# Applying Life Cycle Assessment & Industrial Ecology

A framework to support local renewable energy value chains to drive the Just Transition

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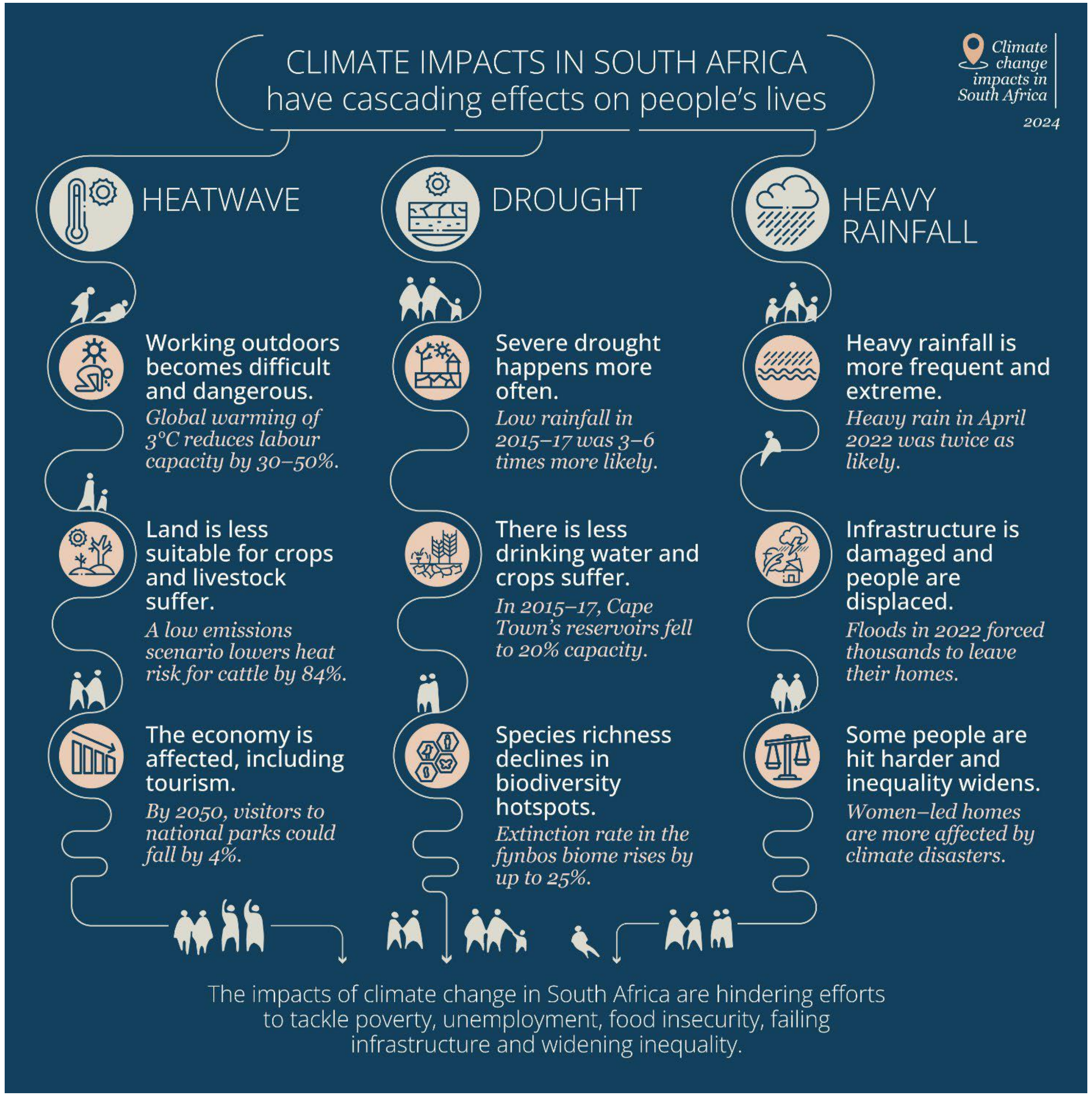
# 1. Context

# 1.1. Climate Change in the South African Context

- The push for low-carbon, renewable energy is driven by intensifying climate change
- *Johnston, P. et al. Climate Change Impacts in South Africa: What Climate Change Means for a Country and its People (2024)*
- Wonderful country
  - 61.5 million people with 12 National languages
  - Rich diversity of plant and animal life
  - 2500 km coastline
  - 3 of the worlds 36 biodiversity hotspots
- Serious economic and social challenges
  - More than half the population lives below the upper-bound poverty level (household income can't cover both food and basic living costs)
  - At least one-third of South Africans between 16 and 64 are unemployed
  - 20% food insecure
- Agriculture
  - 80% of total land
  - Commercial 75% of this land (40 000)
  - Small scale and subsistent 25% of this land (2-3 million)
  - 10% export earnings and 2.5% GDP contribution: 2021/2022 (including fishing, forestry and hunting)
- These assets are at risk due to climate change

# 1.1. Climate Change in the South African Context



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# 1.2. Renewable Energy and Carbon Neutrality

- A global movement toward carbon neutrality
  - International pressure, Carbon Tax, and the Carbon Border Adjustment Mechanism (CBAM)?
  - Leadership changes and paradigm shifts?
  - Either way, a global benefit
- Key interventions include using wind, solar, hydropower, biobased energy, carbon credits, and energy efficiency/productivity
- South Africa's targets *(NDC, RSA)*
  - 398 – 510 MtCO2e – 2025
  - 350 – 420 MtCO2e – 2030
  - Net Zero – 2050
- Mining companies are leading the way
  - South Africa's mining sector has 7.9 GW of the 10.7 GW in the private sector (Stoddard, 2024)

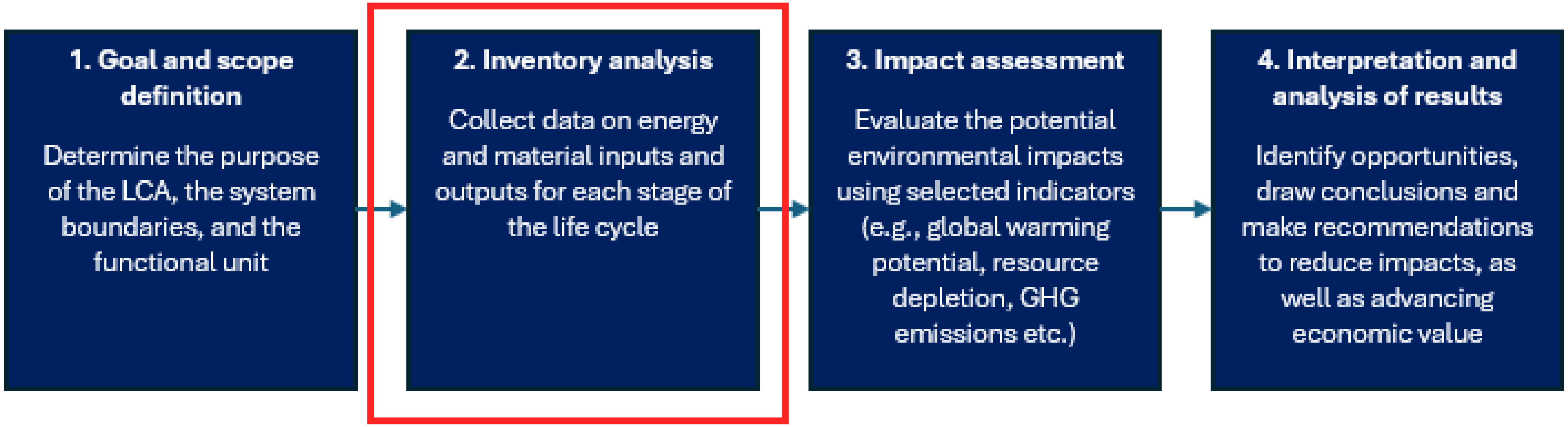
# 1.3. Just Transition

- *Compensating and retraining those who moved out of environmentally hazardous jobs – Labour Unionist* Tony Mazzocchi (1980's)
- *"A set of principles, processes and practices that aim to ensure that no people, workers, places, sectors, countries or regions are left behind in the transition from a high-carbon to a low carbon economy"* - IPCC
- Mining companies do prioritize sharing benefits
  - CSR Plans, SLPs, and RED projects
  - Skills development, training, and scholarships for mine-affected communities
- But…Job and livelihood loss from retrenchment and mine closure
  - 9 600 mining jobs lost in Q1 and Q2 of 2024 (Stats SA, 2024)
  - Coal industry: 91 000 direct employees (Mohlakoana, 2024)
  - Platinum industry: 182 000 direct employees (Minerals Council of South Africa, 2023)
- Post-mine closure planning is crucial to avoid local economic collapse
  - Environmental rehabilitation and justice
  - Concurrent Economic Diversification and Post-Mine Succession Planning (Prof Solomon)

# 2. Background

# 2.1. Life Cycle Analysis (LCA)

- Breaks down products and services into its inputs and outputs from cradle to grave
- Accounts for and assesses environmental impacts holistically
- Highlights environmental hotspots for targeted interventions

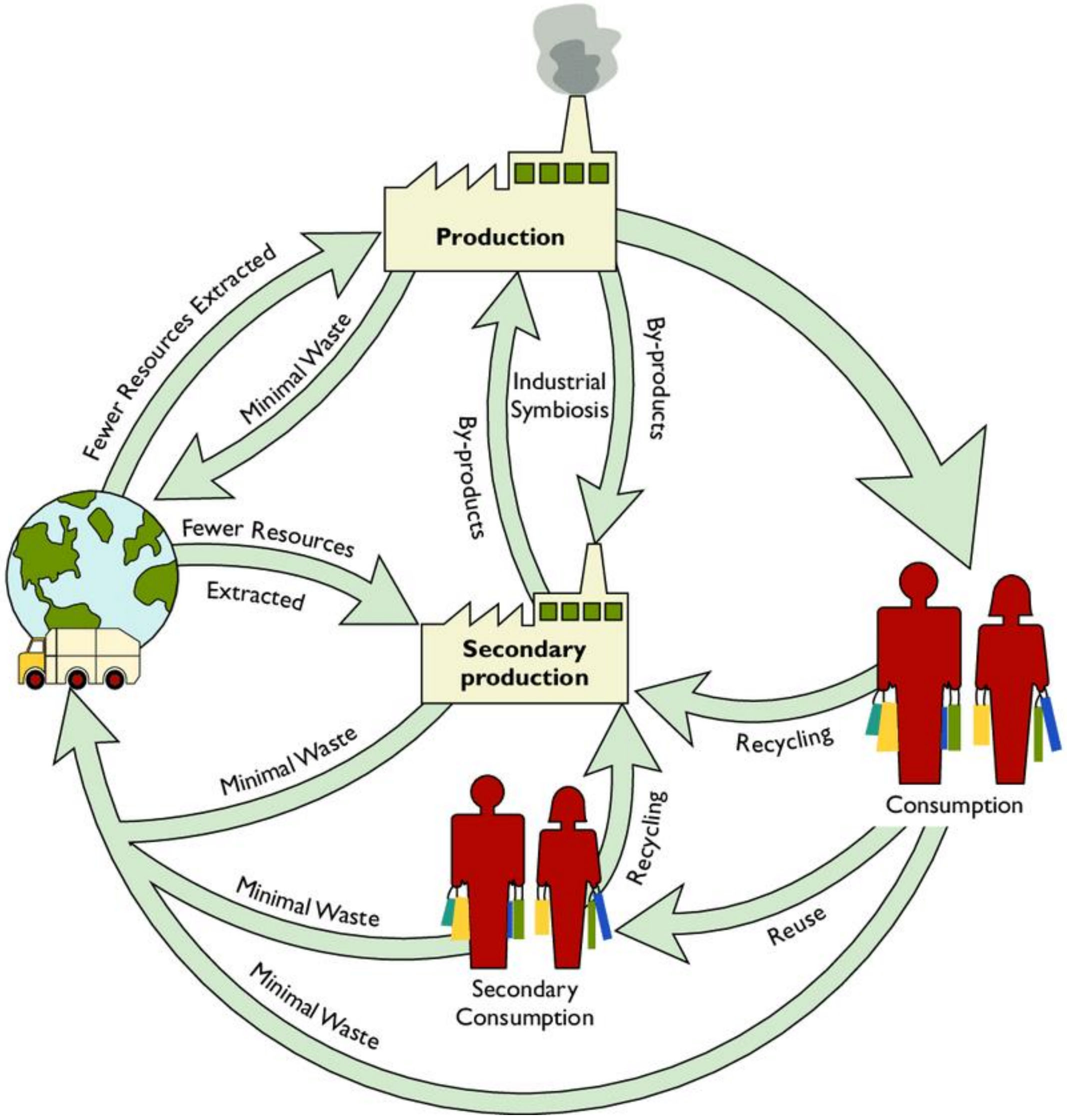


# 2.2. Social Life Cycle Assessment (S-LCA)

- Emphasizes the well-being of affected communities, workers, and stakeholders
- Addresses and evaluates the social impacts of a product or service on society
  - Destruction of ecosystem services (vital for communities)
  - Displacement, compensation, and respect for land rights (particularly for indigenous groups)
  - Labor conditions, community health, and economic benefits
  - Focusses on human rights and community development

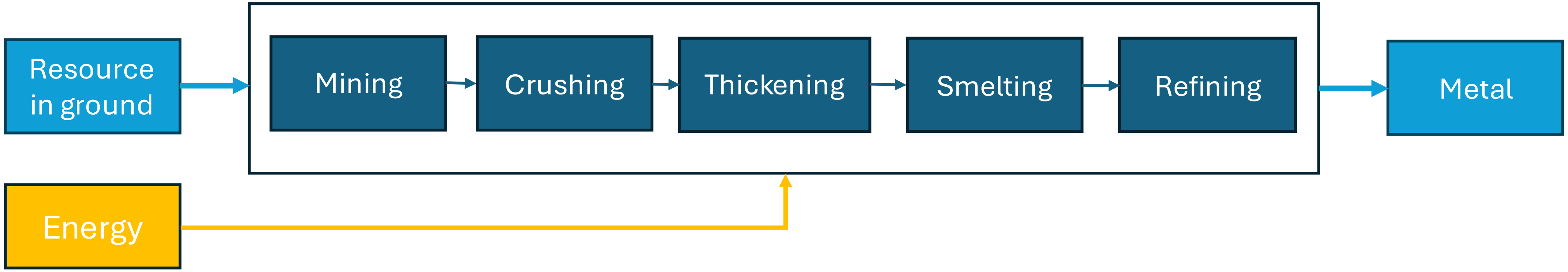
# 2.3. Industrial Ecology

- Aims to optimizes material and energy flows, mimicking natural ecosystems
  - Fosters symbiotic relationships between industries
- The goal is to reduce waste and resource use while providing economic and social benefits
  - One industry's waste can be another industry's raw material
- Involves identifying and linking inputs and outputs of various industrial processes

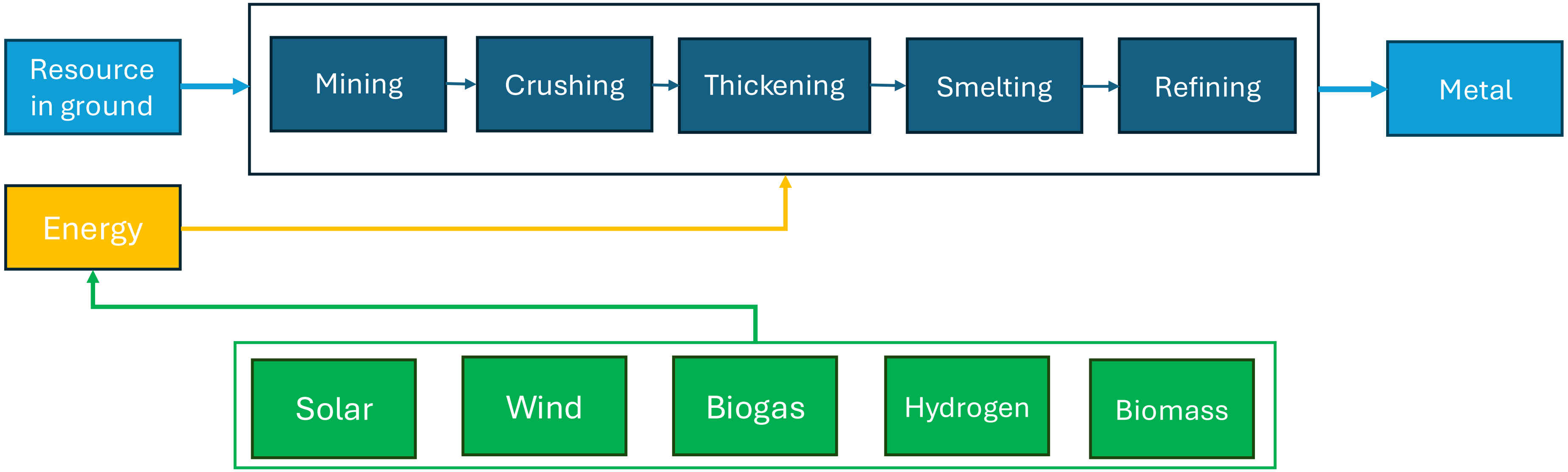


# 3. Methodology

# 3.1. Defining the Mining Process



# 3.2. Defining the Renewable Energy Interventions



# 3.3. Applying LCA and S-LCA: Inventories

| INPUTS | OUTPUTS |
|---|---|
| From Environment | Product and By-product |
| From Technosphere | To Environment (air) |
| From Society | To Environment (water) |
| | To Environment (other) |
| | To Society |

# 3.3.1. Mine Value Chain Inventory

| INPUTS | OUTPUTS |
|---|---|

**From Environment**
- Resource in ground
- Ground and surface water

**From Technosphere**
- Explosives
- Chemicals
- Energy
  - Electricity
  - Coal
  - Natural gas
- Mining and processing equipment
- Spares

**From Society**
- Skilled and unskilled labour

**Product and By-product**
- Ore, concentrate, un-refined mineral or refined metal
- Waste rock and tailings
- Tyres

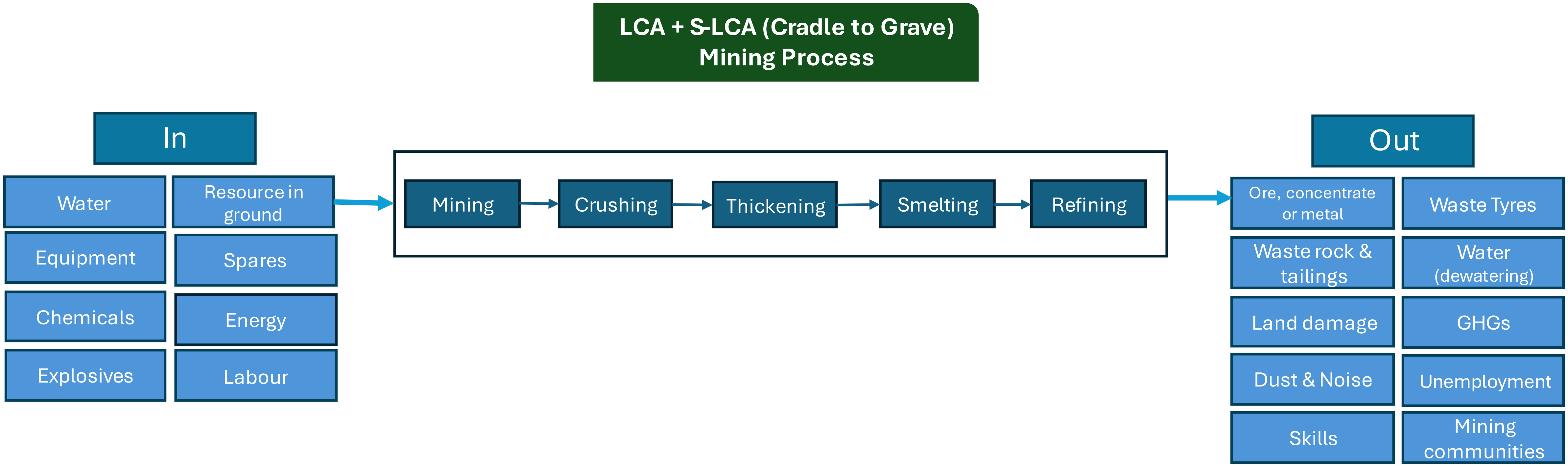
**To Environment (air)**
- Greenhouse gases (GHGs) from manufacturing processes and fossil fuels (e.g., $CO_2$, $NO_x$, $SO_x$)
- Dust and noise

**To Environment (water)**
- Water returned to water bodies

**To Environment (other)**
- Land damage

**To Society**
- Skills
- Unemployment (retrenchment or end life of mine)
- Mining communities

# 3.3.1. Mine Value Chain Inventory



# 3.3.2. Renewable Energy Value Chain Inventory

## Solar PV

| INPUTS | OUTPUTS |
|---|---|
| **From Environment**<br>• n/a<br>**From Technosphere**<br>• Electricity (for manufacturing processes, primarily derived from fossil fuels in many regions)<br>• Silicon (for photovoltaic cells)<br>• Glass (for panels)<br>• Metals (aluminium for frames, silver for conductive layers, and copper for wiring)<br>• Plastics (for encapsulants and backing sheets)<br>• Water (for cooling and cleaning during manufacturing)<br>**From Society**<br>• Skilled and unskilled labour for mining, manufacturing, installation, and maintenance | **Product and By-product**<br>• Clean, renewable electricity generated by solar panels<br>• Manufacturing waste (scrap materials, chemicals)<br>• End-of-life waste (recycling or disposal of panels after their lifespan)<br>**To Environment (air)**<br>• Greenhouse gases (GHGs) from manufacturing processes (e.g., CO2, NOx, SOx)<br>• Potential toxic emissions from the production of silicon and other chemicals<br>**To Environment (water)**<br>• Wastewater<br>**To Environment (other)**<br>• n/a<br>**To Society**<br>• n/a |



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# 3.3.2. Renewable Energy Value Chain Inventory

## Wind

| INPUTS | OUTPUTS |
| --- | --- |
| **From Environment**<br>• n/a<br>**From Technosphere**<br>• Metals (steel for towers, copper for electrical components, rare earth elements for magnets in turbines)<br>• Fiberglass and carbon fibre (for turbine blades)<br>• Concrete (for foundations)<br>• Electricity (for manufacturing components, primarily derived from fossil fuels)<br>• Oil and lubricants (for maintenance of moving parts)<br>**From Society**<br>• Skilled and unskilled labour for mining, manufacturing, installation, and maintenance | **Product and By-product**<br>• Clean, renewable electricity generated by wind turbines<br>• Manufacturing waste (scrap materials, chemicals)<br>• End-of-life waste (recycling or disposal of turbine components, particularly blades)<br>**To Environment (air)**<br>• GHGs from manufacturing processes (e.g., $CO_2$, $NO_x$, $SO_x$)<br>• Minimal emissions during operation<br>**To Environment (water)**<br>• n/a<br>**To Environment (other)**<br>• n/a<br>**To Society**<br>• n/a |

# 3.3.2. Renewable Energy Value Chain Inventory

## Biogas

| INPUTS | OUTPUTS |
| --- | --- |
| **From Environment**<br>• n/a<br>**From Technosphere**<br>• Electricity and heat (to assist the anaerobic digestion process)<br>• Chemicals (potentially for soil pH adjustment and nutrient fertilizer addition)<br>• Water (for slurry preparation)<br>• Biomass feedstock (if purposely grown)<br>• Organic waste (animal manure, food waste, agricultural residues)<br>**From Society**<br>• Skilled and unskilled labour for collection, processing, and maintenance | **Product and By-product**<br>• A mixture of methane (CH4) and carbon dioxide (CO2), used for electricity, heat, or as a vehicle fuel<br>• A nutrient-rich by-product that can be used as a fertiliser<br>• Minimal solid waste, primarily managed as digestate<br>**To Environment (air)**<br>• Leakage: A mixture of methane (CH4) and carbon dioxide (CO2)<br>• GHGs from the combustion of biogas (CO2, CH4 if not fully combusted)<br>• Odors and potential ammonia emissions from digestate handling<br>**To Environment (water)**<br>• n/a<br>**To Environment (other)**<br>• n/a<br>**To Society**<br>• n/a |

# 3.3.2. Renewable Energy Value Chain Inventory

**LCA + S-LCA (Cradle to Grave)**
**Renewable Energy**

**In**

| Solar | Wind | Biogas |
|---|---|---|
| Energy | | |
| Silicon | Steel, Copper, REM | Fertilizer |
| Glass | Fiberglass & carbon fiber | Water |
| Plastics | Concrete | Biomass |
| Water | Oil & lubricants | Organic waste |
| Labour | | |

Solar | Wind | Biogas | Hydrogen | Biomass

**Out**

| Solar | Wind | Biogas |
|---|---|---|
| Green Electricity | | Green Energy |
| Scrap metals | Scrap materials | $CO_2$ and $CH_4$ |
| End of life panels | End of life turbines | Digestate |
| GHG emissions | | Odors |
| Other emissions | | |



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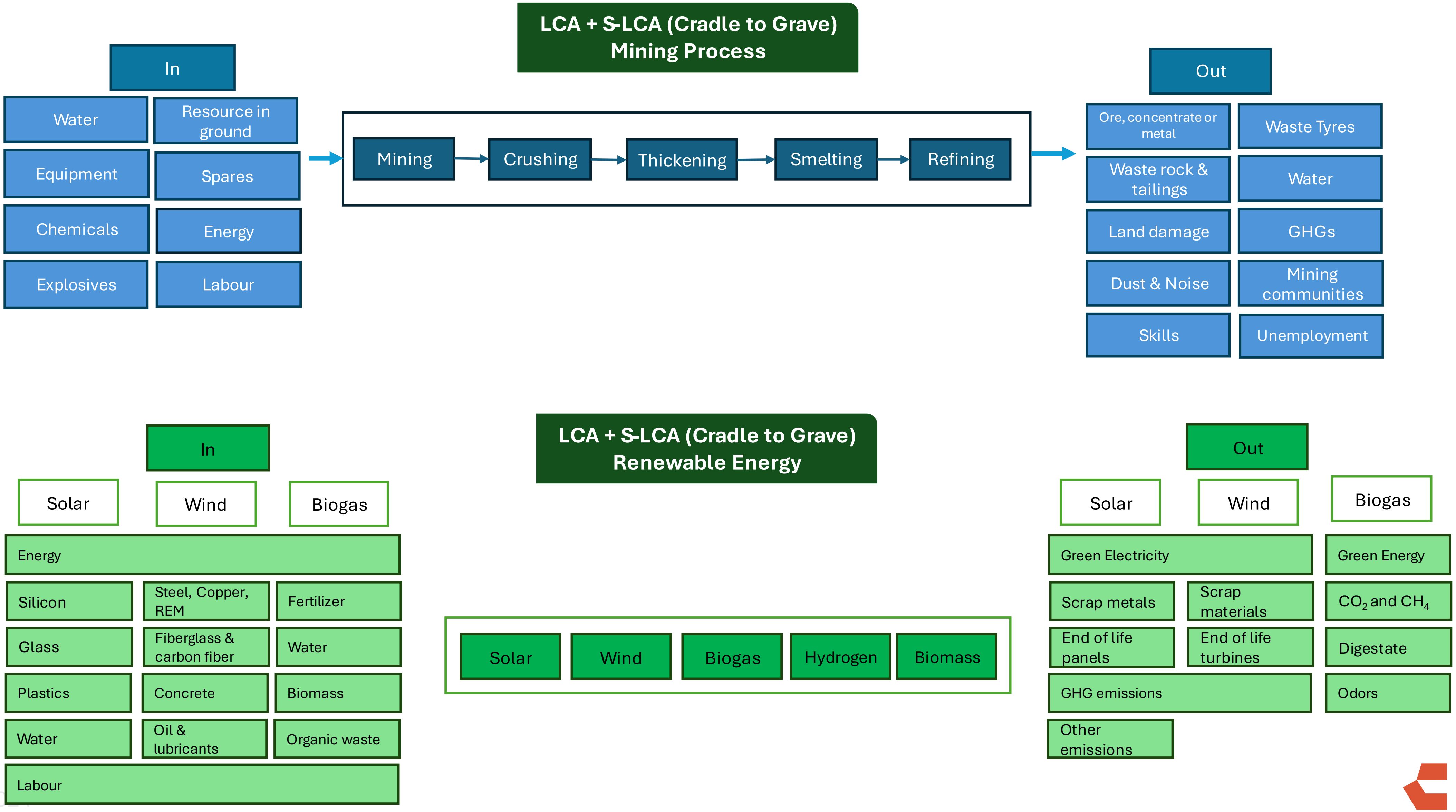
# 3.3.3. Integration of Inventories to Form an Industrial Ecology



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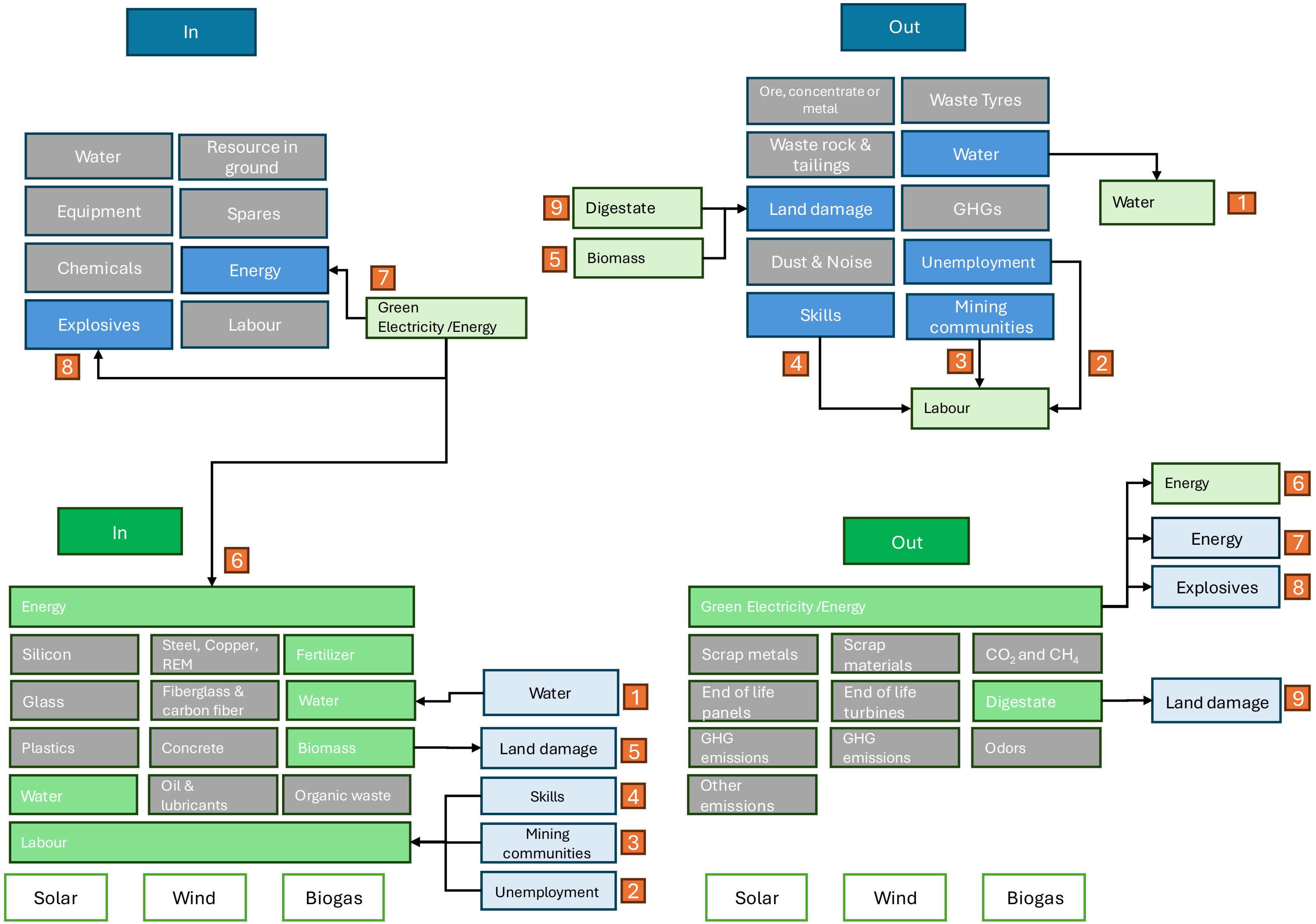


# 4. Findings and Conclusions

# 4.1. Integrating LCA, S-LCA & Industrial Ecology

1. Water (mining value chain) $\rightarrow$ Water (biogas value chain)
    - The dewatering of mines will result in available water for alternative economic opportunities.
    - The water can be used for biomass production which will be turned into bio-based energy.
2. Unemployment (mining value chain) $\rightarrow$ Labour (renewable energy value chain)
    - When the mines slow down production towards end of life, retrenchment is inevitable.
    - If there is a local renewable energy value chain, these people can find direct and indirect employment
3. Mining communities (mining value chain) $\rightarrow$ Labour (renewable energy value chain)
    - When a mining operation begins, it attracts people who wouldn’t have ordinarily settled in that location.
    - The mining communities will have people who are looking for employment, and once again, the local renewable energy value chain can provide direct and indirect employment.

# 4.1. Integrating LCA, S-LCA & Industrial Ecology

4. Skills (mining value chain) → Labour (renewable energy value chain)

- The labour that leaves the mines will be skilled, semi-skilled and un-skilled. A local renewable energy value chain will have the need for all types of labour.

5. Biomass (biogas value chain) → Land damage (mining value chain)

- Biogas can be produced through anaerobic digestion of biomass.
- Biomass fuel pellets can be made from compressed biomass.
- Biomass can be grown on mine damaged land. This provides both economic activities, as well as remediating damaged land.

6. Green electricity/energy (renewable energy value chain) → energy (renewable energy value chain)

- Local manufacturing of renewable energy technology or equipment can use the renewable energy produced.
- If a mine has a renewable energy installation, this energy can be used for the local renewable energy value chain post-mine closure.

# 4.1. Integrating LCA, S-LCA & Industrial Ecology

## 7. Green electricity/energy (renewable energy value chain) → energy (mining value chain)

- The use of green electricity/energy in the mining value chain. This is already commonplace.

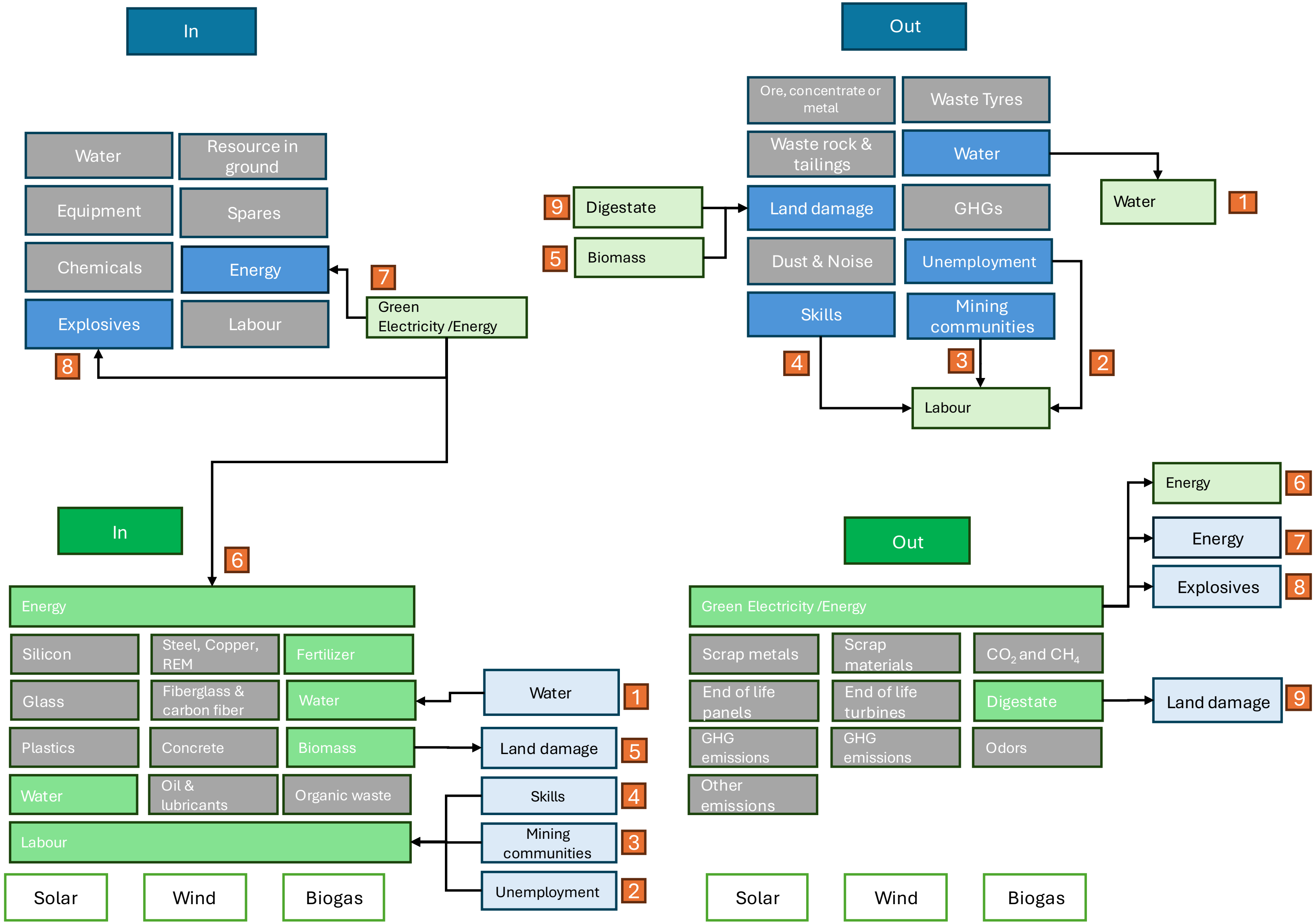
## 8. Green energy (renewable energy value chain) → explosives (mining value chain)

- The mining industry uses explosives that require ammonia in their production.
- There is an opportunity to use renewable energy to produce the ammonia, and thus create local production of green explosives and/or fertilizer.

## 9. Digestate (biogas value chain) → Land damage (mining value chain)

- The production of biogas in an anaerobic digester creates a valuable by-product: digestate.
- This is a nutrient rich liquid stream which can be used for the remediation of mine affected/damaged land.
- Ideally this is applied to the biomass feedstock, which is grown on mine damaged land: recycling loop ensuring minimal loss of both nutrients and water.

# 3.3.3. Integration of Inventories to form an Industrial Ecology



# 4.2. Conclusions and Recommendations

- LCA, S-LCA and IE was integrated into a framework
- By leveraging the synergies between mining activities and renewable energy interventions, significant opportunities exist to create resilient post-mine economies while driving the mining sector towards carbon neutrality
- Start planning creatively for mine closure as soon as possible
- Invest in Skills Development for this Transition

# Thank you