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Material resources for the energy transition

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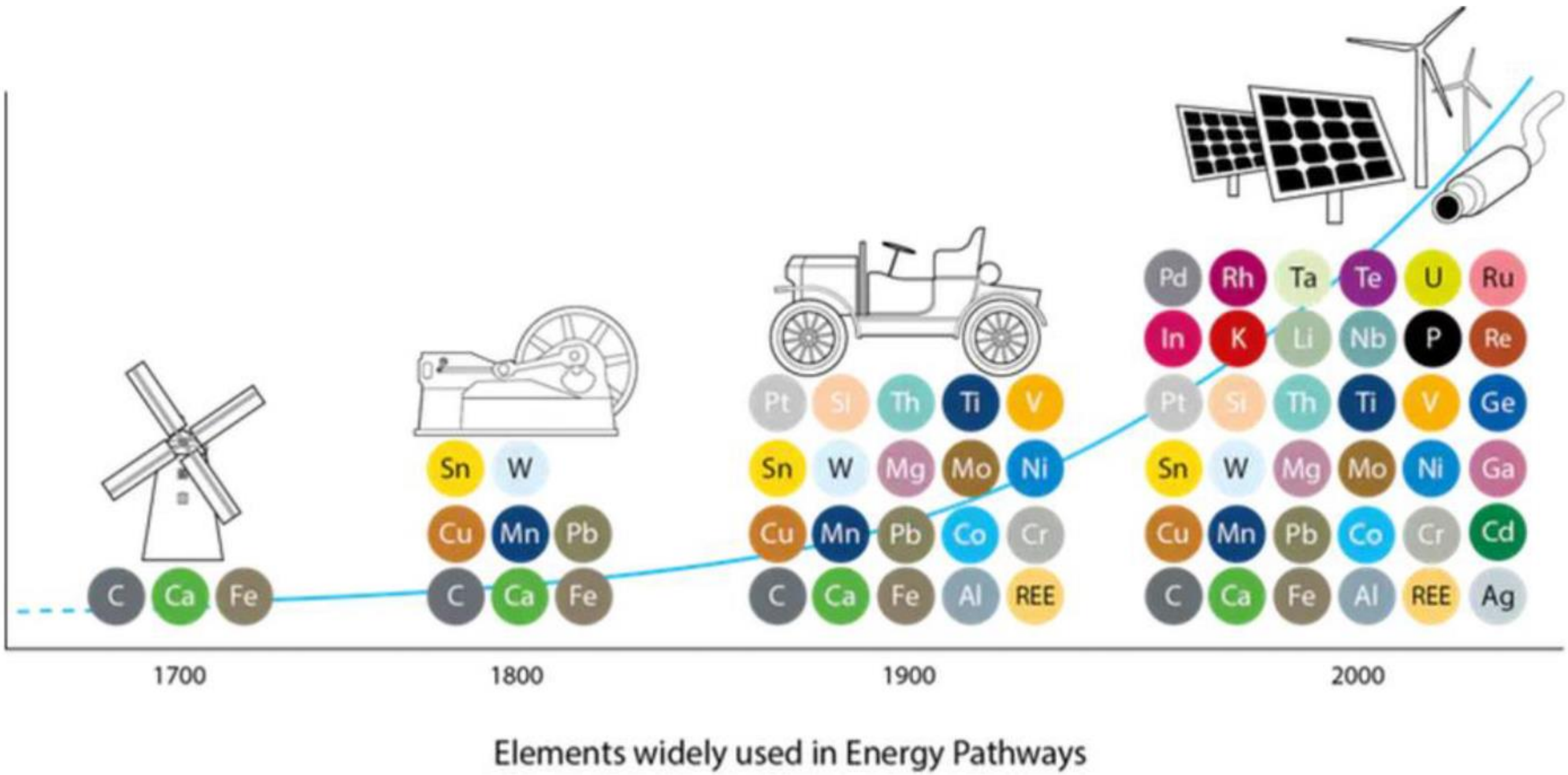
Agenda

- **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

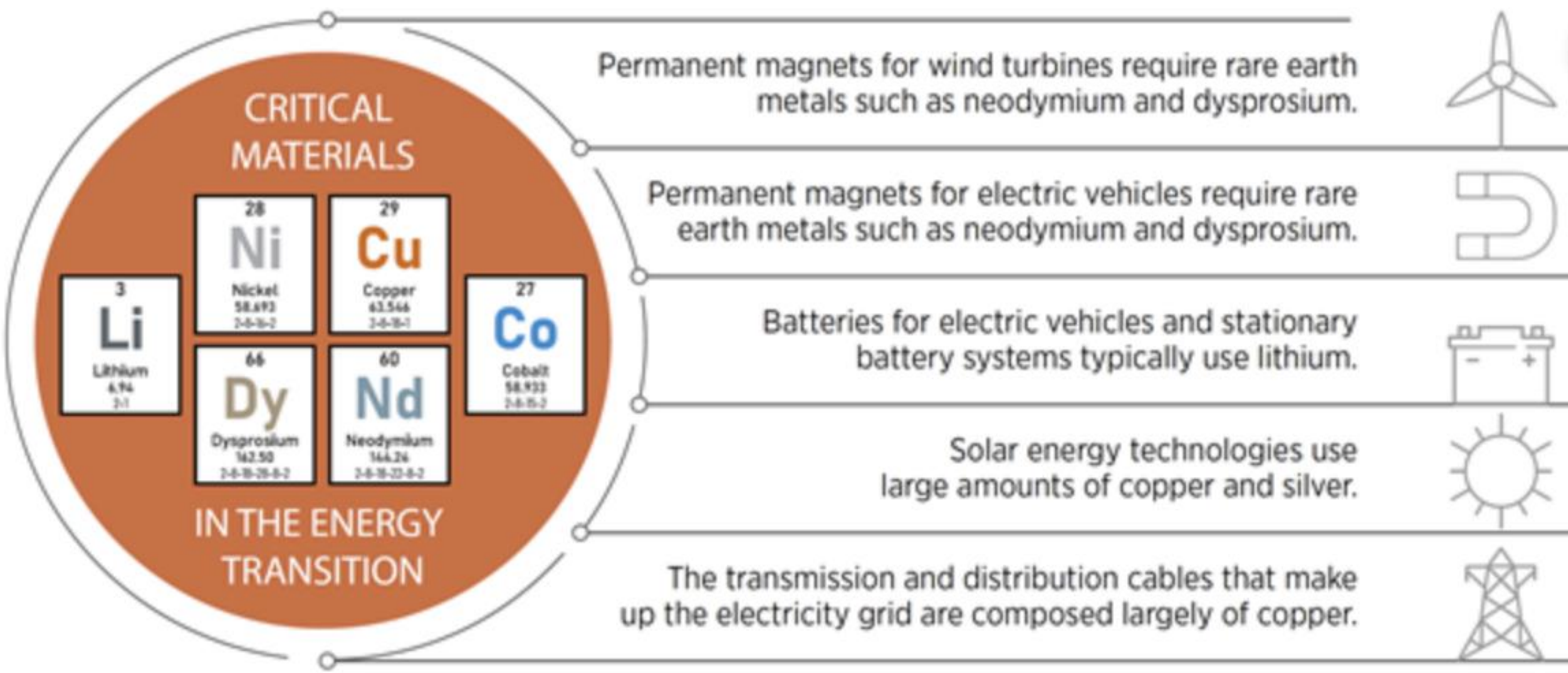


Source: Zepf et al. 2014. Materials critical to the energy industry.
Pehlken 2023. Lecture V01 – Hidden Champions for RE

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 electrolysers.



Source: Critical materials (irena.org), https://www.irena.org/Energy-Transition/Technology/Critical-materials

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Agenda

- Materials demands for energy transition
- **Critical materials**
- Ways out
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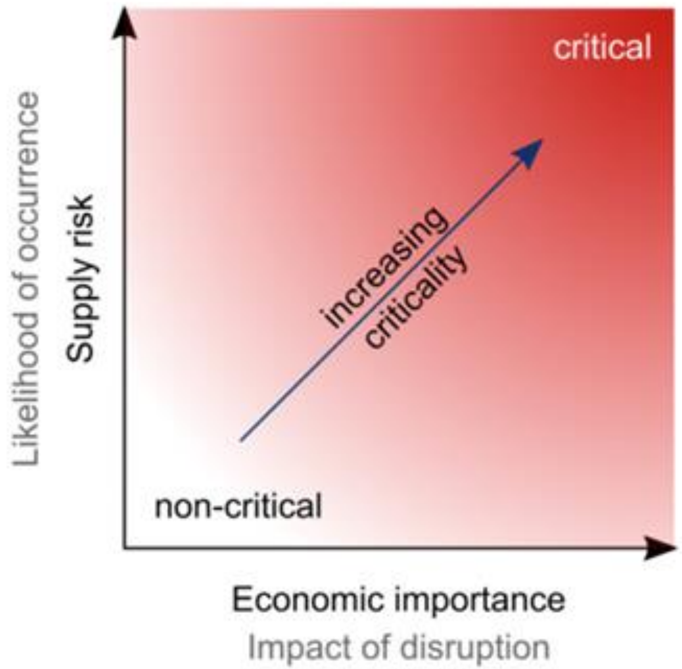
Critical materials

Supply risk:

Trying not to rely on a single provider (source)

- Includes aspects as governance, trade restrictitions, 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

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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Critical materials

Definition (IRENA, 2022)

Materials which…

Demand

- require a significant extraction effort
- a massive ramp-up of supply will be needed

Supply risk

- 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.

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**.

Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/5

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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

Source: Critical and Strategic Raw Materials identified

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Critical materials

Definition (IRENA, 2022)

Critical materials are those which…

Demand

- require a significant extraction effort
- a massive ramp-up of supply will be needed

Supply risk

- 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.

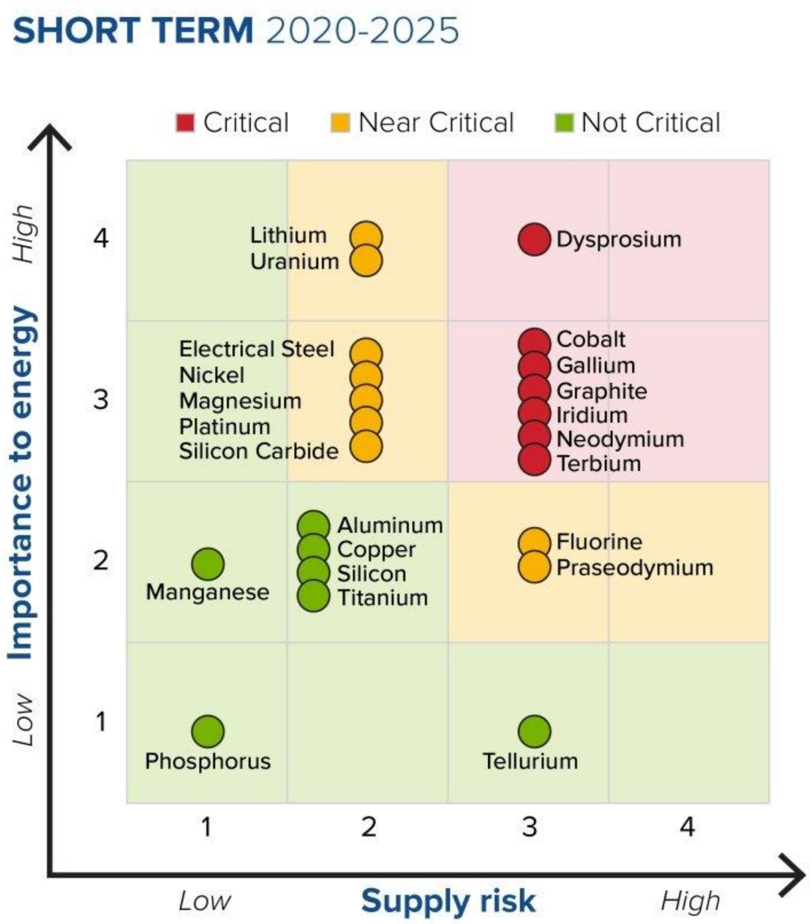
Strategic raw materials are…

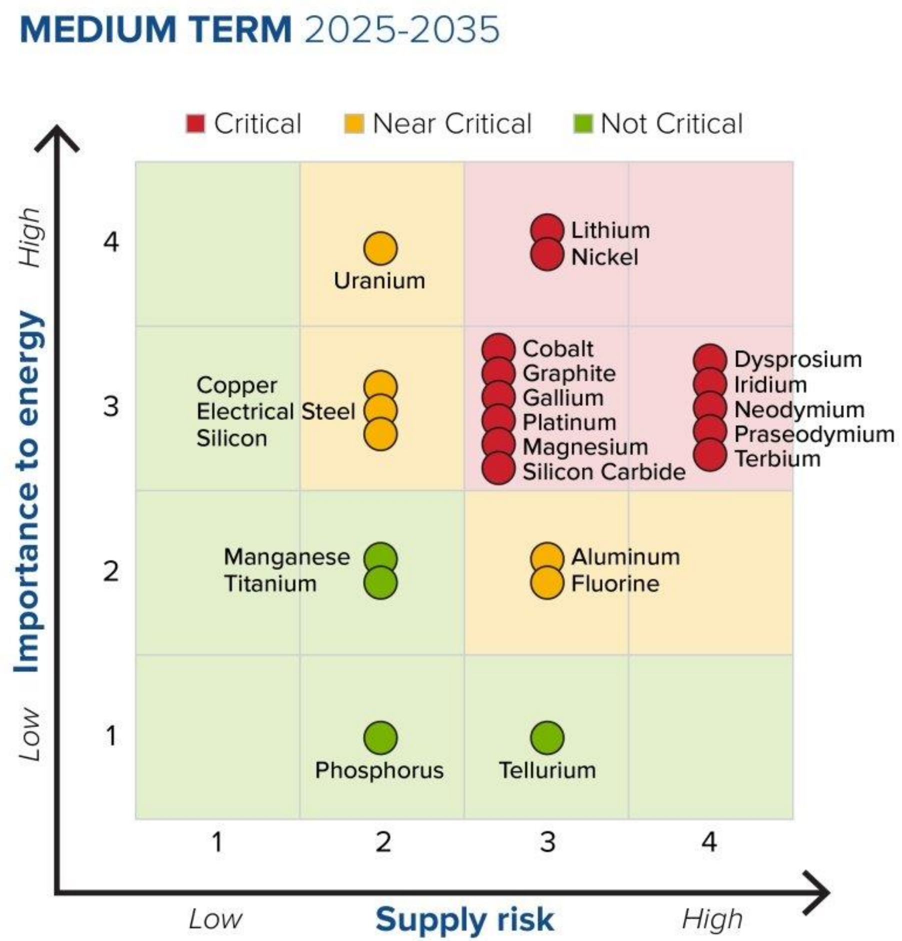
Critical materials of strategic importance for the EU strategic objectives (i.e. military defense, green transition, digitalization). Characterized by:

(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

Overview of critical materials

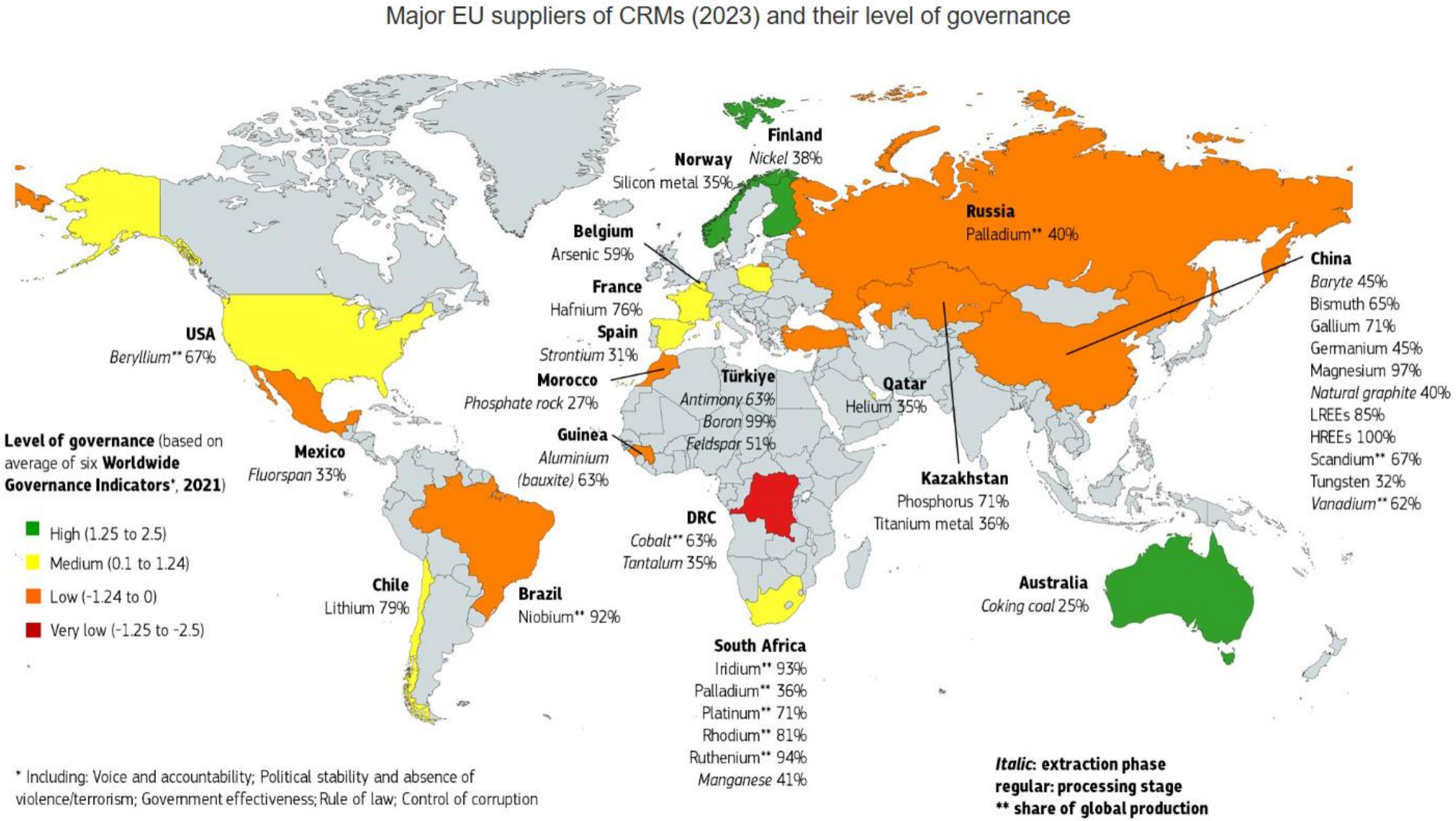




Source: https://www.energy.gov/cmm/what-are-critical-materials-and-critical-minerals

Critical materials

By countries and their „governance“



Source: https://rmis.jrc.ec.europa.eu/eu-critical-raw-materials

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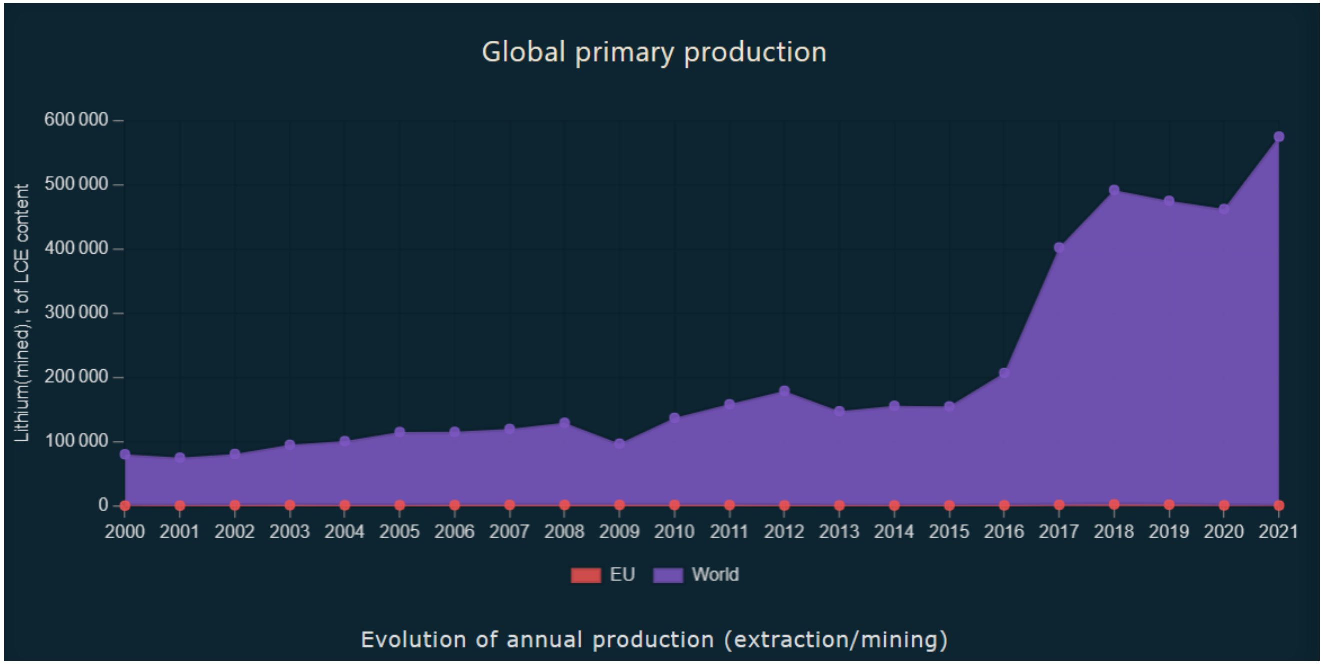
Critical materials

Production rates, historic data
Lithium

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



Source: RMIS - Raw materials' profiles (europa.eu), https://rmis.jrc.ec.europa.eu/rmp/Lithium

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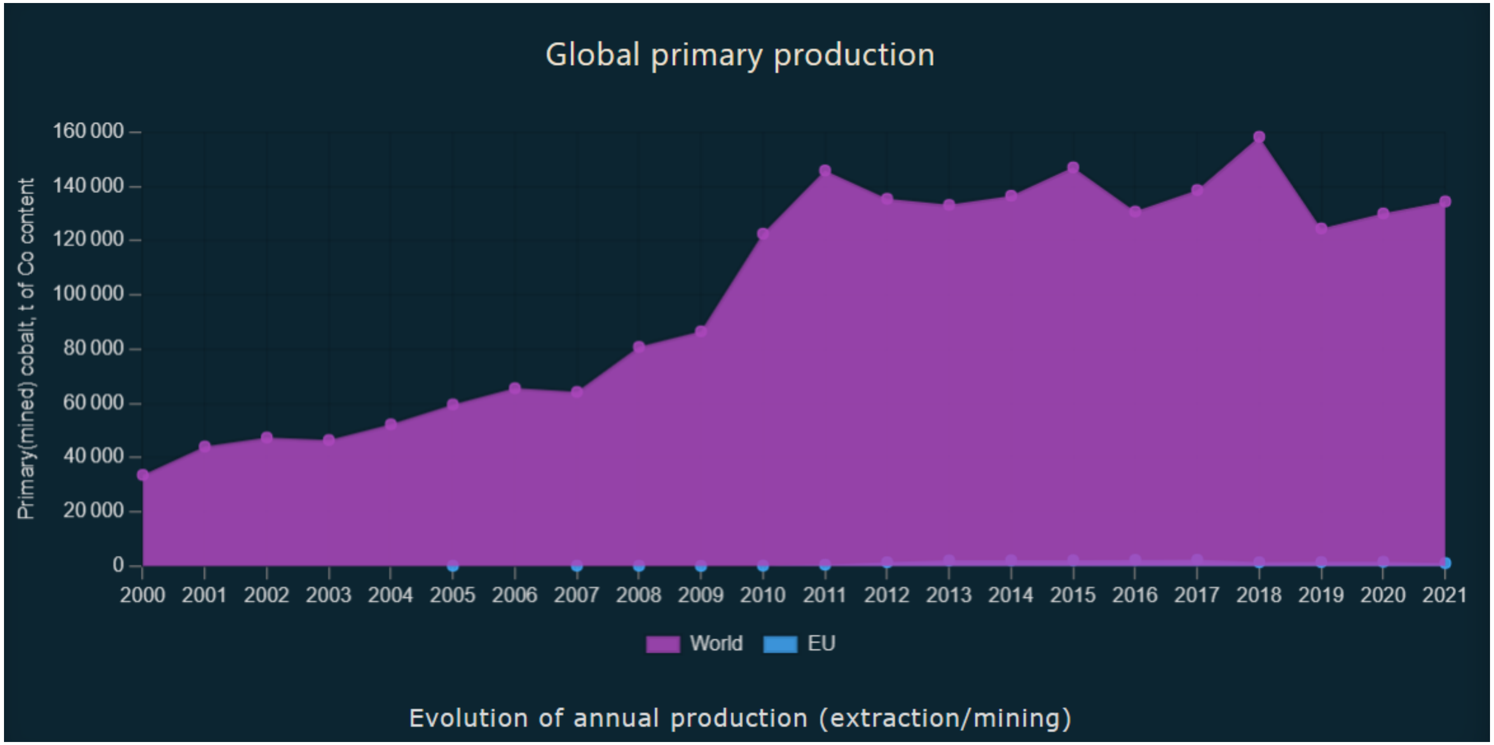
Critical materials

Production rates, historic data

Cobalt

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



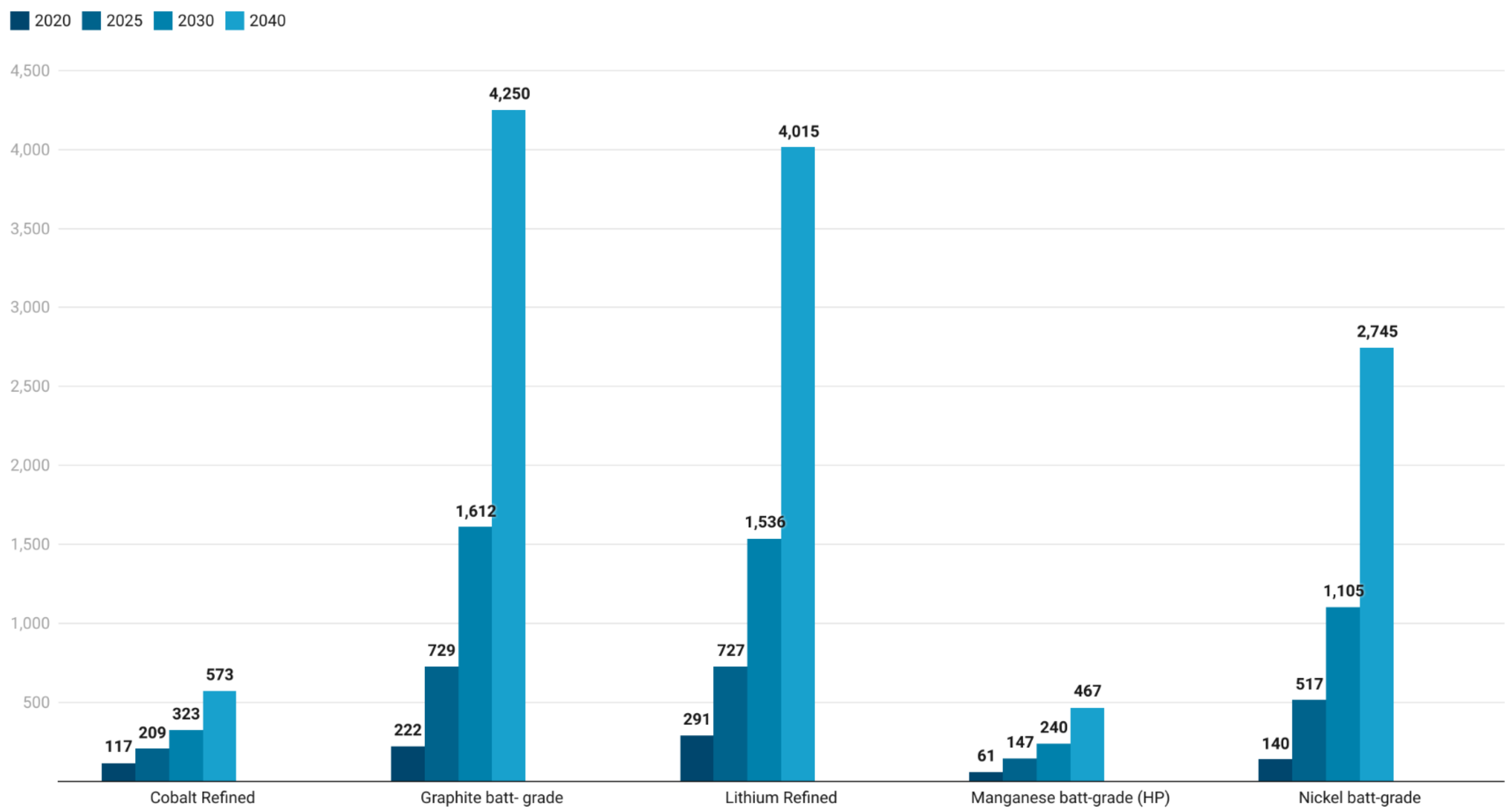
Source: RMIS - Raw materials' profiles (europa.eu), https://rmis.jrc.ec.europa.eu/rmp/Cobalt

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)

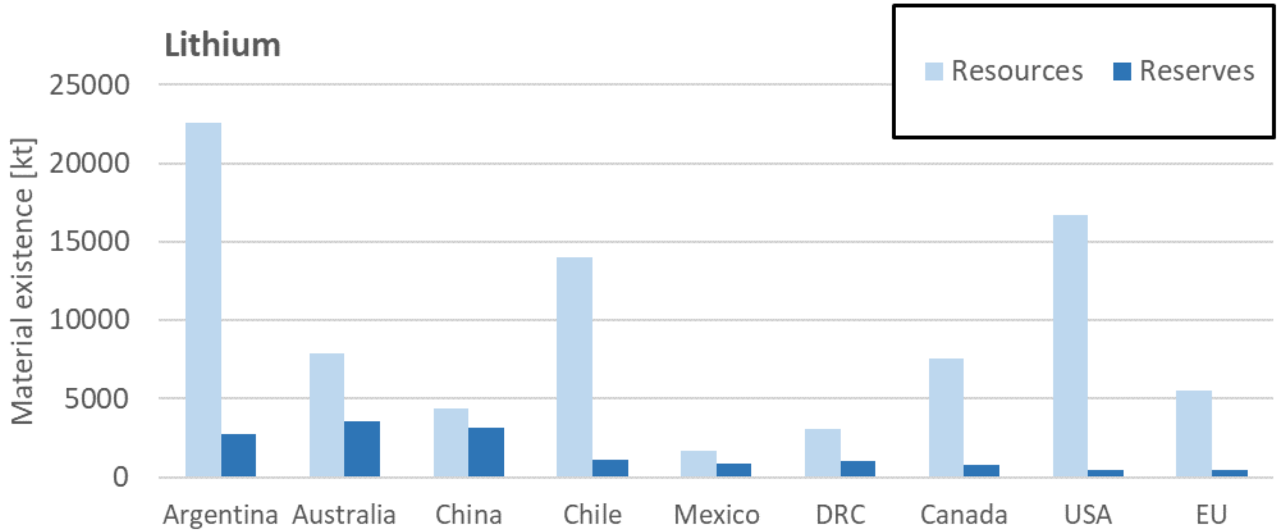
Critical materials

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!



Data source: RMIS - Raw materials' profiles (europa.eu), https://rmis.jrc.ec.europa.eu/rmp/Lithium

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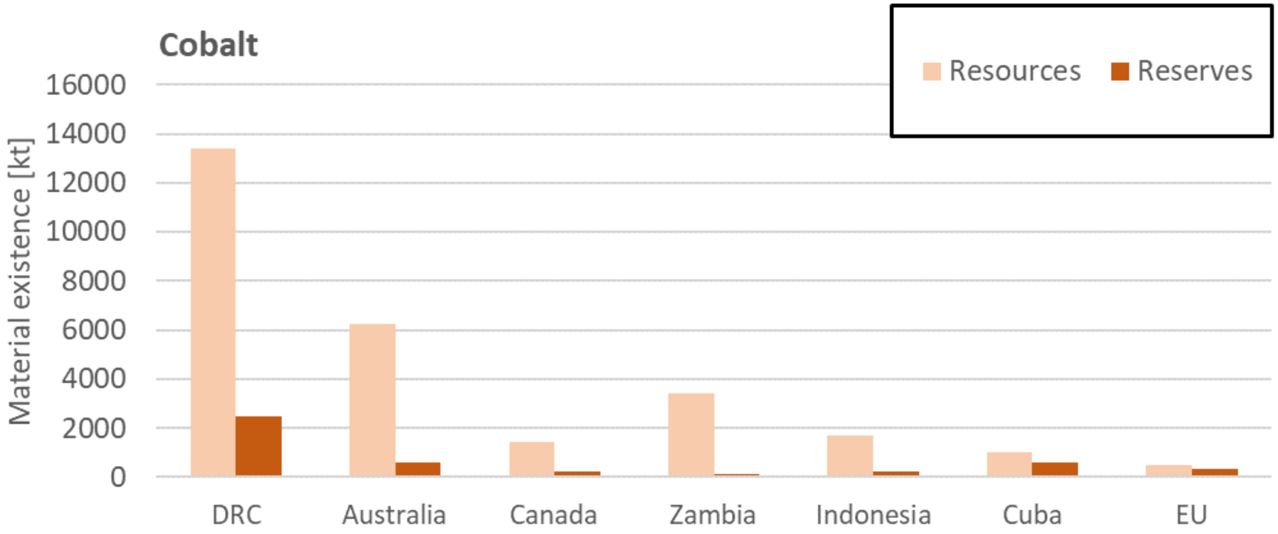
Critical materials

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!



Data source: RMIS - Raw materials' profiles (europa.eu), https://rmis.jrc.ec.europa.eu/rmp/cobalt

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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 (NiSO4)	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)

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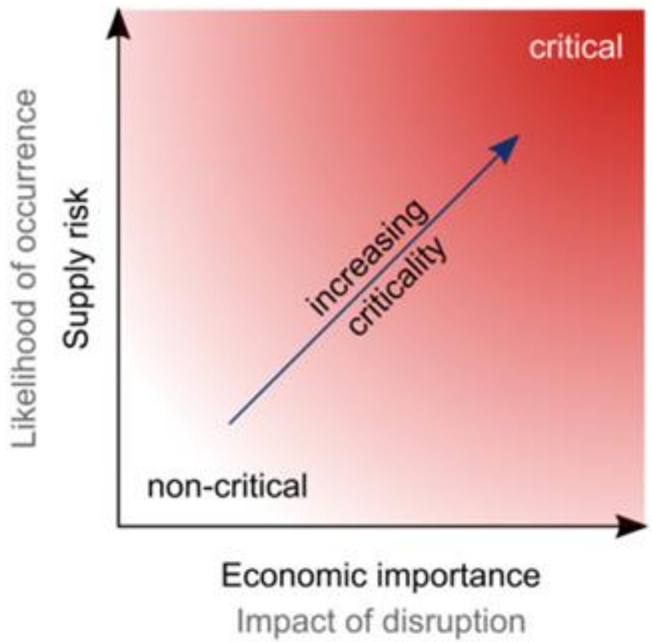
- **Critical materials**
    - **Methodologies**
- Ways out
- Example: electric vehicles

Critical materials

EU methodology

Supply risk



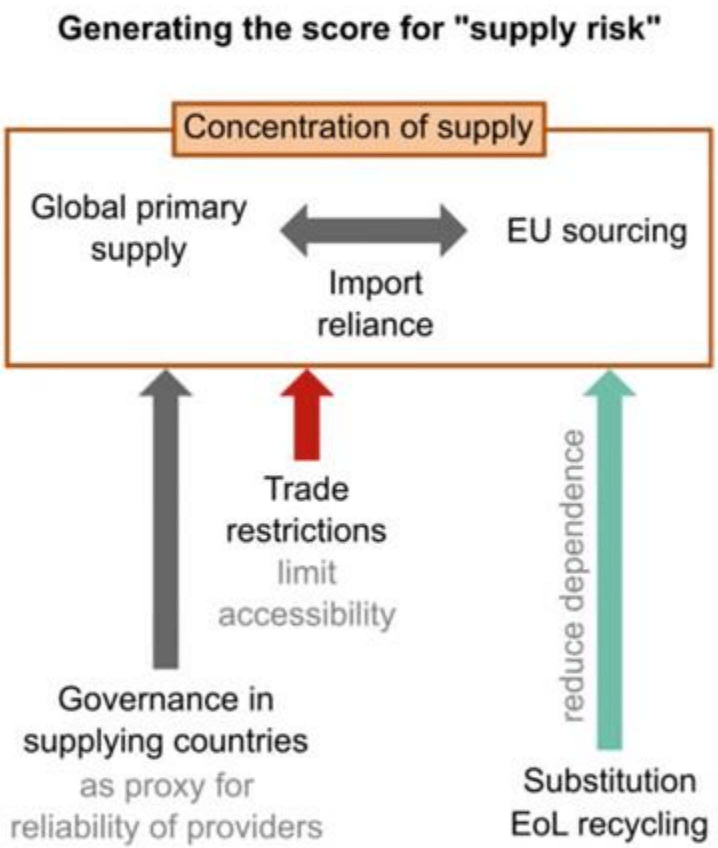


Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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Critical materials
EU methodology

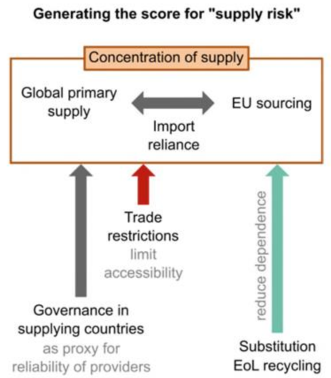

Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

Supply risk

Developed in 2017, revised and more complex now

Uses two main indicators **as basis**:

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 bewteen 1 (or 10000) = monopoly or
1/N (or 10000/N) = hihgly diverse market

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

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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Critical materials
EU methodology

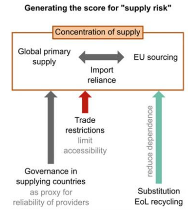


Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

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

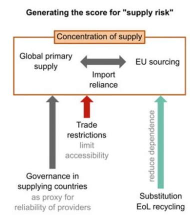
Factors constituting the World Governance Index

Indicator	Sub-indicator	Index
Peace / Security	National Security	Conflicts
		Refugees / Asylum Seekers
		Displaced Persons
	Public Security	Political climate
		Degree of trust
		Violent Crime
		Homicides / 100,000 inhabitants
Rule of Law	Body of Laws	Ratification of International Treaties
		Protection of Property Rights
	Legal System	Independence
		Effectiveness
		Settlement of Contractual Disputes
	Corruption	Corruption Perceptions Index
Human Rights / Participation	Civil and Political Rights	Respect of Civil Rights
		Respect of Physical Integrity Rights
		Freedom of the Press
		Violence against the Press
	Participation	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
	Well-being / Happiness	Subjective Well-being
		Happiness

Source: Worldwide Governance Indicators, https://www.worldbank.org/en/publication/worldwide-governance-indicators

Critical materials

EU methodology



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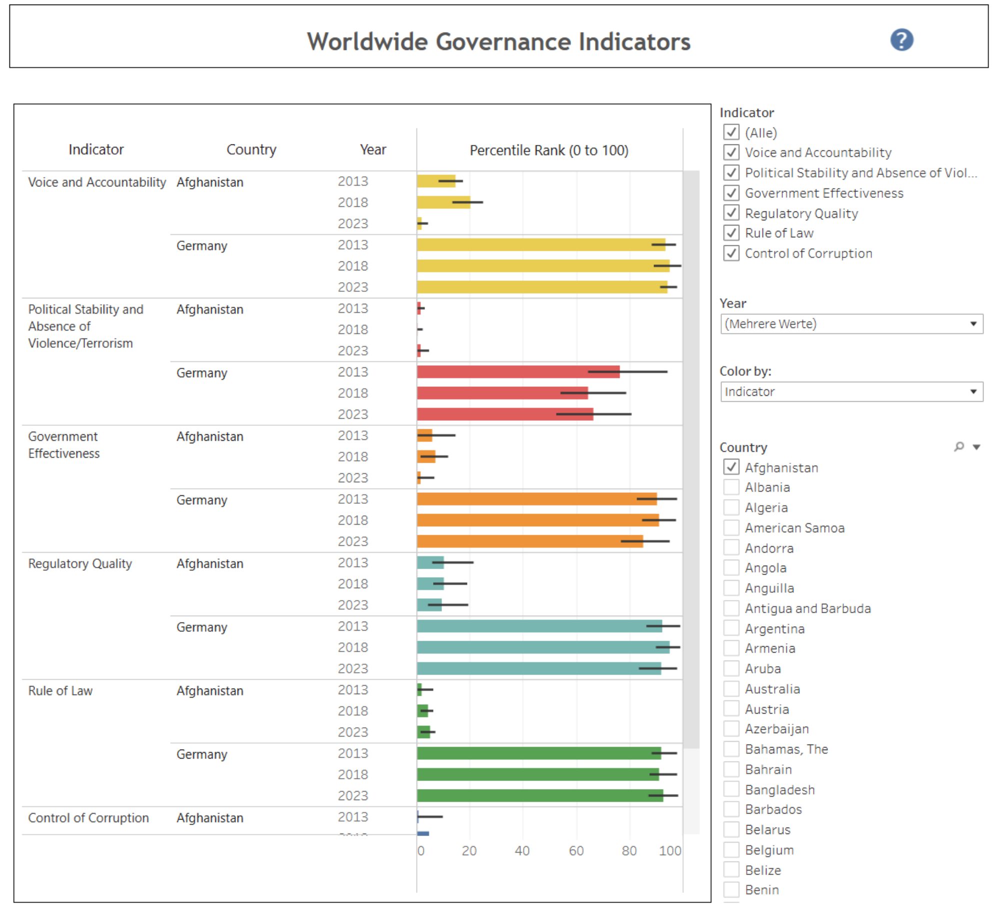
Supply risk

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)*

Source: Worldwide Governance Indicators, https://www.worldbank.org/en/publication/worldwide-governance-indicators/interactive-data-access

Critical materials
EU methodology

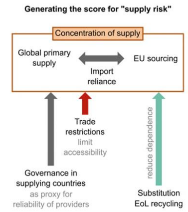


Figure 2: Elements of the equation for calculating the "supply risk" score in the EU criticality methodology.

Supply risk

Developed in 2017, revised and more complex now

Uses two main indicators **as basis**:

Weighting the two indicators

Low supply risk given both in:
- Monopoly with perfect governance
- a very diverse market supply with very low governance

Source: Worldwide Governance Indicators, https://www.worldbank.org/en/publication/worldwide-governance-indicators

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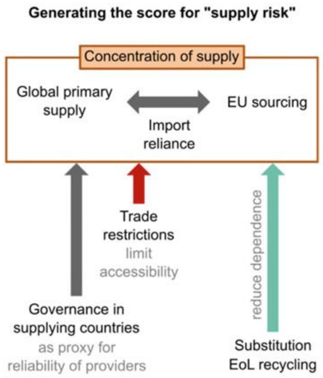
Critical materials

EU methodology



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Supply risk

Developed in 2017, revised and more complex now

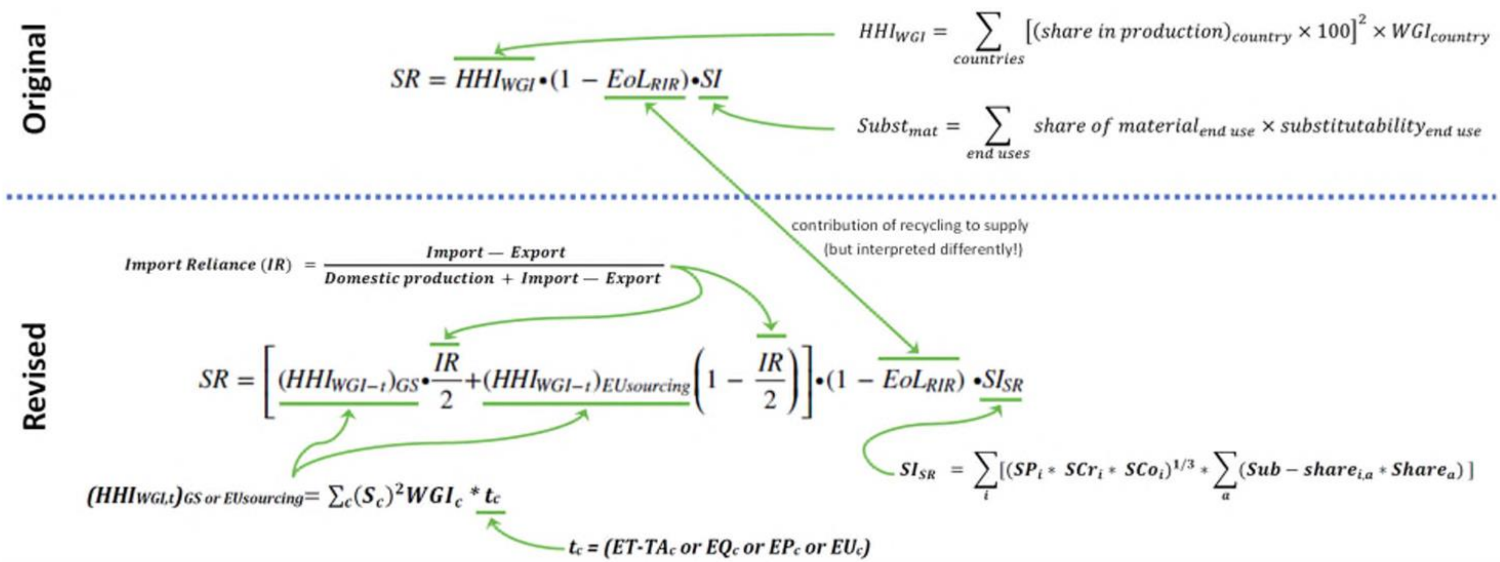

Figure 5: Calculation of the supply risk score in the original and revised EU methodologies (Blengini et al. 2017a; Blengini et al. 2017b; European Commission 2010, 2017b). *SR* = supply risk; HHI_{WGI} = Herfindahl-Hirschmann-Index weighted with the *WGI* = World Governance Indicators; EoL_{RIR} = end-of-life recycling input rate; *SI* = substitutability index; *GS* = global supply; IR = import reliance; HHI_{WGI-t} = HHI_{WGI} but also including trade restrictions (t_c) as a weighting factor; t_c acounts for export taxes and trade agreements ($ET\text{-}TA_c$), export quotas (EQ_c), export prohibitions (EP_c) in non-EU countries while EU countries receive the scoring of 0.8 (EU_c), ; SI_{SR} = 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.

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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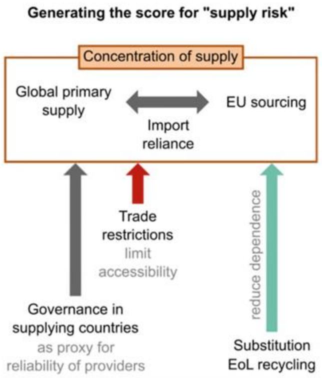
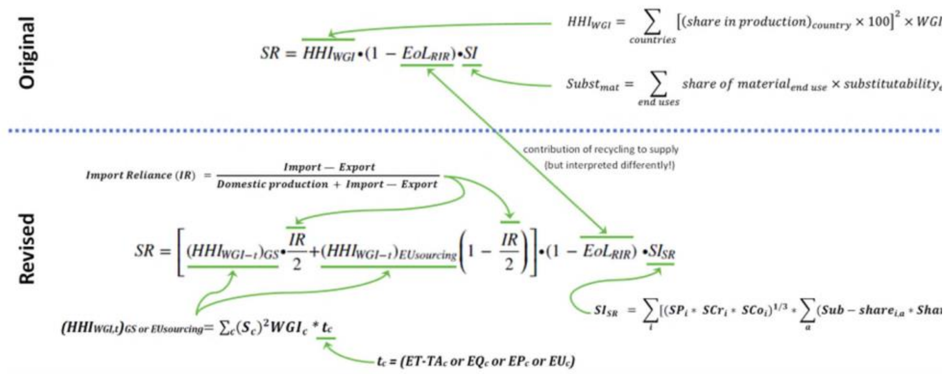
Critical materials

EU methodology



Supply risk

Developed in 2017, revised and more complex now



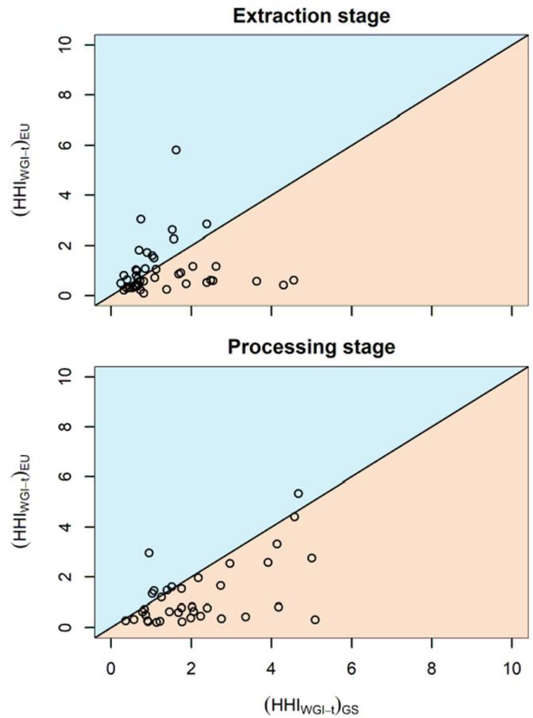


Figure 11: Global vs. EU sourcing at the mining (top) and processing stage (bottom). A dot in the orange half shows a higher risk of global sourcing vs. EU sourcing. A dot in the blue half shows higher EU sourcing risk compared to global. Data from European Commission (2023a).

New features:

- EU vs RoW focus

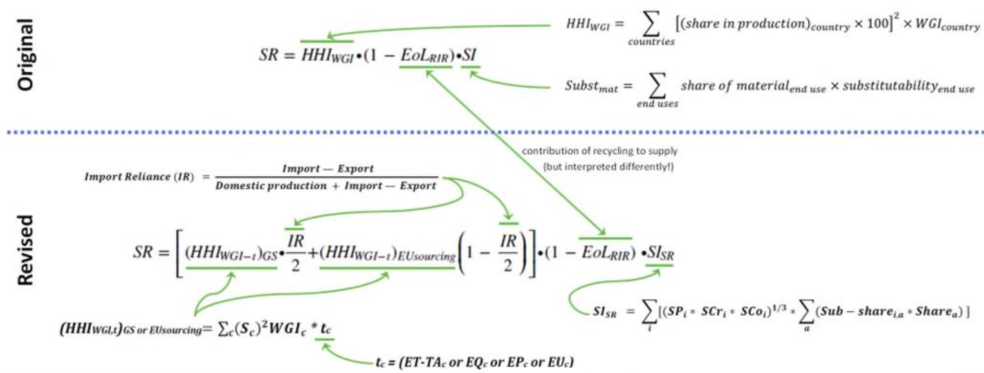
Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

Critical materials

EU methodology

Supply risk

Developed in 2017, revised and more complex now



New features:

- EU vs RoW focus
- Recycling

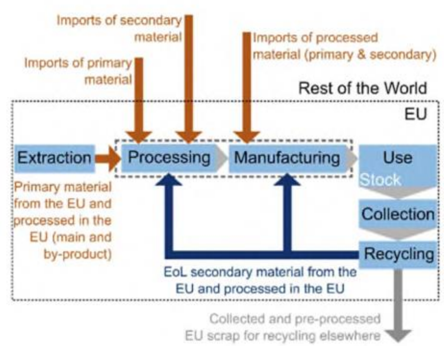
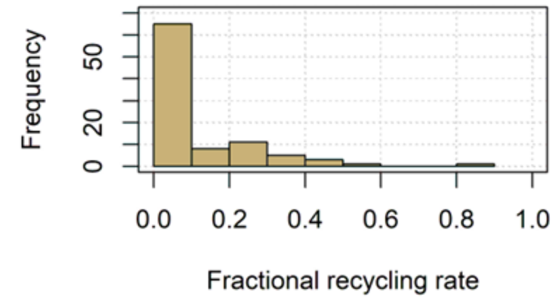
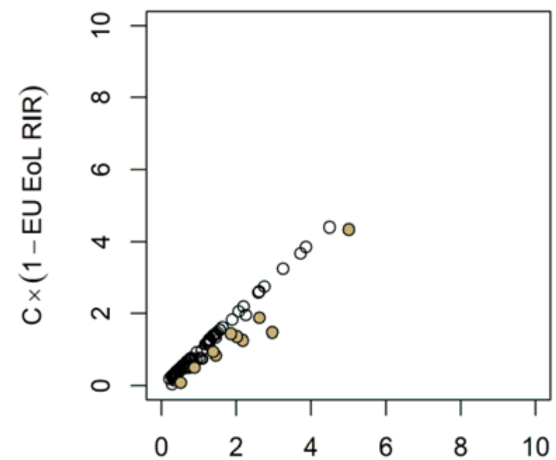


Figure 15: Flow data necessary for calculating the recycling rate (EU EoL RIR) used in the EU criticality methodology. Flows in blue go into the numerator and denominator, while flows in dark orange go into the denominator only (Talens Peiró et al. 2018; Tercero Espinoza 2021). The flow in gray is not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

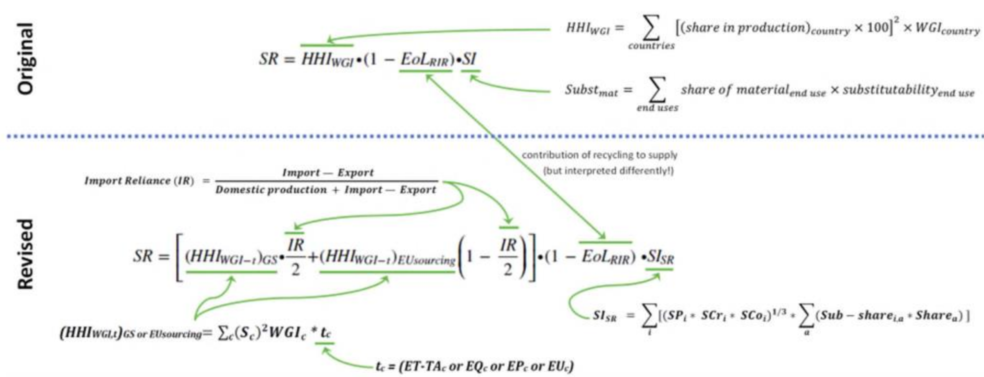
Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

Critical materials

EU methodology

Supply risk

Developed in 2017, revised and more complex now



New features:

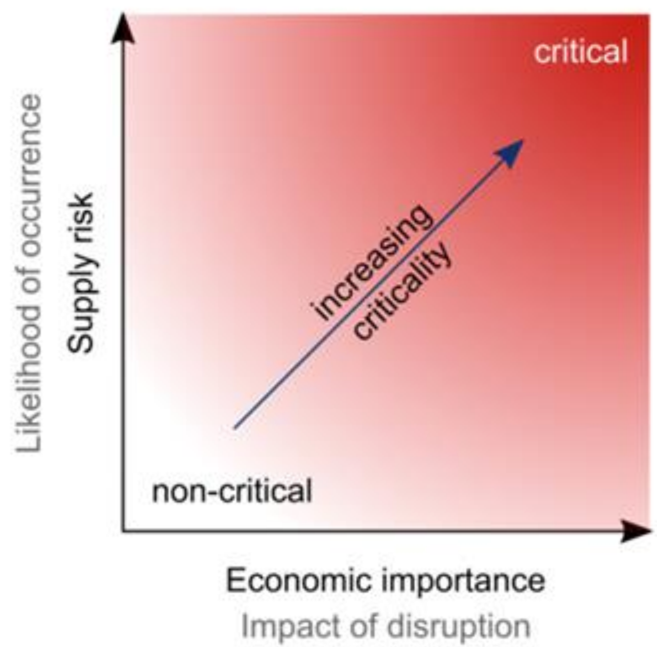
- EU vs RoW focus
- Recycling
- Taxes and trading barriers
- Substitutability

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

Critical materials

EU methodology

Economic importance



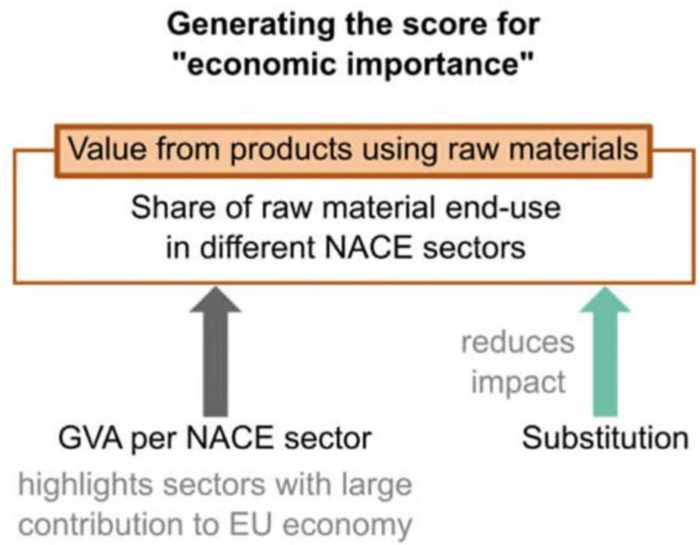


Figure 4: Elements of the scoring equation for economic importance. GVA = gross value added; NACE (*nomenclature statistique des activités économiques dans la Communauté européenne*) is the industry standard classification system used in the European Union.

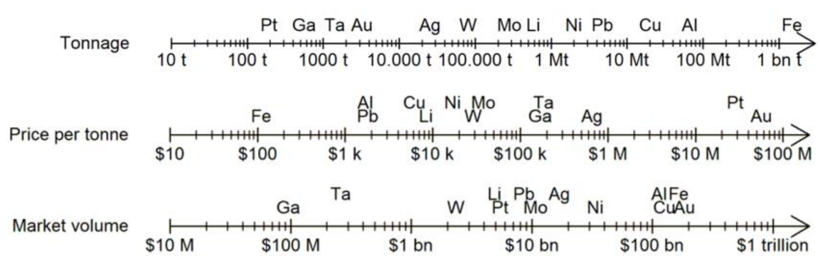


Figure 3: Ranking raw materials by tonnage (global primary production), price (average for 2020) and market volume (tonnage × price per tonne) (DERA 2020; Tercero Espinoza & Erdmann 2018). Pt = platinum, Ga = gallium, Ta = tantalum, Au = gold, Ag = silver, W = tungsten, Mo = molybdenum, Li = lithium,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

Typical economic indicators do not give the picture

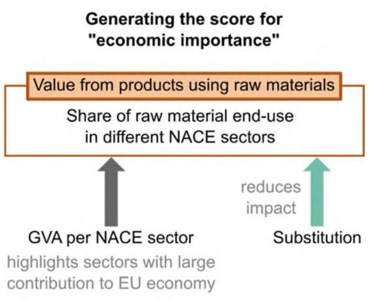
Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

Critical materials

EU methodology

Economic importance

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



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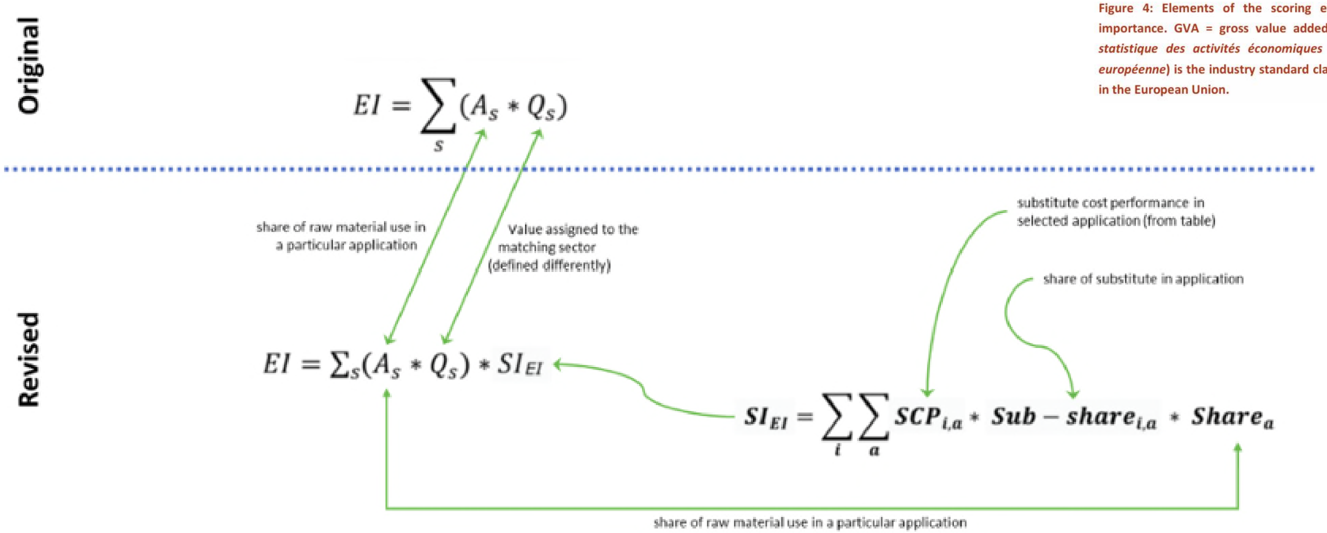

Figure 18: Calculation of the economic importance score in the original and revised EU methodologies (Blengini et al. 2017a; Blengini et al. 2017b; European Commission 2010, 2017b). *EI* = economic importance; A_S = share of raw material use in a particular sector; *Qs* = gross value added of the sector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

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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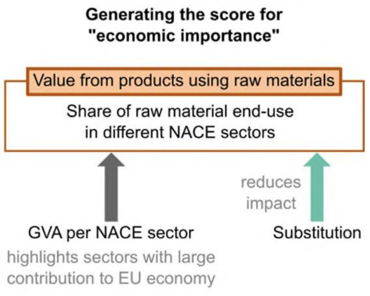
Critical materials

EU methodology

Economic importance

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



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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

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).

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

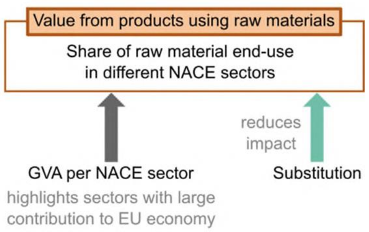
Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

Critical materials

EU methodology

Economic importance

Generating the score for "economic importance"



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

Difficult to estimate the added value of a sector as a result of the use of a particular material
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→ Instead: NACE indices
→ Subsitute cost performance MATRIX

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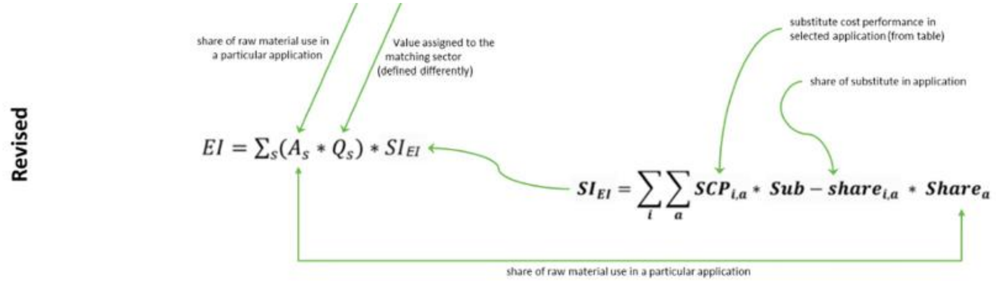

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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Critical materials
EU methodology

Results and analysis

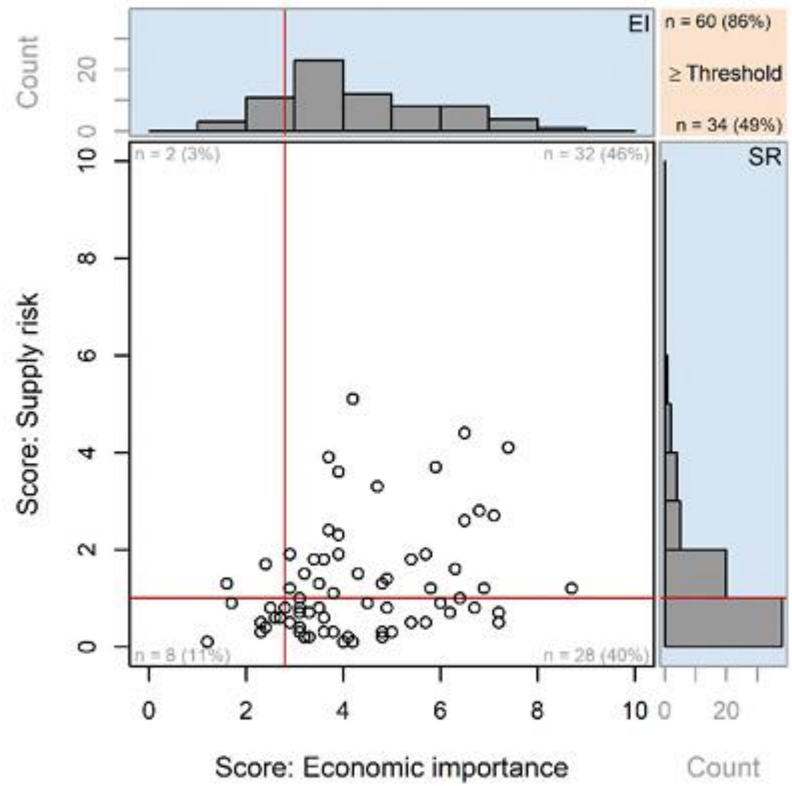

Figure 21: Results of the 2023 criticality study, with some diagnostic additions (data from European Commission 2023a).

Source: https://publica-rest.fraunhofer.de/server/api/core/bitstreams/9498c80d-b958-48a9-857a-dac2d7237cdd/content

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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: • Availability of alternatives • Supply distribution • Supply domination • Extent of Geopolitical Influences • Press Coverage • Price Fluctuations 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: 1. Elements that have not been widely extracted, traded, or utilised in the past 2. Elements that could significantly inhibit large-scale deployment of the new energy-related technologies
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	See BGS_2011 for orginal 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. • Scarcity • Production concentration • Reserve distribution • Recycling Rate • Substitutability • Governance (top producing nation) • Governance (top reserve-hosting nation)
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: • Reserves, • Trades, • Ecological impact, • Processing, • Substitutability, • Recyclability

Source: Technical Report - Assessment of the Methodology for establishing the EU List of Critical Raw Materials. 2017. **JRC Science Hub,** https://ec.europa.eu/jrc

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^{EU})	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		

Source: Baumann et al. 2022. https://doi.org/10.1002/aenm.202202636.

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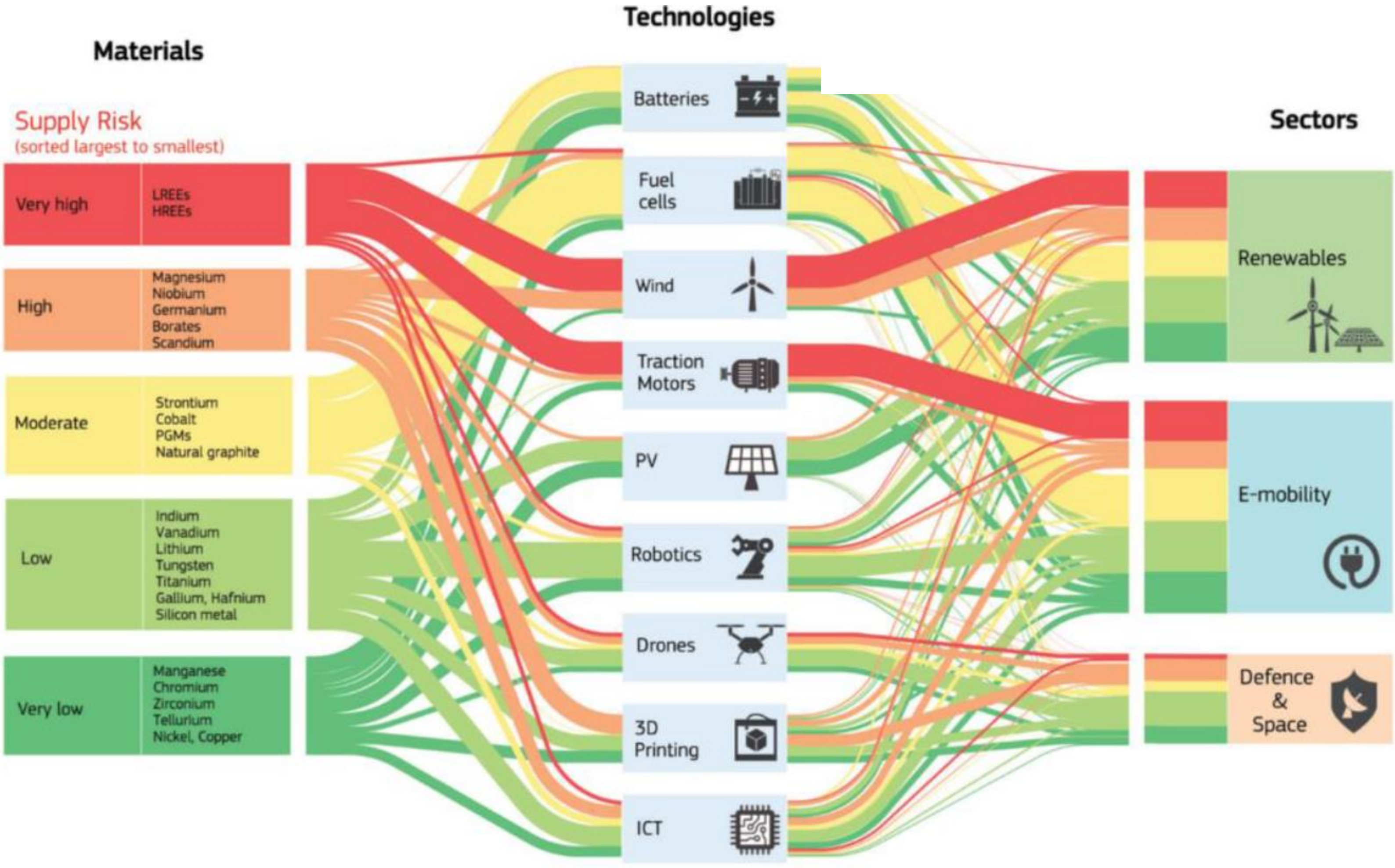
Agenda

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

Critical materials

Supply required for different sectors

Dependencies and fragilities



Source: RMIS - Raw Materials Information System (europa.eu)

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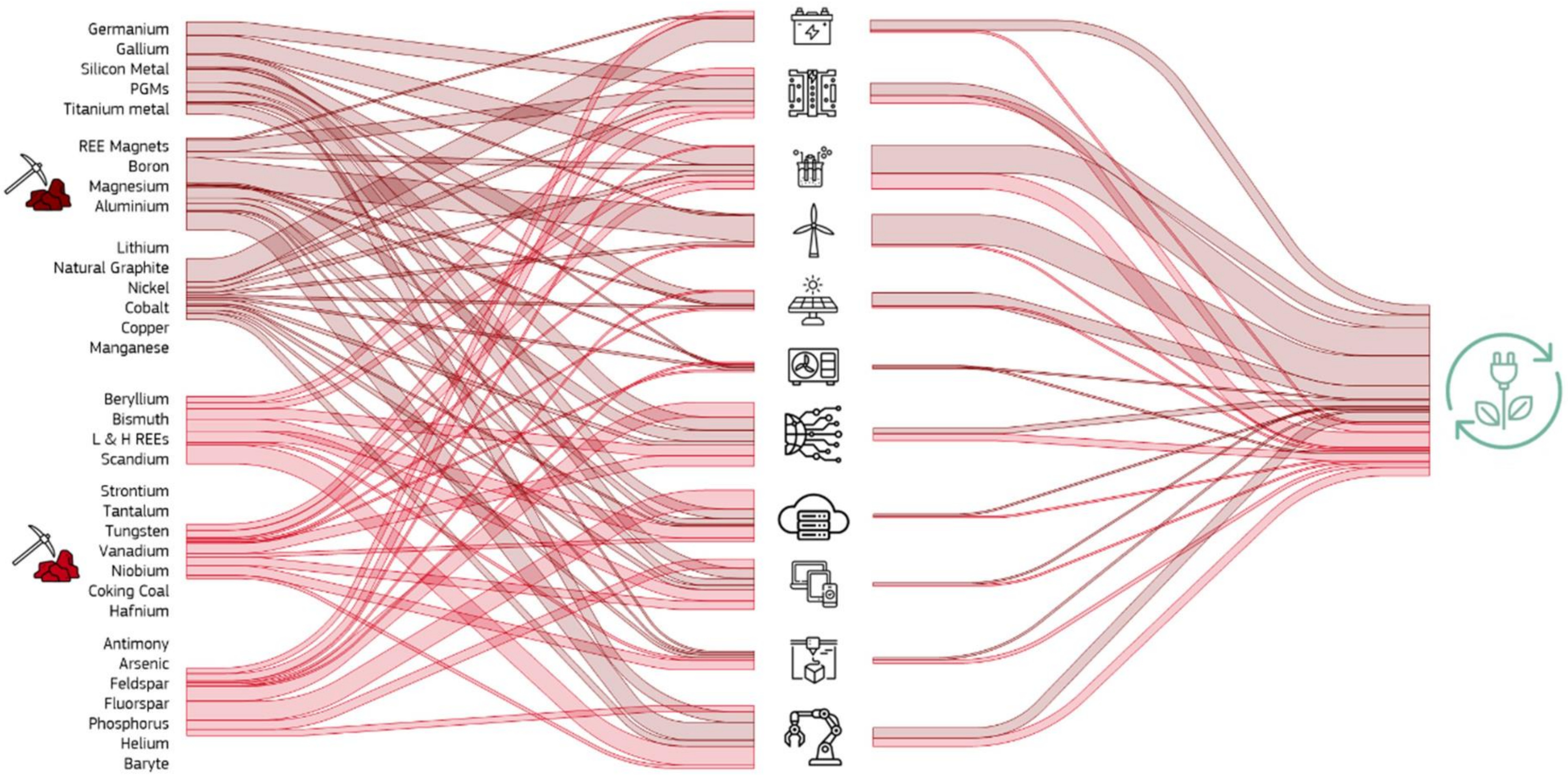
Critical materials

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: RMIS - Raw Materials Information System (europa.eu)

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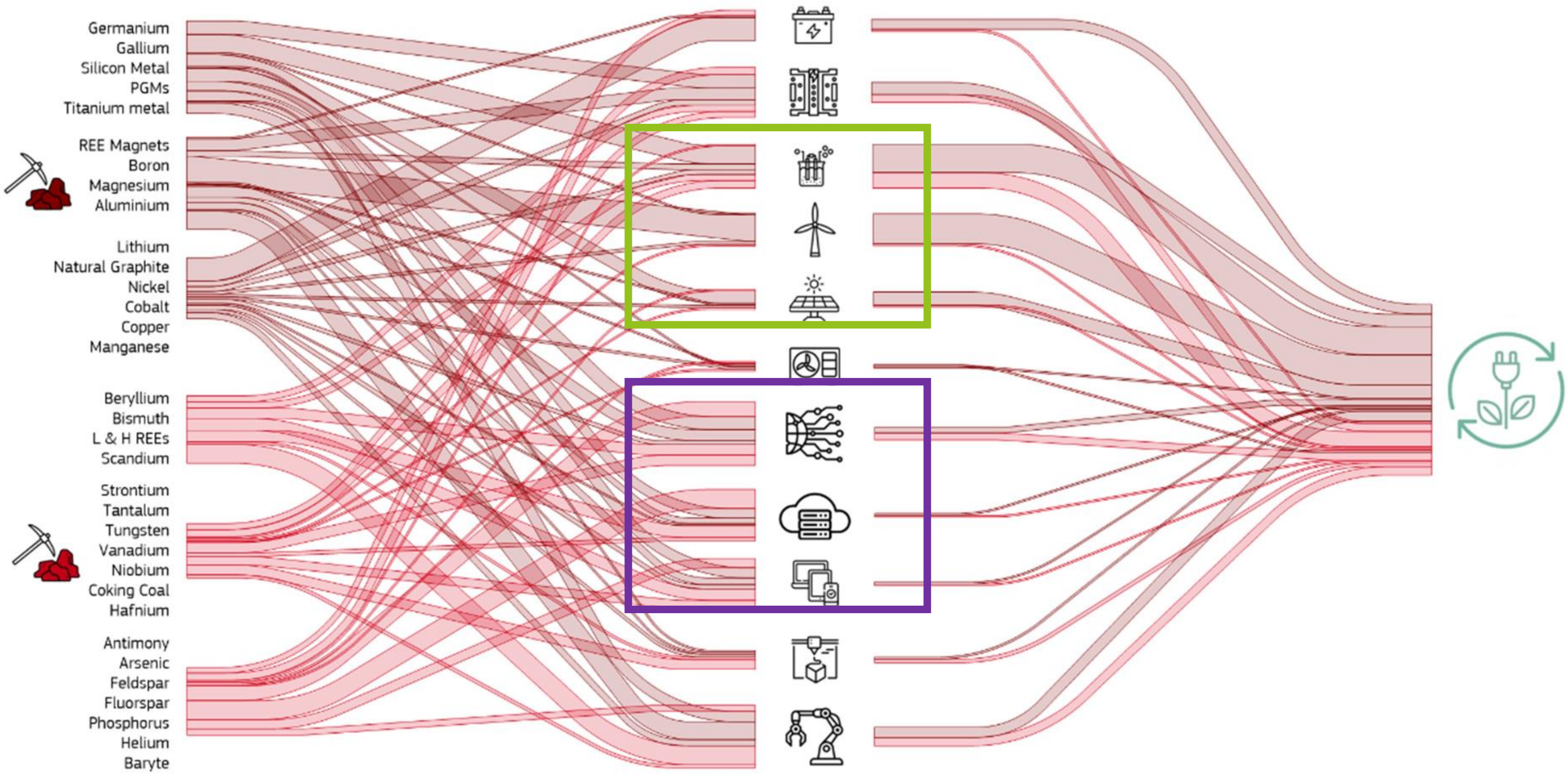
Critical materials

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)

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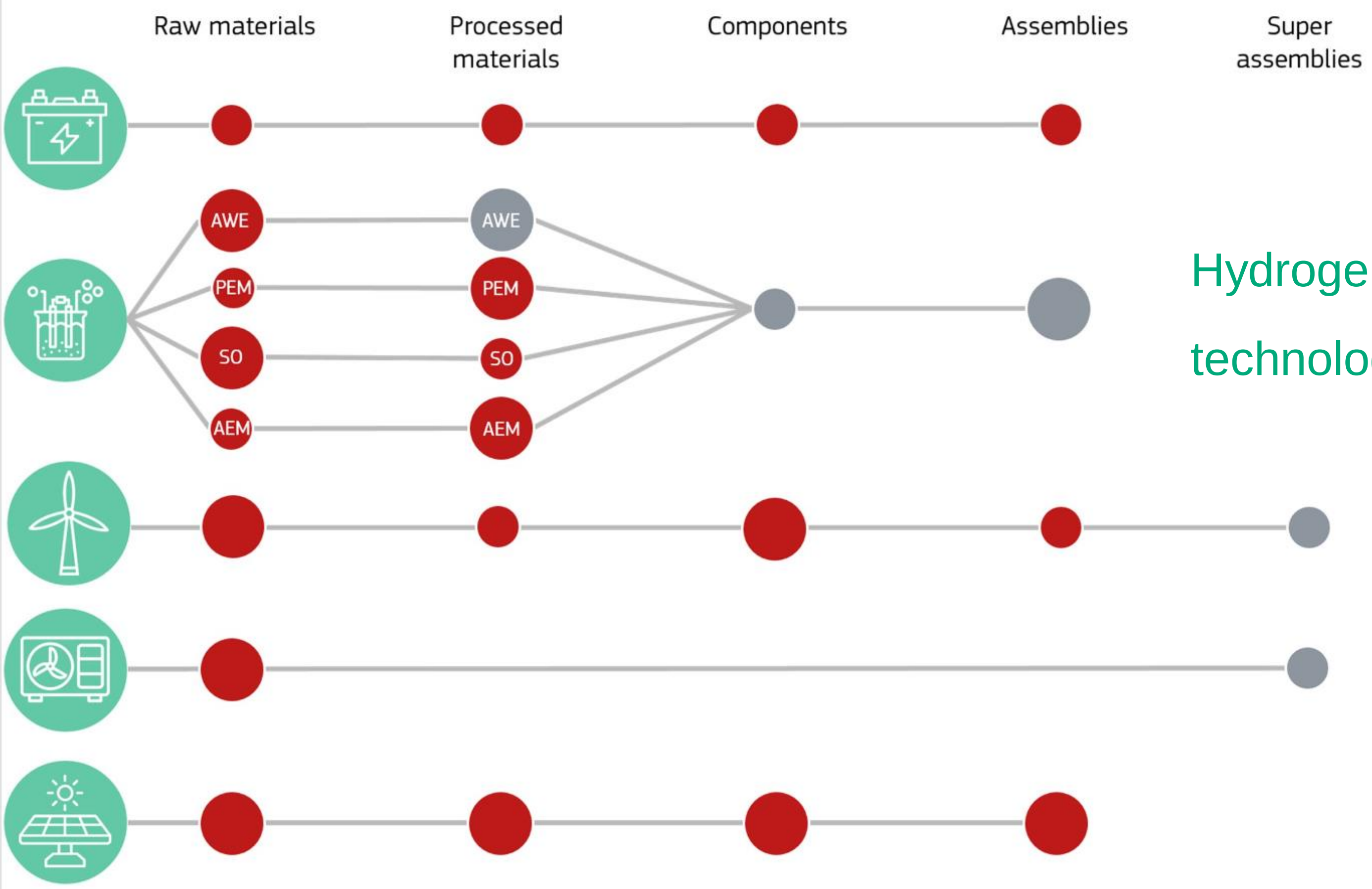
Source: RMIS – Raw Materials Information System (europa.eu)

Critical materials

Supply risks for RE

Supply chain bottlenecks



Hydrogen technologies

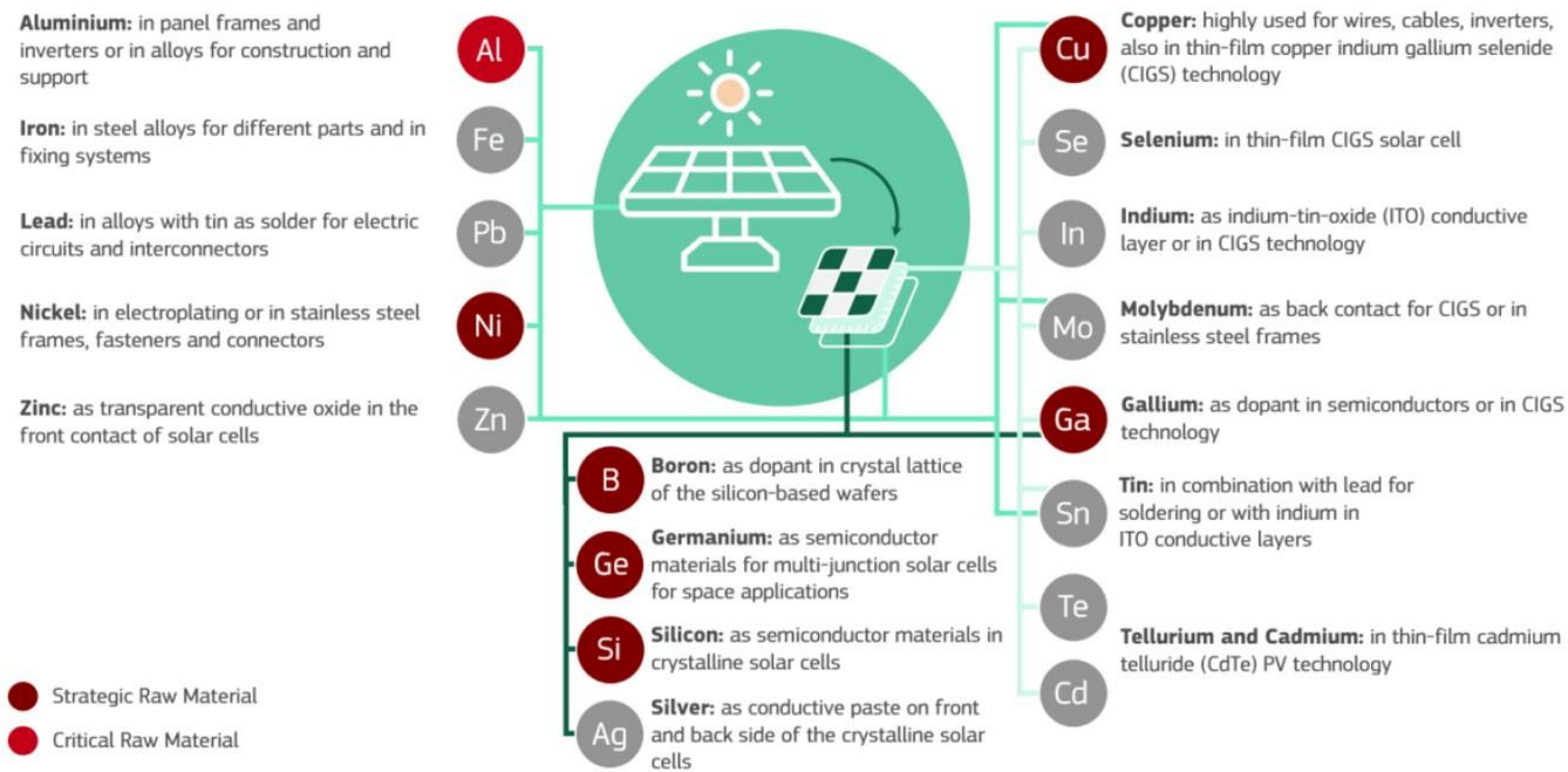
Overview of supply risks, bottlenecks, and supply patterns along the selected supply chains relevant to the renewable energy sector. Source: JRC, 2023.

Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/5

Critical materials

Technology profiles

Photovoltaics



Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/7

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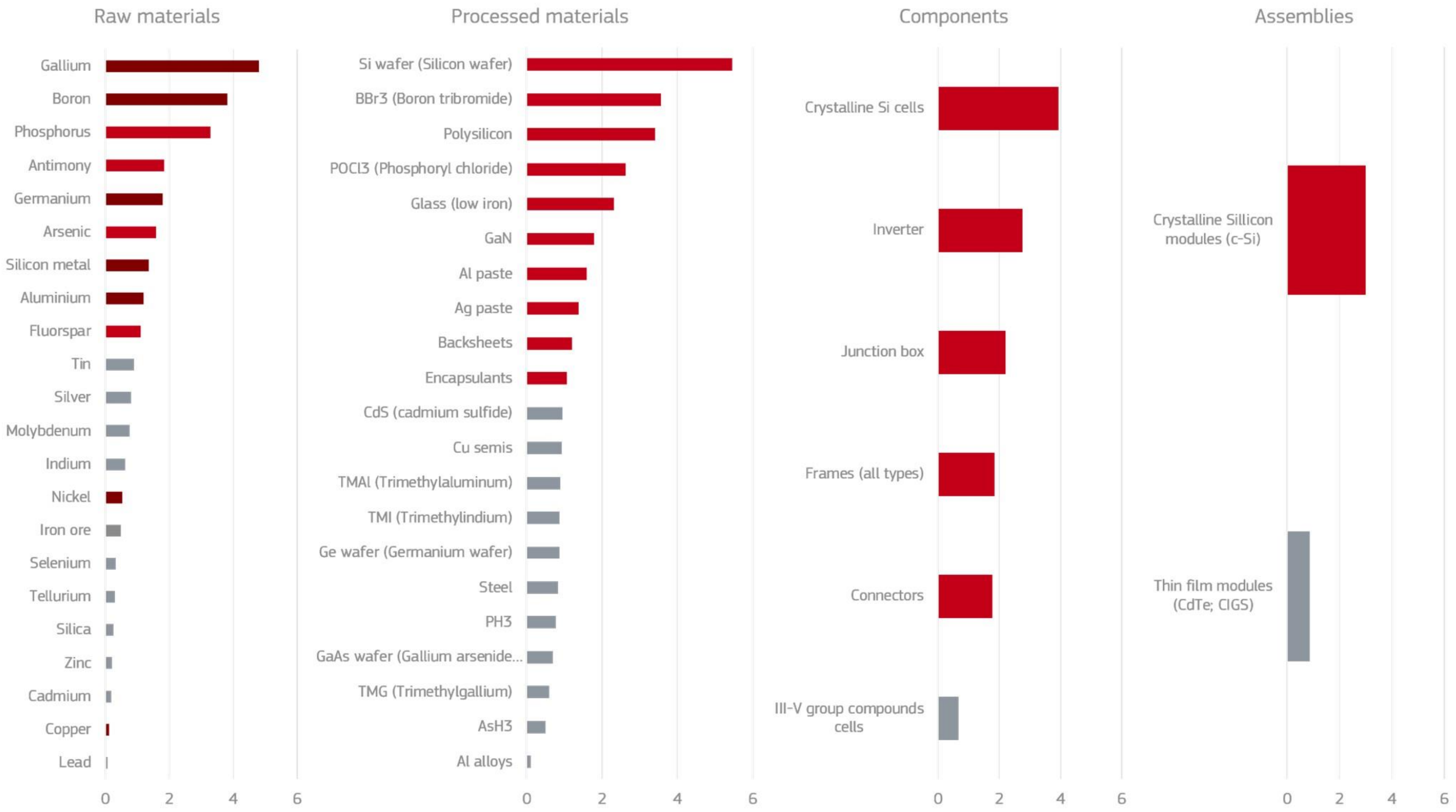
Critical materials

Technology profiles

Photovoltaics- Supply risk for different materials



Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/7

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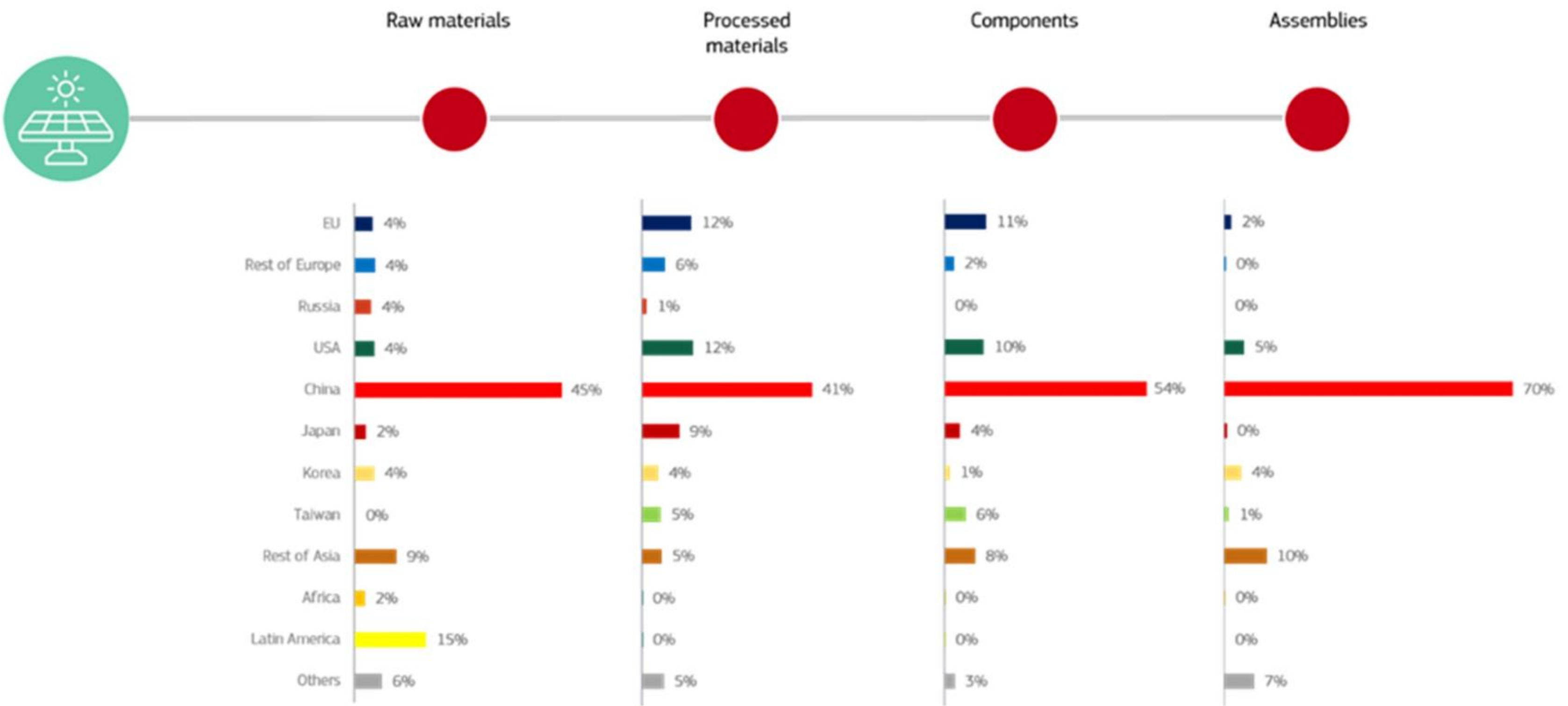
Critical materials

Technology profiles

Photovoltaics

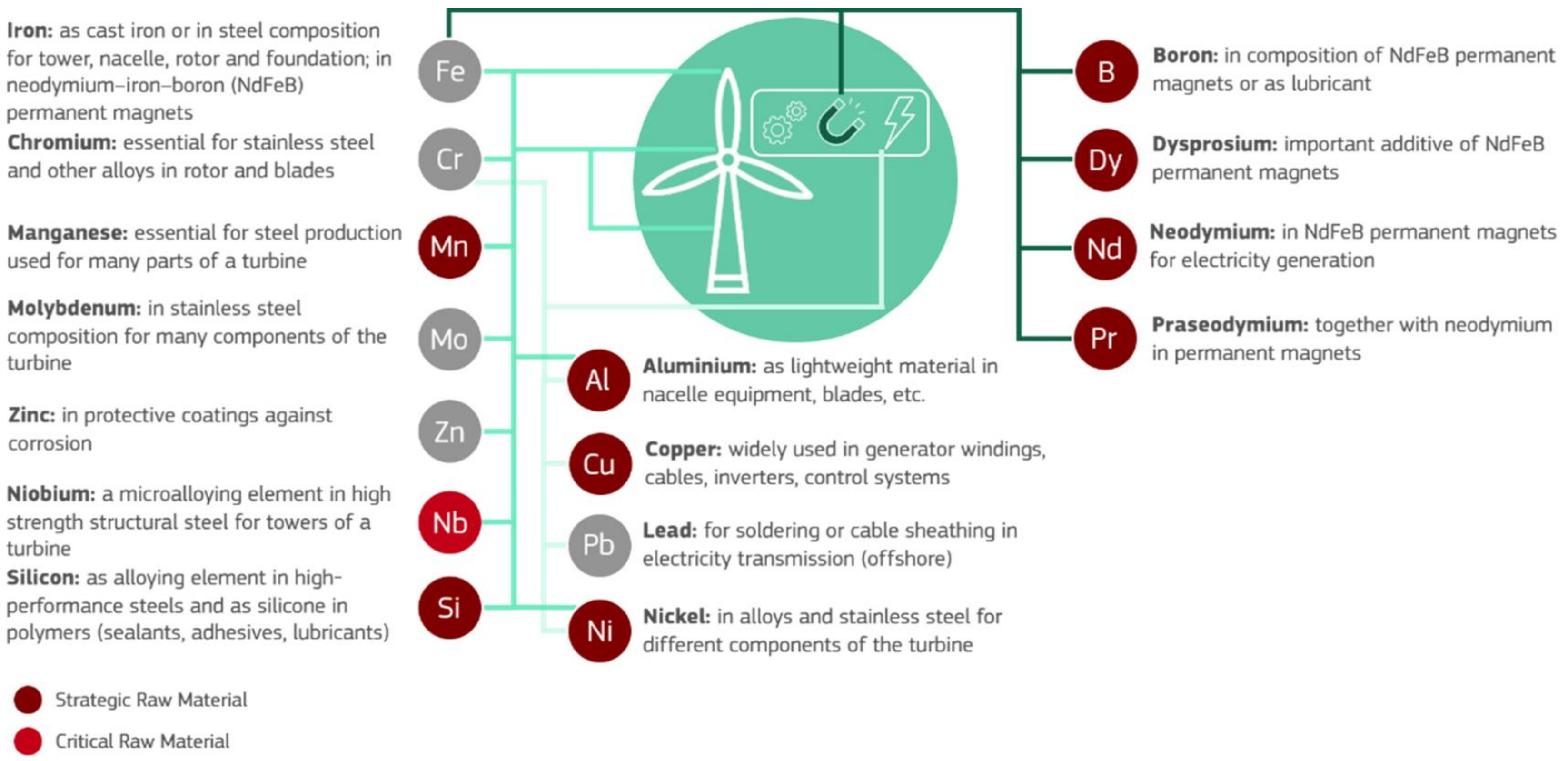


Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/7

Critical materials

Technology profiles

Wind turbines

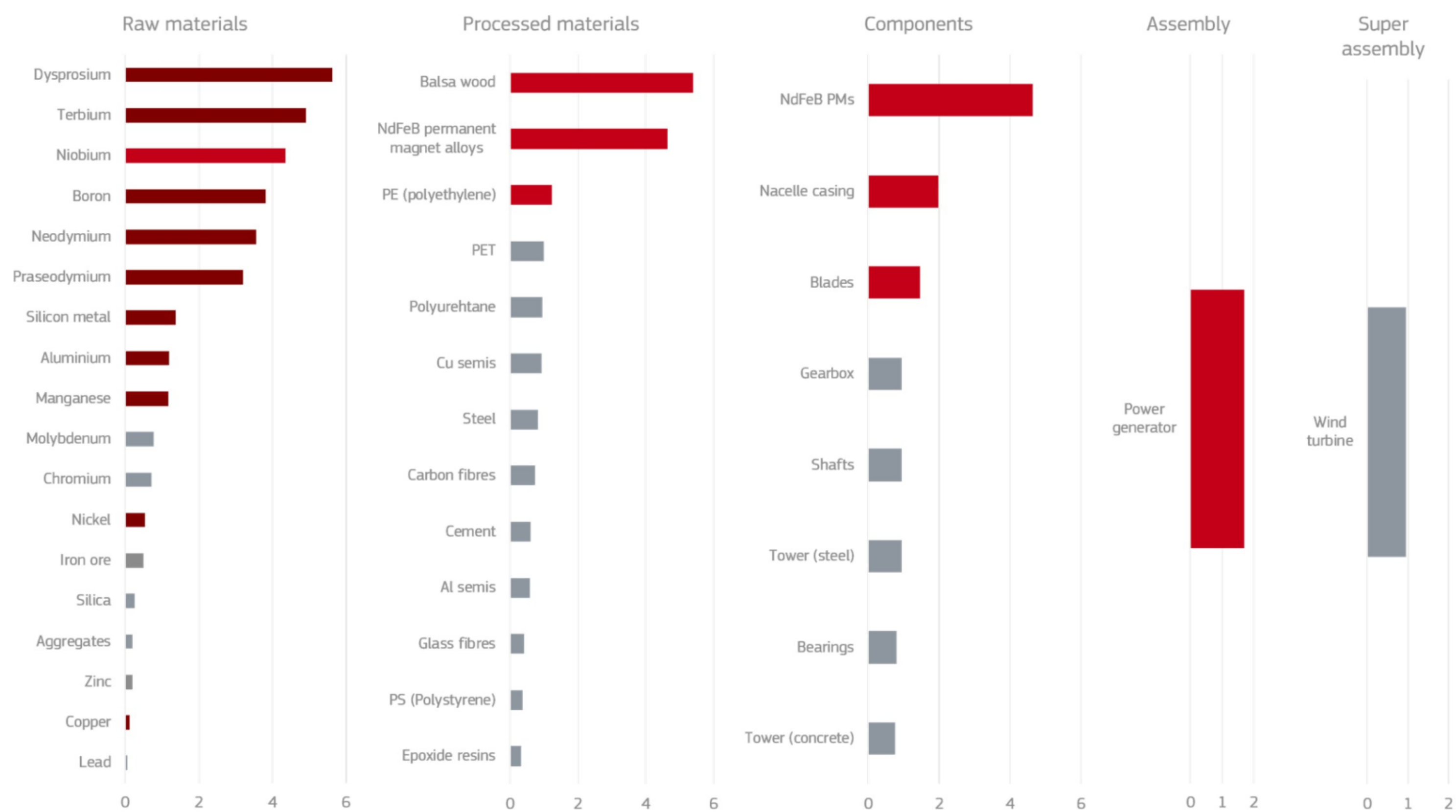


Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/7

Critical materials

Technology profiles

Wind turbines – Supply risk

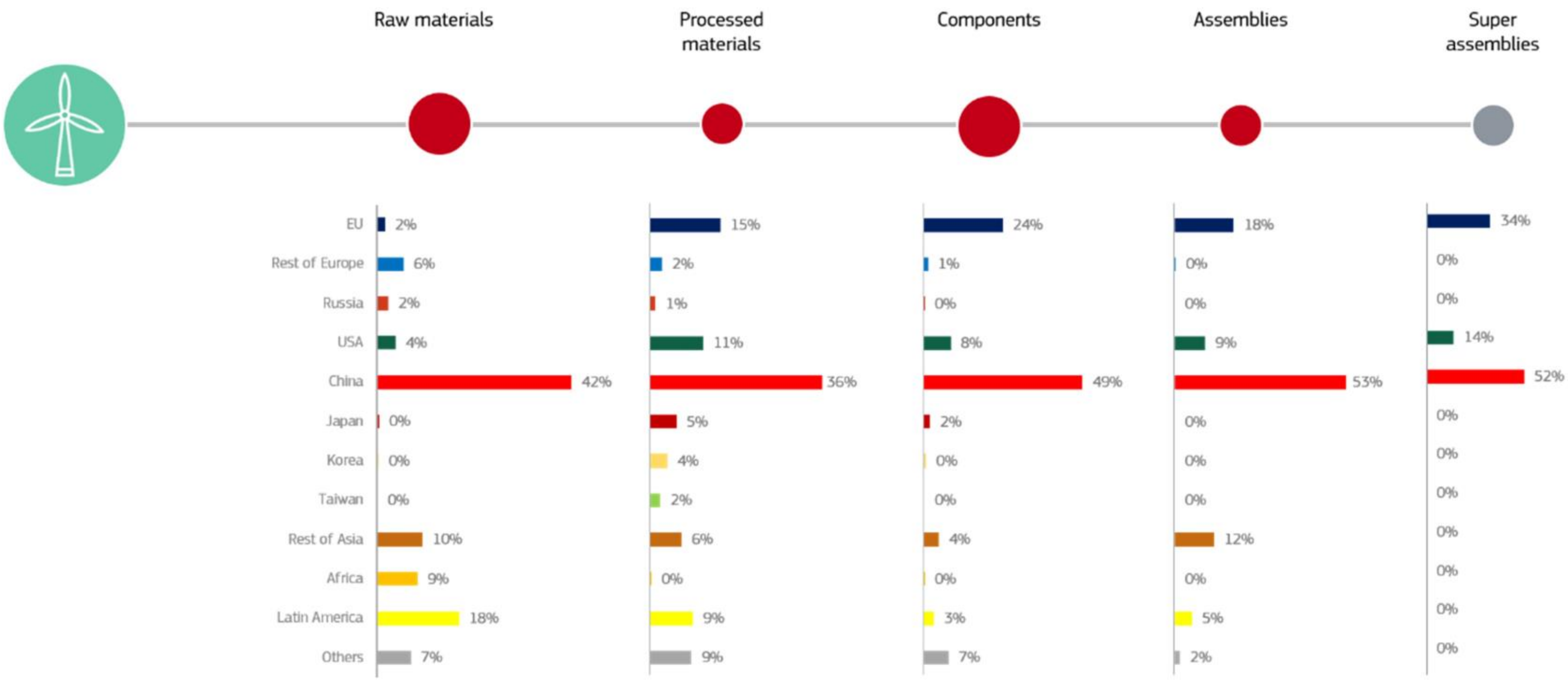


Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/6

Critical materials

Technology profiles

Wind turbines



Source: https://rmis.jrc.ec.europa.eu/techprofiles/ind/6

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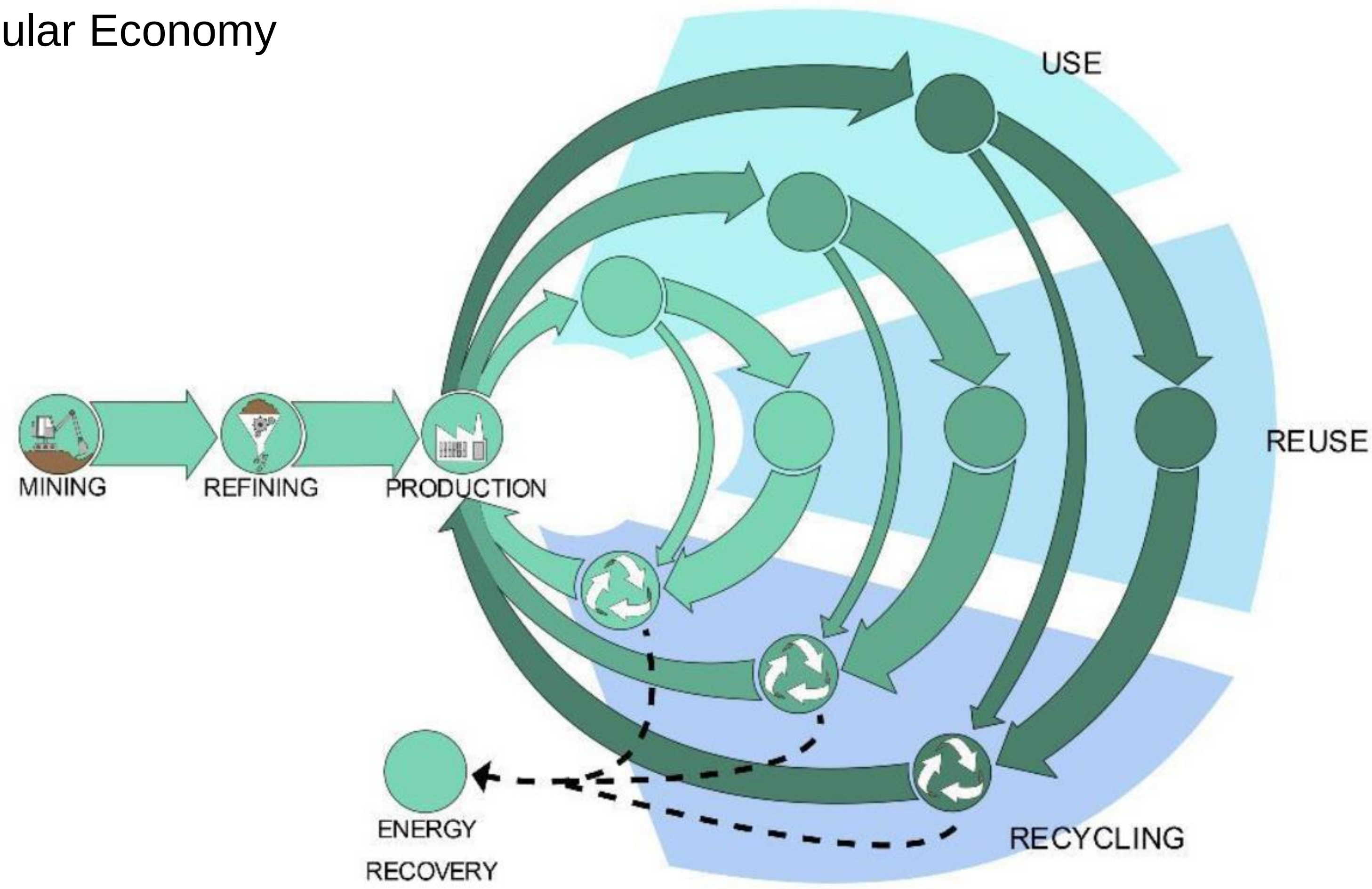
Agenda

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

Critical materials

Ways out

Circular Economy



Source: Pehlken 2023. Lecture V01 – Hidden Champions for RE

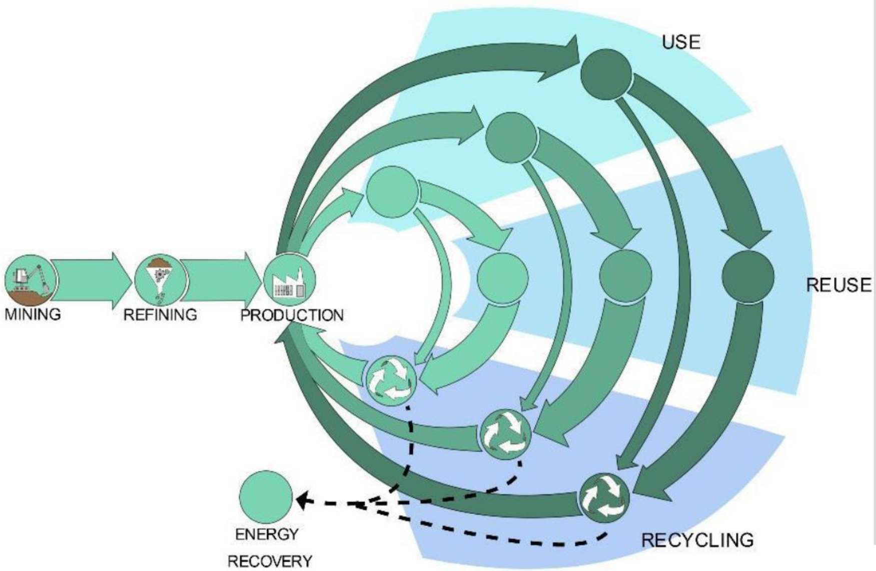
Critical materials

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)



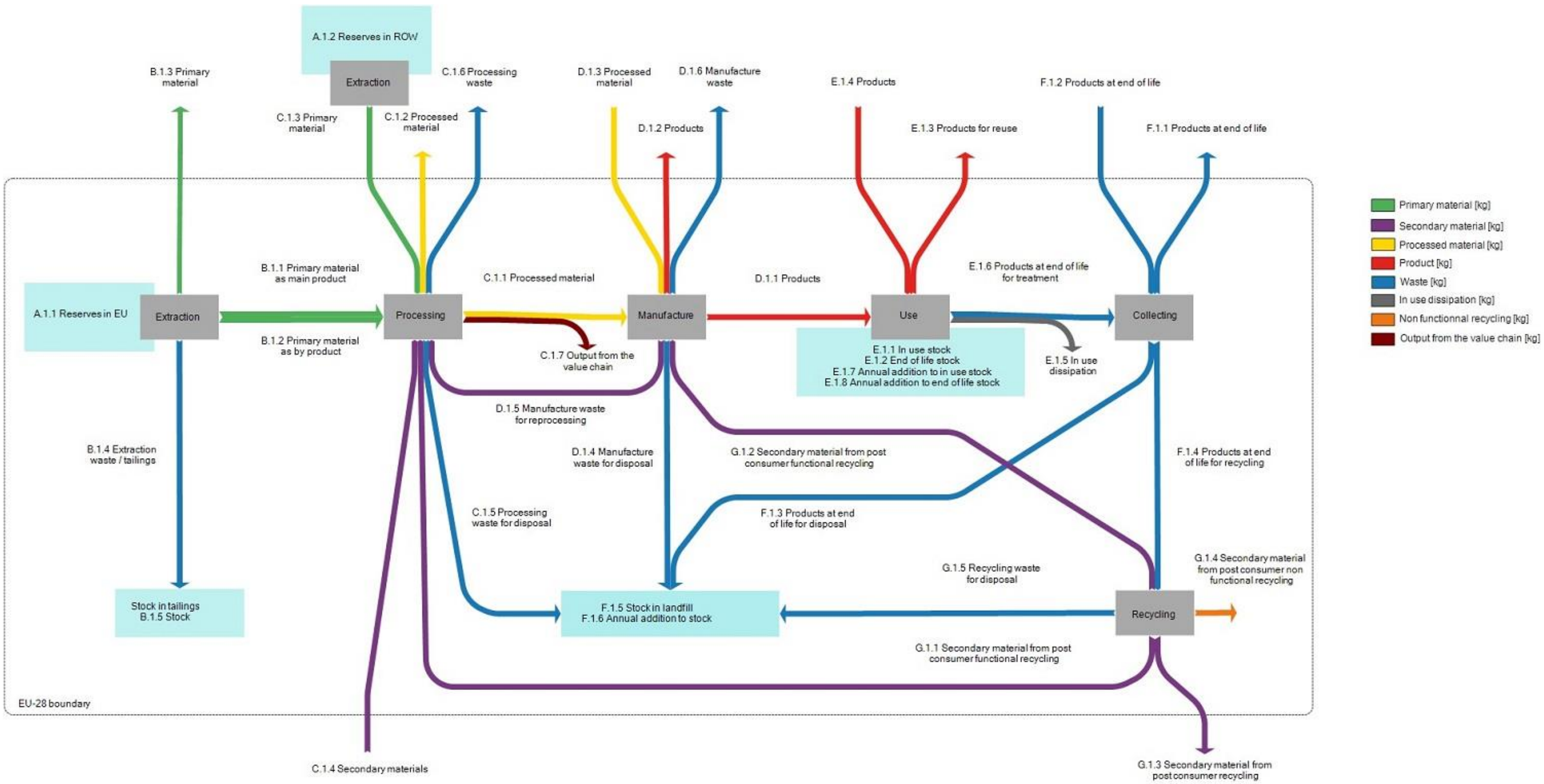
Source: Pehlken 2023. Lecture V01 – Hidden Champions for RE

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



Source: https://rmis.jrc.ec.europa.eu/msa

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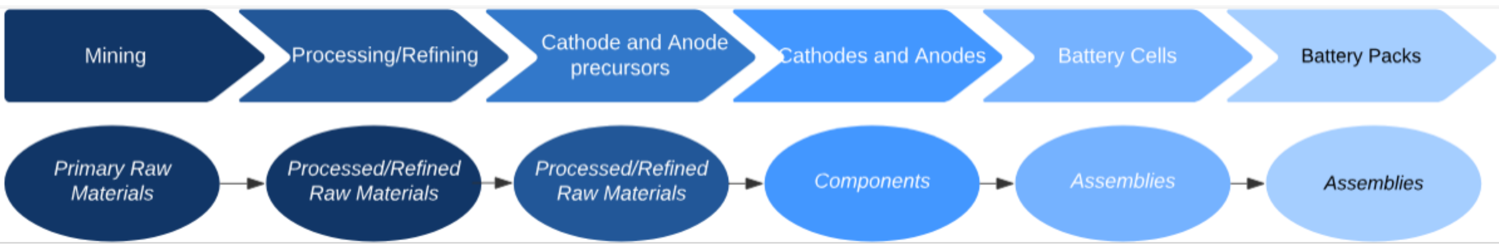

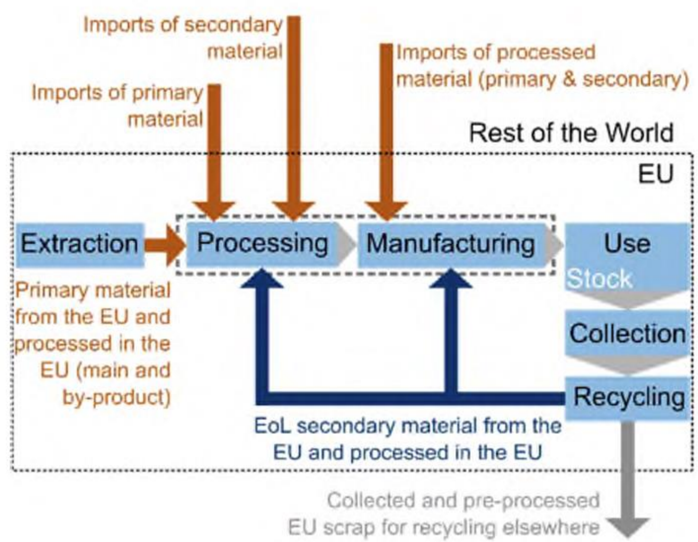

Source: https://rmis.jrc.ec.europa.eu/msa

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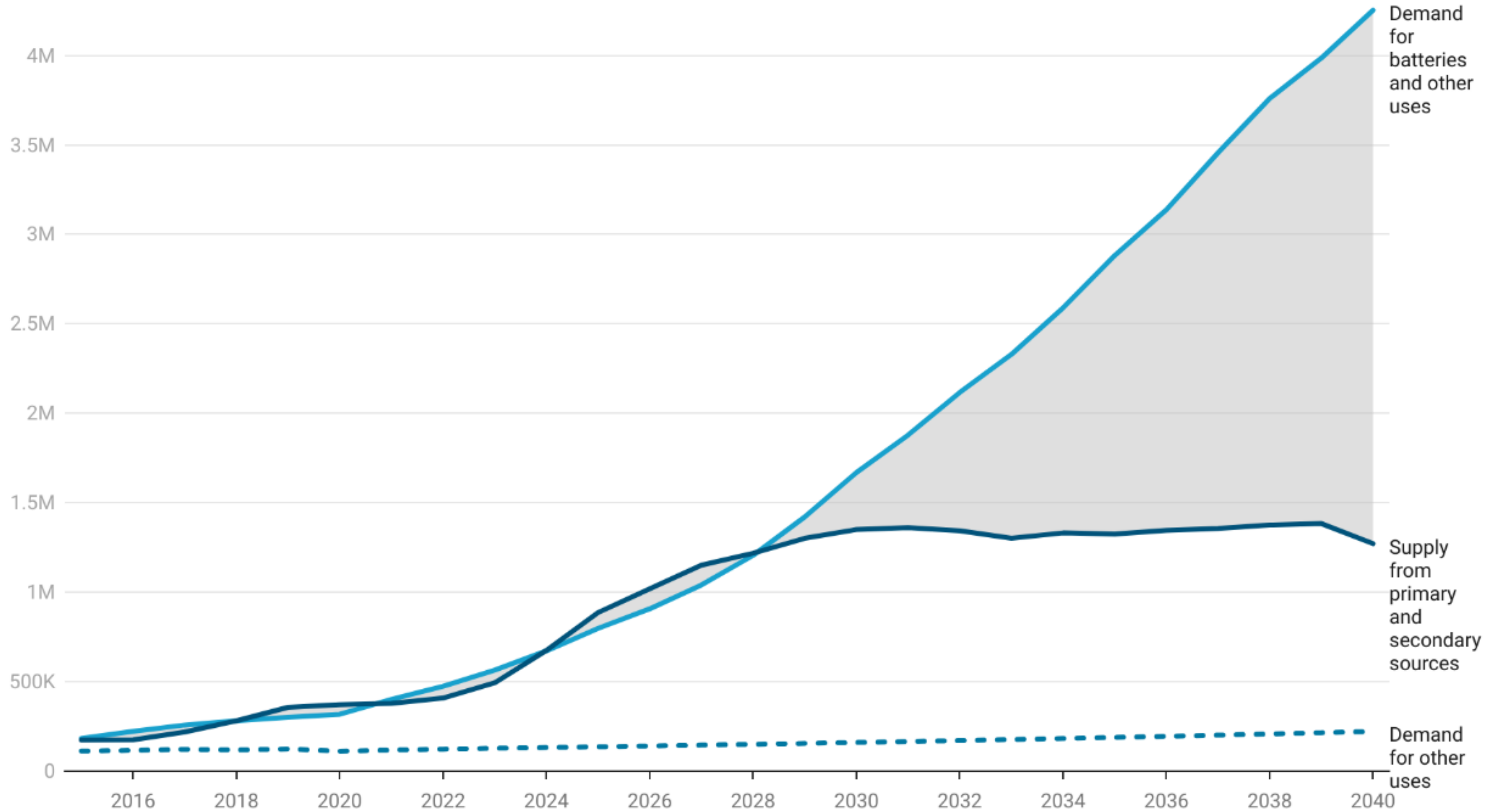
Critical materials

Global demand and supply
Primary and secondary sources

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

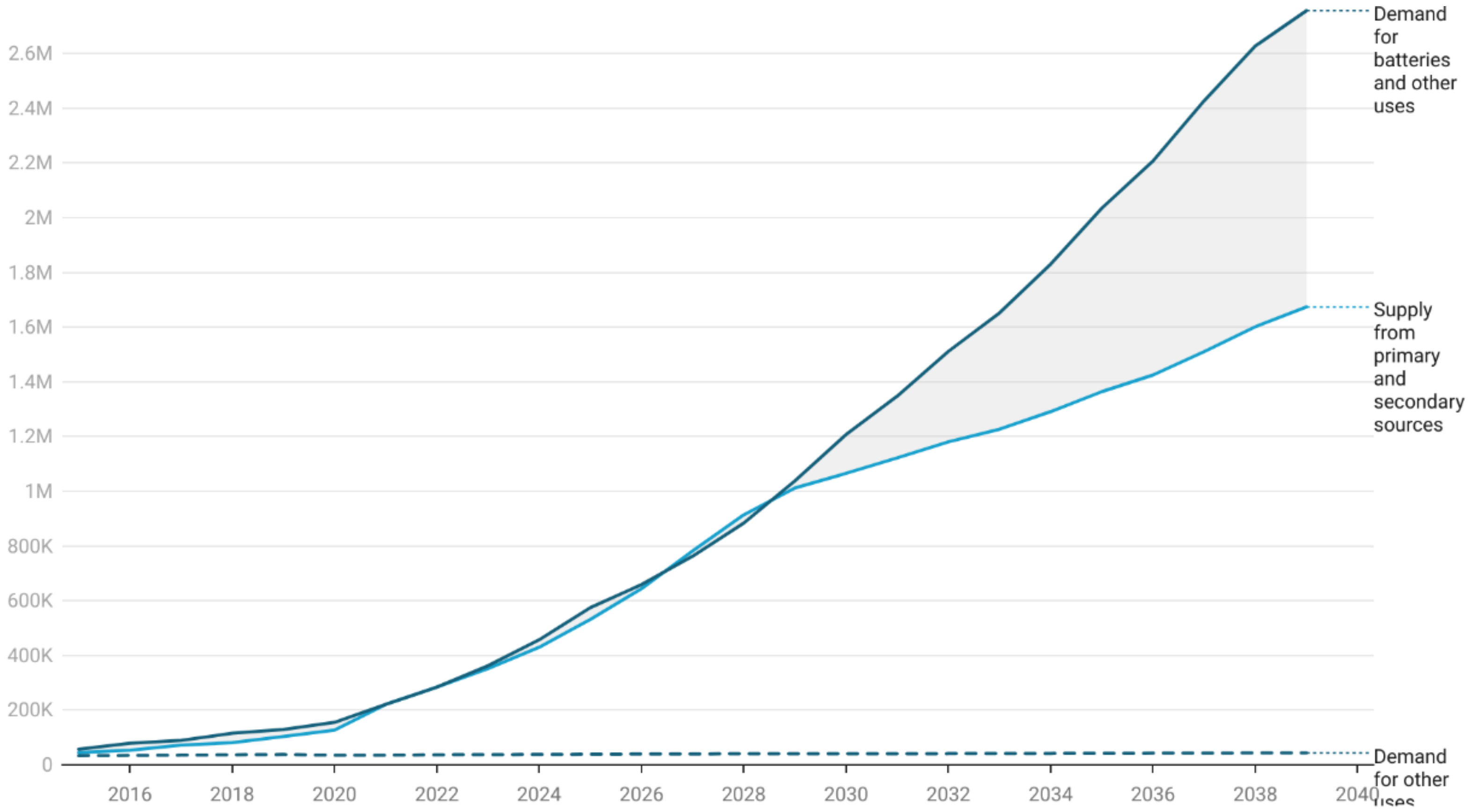


Source: RMIS - Battery supply chain challenges (europa.eu)

Critical materials

Global demand and supply
Primary and secondary sources

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



Source: RMIS - Battery supply chain challenges (europa.eu)

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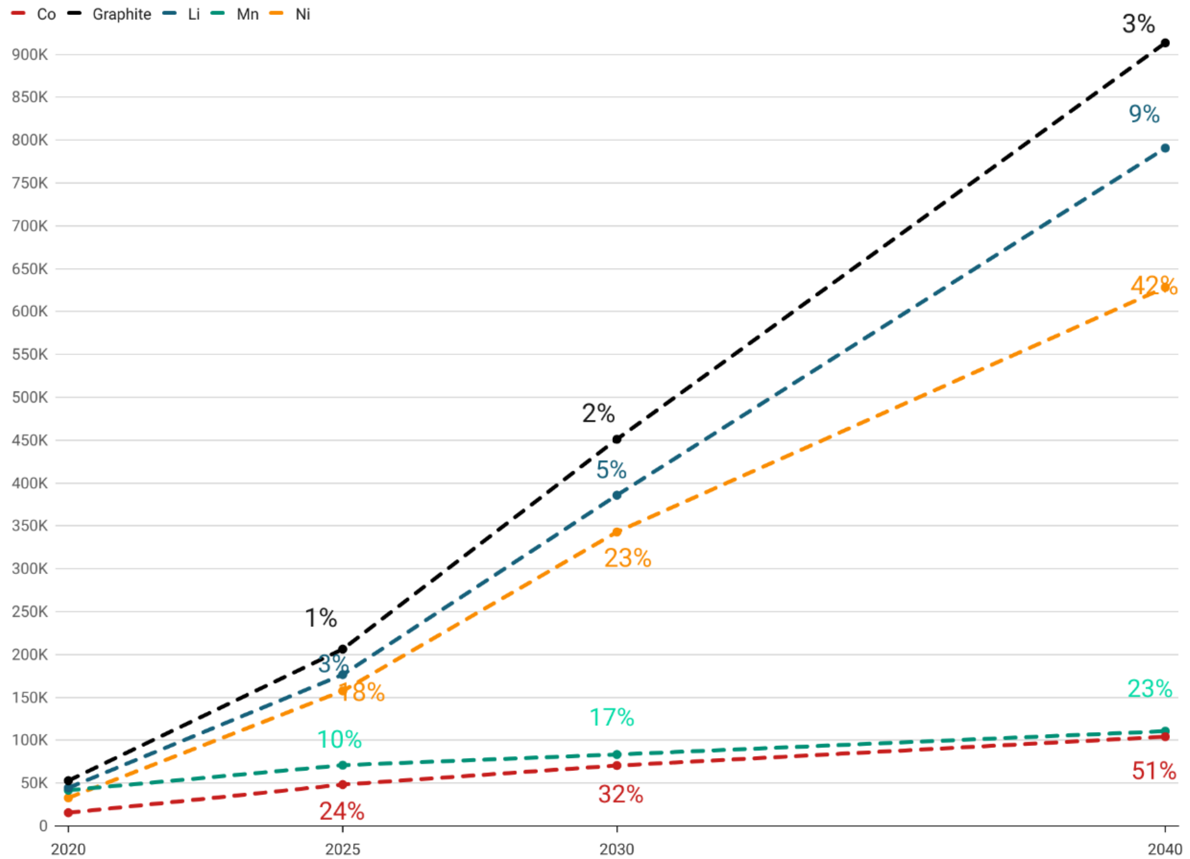
Critical materials

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)



Source: RMIS - Battery supply chain challenges (europa.eu)

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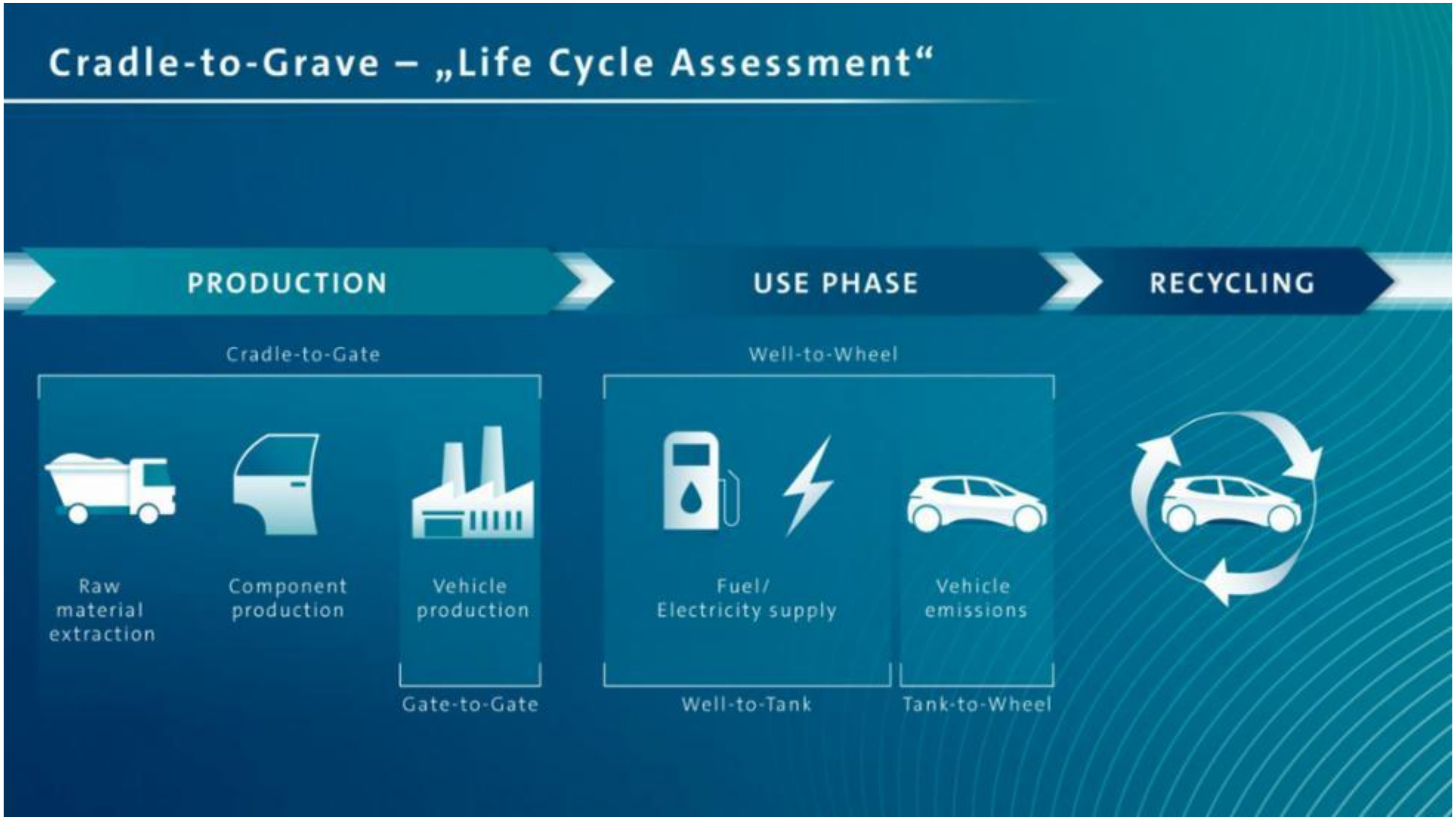
Agenda

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

Critical materials

Example: E-vehicles

Circular Economy



Source: https://www.volkswagengroup.it/ita/media/comunicati-stampa/i-veicoli-elettrici-hanno-il-miglior-bilancio-di-co2

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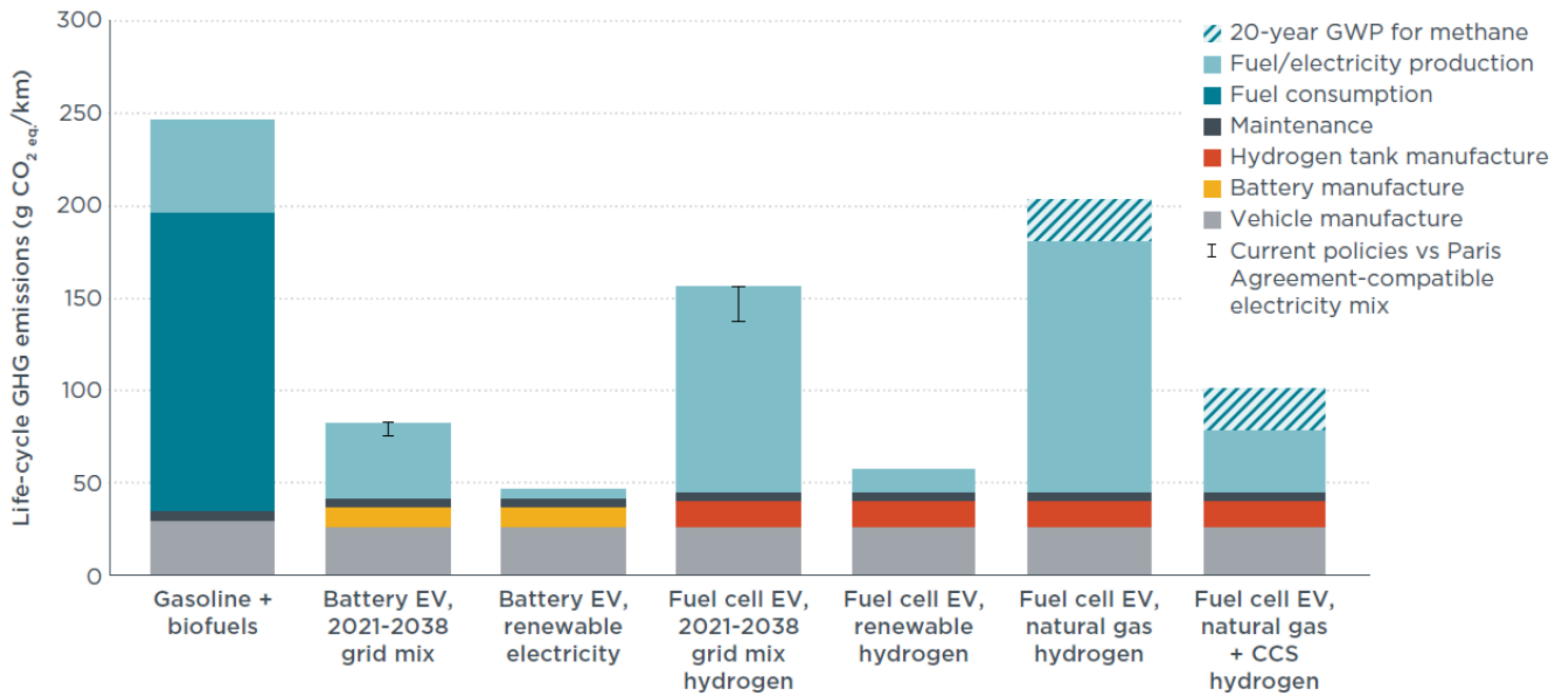
Critical materials

→ 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

Source: Pehlken 2023. Lecture V02 – Hidden Champions for RE

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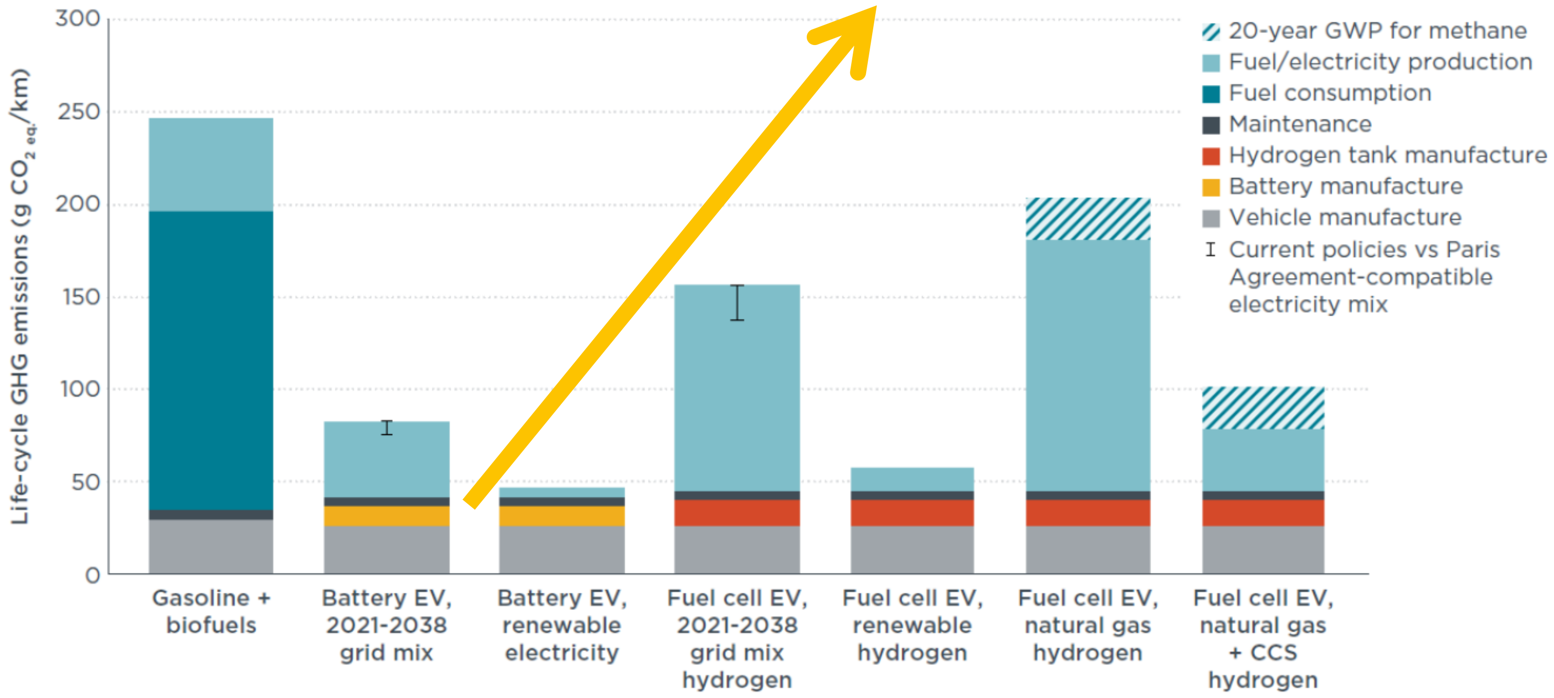
Critical materials

→ Tank-to-wheel analysis

Example: E-vehicles

Circular Economy

→ CO2 is not the only relevant indicator!



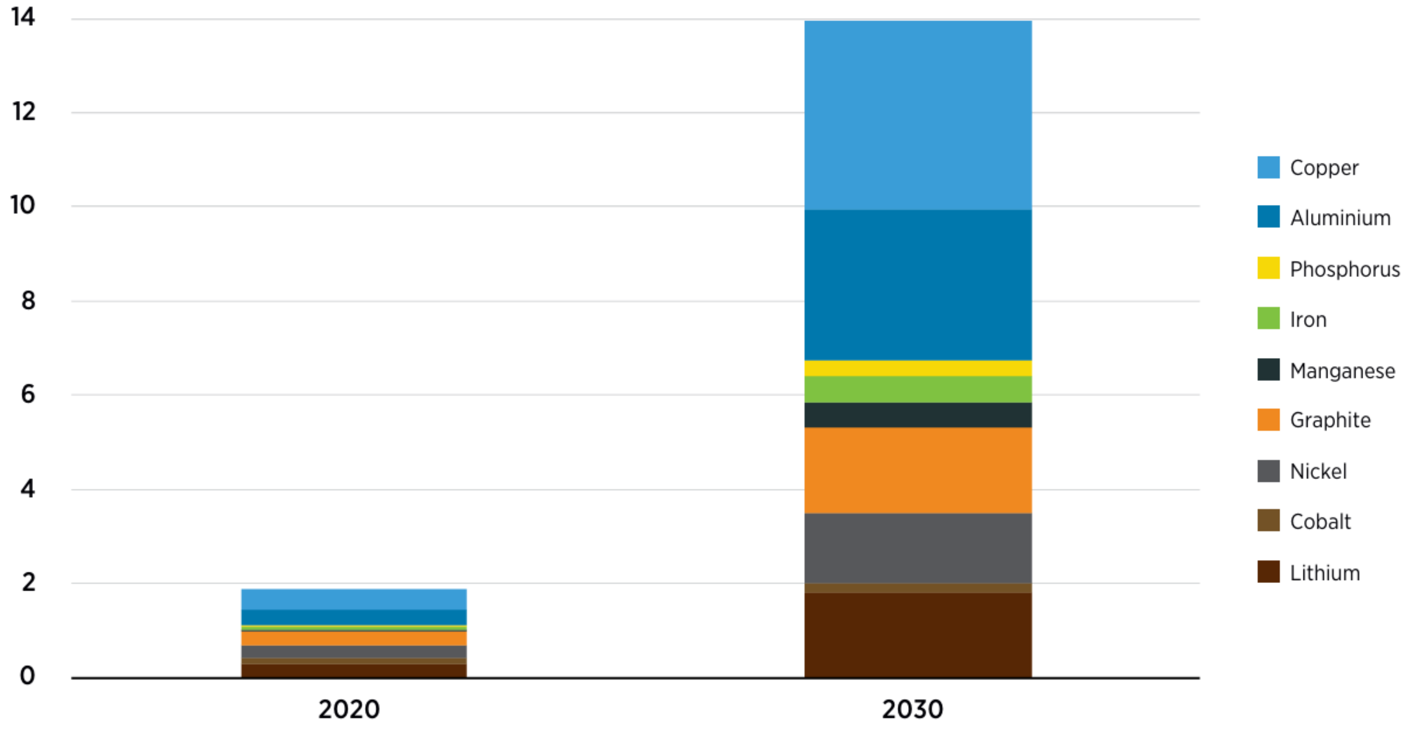
Reference: ICCT WHITE PAPER, GLOBAL COMPARISON OF THE LIFE-CYCLE GREENHOUSE GAS EMISSIONS OF PASSENGER CARS, 2021

Source: Pehlken 2023. Lecture V02 – Hidden Champions for RE

Critical materials

Example: E-vehicles

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



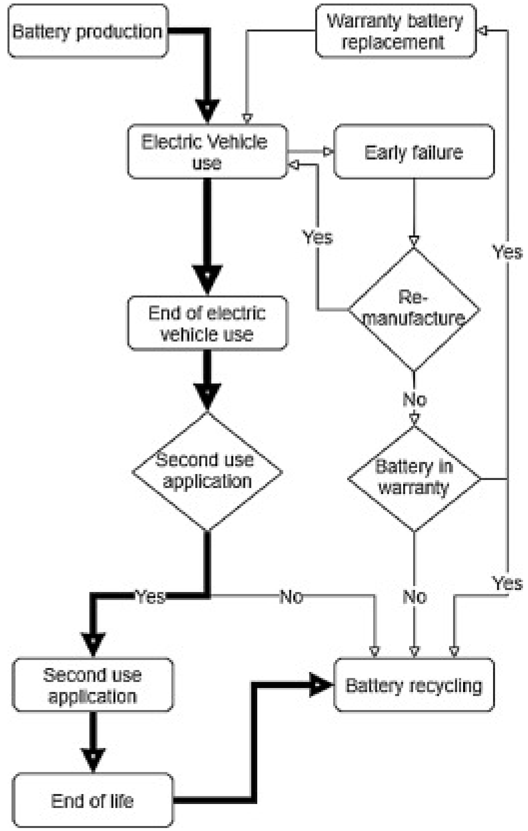
Adapted from: BloombergNEF, 2021a.

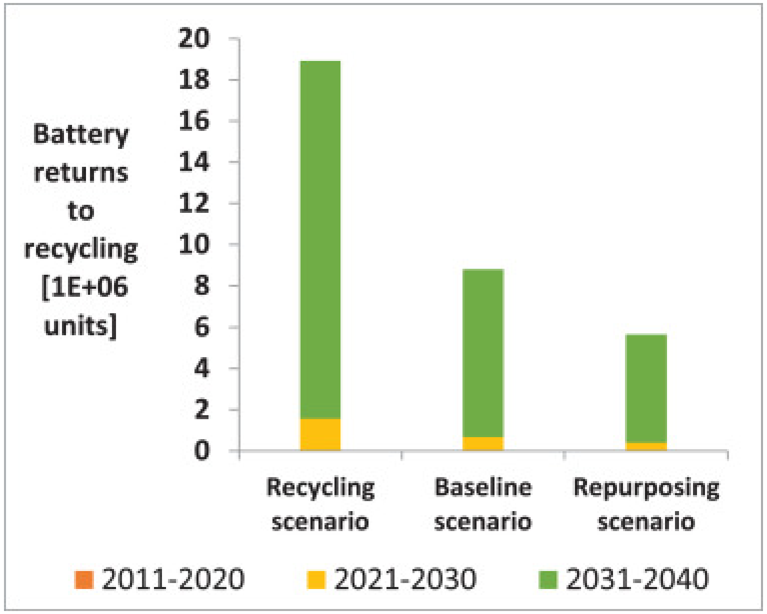
Source: Pehlken 2023. Lecture V02 – Hidden Champions for RE

Critical materials

Example: E-vehicles

Second-life, reusing, refurbishing and recycling…
…for battery materials



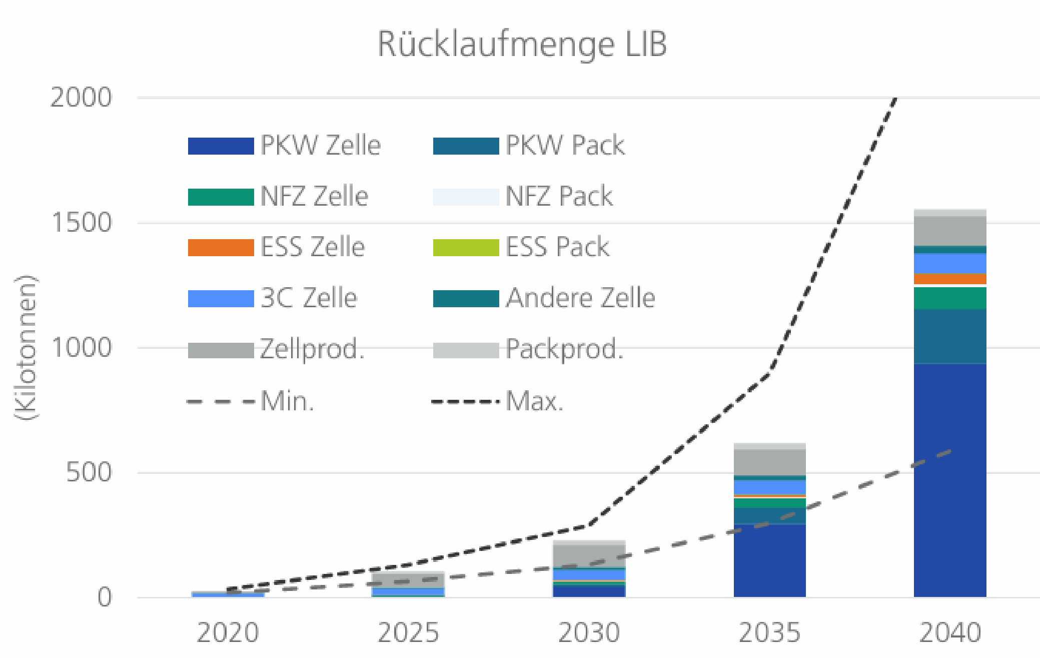


Source: *Forecasting the EU recycling potential for batteries from electric vehicles.* https://doi.org/10.1016/j.procir.2020.01.109 , 2020.

Critical materials

Example: E-vehicles

Second-life, reusing, refurbishing and recycling…
…for battery materials



Mostly e-vehicles!

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.

Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2021/VDMA_Kurzstudie_Batterierecycling.pdf

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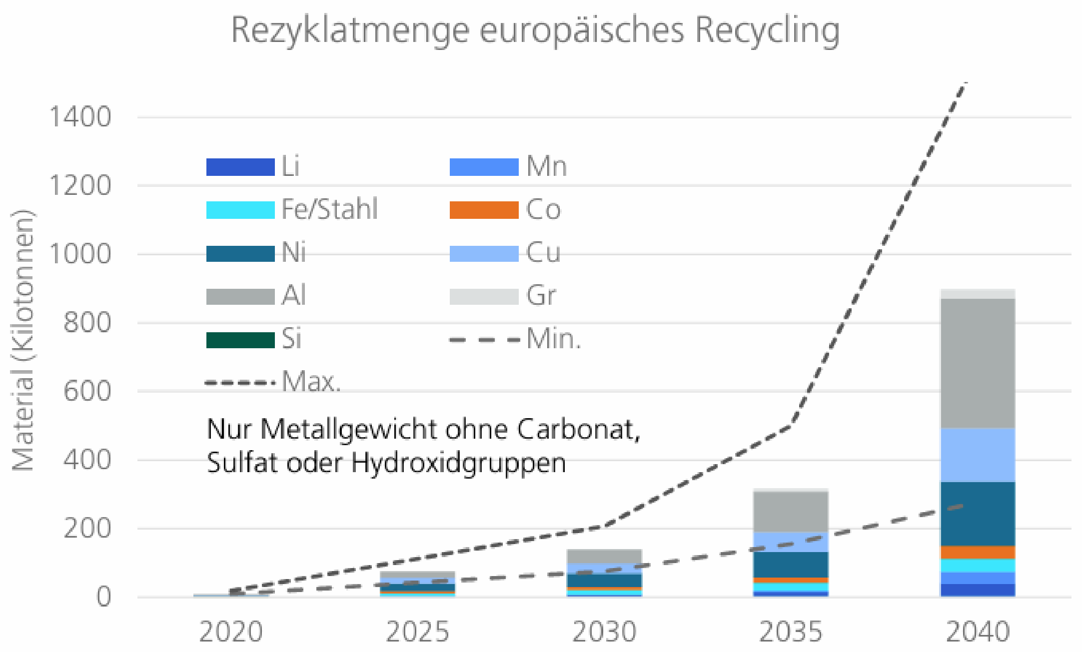
Critical materials

Example: E-vehicles

Second-life, reusing, refurbishing and recycling…
…for battery materials



Li… ☹

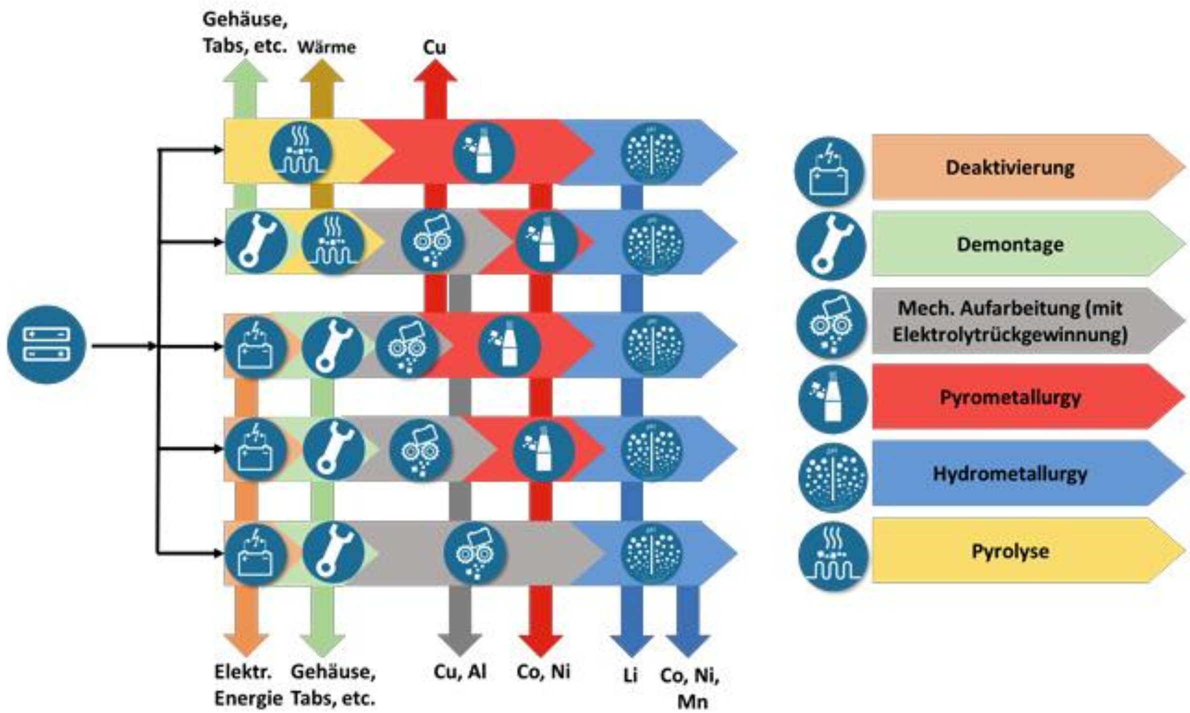
Abbildung 6: Entwicklung von Rezyklatmengen aufgeteilt nach unterschiedlichen Metallen und Rohstoffen bis 2040. Die Balken bilden das Basis-Szenario ab.

Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2021/VDMA_Kurzstudie_Batterierecycling.pdf

Critical materials

Example: E-vehicles

Recycling processes and their outcomes



Energy intensity

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

Source: https://www.isi.fraunhofer.de/content/dam/isi/dokumente/cct/2021/VDMA_Kurzstudie_Batterierecycling.pdf

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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.