CSINK

LEVERAGING LIFE CYCLE ASSESSMENT IN MINING – ADVANCING SUSTAINABILITY IN RAW MATERIAL SUPPLY CHAINS

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MNLT INNOVATIONS PC

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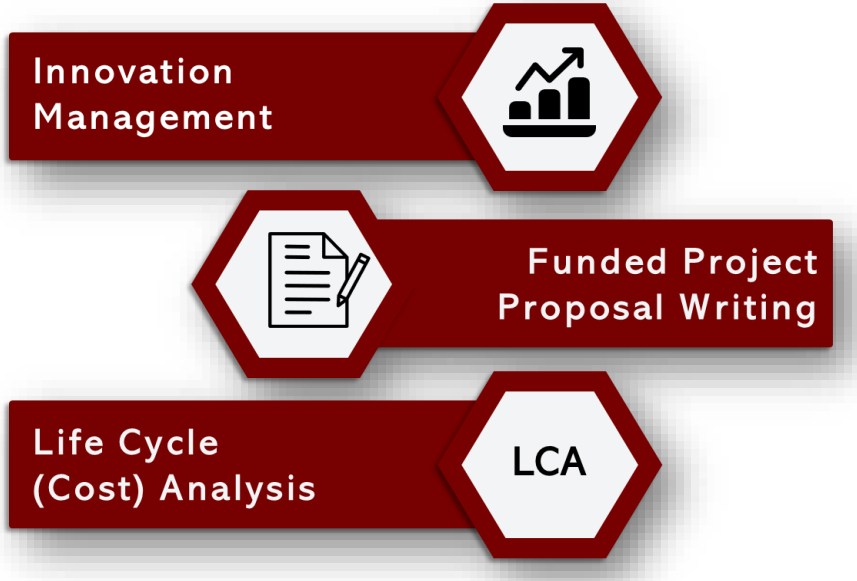
INTRODUCTION
ABOUT ME & MNLT INNOVATIONS

VASILIKI ALEXIOU

- MSc. in Physics & Materials Science, PhD (c) in Life Cycle Assessment (LCA).
- Head of Sustainability/General Manager at MNLT Innovations.



MNLT INNOVATIONS PC

- Founded in 2018 as a spin-off of MONOLITHOS Catalysts & Recycling Ltd., Athens, Greece.
- Engineering consultancy, specializing in Business Planning and Sustainability Assessments.
- Focus on Novel and Innovative technologies, facilitating the Green and Digital Transitions.

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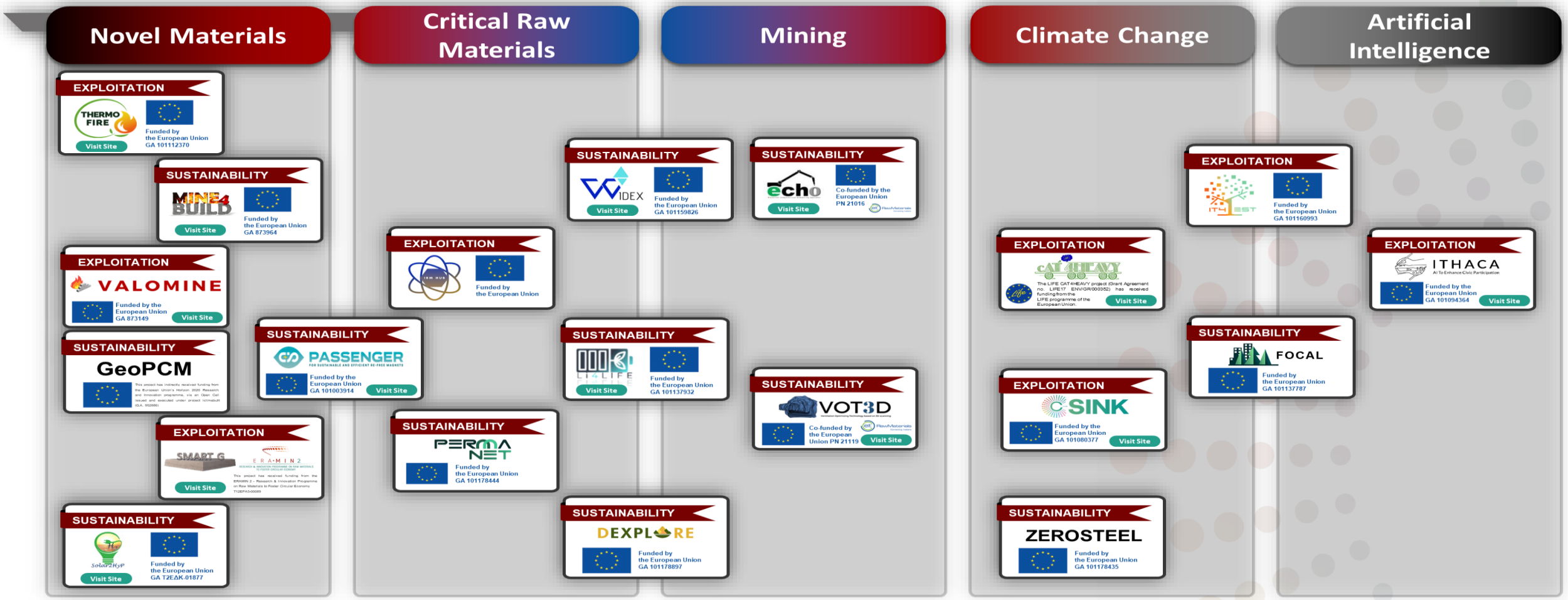
INTRODUCTION
ABOUT ME & MNLT INNOVATIONS



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SEMINAR ROADMAP

- Introduction to LCA
- LCA in Mining: Challenges & Solutions
- Case Studies
- Broader Sustainability Links
- Key Takeaways
- Discussion, Q&A

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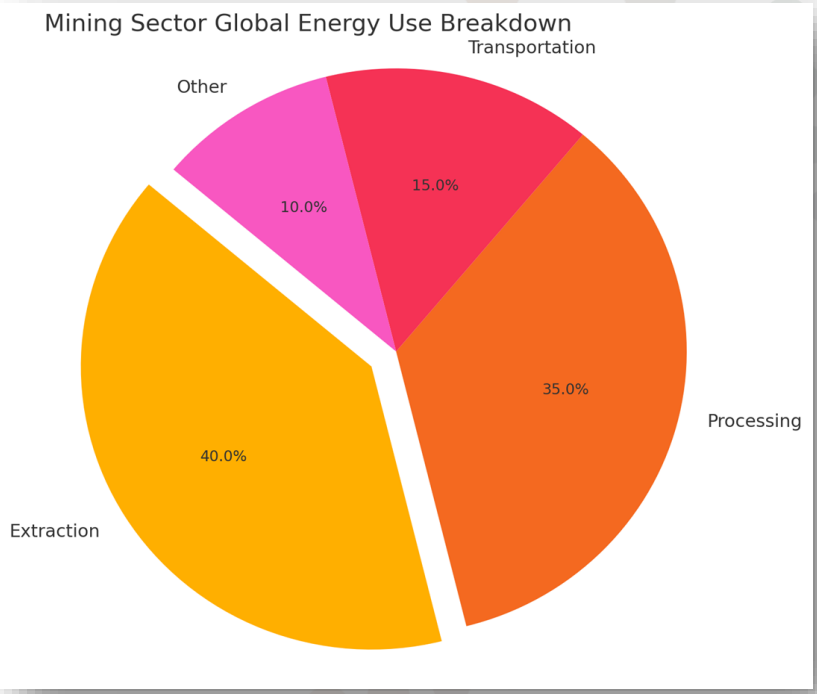
BUILDING SUSTAINABLE VALUE CHAINS: WHY MINING AND LCA MATTER

The EU's Climate Neutrality Goal demands a **55%** emissions cut by 2030.

Did you know that the mining sector accounts for **~8%** of global energy use?

→ requiring massive deployment of clean tech (wind turbines, EVs, batteries)

→ depend on mining (Li, Co, REEs), which often has high environmental/ social costs



As the EU pushes for climate neutrality, how can we ensure raw material supply chains don't undermine sustainability goals?

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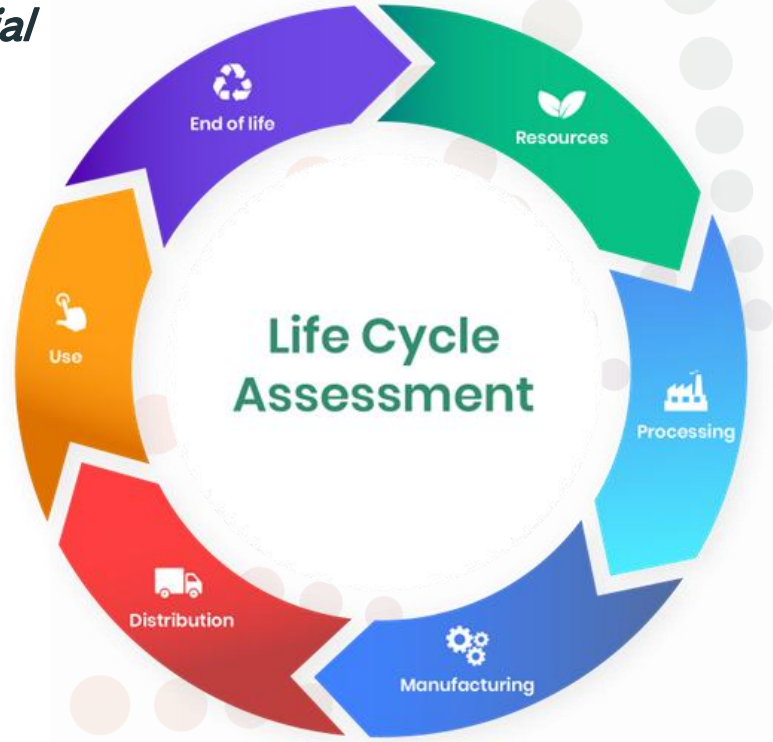
WHAT IS LIFE CYCLE ASSESSMENT (LCA)?

Life Cycle Assessment is an environmental management tool.

The international Organization for Standardisation (ISO, ISO 14040) defines LCA as — A **collection** and **evaluation** of the ***inputs, outputs and potential environmental impacts*** of a product ***through its Lifecyle*** :

1. **Extraction and processing of raw materials**, also called the "cradle"
2. **Manufacturing**
3. **Transportation & Distribution**
4. **Use, maintenance & Retail**
5. **Final waste disposal** or Recycling



LCA is a valuable tool that:

- ✓ Let to ***compare technologies and process.***
- ✓ Find ***innovative and sustainable solutions*** for product and behaviour improvement.
- ✓ Stimulates researchers, businesses and governments to ***identify weaknesses, strengths & opportunities.***

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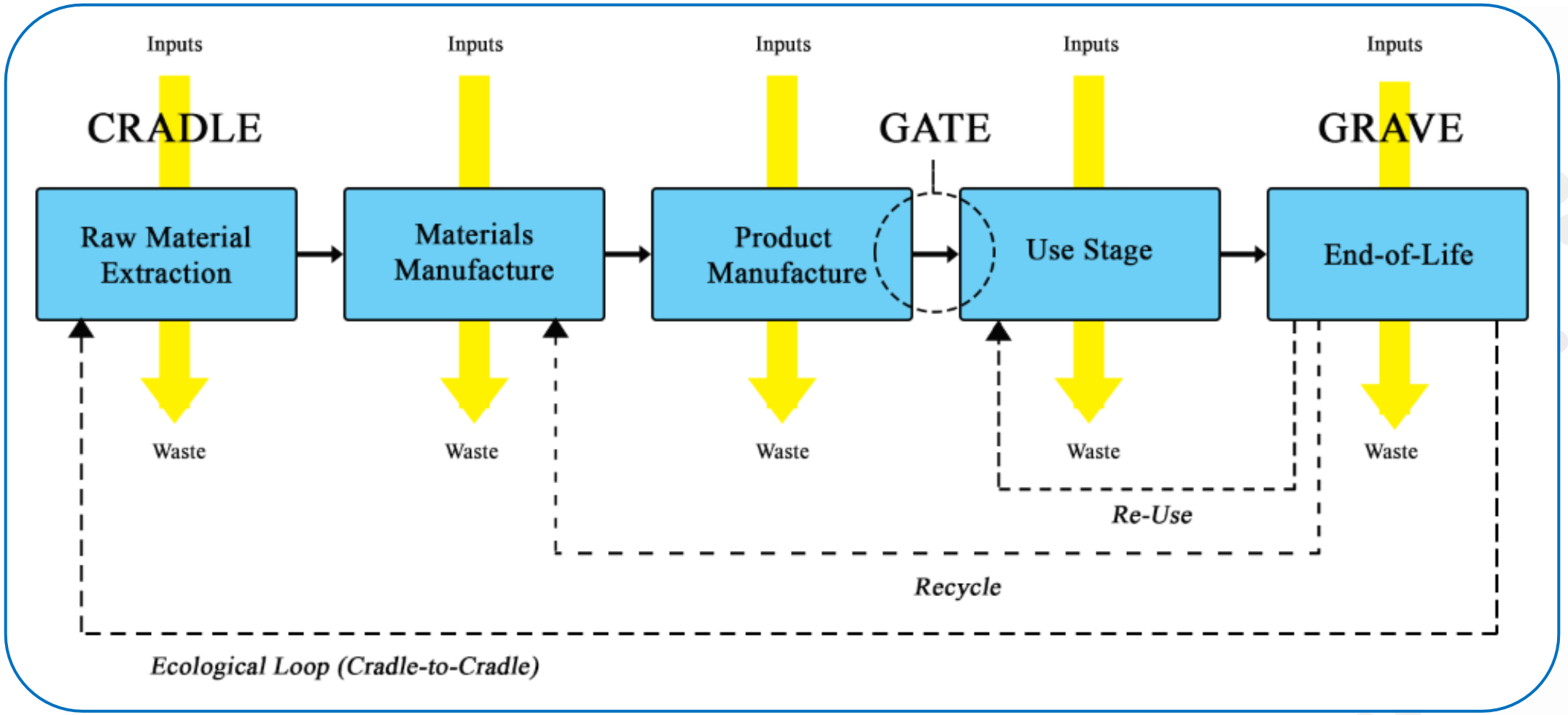
WHAT IS LIFE CYCLE ASSESSMENT (LCA)?



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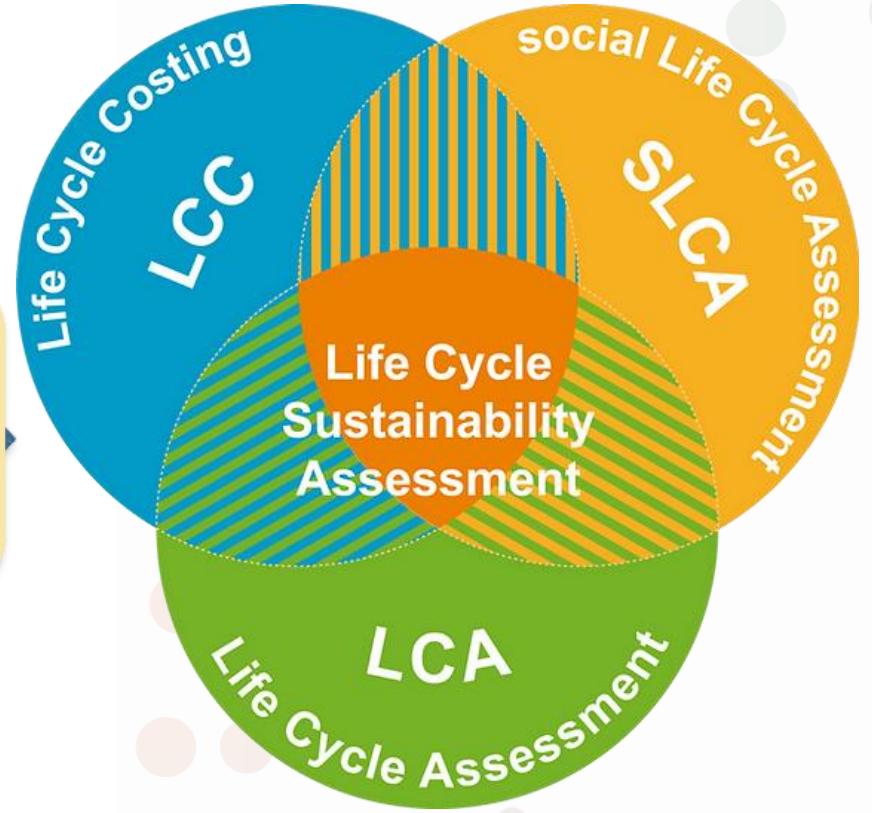
TOOLS FOR HOLISTIC SUSTAINABILITY ASSESSMENT



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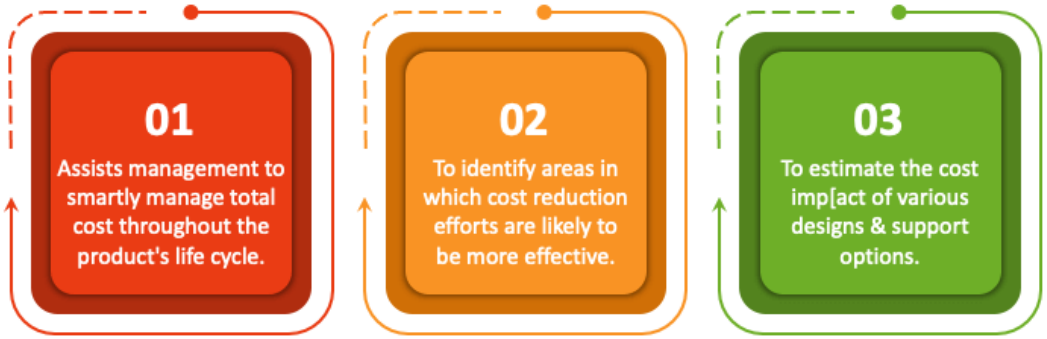
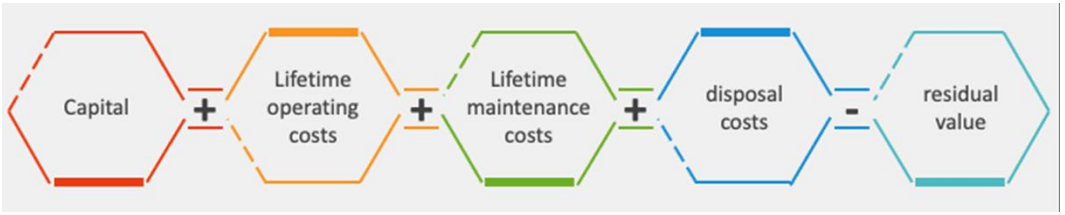
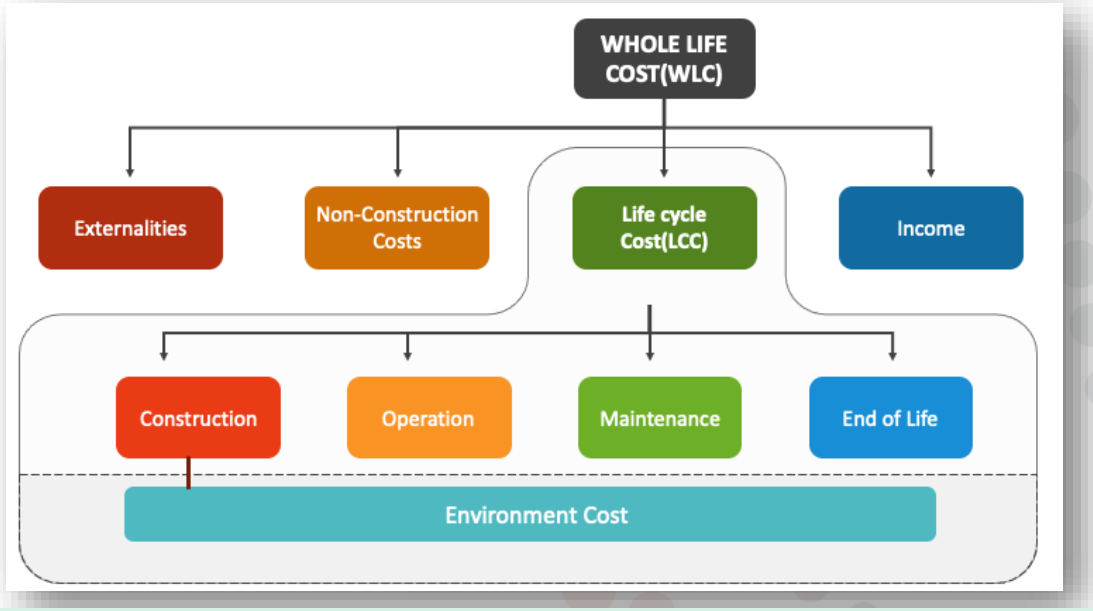
WHAT IS LIFE CYCLE COSTING (LCC)?

- Life Cycle Costing (LCC) is an approach **to evaluating the total cost of a product, process, or project over its entire life.**

Key Objective: To **assess and minimize costs** not only during production but **throughout the entire lifecycle of a product**







- LCC components can be broadly classified into **design & development costs**, **acquisition costs**, **operating costs** and **disposal costs**.
- LCC approach emphasizes the **consideration of total cost for the operation of the equipment from the initial cost.**

Identifying the main **economic drivers** of a product/process/technology involves **analyzing key cost components** throughout its lifecycle to understand their impact on overall economic performance.

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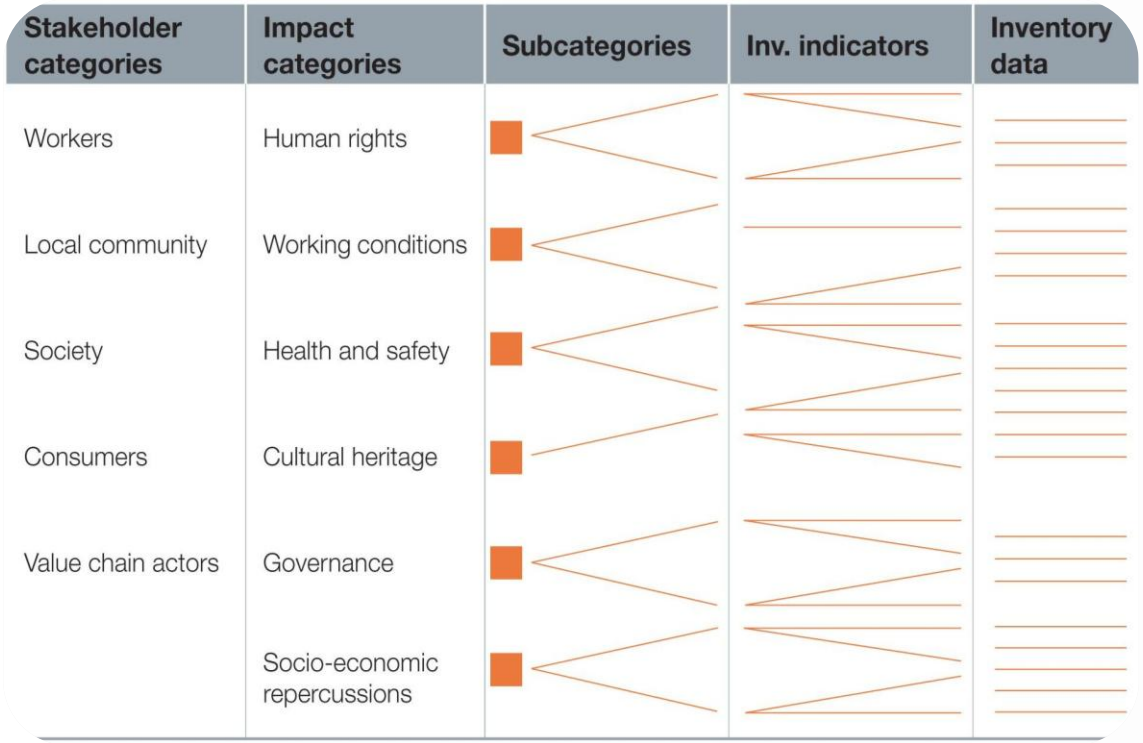
WHAT IS SOCAIAL LIFE CYCLE ANALYSIS (S-LCA)?

- An emerging branch of LCA that **evaluates the social and socio-economic impacts** of a product or process throughout its life cycle.
- It considers aspects like **labor conditions, human rights, community well-being, and social equity**.
- S-LCA is important for **assessing the broader societal implications** of production and consumption choices, complementing the traditional environmental focus of LCA.
- **Data Collection:** Data for S-LCA may include information on worker conditions, health and safety, labor rights, local community engagement, and other social indicators.



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WHAT IS SOCAIAL LIFE CYCLE ANALYSIS (S-LCA)?

Key Social Indicators in S-LCA

Employment Conditions
Wages, working hours, job security, benefits, and opportunities for career advancement.

Labor Rights
Freedom of association, collective bargaining rights, non-discrimination, and prohibition of forced or child labor.

Health and Safety
Risks of accidents, exposure to hazardous substances, occupational diseases, and access to healthcare services

Community Well-being
Education, healthcare, sanitation, social cohesion, cultural heritage preservation, and community development opportunities..

Human Rights
Land rights, indigenous rights, right to livelihood, and access to justice.

Societal Equity
Distribution of social impacts and benefits across different stakeholders, including workers, communities, marginalized groups, and future generations.

Access to Resources
Access to natural resources, infrastructure, and social services, and evaluates potential disparities in resource allocation and access within and between communities.

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LCA METHODOLOGY — PHASES

STEP 1 • Goal & Scope

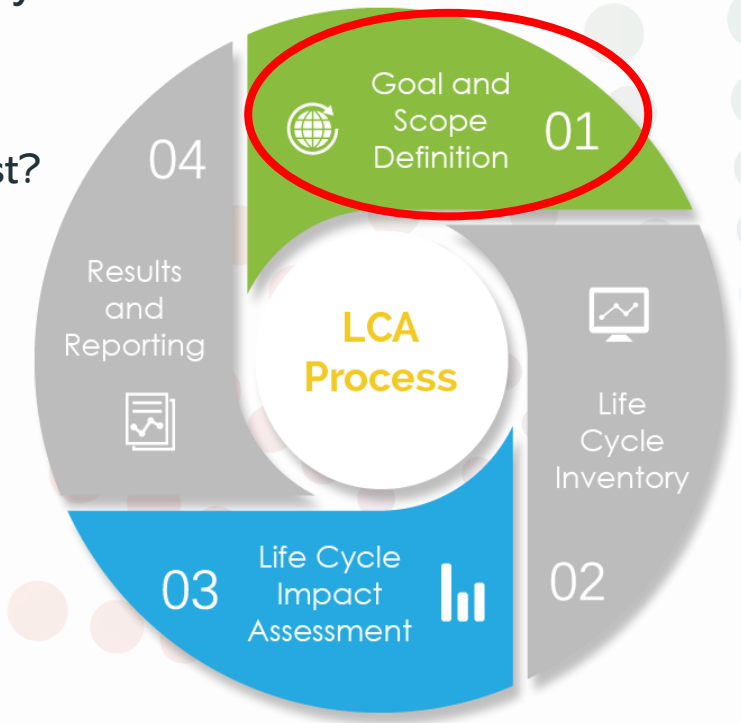
Goal and Scope Definition: Define the objectives of the study & Determine the boundaries in which the assessment is to be made.

- What is the aim of the study?
- What reference system/technology will we compare our system against?
- What are the system boundaries of the analyzed product?
- What is the data availability for the study?

A number of crucial elements shall be determined at this point:

- The function of the system
- The functional unit - emissions & the extractions will be based on
- The system boundaries

- The intended application
- The reasons for carrying out the study
- The intended audience



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LCA METHODOLOGY — PHASES

STEP 2 • Inventory Analysis

Life Cycle Inventory (LCI) Analysis: Collect and quantify the data on the inputs and outputs associated with each stage of the product's life cycle.

Data requirements:

- Description of the process and process flow diagrams
- Mass and energy balance
- Equipment used and related dimensions

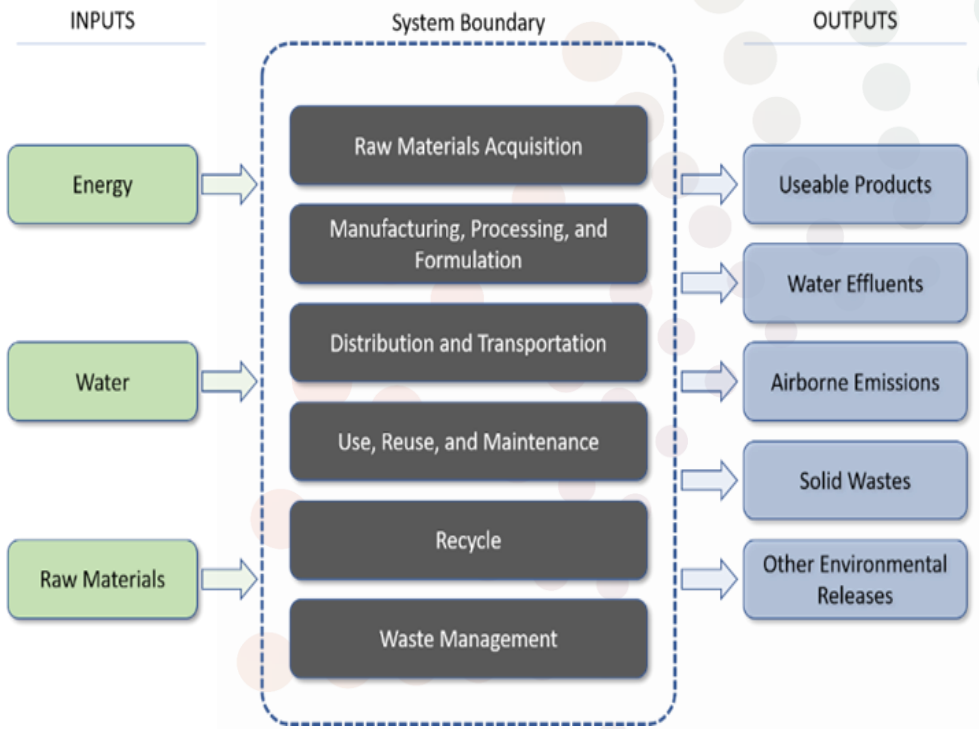
Data Collection

What's Included:

- Inputs: Raw materials, energy, water.
- Outputs: Emissions to air, water, soil, as well as waste.

Challenges: Ensuring data accuracy & completeness is critical for reliable LCI results.

Sources: Can be obtained from direct measurements, databases, industry standards or supplier



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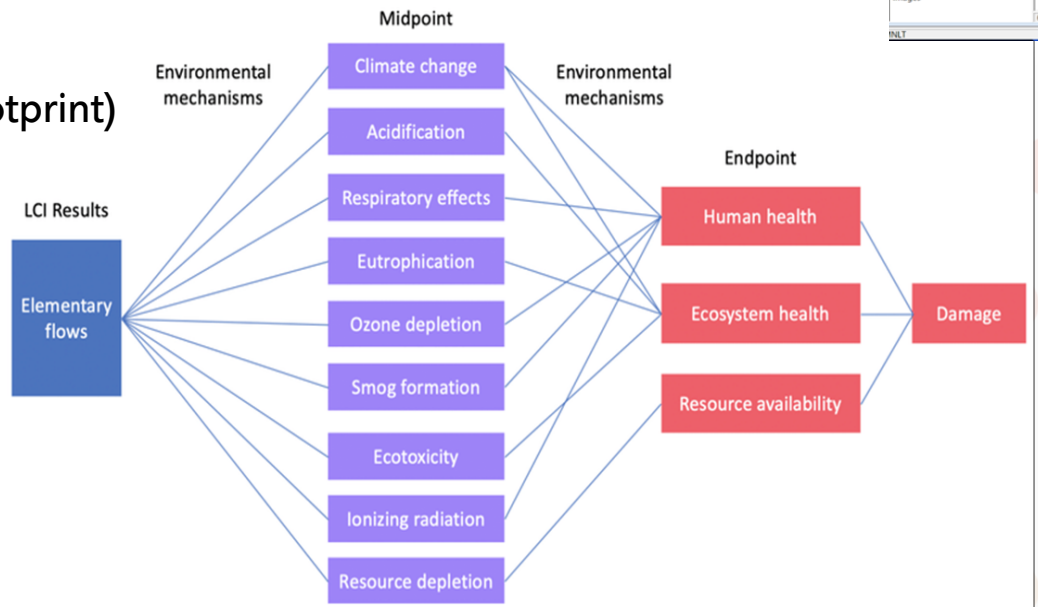
LCA METHODOLOGY — PHASES

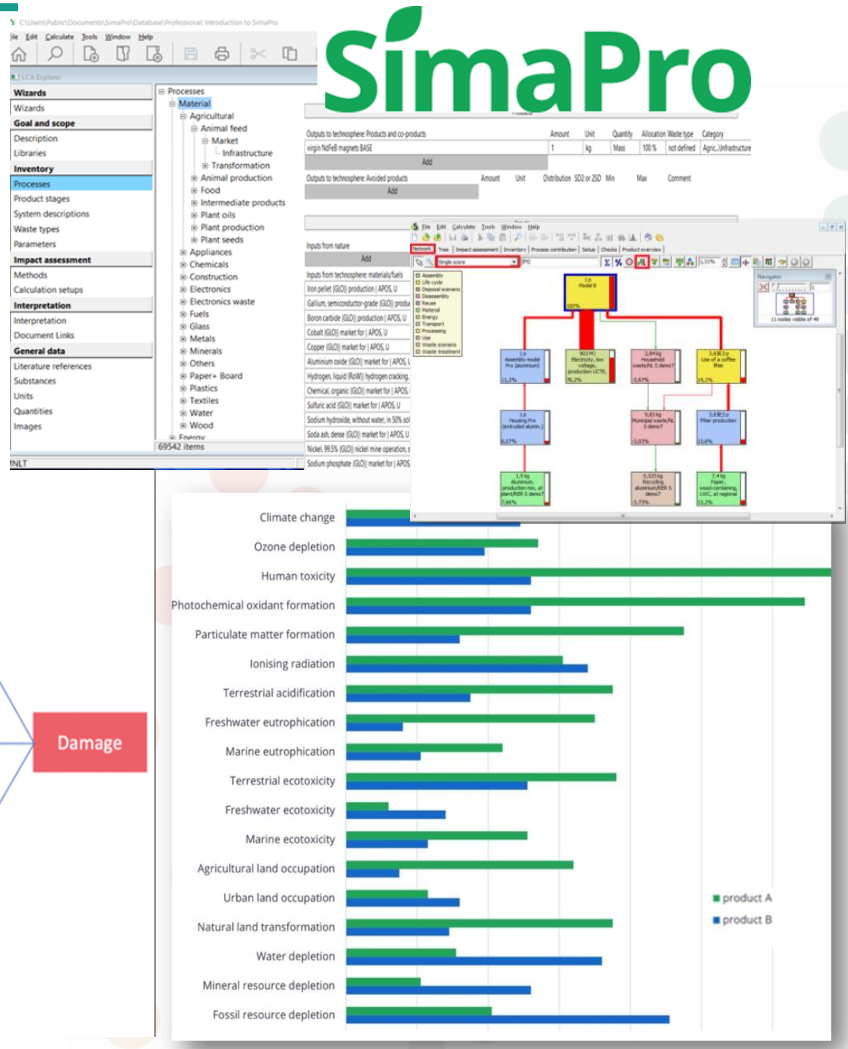
STEP 3 • Impact Assessment

Life Cycle Impact Assessment (LCIA): Assess and quantify the potential environmental impacts identified in the LCI stage (global warming potential, resource depletion, acidification and human toxicity).

Depending on the goal and scope of your analysis, different **impact categories** might apply.

- Climate Change (CO_2 footprint)
- Human toxicity
- Resource use
- Water use
- Land use
- Ecotoxicity
- Acidification
- Eutrophication





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LCA METHODOLOGY — PHASES

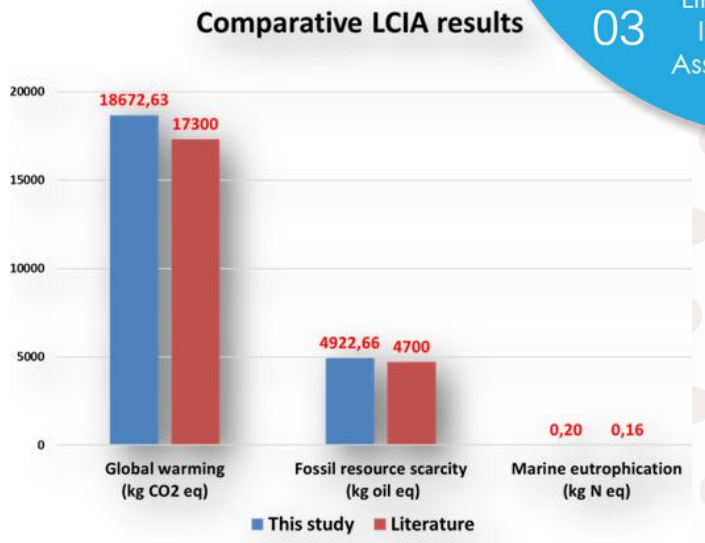
STEP 4 • Interpretation

Interpretation: Analyze and evaluate the LCI and LCIA results to draw conclusions and make recommendations and informed decisions:

- Evaluate the environmental performance of the product/process;
- Compare technologies/processes;
- Identify areas of improvement;
- Explore opportunities for reducing environmental impacts.

The results obtained from LCA studies can:

- ✓ **inform** decision-making,
- ✓ **guide** efforts to **reduce** the environmental impact of a product/process and
- ✓ **support** the transition to more sustainable practices.
- ✓ **align with** EU policies (Circular Economy Action Plan, CRMA).



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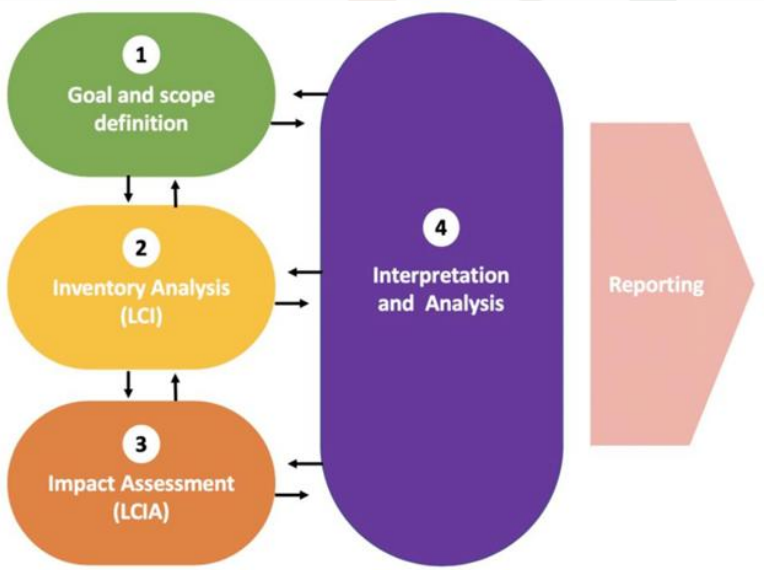
LCA METHODOLOGY — PHASES

Key Activities in LCA Interpretation:

- ✓ **Quality control:** Ensure that the **data and results** obtained in previous stages are **reliable and meet the desired quality standards**.
- ✓ **Sensitivity analysis:** Identify which **variables** have the most significant impact on the results. Adjust key input parameters to see how they influence the LCA outcomes.
- ✓ **Uncertainty analysis:** Assess the **uncertainties** inherent in data and assumptions used throughout the LCA.
- ✓ **Critical analysis:** Evaluate the influence of **chosen boundaries** and **hypotheses** on the LCA outcomes & Ensure that the LCA is transparent and comprehensive.
- ✓ **Comparison of the environmental impacts with economic or social impacts:** to provide a balanced view of the product lifecycle.



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MNLT EXPERTISE IN THE SECTOR

MNLT SUSTAINABLITY TOOLS

SimaPro software for professionals

ecoinvent database

Life Cycle Assessment (LCA)

SimaPro software for professionals

Excel tools

Life Cycle Costing (LCC)

SimaPro software for professionals

PSILCA database

Social Life Cycle Assessment (s-LCA)

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ENVIRONMENTAL HOTSPOTS IN THE MINING INDUSTRY

WHY APPLY LCA IN MINING?

Identifies Hotspots: Where are the biggest impacts? Extraction? Processing? Transport?

Supports EU Policies: Achieve EU climate targets and circular economy objectives.

Aspect	Conventional Mining	Sustainable Mining
Energy Use	⚠️ **High** (~8% of global energy; 3% global electricity for crushing)	✅ Solar-powered processing, efficient technologies
Waste	⚠️ **Very High** (2 tons radioactive waste per ton of rare earths; 99 tons waste rock per ton of copper)	✅ Waste management, recycling tailings, secondary recovery
Water Use	⚠️ **Heavy** (lithium extraction consumes 2.2M liters/ton)	✅ Water recycling, reduced consumption, closed-loop systems
Biodiversity	⚠️ **Major land disturbance** and habitat destruction	✅ Land rehabilitation
Supply Chain Dependency	⚠️ **Materials essential for EVs, renewables, electronics** (Li, Co, REEs)	✅ Promote circular economy, substitute critical raw materials (CRM)

LCA helps quantify these trade-offs, identify hotspots and guide improvements.

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BARRIERS: OVERCOMING CHALLENGES TO LCA ADOPTION

Data Gaps & Quality

- *Lack of standardized datasets for mining-specific processes*
- *Difficulty tracking complex global supply chains*

Collaborative Data Platforms

- *EU-funded databases (ELCD) for mining LCI data*
- *Blockchain for transparent supply chain tracking*

Cost & Resources

- *High upfront investment for LCA software/training*
- *Limited in-house expertise in emerging markets*

Cost-Sharing Models

- *Joint industry-academia LCA tool development*
- *Phased adoption: Start with hotspot analysis*

Stakeholder Alignment

- *Divergent priorities between miners, processors & regulators*
- *Short-term profit vs. long-term sustainability trade-offs*

Policy Incentives

- *Tax breaks for LCA-compliant mines (EU Taxonomy)*
- *Mandatory LCA for mine permits (pilot in Sweden)*

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MNLT EXPERTISE IN THE SECTOR

10+ Sustainability Projects | WP Leader in LCA • LCC • SLCA

MNLT Innovations

ECHO	VOT3D	DEXPLORE	WIDEX	PASSENGER	PERMANET	Li4life	ZEROSTEEL	GeoPCM
Hammering operators	Ventilation technologies	Exploration technologies for deep deposits	Sustainability evaluation of exploration activities	Ree-FREE PM production	PM development aiming at reducing REE content	Battery recycling and recovery of CRMs	Metal production and recycling	Geopolymer Composite Materials



Mining sector

Permanent magnets

Lithium Batteries


Innovative Processes

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DIGITAL INNOVATION & SUSTAINABILITY

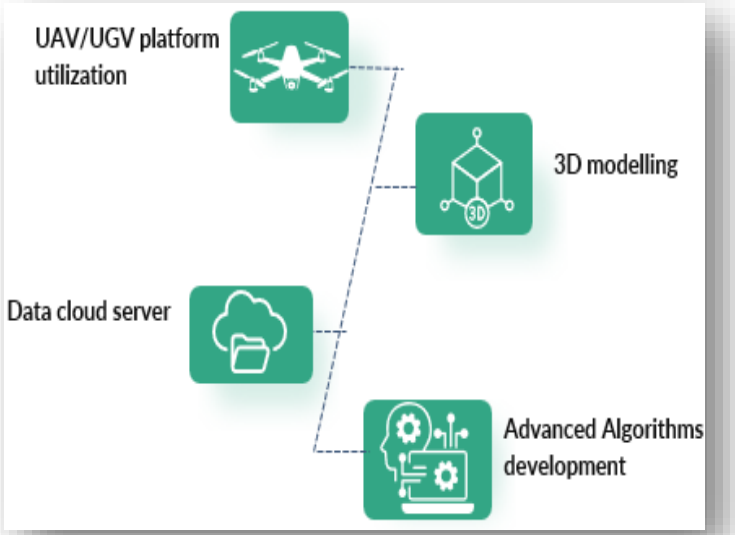
VOT3D project: Ventilation Optimizing Technology based on 3D-scanning

Objective: Robotize the RM sector by introducing modern methods and innovative solutions for the optimization of underground ventilation.

NOVEL AI & 3D MODELLING TECH

UAV/UGV 3D scanning + cloud-based AI to reduce ventilation energy by 30-50%

Replaces manual airflow measurements (error-prone, time-consuming)



MNLT's SUSTAINABILITY ASSESSMENT

Lifecycle Savings (Per Mine)

Environmental:
↓ 1,200 tons CO_2/year (equal to 300 cars)

↓ 15% water use (optimized air cooling)

Economic:
€2.1M saved over 5 years (energy + maintenance)

Social:
80% fewer hazardous manual inspections

VOT3D
Ventilation Optimizing Technology based on 3D-scanning

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THE ELECTRIC REVOLUTION IN MINING

ECHO project: Electrical Computerized Hammering Operator

Objective: A fully electrical breaker hammer (LEH) Vs hydraulic breaker hammers (HBHs) → electric transformation, digitalization, data-based business in the mining industry

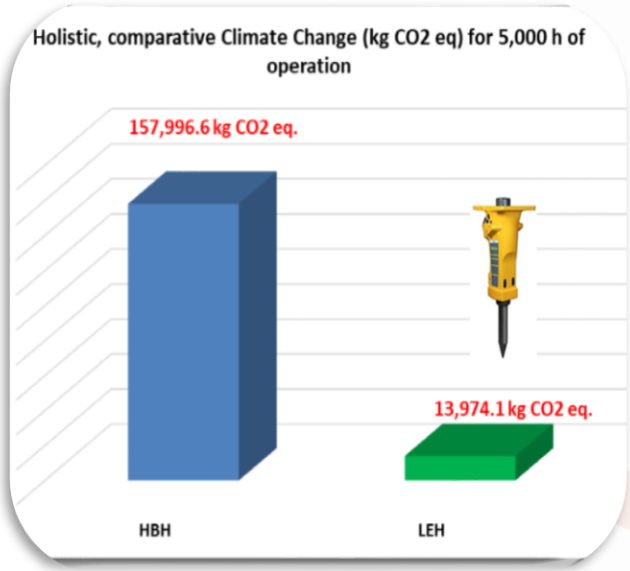
Replacing Hydraulic Breakers with Electric

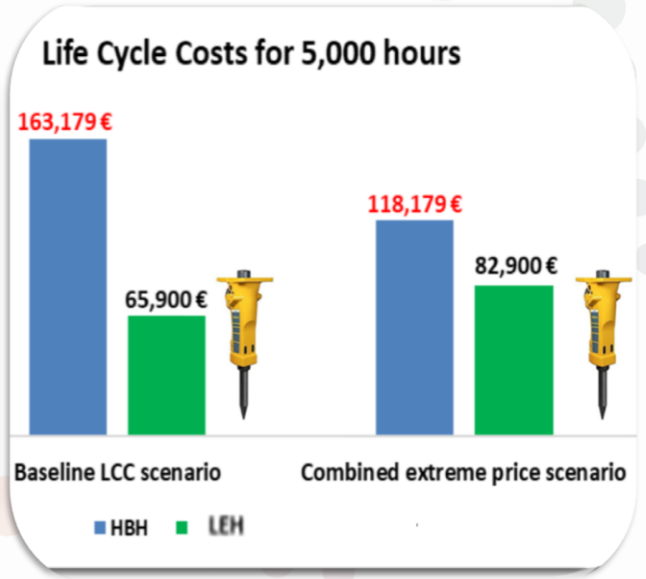
MNLT's SUSTAINABILITY ASSESSMENT

Environmental Impact Assessment
- 98% less Carbon Footprint (Raw extraction phase)
- 91% less Carbon Footprint (Use phase)

Economic Impact Assessment
- 53% more cost-efficient

Social Impact Assessment
- Health and Safety improvement
- Social Well-Being & Community Benefits





Diesel-to-Electric Trucks

- **300-ton electric trucks** cut CO_2 by **80%** vs. diesel.
- **TCO Savings**: $500K/year per truck (lower fuel + maintenance)
- **Challenges**: Upfront cost: **2x diesel price** & Infrastructure: Requires **on-site charging stations**.

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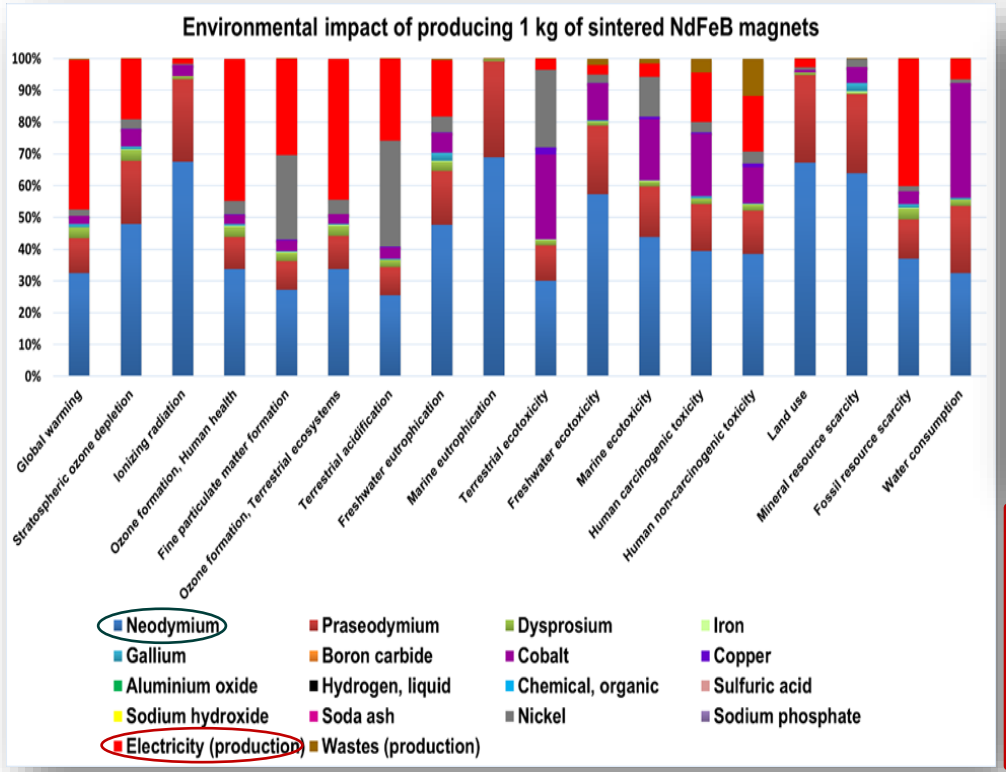
REDUCING MINING IMPACT THROUGH SUBSTITUTION

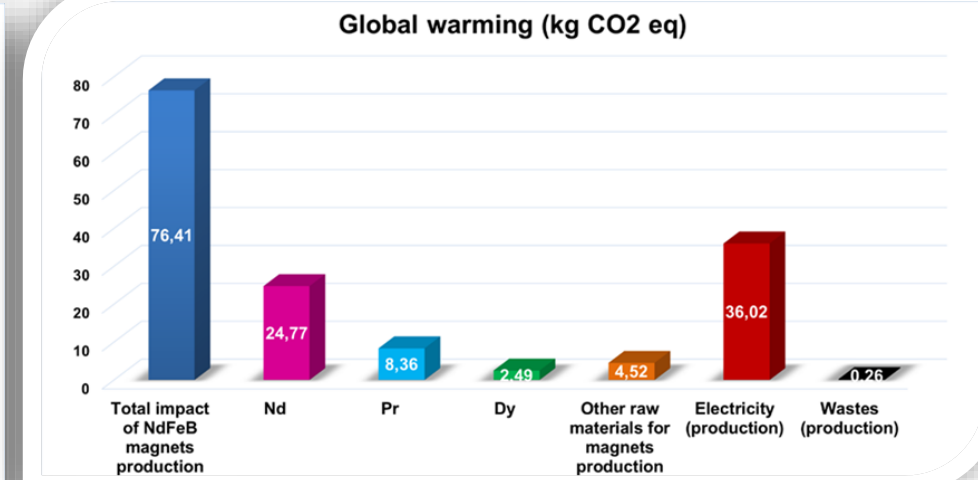
PASSENGER project: Sustainable REE-free permanent magnet production

Benchmarking LCA – NdFeB Magnet Production

Cradle-to-gate: Raw Materials Extraction, processing stages up to the manufacturing of the Magnet

- Strip casting
- Hydrogen decrepitation
- Jet mill
- Align & Press
- Sintering
- Slicing and dicing
- Coat & Magnetize





- Among REEs, Nd accounts for the highest contribution across most impact categories, specifically 24.77 kg CO_2eq.
- Electricity is another significant contributor, responsible for 36.02 kg CO_2eq, largely due to China's coal-dominated energy grid.

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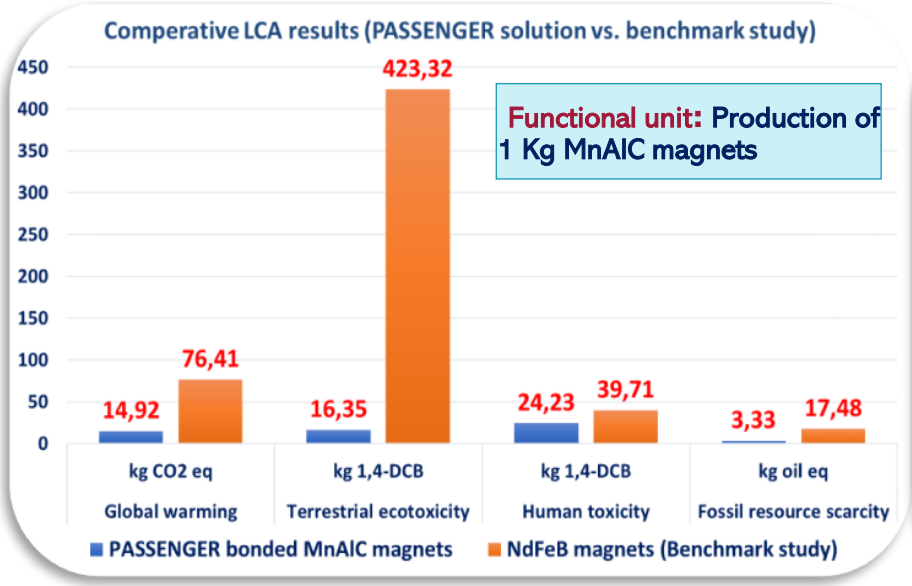
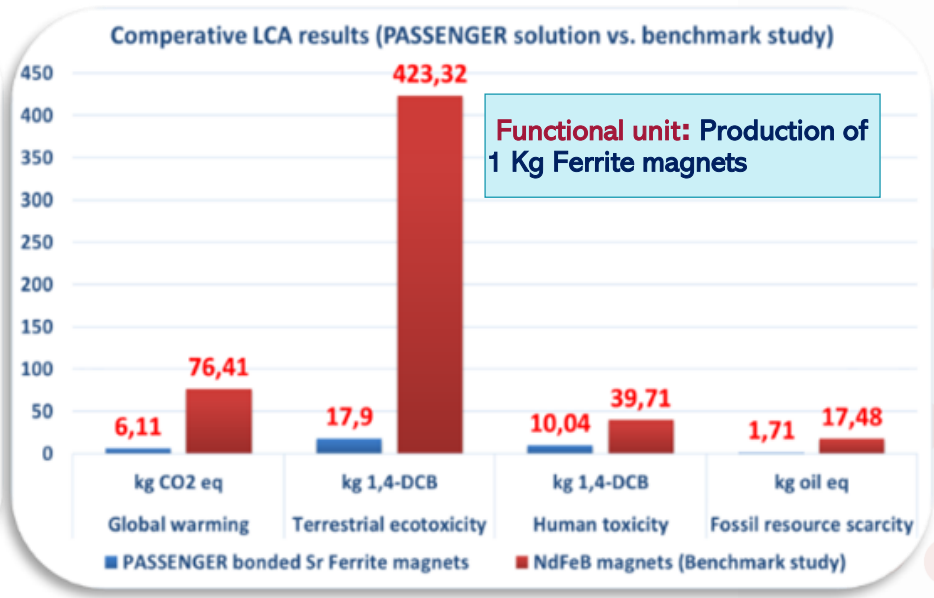
REDUCING MINING IMPACT THROUGH SUBSTITUTION

PASSENGER project: Sustainable REE-free permanent magnet production

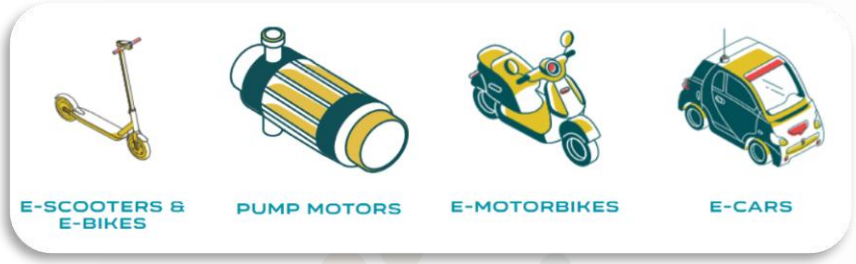
PASSENGER MnAlC & Ferrite Magnet Production





- Sr-Ferrite Magnets Composed of strontium carbonate and iron oxide, readily available & less energy-intensive to process.
- Ferrites have a lower raw material and electricity burden. Sr-Ferrite Magnets:
  - Carbon footprint: 10-20 kg CO_2eq/kg.
  - Represents a **70-85%** reduction compared to NdFeB magnets due to substitution of REEs with lower energy requirements → both material processing and magnet production.

- Mn, Al, and C are more abundant and require less energy-intensive processing compared to REEs.
- MnAlC magnets do not rely on energy-intensive processes, reduced environmental footprint.
- MnAlC Magnets: Carbon footprint: 15-25 kg CO_2eq/kg.
  - Represents a **70-80%** reduction compared to NdFeB, due to substitution of REEs with less energy-intensive materials.



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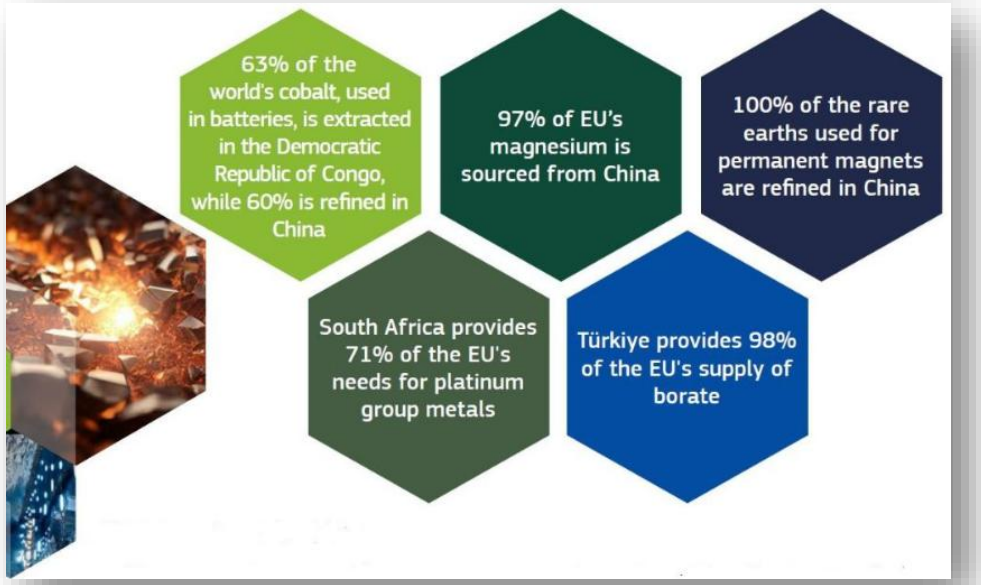
LCA – SUPPORTING THE GREEN TRANSITION

Regulatory Alignment, Green Deal and Critical Raw Materials Act, emphasize reducing environmental impact & securing raw material supplies.

- Ecodesign for Sustainable Products Regulation
- California Title 20
- Circular Economy Development Plan
- Greenhouse and Energy Minimum Standards Act
- Plastic Waste Management Rules
- Chemical Substances Control Law



→Diversifying the Union's imports of raw materials.

→Enhance the EU's resilience and autonomy in CRMs supply chains by 2030.

→Improving **sustainability and circularity of CRMs on the EU market.**

The Corporate Sustainability Reporting Directive (CSRD), requires companies to **disclose/report their Environmental, Social, and Governance (ESG) metrics** of the activities across their value chain.

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LCA – SUPPORTING THE GREEN TRANSITION

✅ What is the EU Battery Passport?

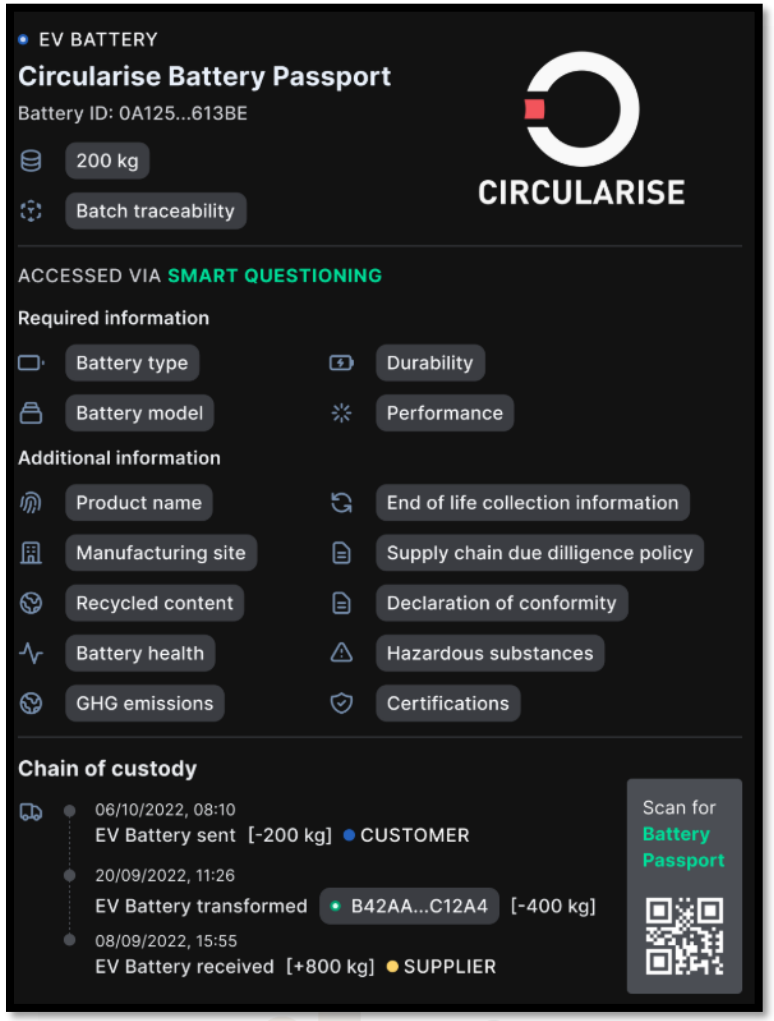
- **Effective from February 1, 2027**, all EV & industrial batteries **must have a unique Battery Passport** linked to a **QR code**, ensuring **traceability, safety, and sustainability**.

✅ Why is it Important?

- **Tracks the entire battery lifecycle** (production → use → recycling).
- Ensures compliance with **EU environmental & recycling standards**.
- Helps **reduce hazardous materials** in batteries.
- Provides **transparency for consumers and manufacturers**.

✅ What information needs to be included?

- **Identification:** Unique **serial number**, **visible & unalterable** on the battery.
- **Basic Characteristics: Production date, type, model, chemical composition, intended use & manufacturer/importer details.**
- **Performance & Durability Data: Lifecycle statistics & Tracking of** updated by repair/repurposing parties.



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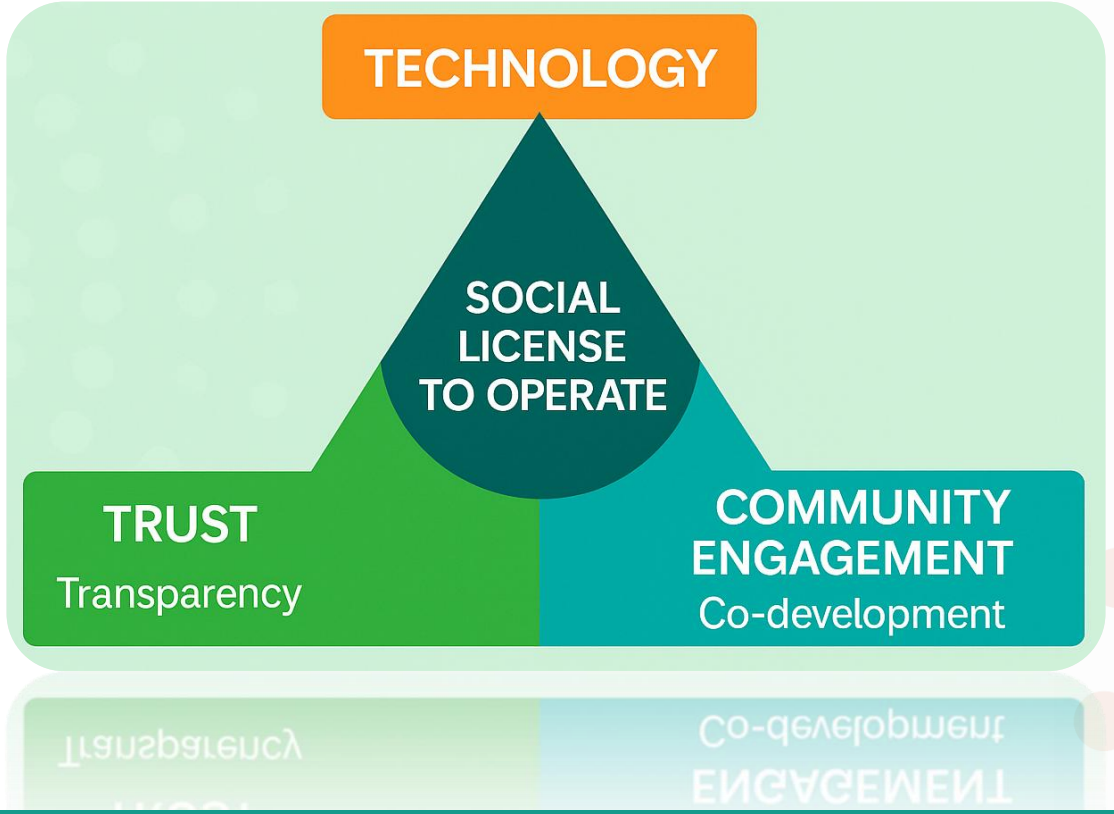
SOCIAL ACCEPTANCE: THE HIDDEN KEY TO MINING'S FUTURE

Social License to Operate

- *60% of mining projects face delays due to local opposition"* (ICMM-International Council on Mining and Metals, 2023)
- Top concerns: Water pollution (45%), land use (30%), job promises unmet (25%)



- **Digital transparency:** Live air/water data shared via public dashboards
- **Jobs in tech:** Training locals to operate drones/AI tools (e.g., Chile's 'DigiMine' program)

When **trust** and **inclusion** go **hand in hand** with **technology**, we don't just follow the rules — we create **real value for people, the industry and the planet**.

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FINAL TAKEAWAYS

Mining is essential, but energy- and resource-intensive.

LCA as a Tool

- Life Cycle Assessment (LCA) identifies environmental hotspots and supports better decisions.
- LCA pinpoints where to act in mining supply chains.

Sustainability Strategies

- Digital transition, Electrification, Substitution strategies (like CRM reduction) lower mining impacts.
- LCA is a cross-sector tool — critical for achieving EU climate and sustainability goals.

Action & Trust

- Policy and tools exist—start small, scale fast.
- Transparent, science-based assessments drive responsible innovation.

Sustainability is no longer optional.
It's expected, measured, and rewarded.
LCA helps make it real — and trusted.

C-SINK

THANK YOU FOR YOUR ATTENTION!

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