FROM THEORETICAL SCALE TO PRECISION ENGINEERING IN SUSTAINABILITY DATA

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Agenda

1. About TianGong
2. From automation to quality
3. Evaluating quality
4. Concluding remarks

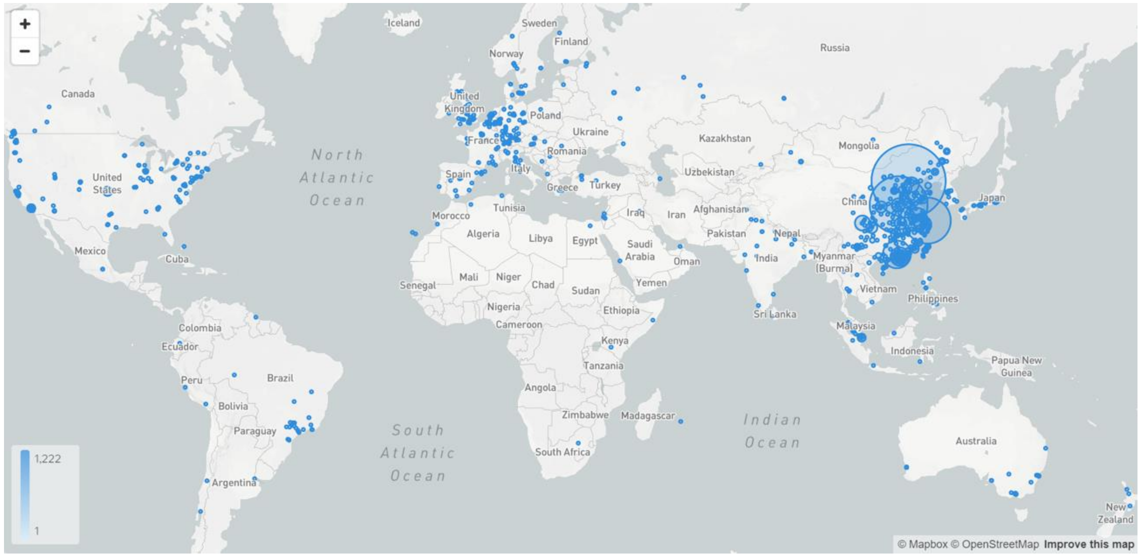
3 What is TianGong?

- A community-driven, AI-powered initiative to develop and maintain open, transparent LCA background database.
- Led by Tsinghua University with 43 investigators and 200+ researchers.

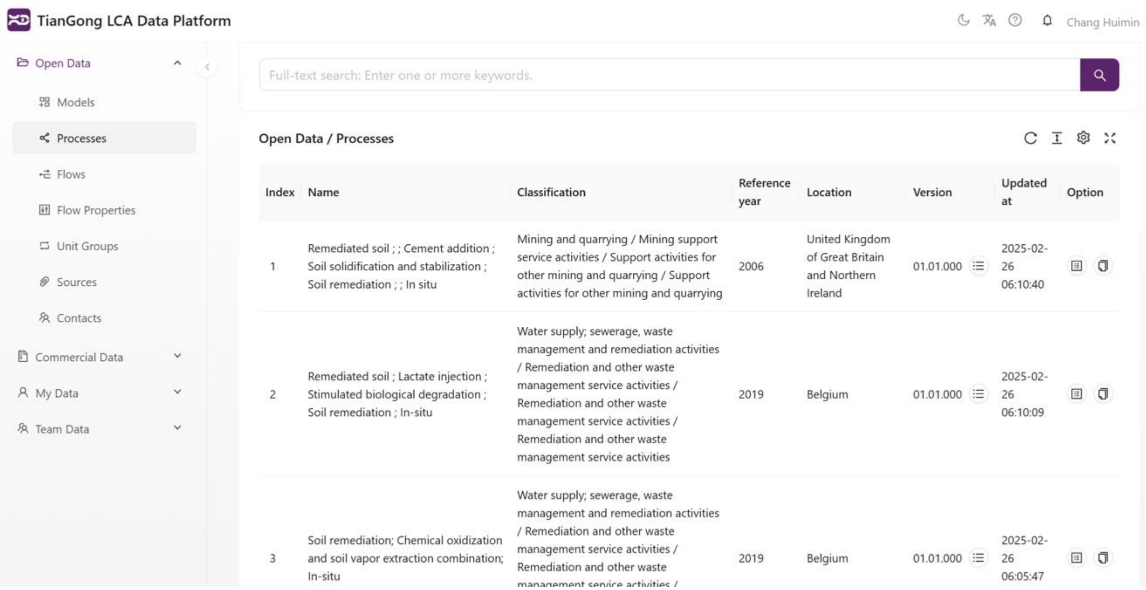
Sample stats

Database	ecoinvent	GaBi	USLCI	TianGong Database
Unit process	~15,000	~17,000	~600	4,315
Geographical coverage	Primarily Europe	Primarily Europe	US	China
Time to develop	~20 years	~20 years	~10 years	1 year

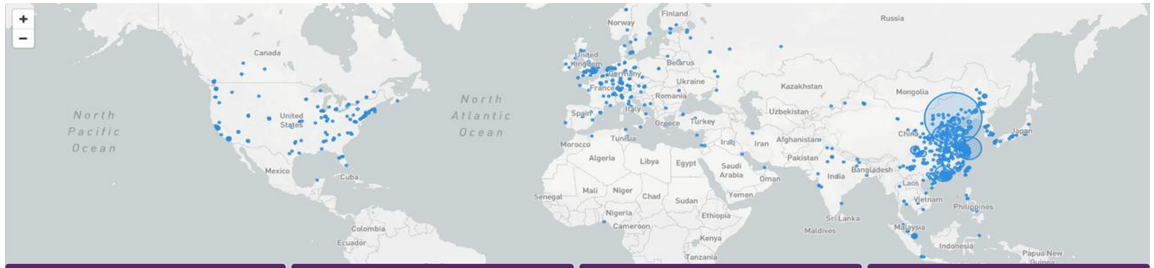
User locations



4 TianGong Database (currently, based largely on the literature)



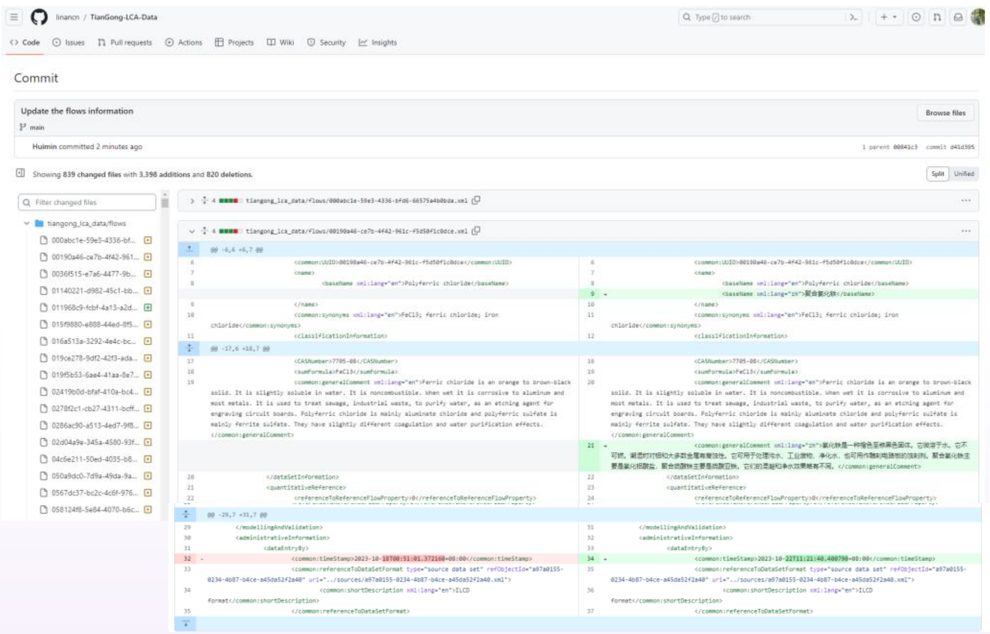
Index	Name	Classification	Reference year	Location	Version	Updated at	Option
1	Remediated soil ; ; Cement addition ; Soil solidification and stabilization ; Soil remediation ; ; In situ	Mining and quarrying / Mining support service activities / Support activities for other mining and quarrying / Support activities for other mining and quarrying	2006	United Kingdom of Great Britain and Northern Ireland	01.01.000	2025-02-26 06:10:40	
2	Remediated soil ; Lactate injection ; Stimulated biological degradation ; Soil remediation ; In-situ	Water supply; sewerage, waste management and remediation activities / Remediation and other waste management service activities / Remediation and other waste management service activities / Remediation and other waste management service activities	2019	Belgium	01.01.000	2025-02-26 06:10:09	
3	Soil remediation; Chemical oxidization and soil vapor extraction combination; In-situ	Water supply; sewerage, waste management and remediation activities / Remediation and other waste management service activities / Remediation and other waste management service activities /	2019	Belgium	01.01.000	2025-02-26 06:05:47	



Visitors	Regions	Visits	Downloads
150,000+	88	2,300,000+	21,000

https://lca.tiangong.earth/

Data sources	Unit processes	Flows
1,188	4,315	96,518



Transparent, and traceable

5 TianGong Database

Deployment Options

SaaS / Online: immediate access and collaboration

Private Deployment: Docker-based local deployment for enterprise security

Developer Tools

MCP: Local/Remote servers for AI Agents

(https://github.com/linancn/tiangong-lca-mcp)

Python SDK: Data structures and validation for LCA workflows ***(tidas-tools)***

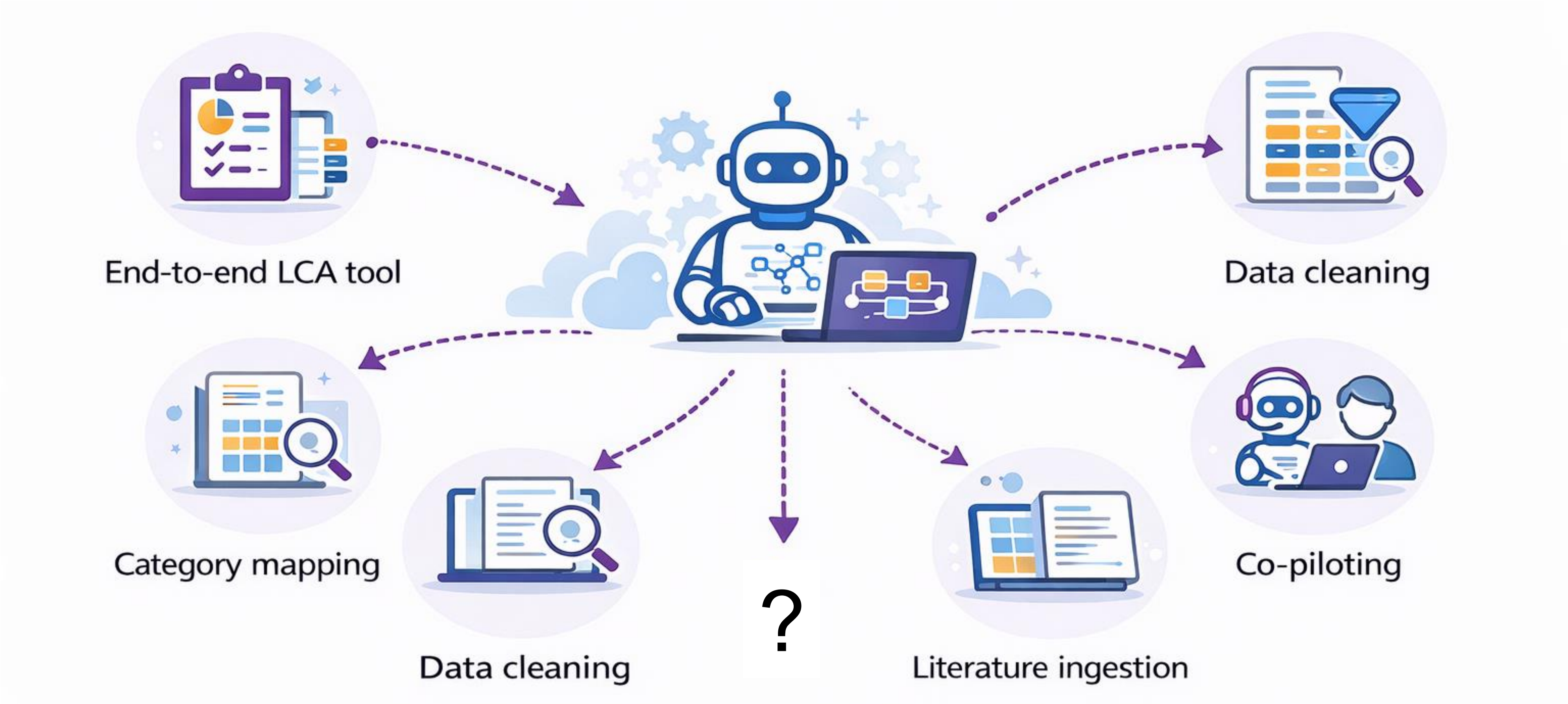
Embedding model: Trained on LCA datasets and process semantics, improving data understanding

Open LCA database. Flexible deployment. Ready for AI.

https://lca.tiangong.earth/

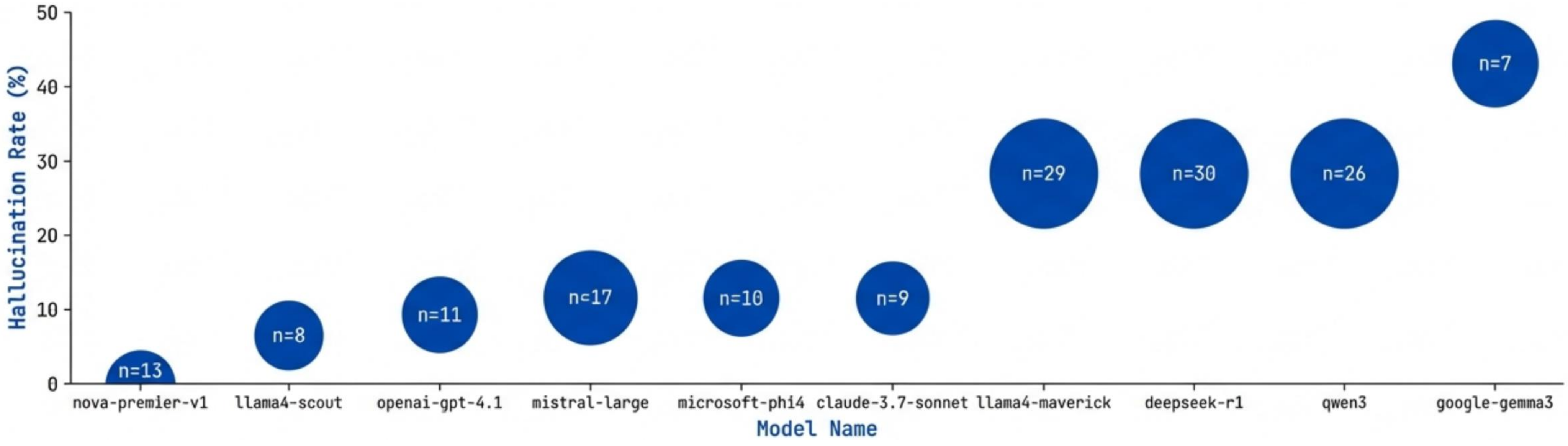
FROM AUTOMATION TO QUALITY

7 Proliferation of AI in LCA



8 Reality check

- **37.2%** of responses contained **incorrect or misleading information**
- **Up to 40% hallucination on citation** for some models

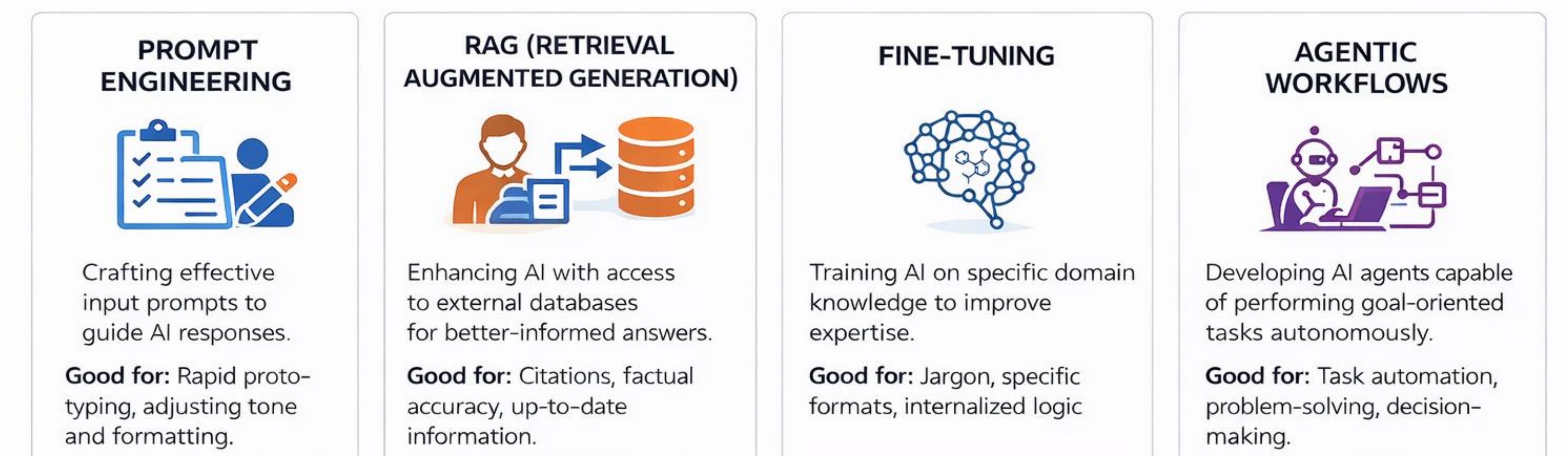


Source: Donaldson, A., Balaji, B., Oriekezie, C., Kumar, M. & Patouillard, L. An Expert-grounded benchmark of General Purpose LLMs in LCA. 2025. https://arxiv.org/abs/2510.19886

Quality concerns: 2025 ACLCA challenge session feedback

- "**AI needs deep training by subject matter experts** before being trusted to select appropriate technologies."
- "AI needs more **stringent, specific rubrics** compared to human expert judgment."
- "At least initially, **human-inspection by sector-expert** on technological representativeness is needed."
- "AI should not both perform and validate allocation; needs **clear documentation for human-verification**."
- "Currently don't trust AI fully for **source credibility assessment**; would require **human checks** initially"
- "Common conventions (e.g., medium voltage preference) can be used to flag **unconventional AI choices for human review**."

Approaches for improving the performance of AI



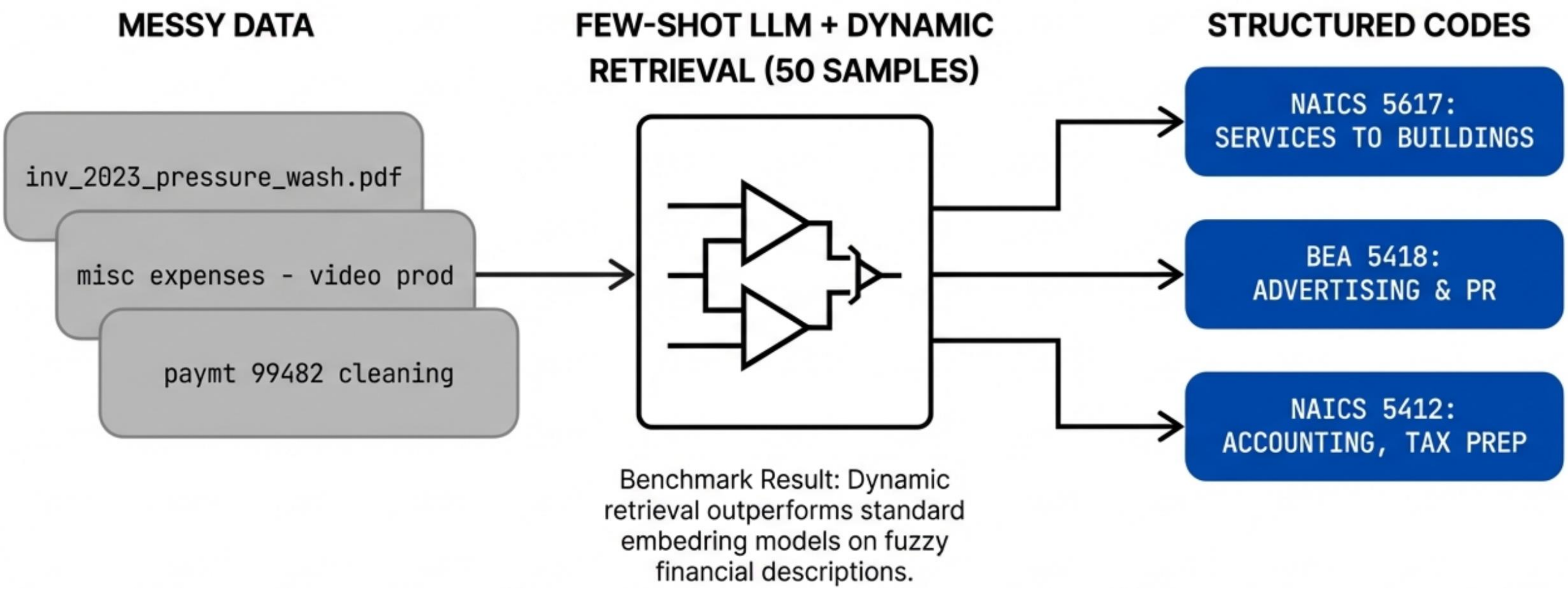
Giving **detailed instructions** on homework assignments

Giving the **references info to be cited** in their homework

Giving an **intensive review on a specific subject** before the exam

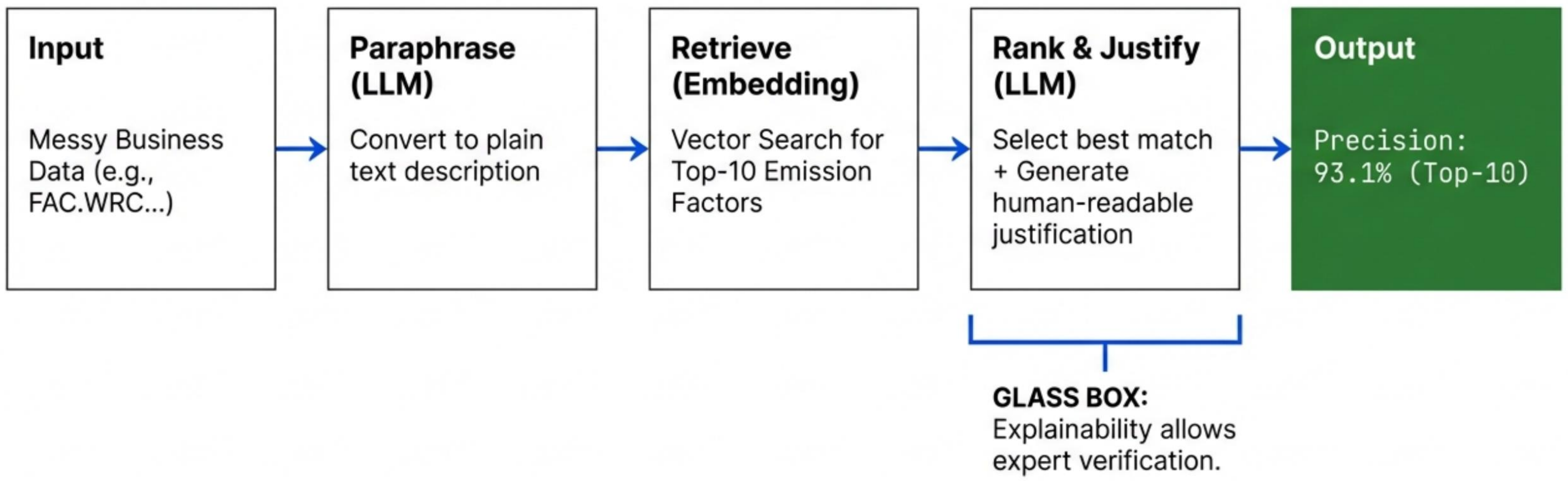
Allowing students to **work together** on a homework assignment

ATLAS for mapping (prompt engineering w/ RAG)



Source: Watershed (https://neurips.cc/virtual/2024/100600)

PARAKEET (prompt engineering w/ paraphrasing + RAG)



Source: Amazon (https://www.amazon.science/publications/parakeet-emission-factor-recommendation-for-carbon-footprinting-with-generative-ai)

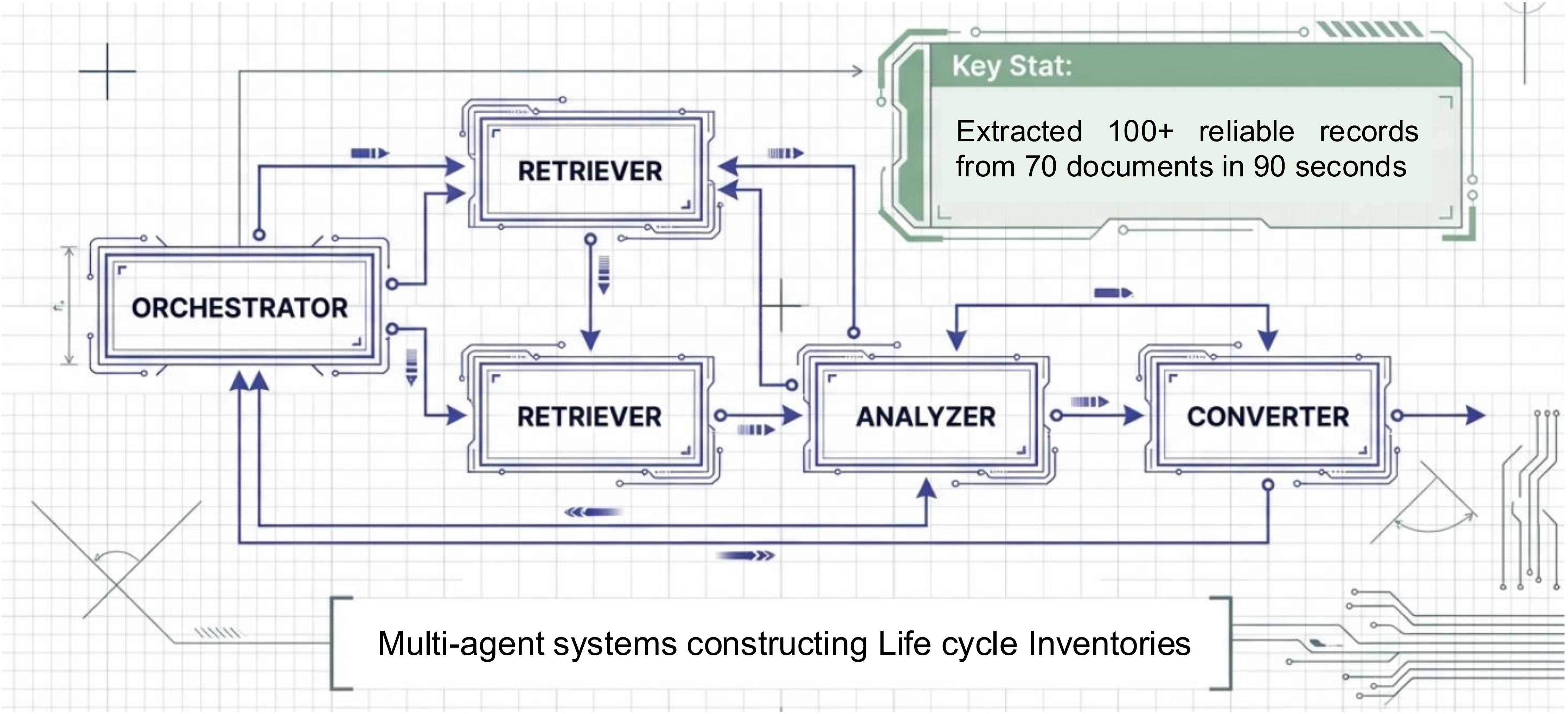
Fine Tunning using domain-specific knowledge: TianGong

Redacted (manuscript under preparation)

LCA domain-specific embedding outperformed raw or generic embedding models at all cutoff-rank values (*K*)

Source: TianGong: manuscript under preparation

Agentic workflow: High- LCA Data Extraction at Scale



Source: TianGong from Tsinghua University **(see Jinliang's presentation later today)**

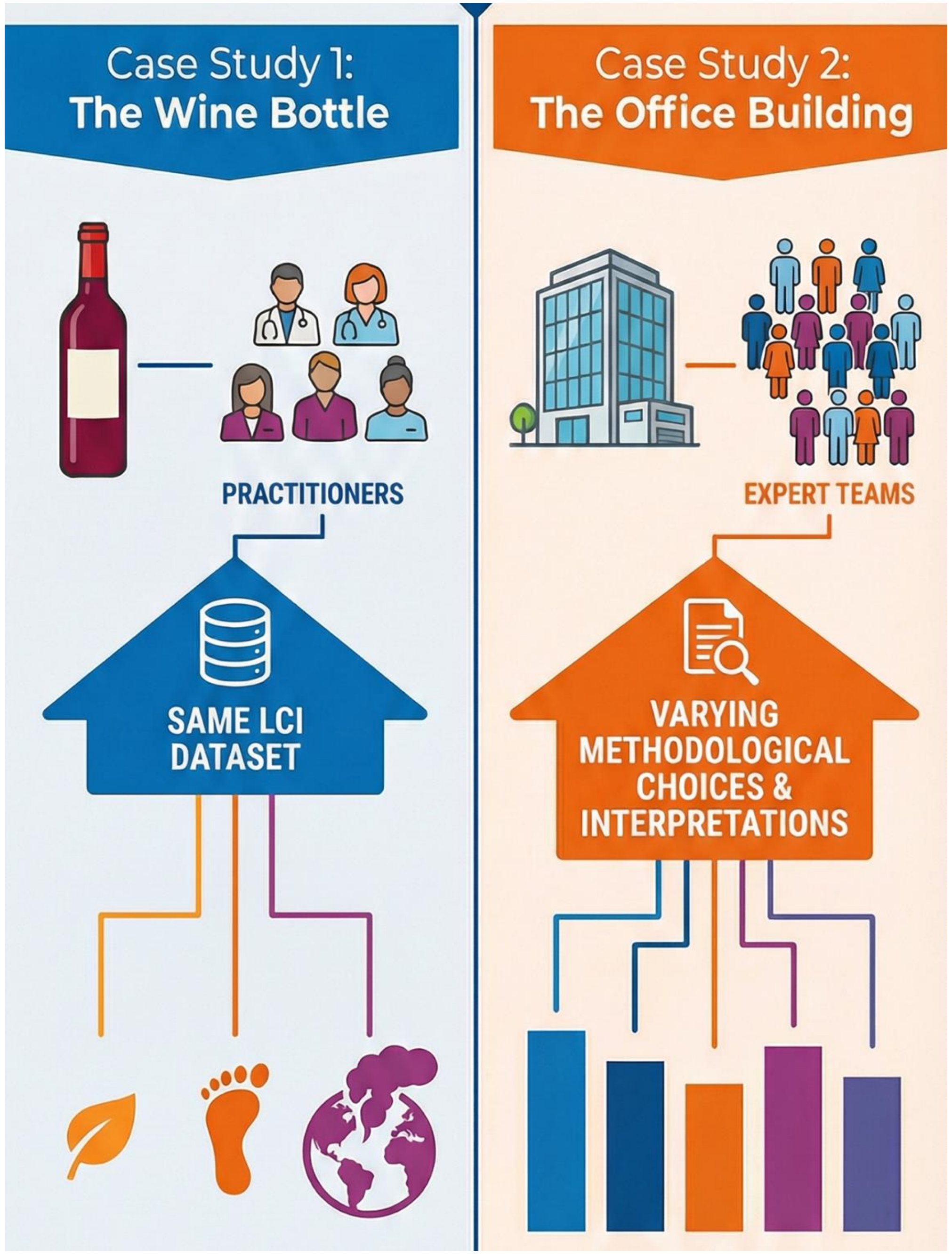
EVALUATING QUALITY

Challenges

- **The "Ground Truth" Paradox:** High-quality labeled LCA datasets are scarce, and experts often don’t agree with each other.

The "Ground Truth" Paradox

- **Practitioner Effect (Literature):**
  - Independent practitioners produce **+-20% difference** on a simple product w/ same LCI dataset (Scrucca et al., 2020).
  - Round-robin study shows a **X 7 variation** (10 v.s. 71 kg CO_2-eq m^{-2} yr^{-1}) on the same building with different (process) LCI datasets.
- AI cannot simply "predict" the expert's consensus, because often there is none.



Challenges

- **The "Ground Truth" Paradox:** High-quality labeled LCA datasets are scarce, and experts often don’t agree with each other.
- **Goal & Scope Dependency:** Quality is not absolute; it depends on the study's context.

The "Ground Truth" Paradox: from ACLCA 2025

LCA is not binary. Decisions on **Allocation (Economic vs Mass)** and **System Boundaries** are **subjective** and **context-dependent**.

Challenges

- **The "Ground Truth" Paradox:** Not only that high-quality labeled LCA datasets are scarce, but also that experts often don’t agree with each other.
- **Goal & Scope Dependency:** Quality is not absolute; it depends on the study's context.
- **Hallucination:** Studies show that LLMs are rather lazy; they would gladly make things up rather than laboring to find the truth.
- **Traceability in Agentic Swarms:** Tracing the root cause of an error is becoming increasingly complex as multiple agents interact with each other.

How to navigate?

- **The "Ground Truth" Paradox:** the goal is to set the boundaries for acceptable options (and their quality hierarchies, if any).
  - For procedural quality: synthetic Q&As based on smart chunking + human validation

Example: synthetic Q&A pair

Category 1: Goal & Scope Definition

Testing the AI's ability to detect ambiguity and enforce definition requirements.

- **Example: Functional Unit Sufficiency**
  - **Scenario/Prompt:** "A study compares two beverage packaging options (Glass vs. PET) and reports results in 'kg CO2e per bottle produced.' Is this functional unit sufficient for a comparative assertion intended for public disclosure?"
  - **Reference Anchor:** ISO 14044, Clause 5.2.3 (Functional Unit Requirements).
  - **Expected "Gold" Answer: No.** The functional unit is insufficient.
- **Required Reasoning:**
  1. Per bottle" describes a reference flow, not a functional unit.
  2. It fails to define the **performance characteristics** (e.g., volume delivered: 500ml) and **duration/quality** (e.g., shelf life or carbonation retention).
  3. Without equating the service provided, the comparison is invalid under ISO standards.
- **Critical Failure Flag:** If the AI answers "Yes" or proceeds to compare the materials without flagging the ambiguity,.

How to navigate?

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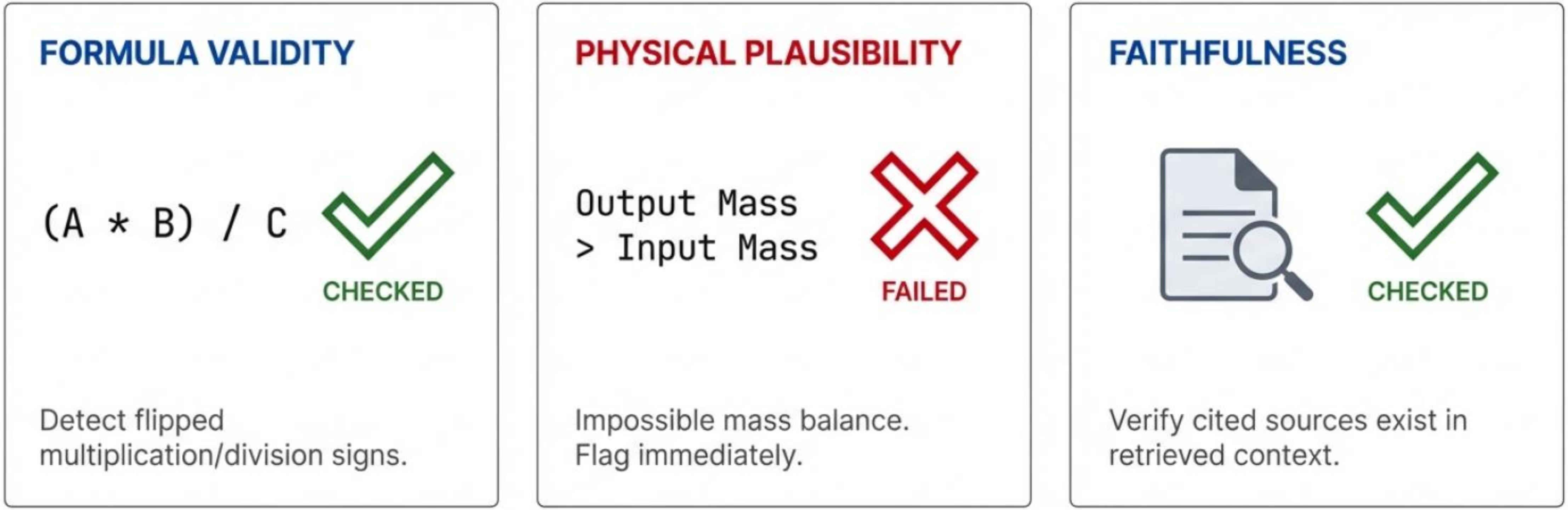
  - For procedural quality: synthetic Q&As based on smart chunking + human validation
  - For empirical validity: property eval + key ground truth ranges (e.g., electricity)

Empirical validity: Property Evals as the First Line of Defense



Source: Parikh and Dumit (2025). *A practical framework for LLM system evaluations for multi-step processes*, Watershed (https://watershed.com/blog/a-practical-framework-for-llm-system-evaluations-for-multi-step-processes)

How to navigate?

- **The "Ground Truth" Paradox:** the goal is to set the boundaries for acceptable options (and their quality hierarchies, if any).
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  - For empirical validity: property eval + key ground truth ranges (e.g., electricity)
- **Goal & Scope Dependency:** Machine-readable G&S template

Context-awareness: machine-readable G&S template

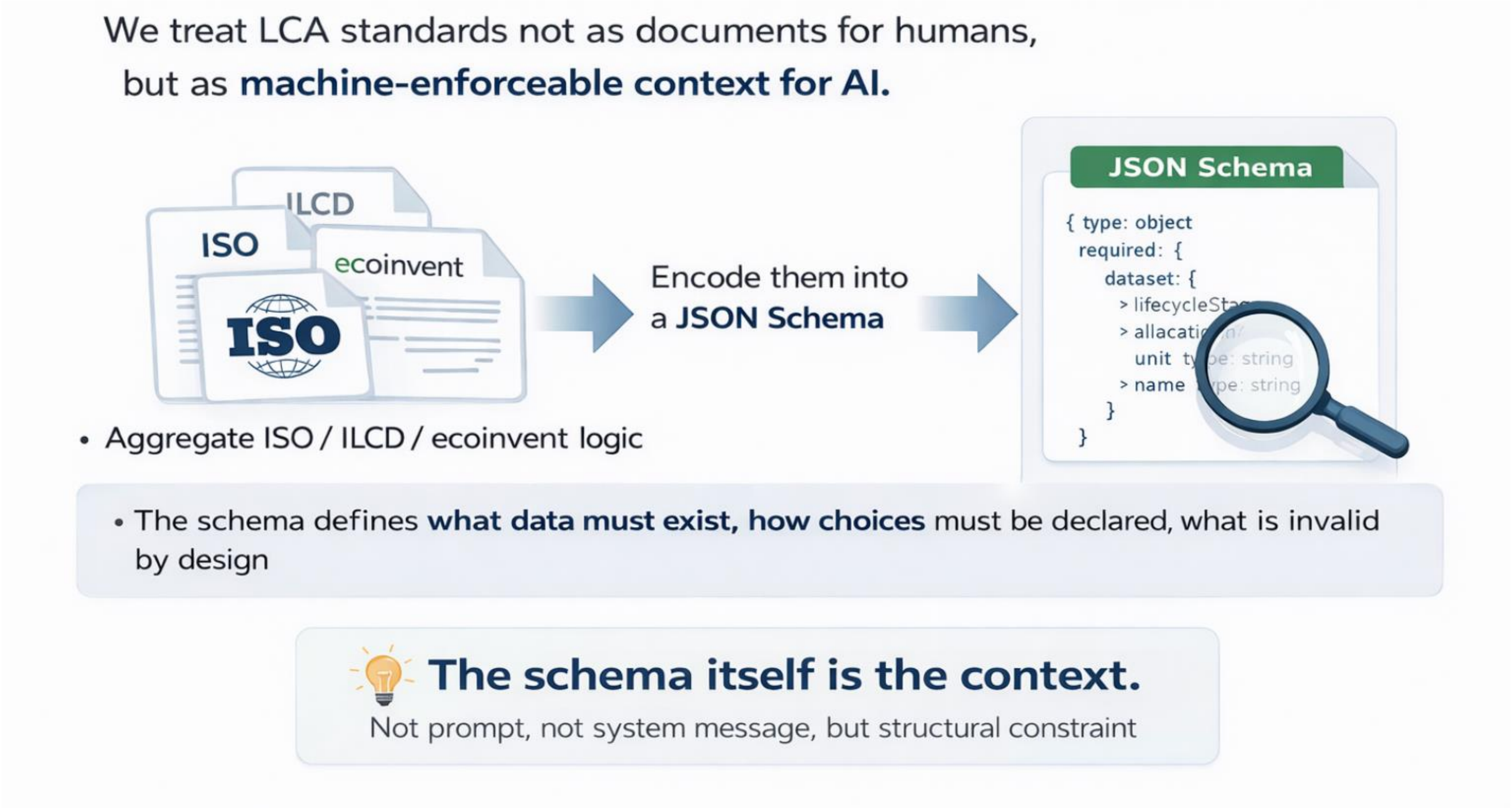
- Addresses "it depends" problem by constraining the choice of method and data based on the context.

```
{
  "GOAL_DEFINITION": {
    "intended_application": "comparative_assertion",
    "intended_audience": "public_consumer",
    "comparative_assertion_public": true,
    "regional_context": "US-NA",
    "methodology_trigger": "ISO_14044_Clause_5.3"
  }
}
```

TRIGGER: Must enforce sensitivity analysis & critical review.

CONSTRAINT: Triggers specific PCRs and Grid Mixes.

Example: TIDAS—procedural quality via schema-as-context



Source: *https://tidas.tiangong.earth/en/docs/intro*

How to navigate?

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  - For procedural quality: synthetic Q&As based on smart chunking + human validation
  - For empirical validity: property eval + key ground truth ranges (e.g., electricity)
- **Goal & Scope Dependency:** Machine-readable G&S template
- **Hallucination & Faithfulness:** Hallucination check—*does the reference exist*?
- **Traceability in Agentic Swarms:** Minimum documentation requirement including the documentation of key “reasoning” or “chain-of-thought”.

Standardizing Minimum Documentation Requirement

A. **System Provenance:** Model version, exact prompt log, and timestamp to trace hallucinations.

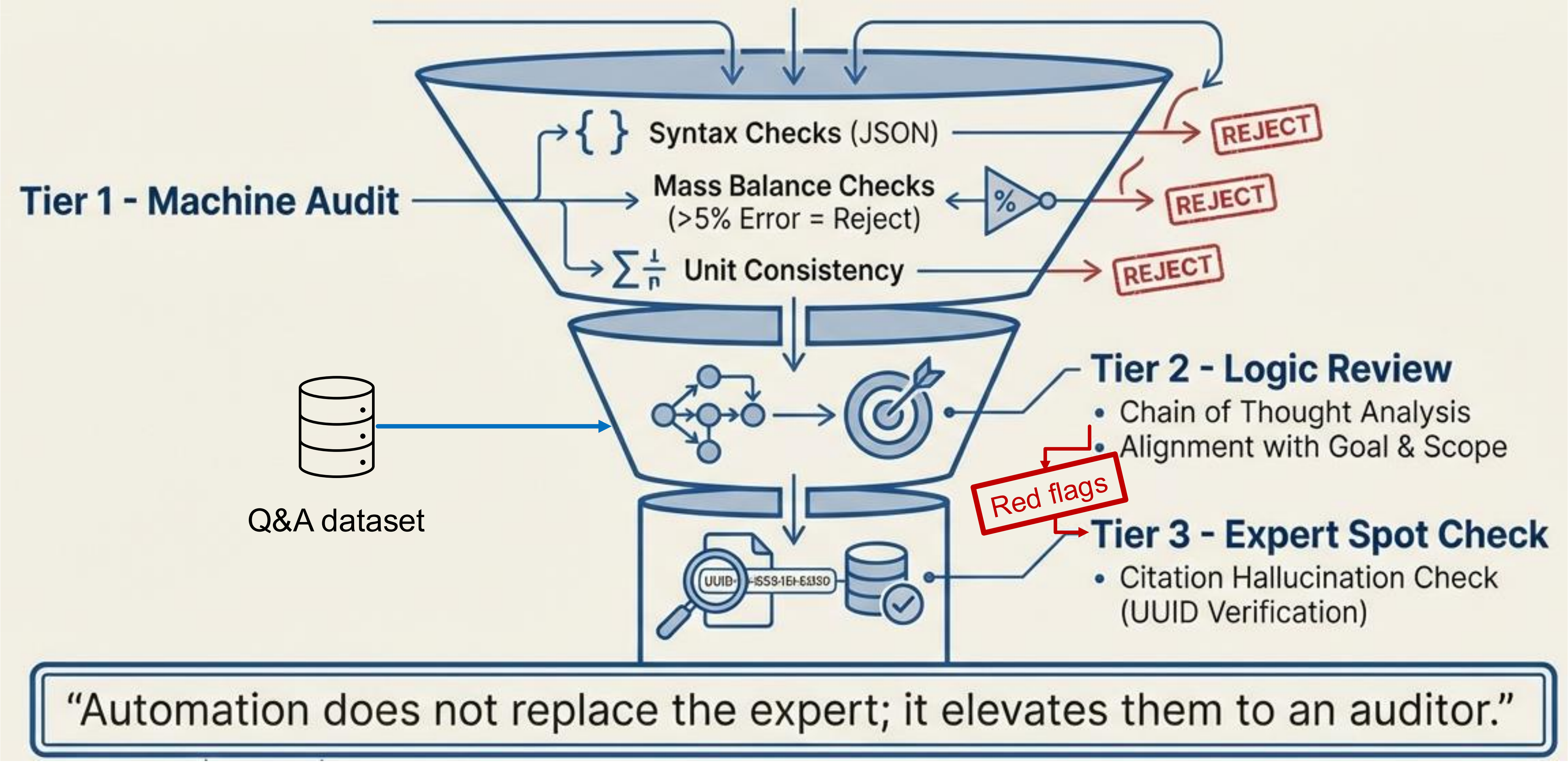
B. **The "Context Key" (Goal & Scope)**.

C. **The ”Chain of Thought" (Logic):** A log of decision hierarchies (e.g., *“Attempted System Expansion → Failed → Economic Allocation*)

D. **Data Integrity:** Secondary data must link to unique **UUIDs/DOIs** (check citation hallucination)

E. **Automated audit trails:** Generated mass/energy balance checks and unit consistency flags.

Overall Evaluation Protocol: a tiered approach



CONCLUDING REMARKS

Concluding remarks: Toward Trustworthy AI for LCA

- **Automation to precision:** The field is moving from *automation* with questionable quality to *precision engineering*.
- **Solving "It Depends" problem is crucial:** a choice should be evaluated against machine readable goal & scope context.
- **Scale Eval:** Synthetic Q&As + Property Eval + selective numerical validation would be the first line of defense.
- **Traceability and Documentation:** Unified provenance models and standardized documentation requirement.
- **Human-in-the-loop:** The goal is to making human audits more effective at scale.

“As LCA grows more intelligent and scalable, so must the way we evaluate it.”

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