



SAPIENZA
UNIVERSITÀ DI ROMA

CIRCULAR ECONOMY AND THE ROLE OF RAW MATERIALS IN THE ENERGY TRANSITION

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1. INTRODUCTION: CIRCULAR ECONOMY

The circular economy is a production and consumption model that aims to **maintain the value of products, materials, and resources in the economy** for as long as possible while **minimising waste generation**.

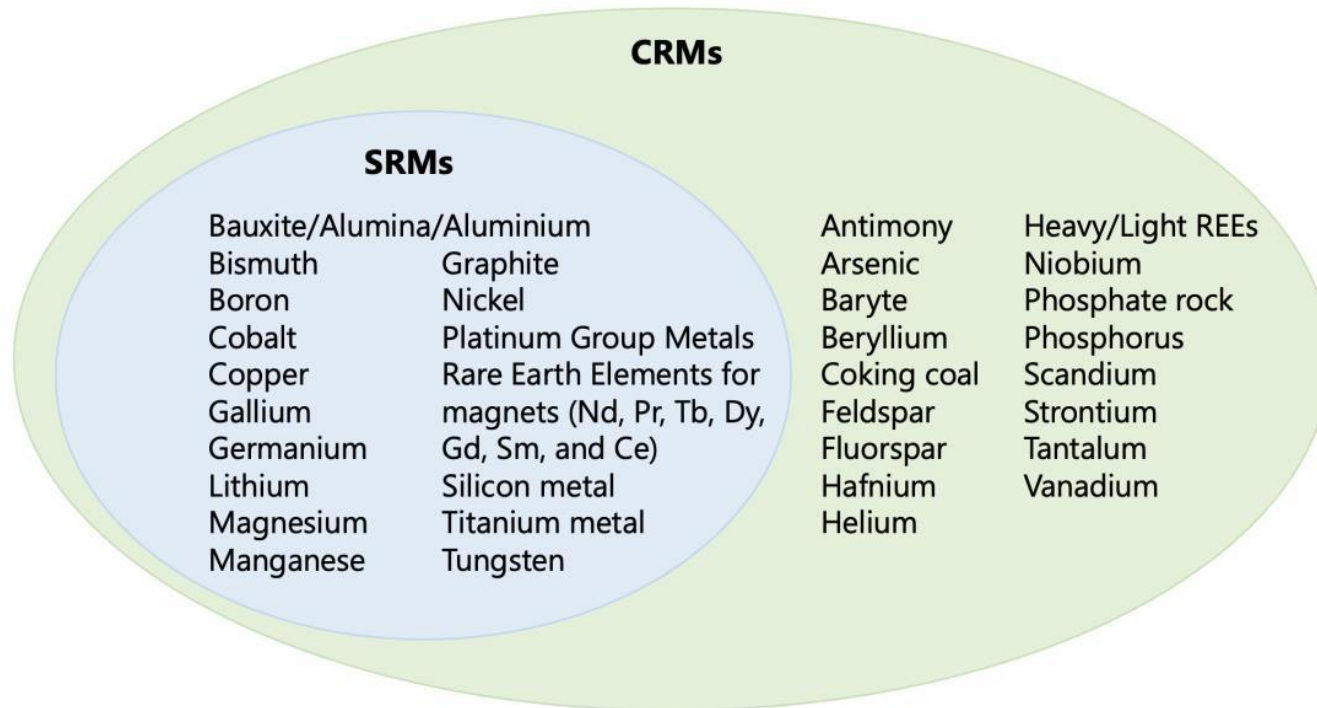


SUSTAINABLE DEVELOPMENT GOALS



1. INTRODUCTION: CIRCULAR ECONOMY

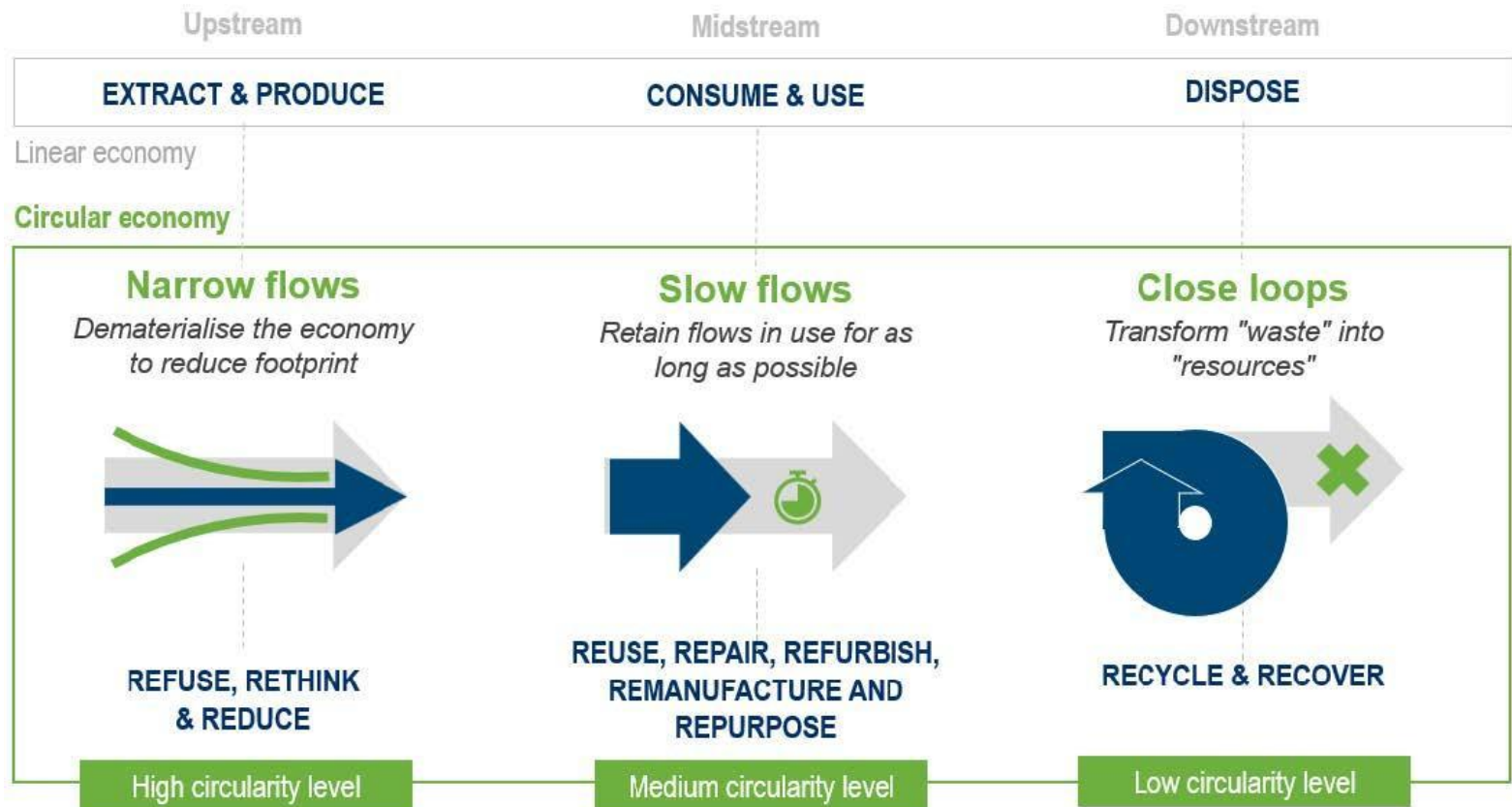
CRITICAL RAW MATERIALS



Source: Circularity strategies and sustainable resource management to safeguard the clean energy transition, IEEP 2024

CRM: Critical Raw Materials
SRM: Strategic Raw Materials

1. INTRODUCTION: CIRCULAR ECONOMY



Source: The Circular Economy in Cities and Regions of the European Union, OECD 2025

1. INTRODUCTION: CIRCULAR ECONOMY

Refuse

- Eliminating the use or demand for materials or products.
- E.g. prohibit single-use plastics,

Rethink

- Reformulating consumption and use models enabling cities and regions to intensify resource utilisation
- E.g. 15-minute city concept

Reduce

- Increasing material efficiency during the manufacturing or use phases of products and services

Reuse

- The use of products and materials for their original purpose or by a new user

Repair

- To prevent the disposal of products

Refurbishing

- Restoring products and infrastructure to an updated or improved condition

Remanufacturing

- To enable discarded products or their components to be transformed into new items

Repurposing

- Adapting discarded items for new uses
- E.g. transforming old railways into bike paths

Recycling

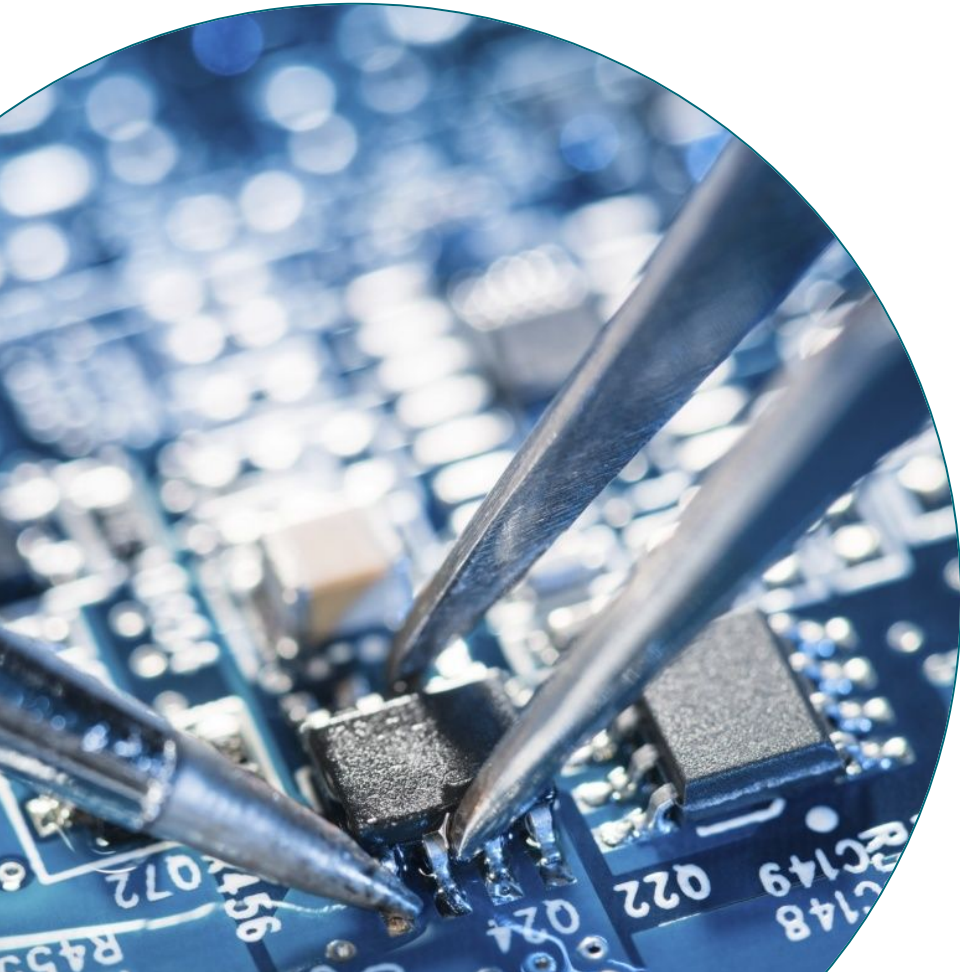
- The processing of discarded materials to produce new resources of either the same or lower quality

Recovery

- Extracting value from non-recyclable materials, often through waste to energy technologies.

2. KEY PRODUCT VALUE CHAINS

ELECTRONICS AND ICT



- In 2020, less than 40% of electronic waste was recycled in the EU.
- 'Circular Electronics Initiative'
- Regulatory measures for mobile phones, tablets and laptops, designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling.
- Implementing the 'right to repair' and to update obsolete software.
- Introduction of a common charger, improving the durability of charging cables.
- Collection and treatment of waste electrical and electronic equipment.

2. KEY PRODUCT VALUE CHAINS

BATTERIES AND VEHICLES



The aim is to swiftly enhance the sustainability of the emerging battery value chain for electro-mobility and boost the circular potential of all batteries.

- Improving the collection and recycling rates of all batteries, ensuring the recovery of valuable materials and providing guidance to consumers.
- When alternatives are available, phase out the use of rechargeable batteries.
- Taking account of the carbon footprint of manufacturing.

2. KEY PRODUCT VALUE CHAINS

PACKAGING



In 2017 packaging waste in Europe reached a record: 173 kg per inhabitant, the highest level ever.

- Reducing (over)packaging and packaging waste.
- Re-use and recyclability of packaging, including considering restrictions on the use of some packaging materials for certain applications.
- Drinking Water Directive to make drinkable tap water accessible in public places.

2. KEY PRODUCT VALUE CHAINS

PLASTICS



EU Strategy for Plastics in the Circular Economy. To increase the use of recycled plastics and contribute to a more sustainable use of plastics, mandatory recycled content requirements and waste reduction measures will be proposed for packaging, construction materials and vehicles.

- Restricting intentionally added microplastics.
- Developing methods for measuring unintentionally released microplastics
- Use of biodegradable or compostable plastics

2. KEY PRODUCT VALUE CHAINS

TEXTILES



It is estimated that less than 1% of all textiles worldwide are recycled into new textiles. Also, 60% by value of clothing in the EU is produced elsewhere.

- Developing ecodesign measures to ensure textile products are fit for circularity, ensuring the uptake of secondary raw materials and tackling the presence of hazardous chemicals.
- Providing guidance to achieve high levels of separate collection of textile waste.
- Boosting the sorting, re-use and recycling of textiles.

2. KEY PRODUCT VALUE CHAINS

CONSTRUCTION AND BUILDINGS



It requires vast amounts of resources and accounts for about 50% of all extracted material. The construction sector is responsible for over 35% of the EU's total waste generation and a 5-12% of total GHG emissions.

- Introduction of recycled content.
- Improving the durability and adaptability of built assets in line with the circular economy principles
- Reducing soil sealing, rehabilitate abandoned or contaminated brownfields and increase the safe, sustainable and circular use of excavated soils.

2. KEY PRODUCT VALUE CHAINS

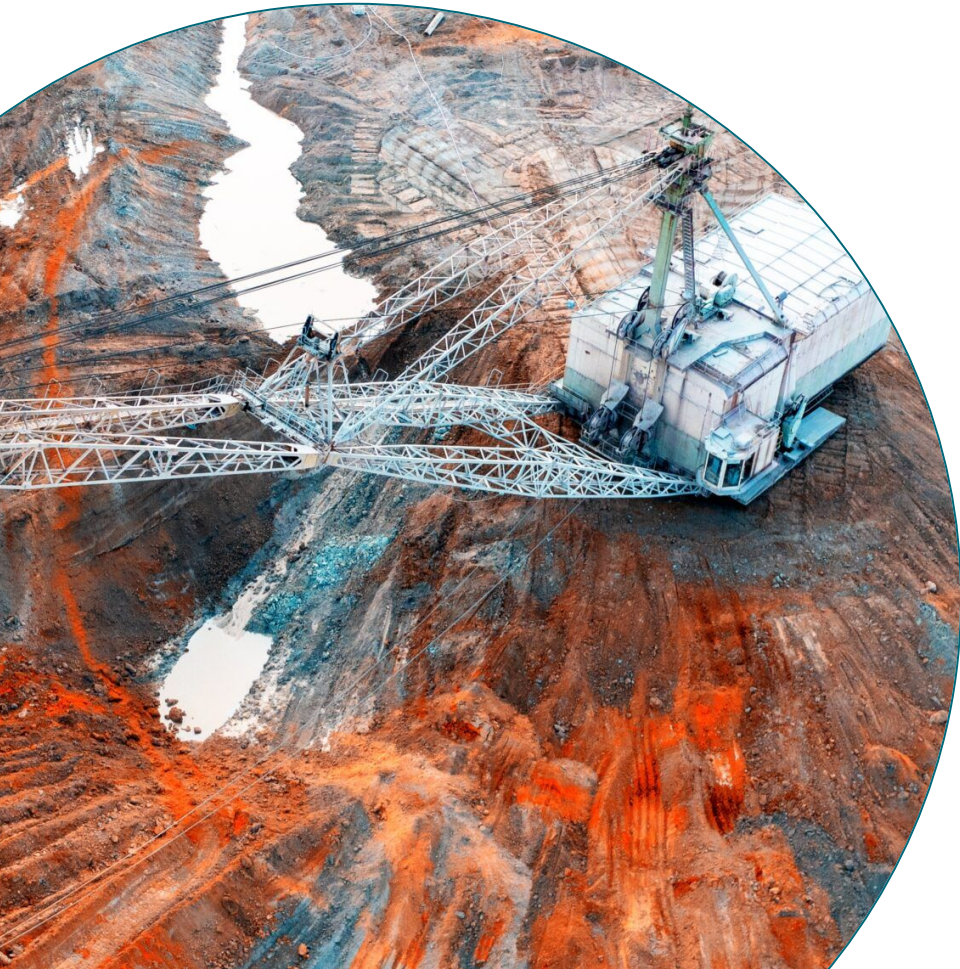
FOOD, WATER AND NUTRIENTS



While the food value chain is responsible for significant resource and environmental pressures, an estimated 20% of the total food produced is lost or wasted in the EU. The new Water Reuse Regulation will encourage circular approaches to water reuse in agriculture, including in industrial processes. Furthermore, the Commission will develop an Integrated Nutrient Management Plan, with a view to ensuring more sustainable application of nutrients and stimulating the markets for recovered nutrients

2. KEY PRODUCT VALUE CHAINS

CRITICAL RAW MATERIALS



Metals and minerals are fundamental for advanced materials, tools and machinery used to sustain all primary and secondary industry sectors.

Europe is using 23% of the world's mine production for metals and minerals but only produces 2-3 % itself (2017)

List of critical raw materials:

- Supply risk
- Economic importance
- Critical Raw Materials Act published promotes assertive, cooperative and sustainable trade policy by securing supply through increased mining, processing and recycling.

2. KEY PRODUCT VALUE CHAINS

CRITICAL RAW MATERIALS

The Critical Raw Materials Act is now emphasizing the role of circularity as a lever for resource security, keeping resources “in the loop” domestically to mitigate import dependencies and supply disruption risks.

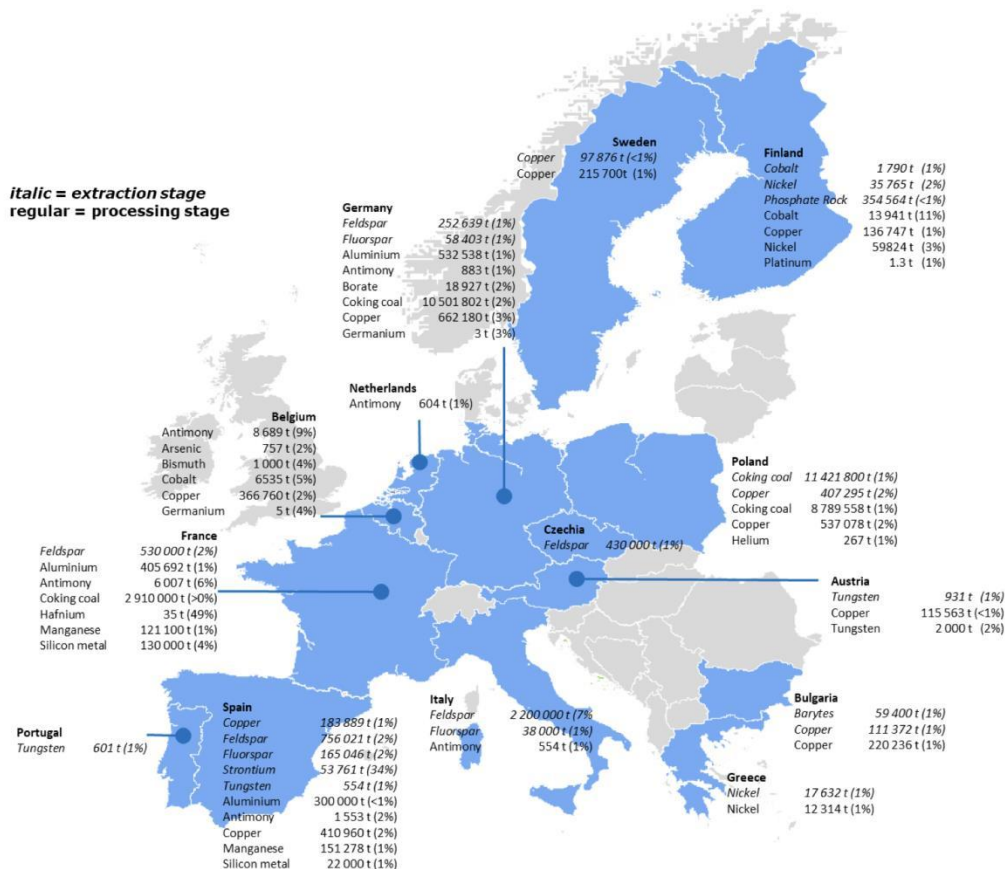
- Boosting the domestic availability of CRMs by facilitating domestic extraction, processing, and recycling of CRMs
- Diversifying the EU's external supply



Source: EIT Raw Materials, 2019

2. KEY PRODUCT VALUE CHAINS

CRITICAL RAW MATERIALS



Source: European Commission, 2023

It is necessary to address:

- The EU's low diversification of supply sources and consideration of EU domestic sourcing of CRMs.
- The adverse social, environmental, and human rights impacts of CRM mining operations.
- The lack of circularity for CRMs in existing regulatory frameworks
- Research & innovation to provide necessary solutions across the CRM value chain.

2. KEY PRODUCT VALUE CHAINS

CRITICAL RAW MATERIALS



Source: European Commission, 2023

2. KEY PRODUCT VALUE CHAINS

SECONDARY RAW MATERIALS



Secondary raw materials are recycled materials that can be used in manufacturing processes instead of or alongside virgin raw materials.

- It reduced material and energy use;
- reduced impacts on the climate and the environment;
- reduced manufacturing costs.

SRM barriers:

- The absence of EU-wide quality standards for certain materials.
- Difficulties linked to the trading of SRM across the EU.
- The potential presence of chemicals of concern in recycled materials.

3. ENERGY TRANSITION

The sustainable energy transition is a transformative shift in how energy is produced, distributed and consumed, aiming to move away from fossil fuels towards a system centred on renewable energy sources such as solar, wind, hydropower and geothermal



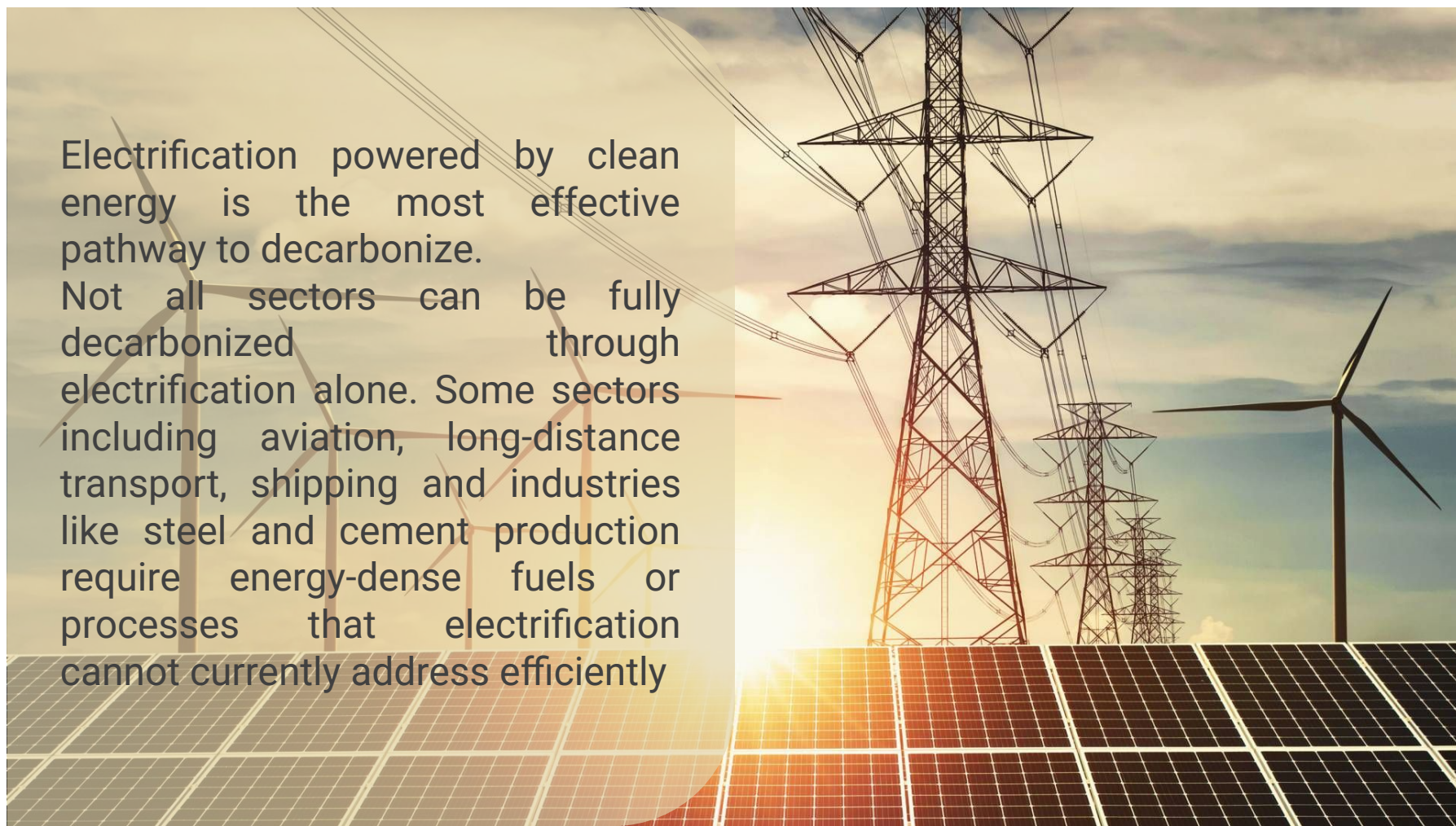
3. ENERGY TRANSITION



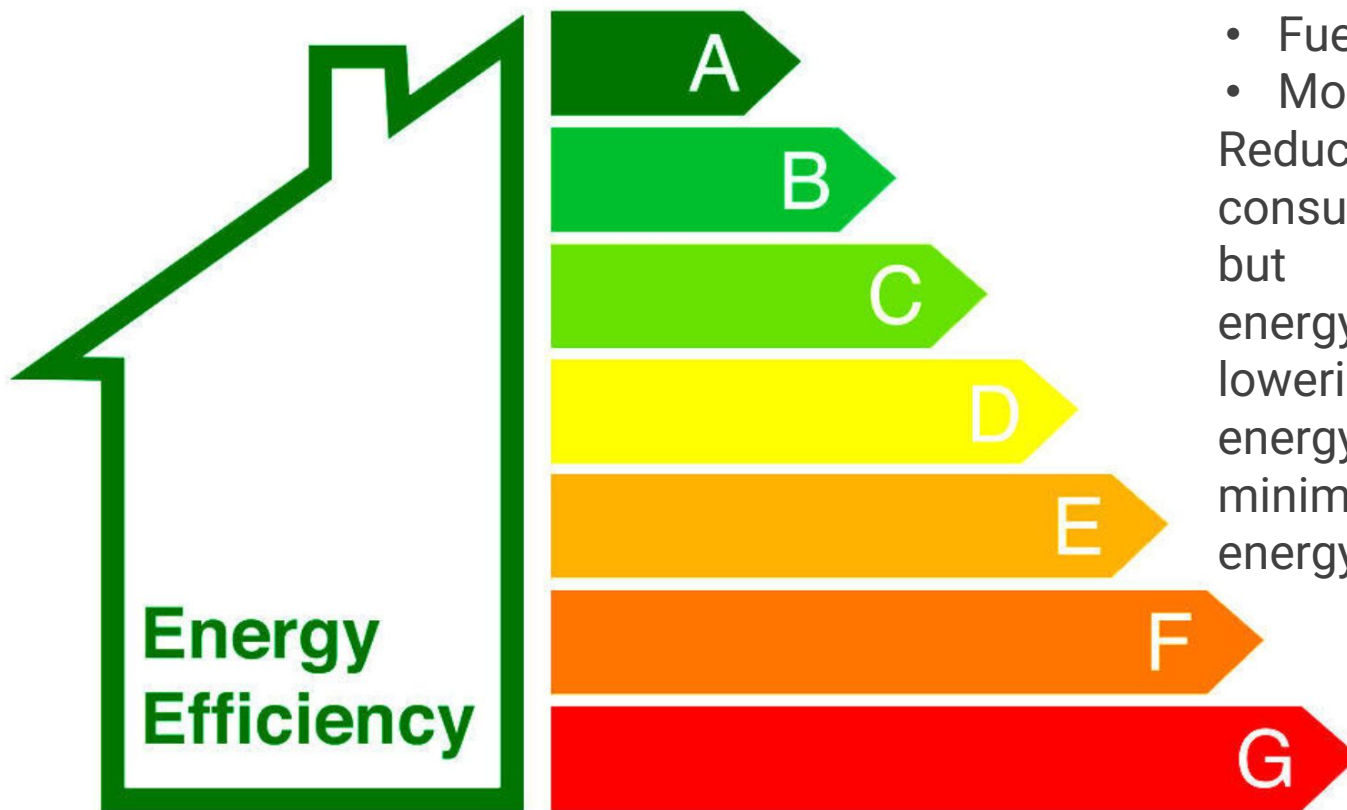
Source: UNDP, 2025. Public buildings in Rwanda

3. ENERGY TRANSITION

Electrification powered by clean energy is the most effective pathway to decarbonize. Not all sectors can be fully decarbonized through electrification alone. Some sectors including aviation, long-distance transport, shipping and industries like steel and cement production require energy-dense fuels or processes that electrification cannot currently address efficiently



3. ENERGY TRANSITION



- Insulated buildings
 - Fuel-efficient vehicles
 - Modern appliances
- Reduce energy consumption and costs but also strengthen energy security by lowering reliance on energy imports and minimizing strain on energy systems

4. CRITICAL RMs IN THE ENERGY TRANSITION

Although renewable technologies such as wind and solar do not consume fuel during operation, their production and deployment require significantly more material input compared to fossil fuel infrastructure.

High-performance batteries rely on lithium, cobalt, and nickel; rare earth elements are critical for powerful magnets used in wind turbines; and hydrogen systems require nickel or platinum group metals.



4. CRITICAL RMs IN THE ENERGY TRANSITION

The extraction and use of critical raw materials for the European Union's clean energy transition are at the heart of an increasingly complex debate.

The demand for CRMs is driven by the technologies powering the energy transition.

- Electric vehicles (EVs), electricity networks, and solar photovoltaics alone are projected to account for up to 95% of global CRM.
- Aluminium and copper dominate by volume
- Lithium, nickel, and zinc represent 80% of CRM demand for clean energy.



4. CRITICAL RMs IN THE ENERGY TRANSITION

Table 1: Critical mineral needs for clean energy technologies¹¹

	Solar	Wind	Battery storage	Hydrogen	Electricity networks
Copper	●	●	●	●	●
Cobalt	●	●	●	●	●
Nickel	●	●	●	●	●
Lithium	●	●	●	●	●
Rare Earth Elements	●	●	●	●	●
Chromium	●	●	●	●	●
Zinc	●	●	●	●	●
Platinum Group Metals	●	●	●	●	●
Aluminium	●	●	●	●	●

Colour indicates the relative importance of minerals for a particular clean energy technology (● = high; ● = moderate; ● = low).

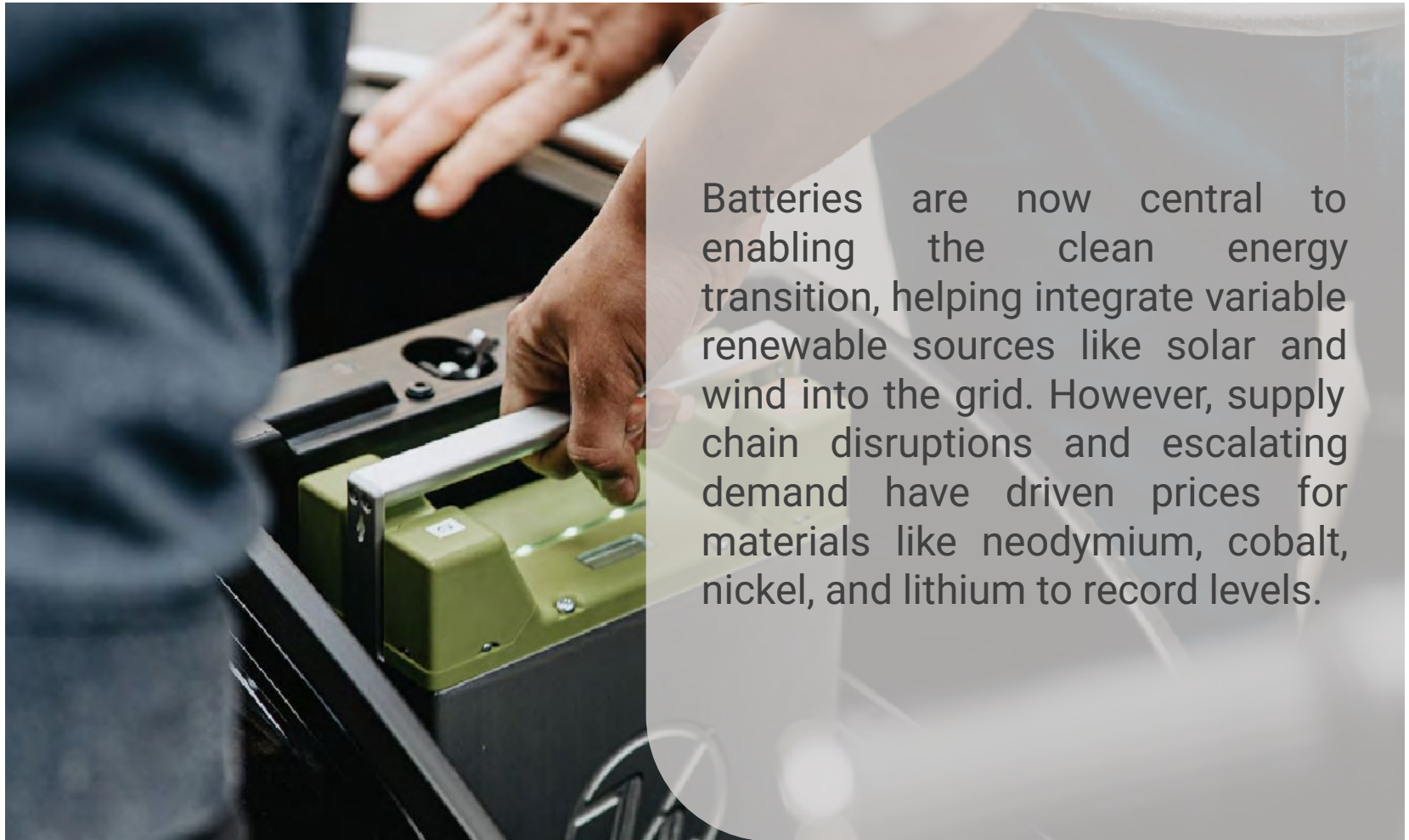
Geopolitically, the supply of critical materials is becoming increasingly significant. Many CRM supply chains are more geographically concentrated than those of oil or gas.

China accounts for over 90% of global rare earth metal production and holds unmatched processing expertise.

This creates vulnerabilities tied to physical disruptions, trade barriers, or political shifts in supplier countries

Source: For a circular energy transition, Gate C (2023)

4. CRITICAL RMs IN THE ENERGY TRANSITION



Batteries are now central to enabling the clean energy transition, helping integrate variable renewable sources like solar and wind into the grid. However, supply chain disruptions and escalating demand have driven prices for materials like neodymium, cobalt, nickel, and lithium to record levels.

4. CRITICAL RMs IN THE ENERGY TRANSITION

End-of-life value loss

- Under 10% of solar PV modules are recycled, with most value retained only in aluminium and copper, while silver and silicon go unrecovered.
- Lithium-ion battery recycling (with a collection rate below 5%) is similarly limited, recovering cobalt, nickel, and copper through energy-intensive processes but losing lithium and aluminium.
- Rare earth elements from wind turbine magnets are currently not recycled at all.

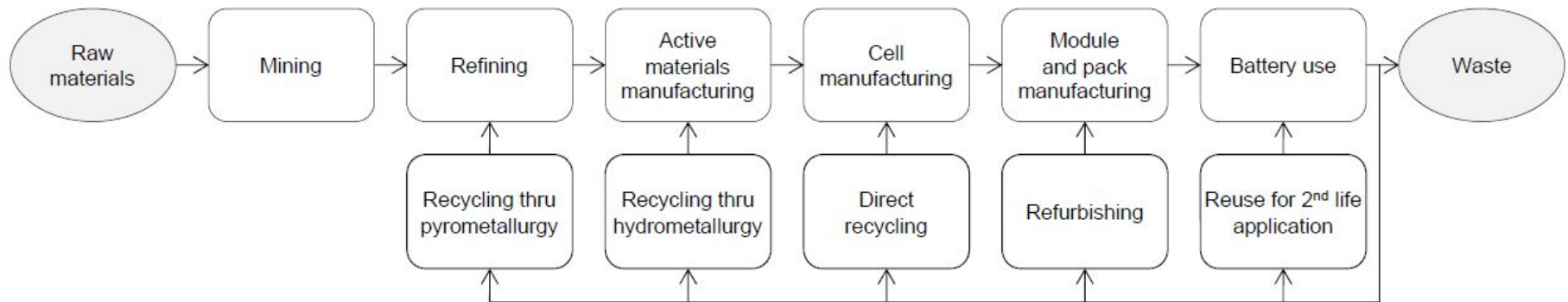


4. CRITICAL RMs IN THE ENERGY TRANSITION

Circular practices can help reduce emissions, conserve biodiversity, improve supply chain resilience, and generate new economic value and employment. To make this shift, three key strategies must be implemented:

- design energy assets for circularity from the outset,
- develop integrated circular value chains, establish supportive economic and policy frameworks.

The transition of the renewable energy sector to a circular economy is essential to ensure the reliability and resilience of critical materials supply



Source: For a circular energy transition, Gate C (2023)

5. CONCLUSIONS

The transition to a sustainable energy system, based on renewable sources such as wind, solar, and hydropower, is essential for achieving climate goals and reducing dependency on fossil fuels. However, this shift brings with it an unprecedented demand for critical raw materials (CRMs)—many of which are finite, geopolitically sensitive, and environmentally intensive to extract.



5. CONCLUSIONS

Currently, end-of-life value loss in CRM-intensive technologies such as solar panels, wind turbines, and lithium-ion batteries is substantial, with recycling rates remaining strikingly low.

This not only represents a loss of valuable materials but also increases pressure on virgin resource extraction.

- Designing renewable energy technologies for circularity, enabling easy disassembly, material recovery, and reuse.
- Scaling up efficient and economically viable recycling technologies, especially for hard-to-recover elements such as rare earths and lithium.
- Creating well-functioning markets for secondary raw materials, supported by harmonised quality standards and transparent regulation across the EU.
- Investing in research and innovation to unlock new solutions across the CRM value chain, from sustainable mining to advanced material substitution.

6. REFERENCES

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THANK YOU!



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