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openLCA

An approach for validating life cycle assessment data

Lingjie Ji, GreenDelta GmbH
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Content

- What is reality?
- Approach
- Application of This Approach
- Outlook and Discussion

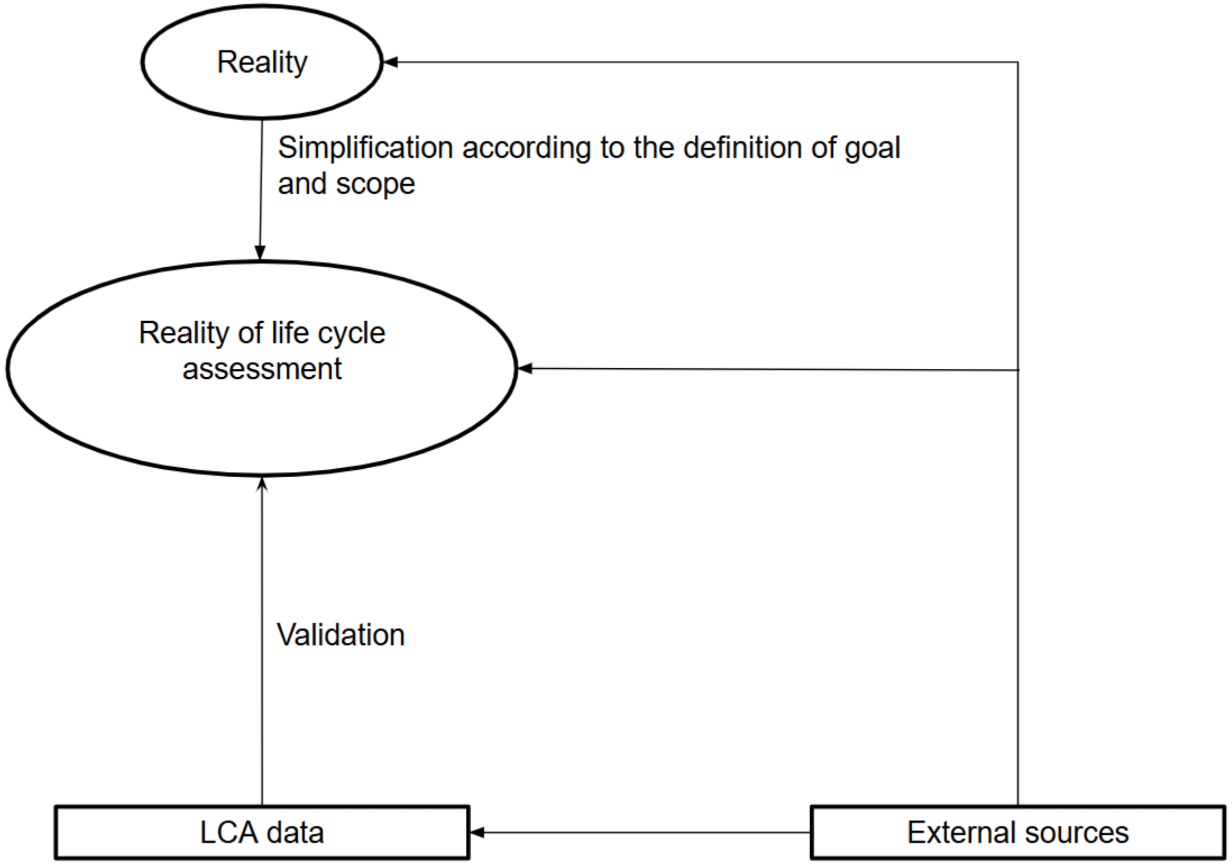
What is reality?

- **Difference between reality and the concept of reality in relation to life cycle assessment data**

Aspect	Reality	Reality in relation to life cycle assessment
Definition	Actual state of processes, materials, and environmental impacts in the physical world	Simplified and reduced representation of reality for practical analysis
Complexity	Fully complex, all variables and interactions	Systematically reduced variables, focus on key factors
Measurability	Not fully measurable or predictable	Modeling and data estimation
System boundaries	Infinitely complex	Defined and limited system boundaries

What is reality?

- **Linking Reality, Life Cycle Assessment, and Data Validation**



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What is reality?

- Types of Deviations in Life Cycle Assessment (LCA)
  - qualitative deviations: environmental flows or processes are not accurately or fully captured
  - quantitative deviations: magnitude of input or output flows differs substantially from reality
    - mass imbalance is a specific form of quantitative deviation

Approach

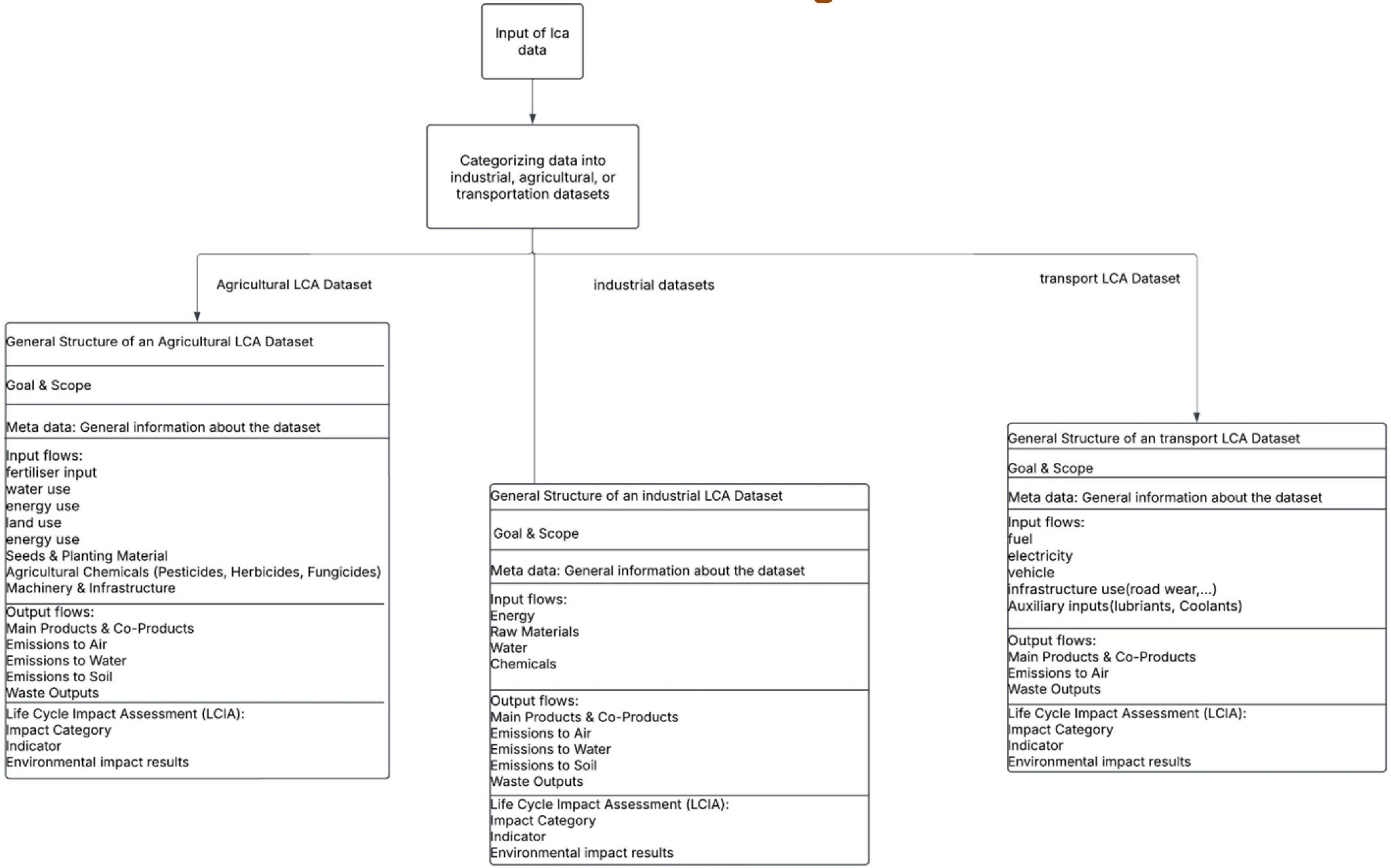
- Sources for Validation
  - Archetypal Process Structures
    - typical configuration of input and output flows
  - Empirical and Field Data
    - Direct Measurements
    - Satellite Imagery
  - Industry Reports and Case Studies
    - Corporate Sustainability Reports (CSRs)
    - LCA studies
  - Scientific Literature
    - BAT documents
  - Industry-Specific Data Sources
    - Agriculture: FAOSTAT
    - Transport: TREMOD (Transport Emission Model)

Approach

1. Assign the dataset to a category (e.g., agricultural, industrial, or transport)
2. Clarify Goal and Scope of the Dataset
3. Identify Qualitative Deviations using Archetypal Process Structures
4. Identify Quantitative Deviations
    - e.g., mass balance or energy balance calculations
    - Convert external Data into LCA compatible data
    - Comparison of data with other external sources
5. Generate a Validation Score

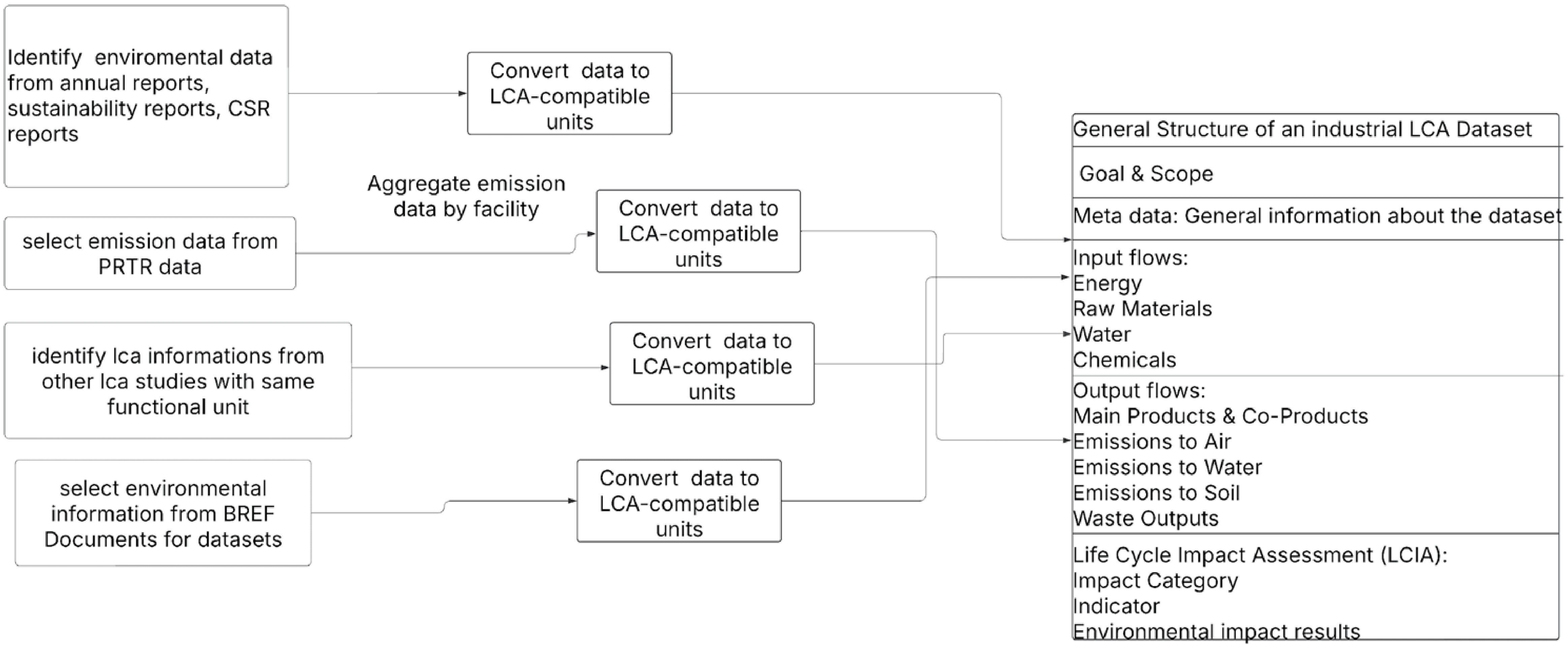
Approach

- **LCA datasets can be classified into various categories**



Approach

- **For Industrial LCA datasets:**



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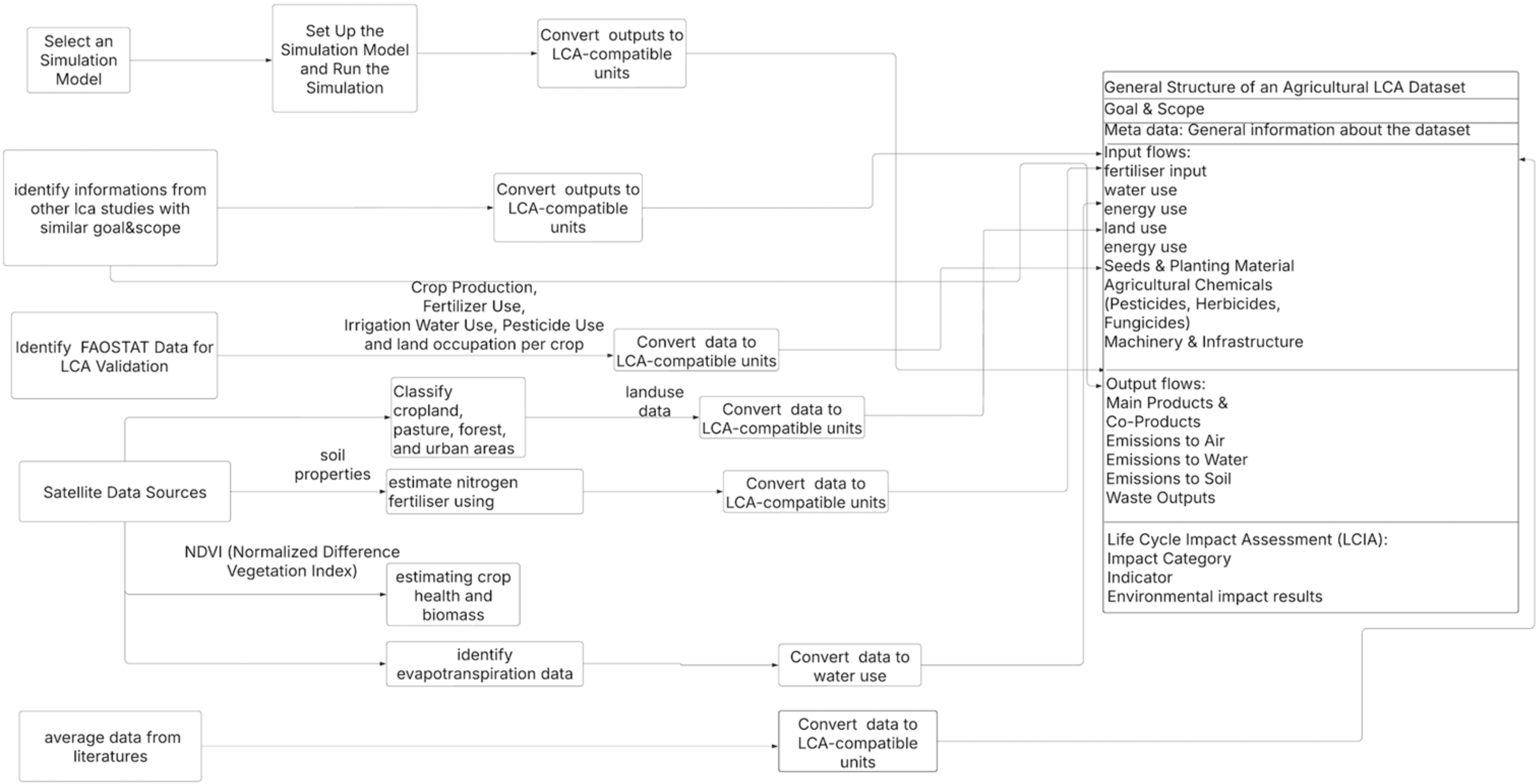
Approach

- **For agricultural LCA datasets:**



Application of This Approach

- Use case for 1 kg of apple production: get datasets from an AI model
- Identify external sources.

  - Types of Sources Used for this case:
    - Archetypal Process Structures

    - FAOSTAT
      - Country-level pesticide, fertilizer, land use and water use data.
      - Converted by dividing national totals by crop production volumes
    - LCA Studies
      - Detailed LCI values from apple production studies
    - Satellite Data
      - precipitation and evapotranspiration, and data from remote sensoring
      - Used to estimate irrigation requirements.
    - Literature Ranges
      - Minimum and maximum values reported across crops/regions

Planting		
Input	Amount	Unit
electricity	100	kWh/a
water for irrigation	500	m^3/a
fertiliser	50	kg N/a
pesticide	20	L/a
heat	100	MJ/a
seeds	1000	kg/a
Output Flow	Amount	Unit
CO_2 emissions from transportation	5	tons/a
NOx emissions from machinery	1	ton/a
Water pollution from fertiliser use	500	m^3/a
Soil contamination from pesticide use	20	L/a
Heat emissions from equipment operation	50	MJ/a
Solid waste from machinery maintenance	100	kg/a
Scrap materials from equipment disposal	50	kg/a
Pruning		
Input Flow	Amount	Unit
Electricity	12	kWh/a
Heat energy	0	MJ/a
Tractor fuel	12	L/a
Chainsaw oil	0.4	L/a
Water for irrigation	0	m^3/a
Pesticides (e.g. insecticides, fungicides)	0	L/a
Fertilisers (e.g. nitrogen, phosphorus)	0	kg/a
Herbicides	0	L/a
Fungicides	0	L/a
Seeds	100-200	seeds/a
Area (occupation)	1	h/a
Output Flow	Amount	Unit
Carbon dioxide emissions	1.2	kg CO_2e/a
Nitrogen oxide emissions	0.05	kg NOx/a
Particulate matter emissions	1.5	µg/m^3/a
Water pollution (wastewater)	0	m^3/a
Soil erosion	1.2	m^2/a
Scrap materials (wood chips, branches)	10	m^3/a
Wastewater treatment chemicals	0.5	kg/a

Fertilisation		
Input	Amount	Unit
Fertilizer	10	kg
Electricity	0.25	kWh
Heat energy	0.01	MJ
Water for irrigation	10	L
Fuel oil or diesel (for tractor)	0.1	L
Output Flow	Amount	Unit
Carbon dioxide emissions	0.1	kg /h
Nitrogen oxide emissions	0.01	kg /h
Fertilizer runoff into water	10	L/a
Soil disturbance emissions	5	kg/h
Fuel combustion byproducts	0.05	kg/h
Pest management		
Input	Amount	Unit
Electricity	15	kWh
Heat energy	0.05	MJ
Pesticide (insecticide/fungicide)	5	L
Water for pesticide application	50	L
Fuel oil or diesel (for sprayer and fogger)	0.2	L
Air Blower	100	m^3/h
Output	Amount	Unit
Carbon dioxide emissions (CO_2)	5	kg
Methane emissions (CH_4)	0.01	kg
Nitrogen oxide emissions (NOx)	0.005	kg
Ammonia emissions (NH_3)	0.001	kg
Water pollution (wastewater)	50	L
Soil contamination (heavy metals)	0.01	kg

Pollination		
Input Flow	Amount	Unit
Electricity	42	kWh
Water for Irrigation	50	L/h
Heat Energy	0.1	MJ
Pesticide (insecticide/fungicide)	10	L/w
Fertiliser	50	kg/
Pollinator Attractants (e.g. sugar, water)	20	L/w
Seeds or Propagation Materials	1000	units/m
Output Flow	Amount	Unit
Carbon dioxide emissions (CO_2)	1.5	kg/w
Nitrogen oxide emissions (NOx)	0.3	kg/w
Particulate matter emissions (PM)	0.2	kg/w
Water pollution (e.g., chemical runoff)	10	L/w
Soil contamination (e.g., heavy metals)	5	kg/m
Wastewater (e.g., irrigation water, cooling systems)	50	L/h
harvesting		
Input Flow	Amount	Unit
Fruit Picker	200	apples/h
Harvesting Machine	1500	apples/h
Sorting Machine	750	apples/h
Packaging Machine	300	boxes/h
Drying Tunnel	1500	apples/h
Electricity	42	kWh/day
Water for Irrigation	10	m^3/w
Fertiliser	20	kg/
Pesticide	10	kg/a
Heating System	5000	kWh/a
Transport Services (Truck)	1000	km/
Output Flow	Amount	Unit
CO_2 Emissions from Electricity Generation	0.02	kg CO_2/h
Methane Emissions from Fertiliser Application	0.001	kg CH_4/
Nitrogen Oxides Emissions from Tractor Emissions	0.0005	kg NOx/day
Water Pollutants from Wastewater Treatment	1	m^3 wastewater/day
Scrap Materials from Packaging	0.5	kg scrap materials/m
Nitrogen Leachate from Soil	0.02	kg N/ha/a
Air Pollutants from Drying Tunnel Emissions	0.01	kg/h

Application of This Approach

Identifying qualitative deviations: a typical archetypal structure for perennial fruit crop systems (like apple orchards) includes:

Expected Inputs	Expected Outputs,Main product: apples (kg/a)
Water for irrigation	Co-products: biomass waste (prunings, leaves)
Fertilizers (N, P, K)	Emissions to air: CO_2, CH_4, N_2O, NO_x, particulates
Pesticides, fungicides, herbicides	Emissions to soil: nutrient leaching, pesticide residues
Energy inputs: electricity, fuel	Emissions to water: runoff, erosion losses
Seeds or planting stock	Solid waste: packaging, machinery maintenance waste
Machinery use and possible maintenance	
Land use and occupation	

Key missing or incomplete flows identified:

- **N_2O emissions** from nitrogen fertiliser use not included
- **Land occupation/use** is limited to one stage
- **Fate of biomass** not modeled

Application of This Approach

- **Identifying quantitative deviations: Mass balance of this dataset**:

Process	Total Mass Input (kg/year)	Total Mass Output (kg/year)	Mass Imbalance (kg/year)	Relative Mass Imbalance
Planting	5.01E+05	5.06E+05	5.10E+03	1.02%
Pruning	1.04E+01	5.00E+03	4.99E+03	48086.22%
Fertilisation	2.01E+01	2.52E+01	5.07E+00	25.24%
Pest Management	5.44E+01	5.50E+01	6.09E-01	1.12%
Pollination	4.38E+05	4.39E+05	7.83E+02	0.18%
Harvesting	3.94E+07	3.99E+07	5.63E+05	1.43%

- **Pruning and fertilization show a high imbalance**

Application of This Approach

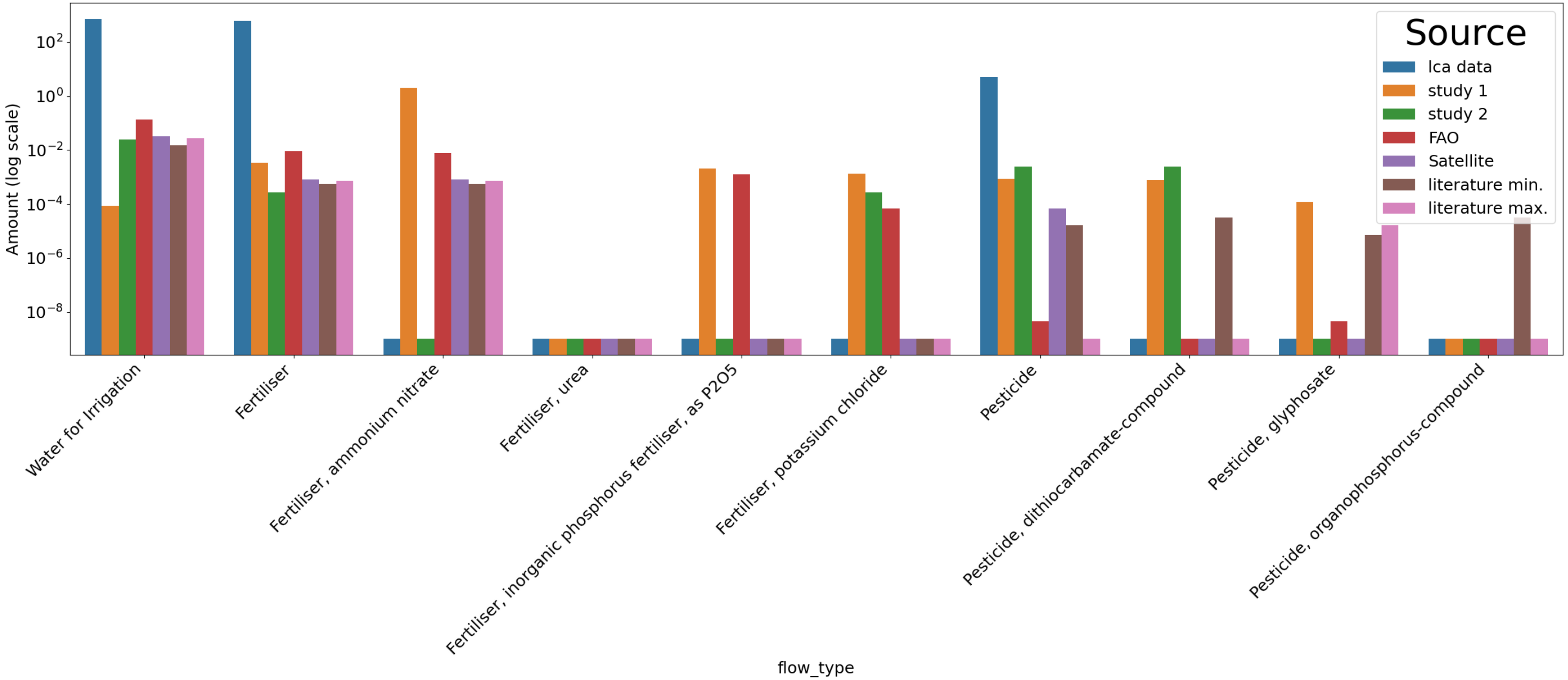
- LCA-Compatible Data from Other Sources: Using Remote Sensing for LCA-Compatible Irrigation Data
- Satellite platforms (e.g., FAO WaPOR) provides data on evapotranspiration (ET) and precipitation.
- Soil parameters like Relative Soil Moisture (RSM) and Available Water Content (AWC) are extracted from the Harmonized World Soil Database.
  - Irrigation Amount (mm) = Evapotranspiration (mm) - Effective Precipitation (mm) - Soil Moisture storage
  - Soil Moisture Storage = Relative Soil Moisture * Available Water Content

Parameter	Value	Unit
Evapotranspiration (ET)	436.4	mm/year
Precipitation	278.1	mm/year
Relative Soil Moisture (RSM)	0.39	%
Available Water Content (AWC)	159	mm
Soil Moisture Storage	0.6201	mm
Irrigation Area	0.02979	m^2
Calculated Irrigation Depth	157.68	mm/year
Irrigation Volume	0.0047	m^3/year

Application of This Approach

Identifying Quantitative deviations: Comparison of lca data across different sources

- **AI-generated (LCA) values** are significantly higher than other sources for:
  - Water for irrigation, Total fertilizer, Pesticides



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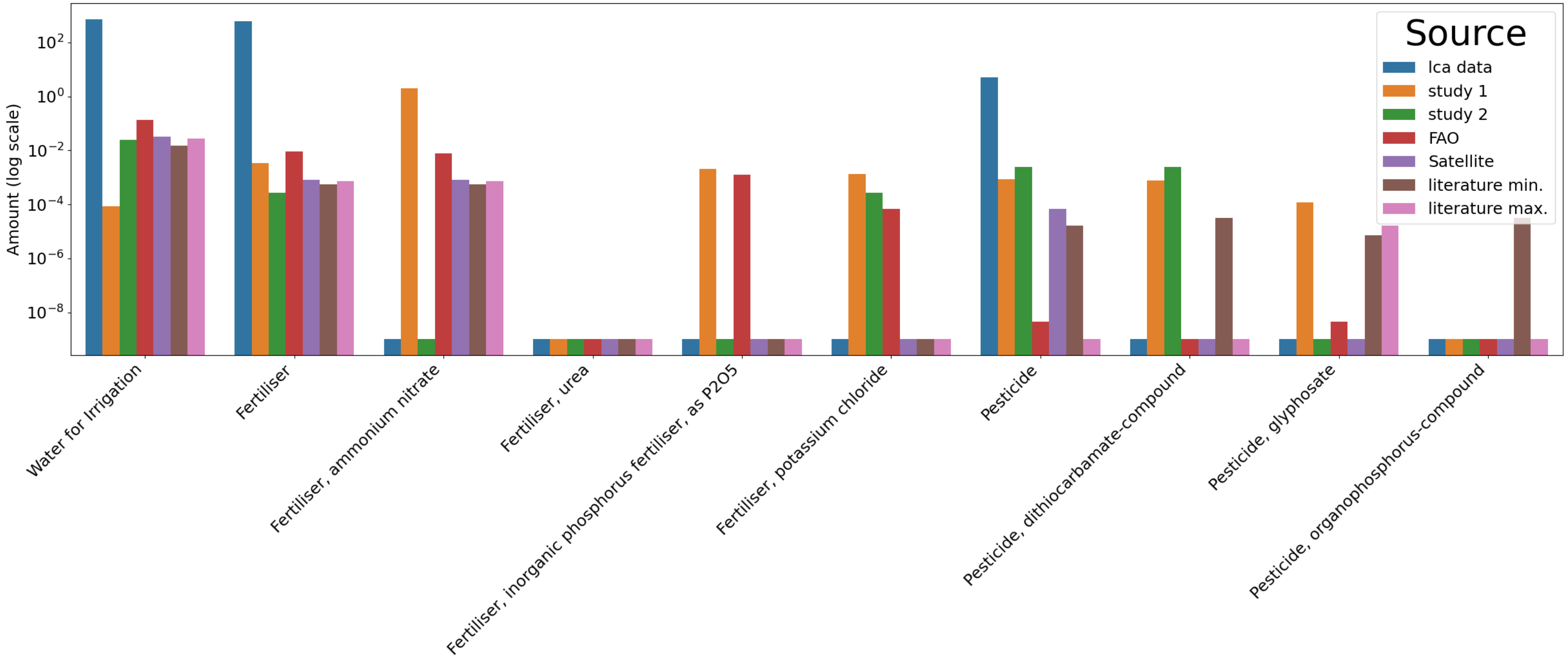
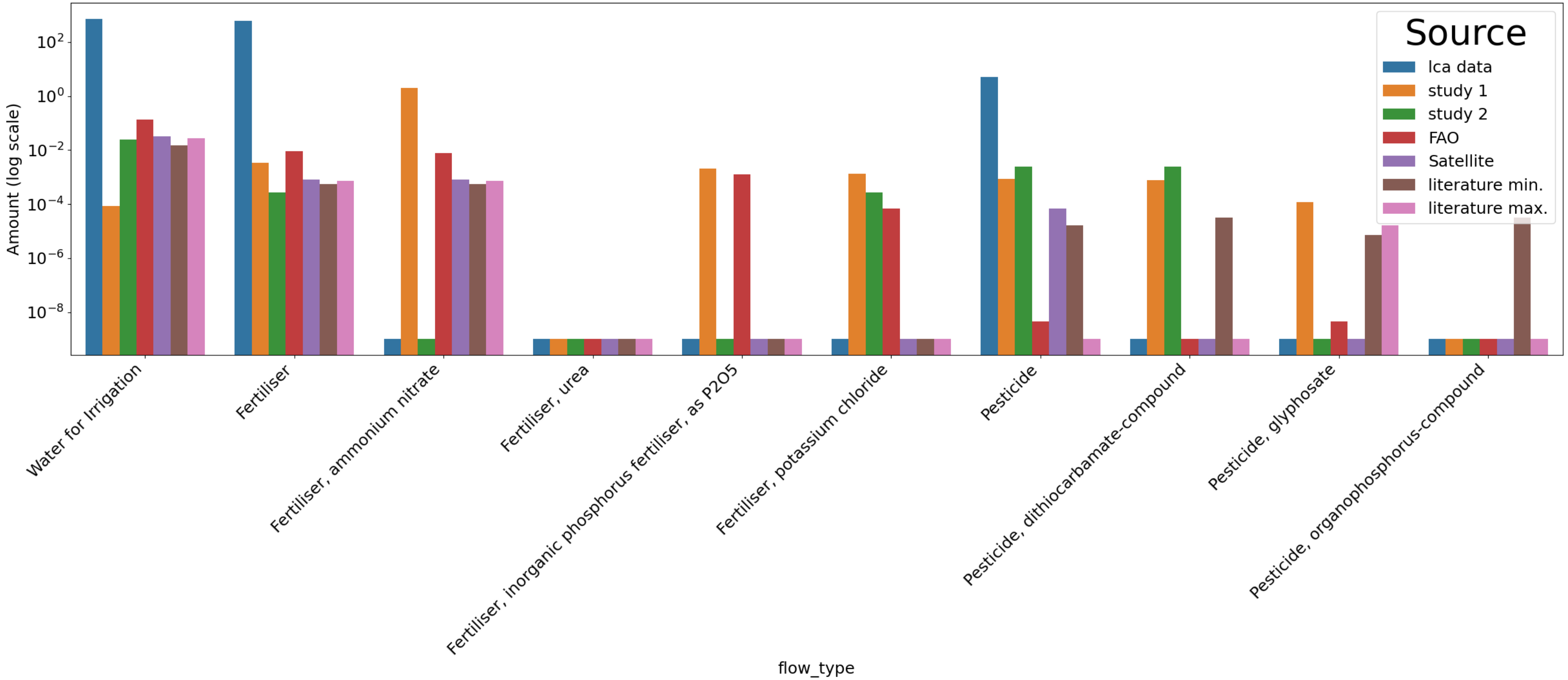
Application of This Approach

- **LCA Studies:**
  - **provide data that is already structured according to LCA methodology**
  - **fall within literature min/max ranges.**



Application of This Approach

- **FAOSTAT:**
  - **Some values are unexpectedly high or low: likely based on country-level averages divided across crop volumes**



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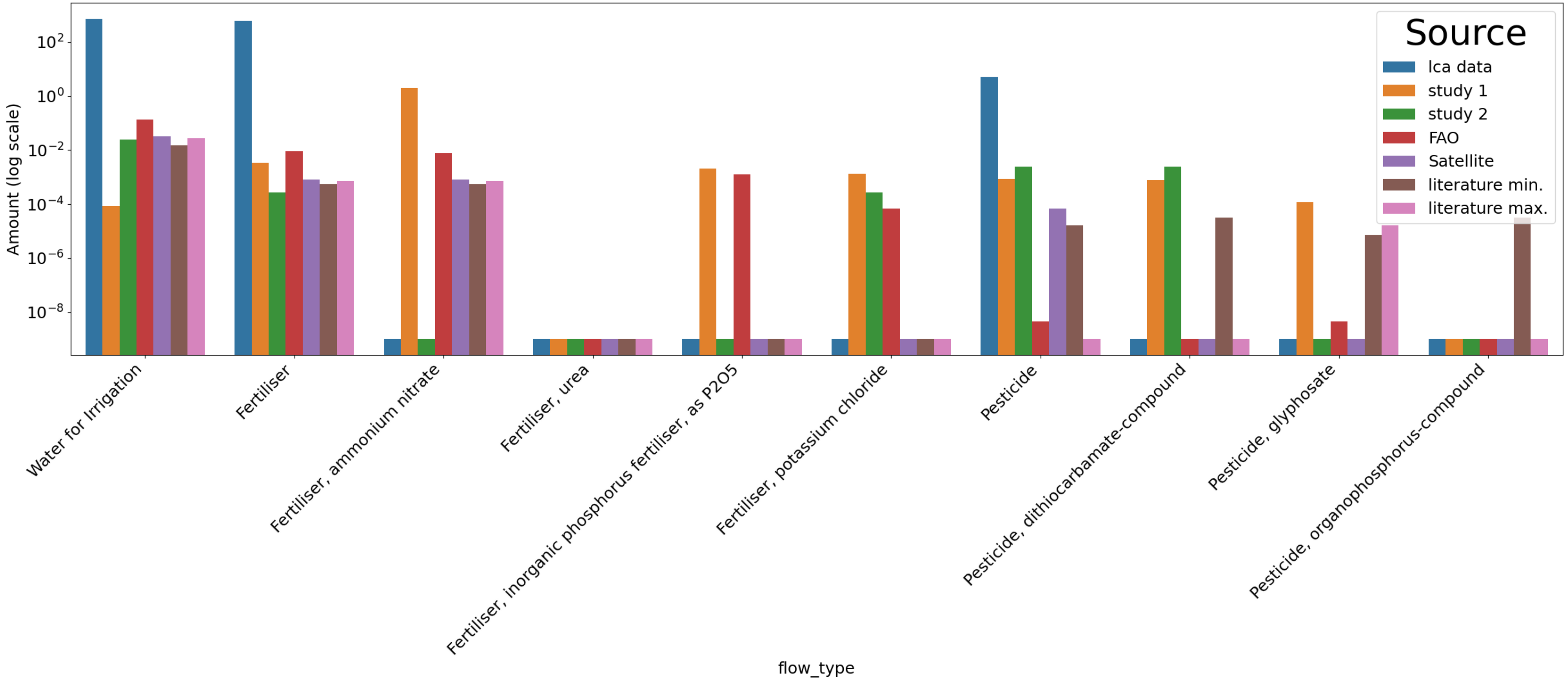
Application of This Approach

- **Satellite: shows consistency in water and pesticide use with other sources**
- **Literature Ranges (Min/Max) provide the widest spread, capturing extremes across regions types.**



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Outlook and Discussion

- Reliability of external sources should be considered.
- Expand validation framework to other crops and systems to generalize this approach.
- Deviation Reporting: Quantify and visualize deviations, highlight suspicious flows, or suggest corrections

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Thank you!

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