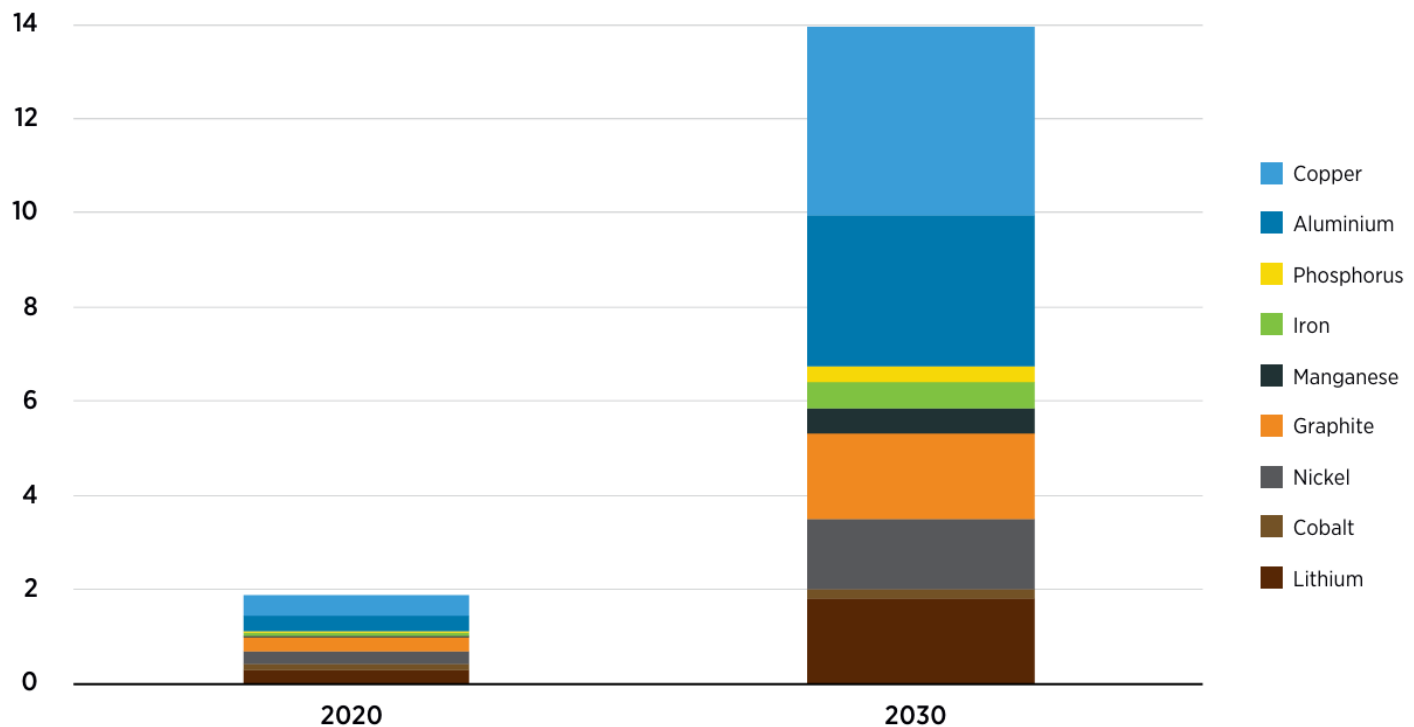


Reference: ICCT WHITE PAPER, GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF PASSENGER CARS, 2021

# Critical materials

## Example: E-vehicles

Projections of demand for **battery** materials (IRENA 2022)

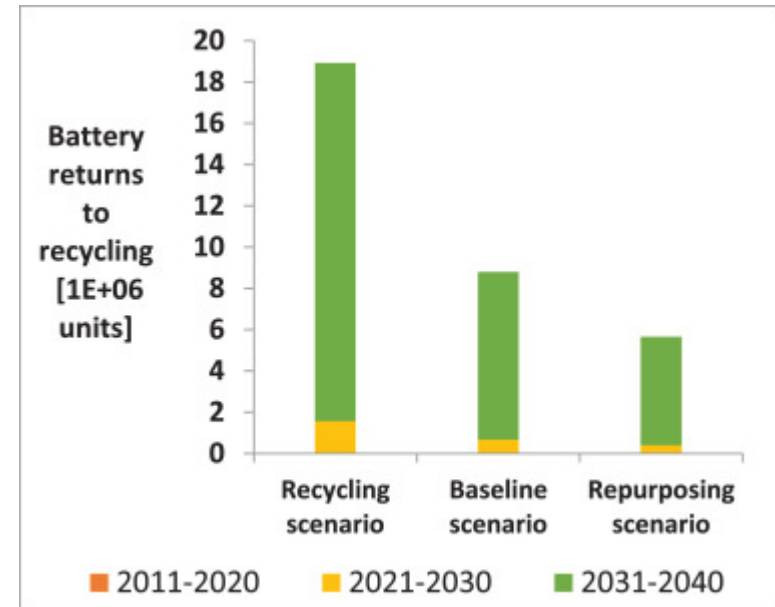
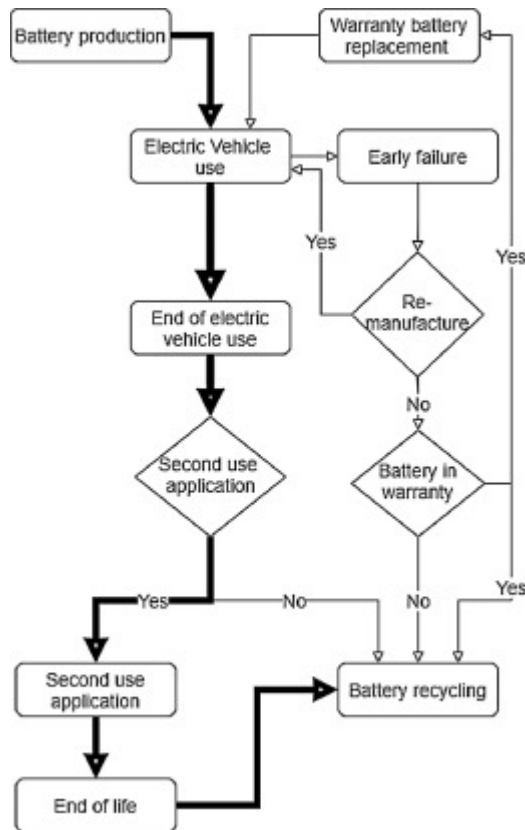


Adapted from: BloombergNEF, 2021a.

# Critical materials

## Example: E-vehicles

Second-life, reusing, refurbishing and recycling...  
...for **battery** materials



# Critical materials

## Example: E-vehicles

Second-life, reusing, refurbishing and recycling...  
...for **battery** materials

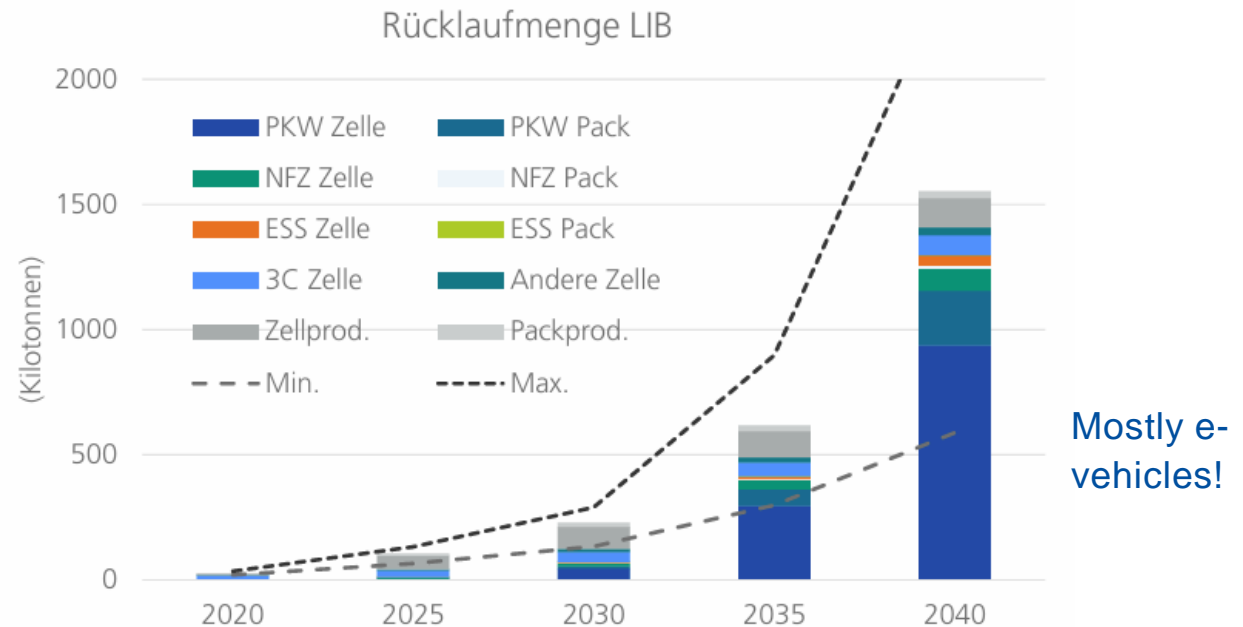
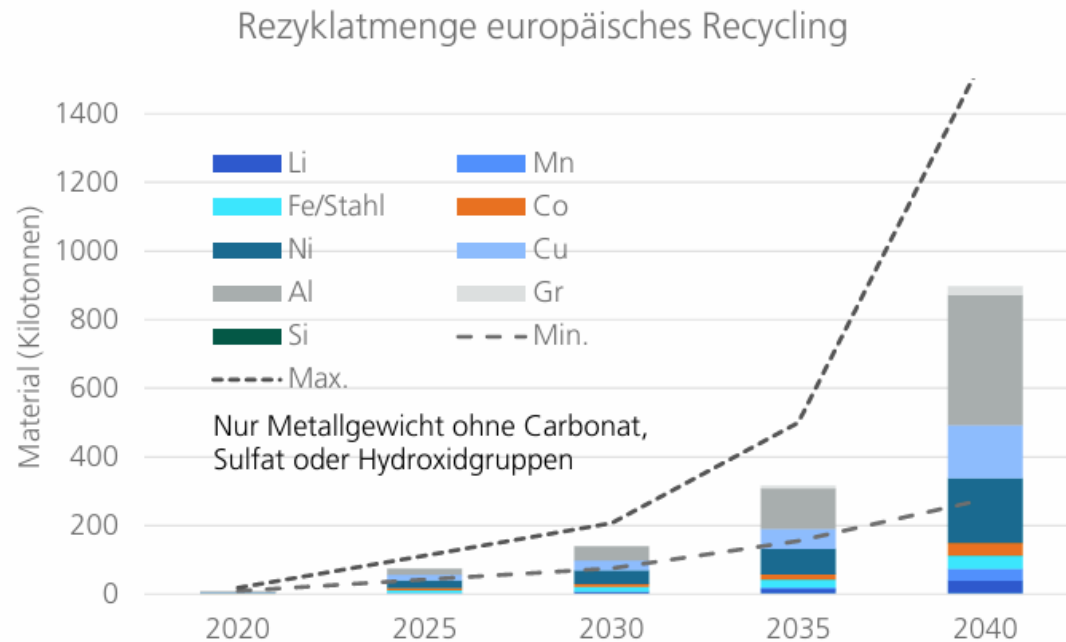


Abbildung 4: Prognose zur Rücklaufmenge gebrauchter LIB aus unterschiedlichen Anwendungen (PKW, Nutzfahrzeuge: NFZ, stationäre Speicher: ESS, „Computing, consumer, communication“: 3C) und von Zellproduktionsschrotten in ein europäisches Recycling. Die Balken bilden das Basis-Szenario ab.

# Critical materials

## Example: E-vehicles

Second-life, reusing, refurbishing and recycling...  
...for **battery** materials



Li... ☹️

Abbildung 6: Entwicklung von Rezyklatmengen aufgeteilt nach unterschiedlichen Metallen und Rohstoffen bis 2040. Die Balken bilden das Basis-Szenario ab.

# Critical materials

## Example: E-vehicles

### Recycling processes and their outcomes

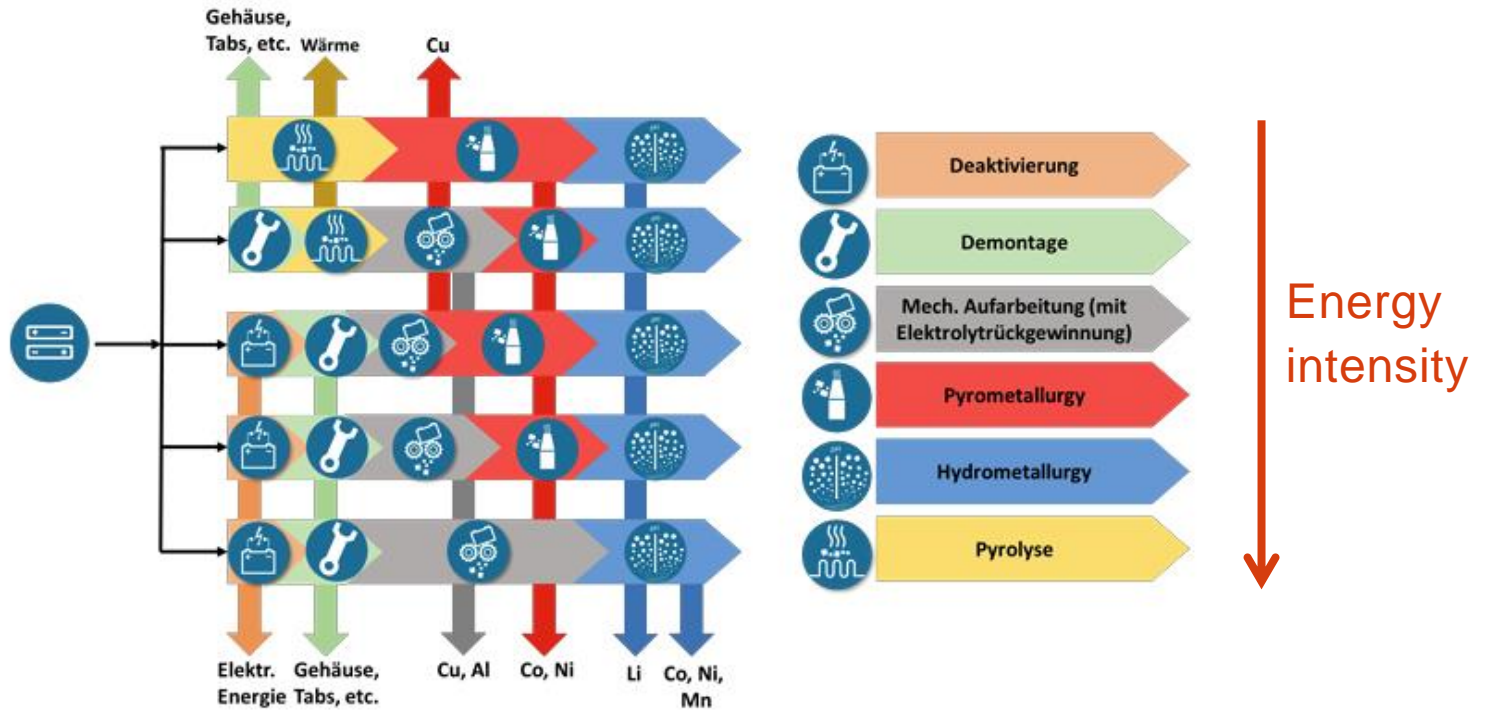


Abbildung 8: Mögliche Prozessrouten des Recyclings von Lithium-Ionen-Batterien. [Doose2021]

# Critical materials

## Take aways

- **Critical materials** (amount or origin) are required for many technologies within the energy transition:
  - Wind, PV, batteries, smart-grids
- **Demands** for these materials are expected to „sky-rocket“ as compared to current demands
- **Depletion times** in the range of a decade for future demands and current reserves!
- **Recycling and second life:**
  - Possible but:
    - Energy intensive!
    - Low recyclability rates for some materials
    - Potential for yearly supplies from recycling processes in the EU: 40% for Cobalt and ca. 15% for Lithium, Nickel und Copper for new batteries.