Artificial intelligence in LCA: Technical, Ethical, and Organizational reflections

UNEP Life Cycle Initiative Working Group

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Agenda

- WG Overview
- Context and Research Approach
- Methods
- Outcomes
- Conclusion and Future Work

Working Group: Overview

Life Cycle Initiative

- Initiated by the Life Cycle Initiative (hosted by UNEP) within the GLAD network
- 25+ members from academia, industry, and policy
- Two sub-groups
  - WG1 - Opportunities and Technical Challenges
  - WG2 - Social, Organization and Ethical implications
- Current Progress

Artificial intelligence meets LCA: a critical analysis from technical, ethical, and organizational perspectives *(in preparation)*

An Expert-grounded benchmark of General Purpose LLMs in LCA, https://arxiv.org/abs/2510.19886 *(under review)*

Contextual Perspective

- Efficiency vs. Effectiveness
  - Efficiency = Faster assessment utilizing fewer resources (e.g., automating data collection, reduced manual effort)
  - Effectiveness = Higher quality (e.g., robust, transparent, and ISO-compliant results that support sound decisions)
- Responsible adoption
  - Ethical Risks (Bias, transparency, privacy, ...)
  - Organizational implications (key adoption challenges, validation, ...)

Research Approach

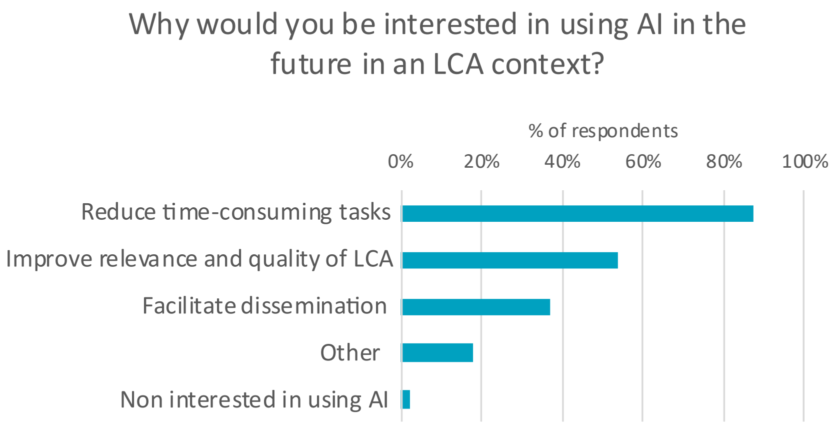
- Literature review
  - AI-LCA applications → academic and industrial developments
  - Ethical values → ethical principles in AI, ethical values in LCA
  - Organizational implications→ possible transformations, affected stakeholders
- LCA community survey
  - Current practice of AI in LCA → frequency and purpose of use of AI
  - Ethical values → perception of ethical risks and values
- Integrated LLM and expert evaluation
  - Ethical Risks → perception of ethical risks and value
  - Technical maturity, potential to enhance LCA practices, operational feasibility → analysis of current AI-LCA applications

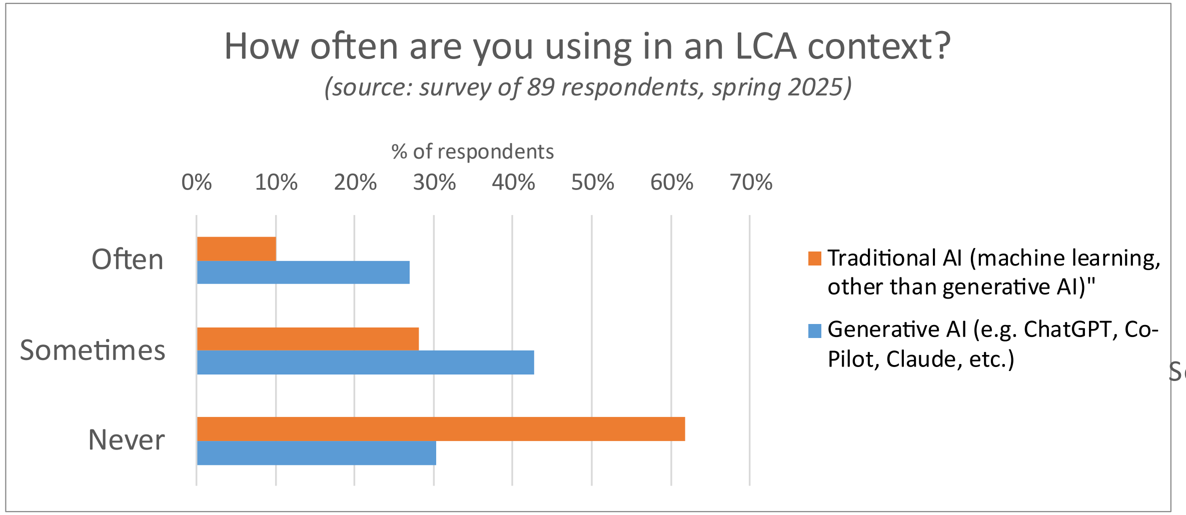
Outcome Snapshot

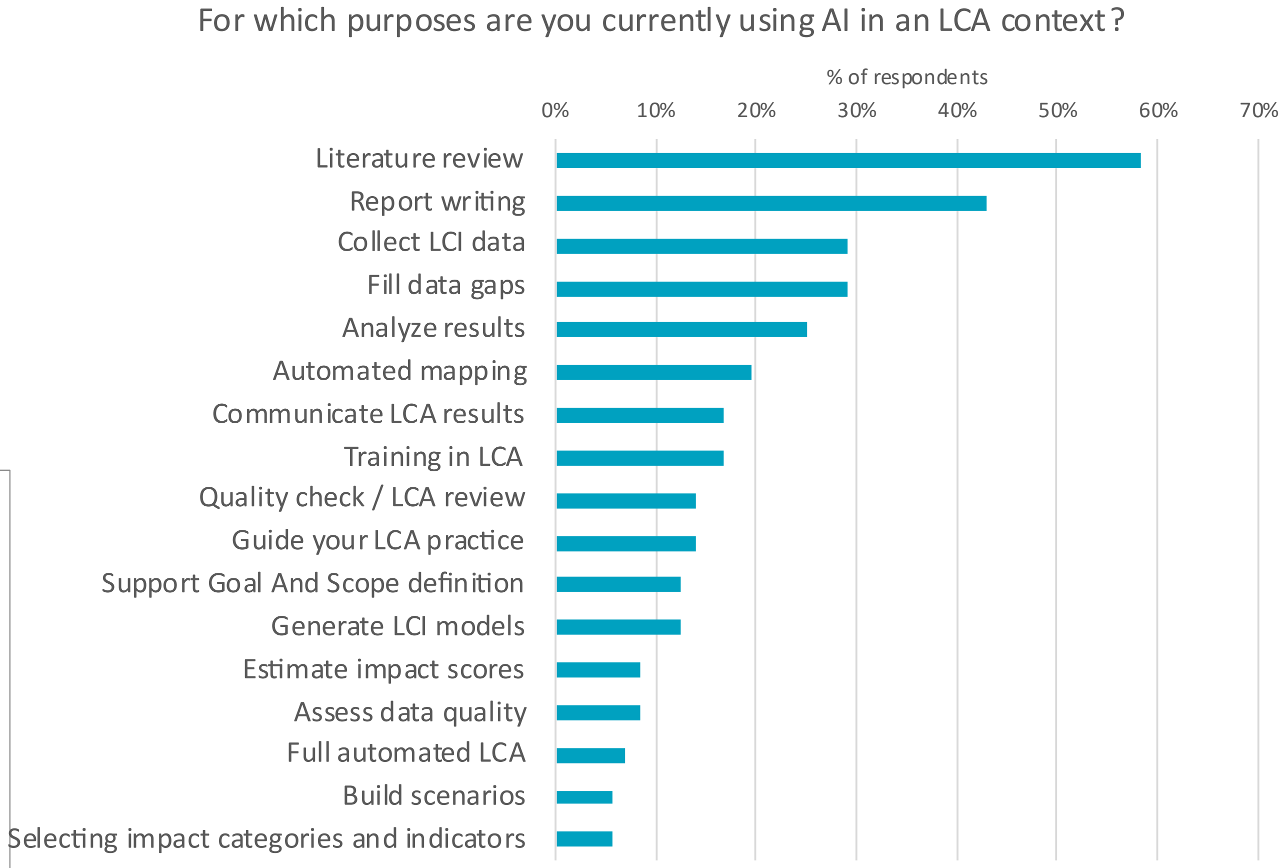
- LCA workflow steps wise mapping of AI-LCA applications
- Current AI practices in LCA
- Ethical risks of integrating AI in LCA
- Organizational implications
- Evaluation of AI-LCA applications on effectiveness and ethics criteria

AI in LCA: Current Practice

Based on 89 respondents (Researchers 44%, Practitioners 39%) - March to May 2025

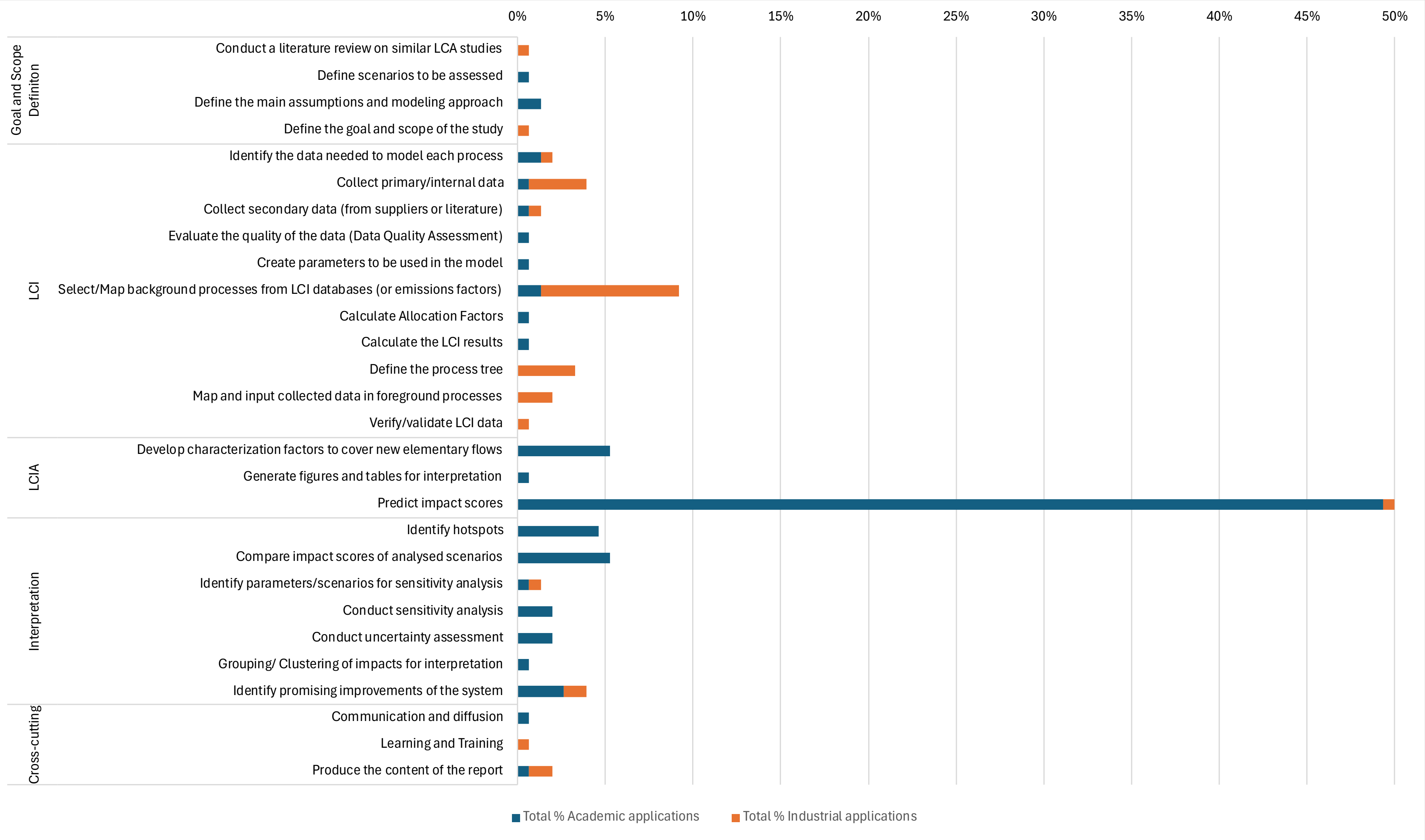






Source: [1]

Mapping of AI-LCA applications

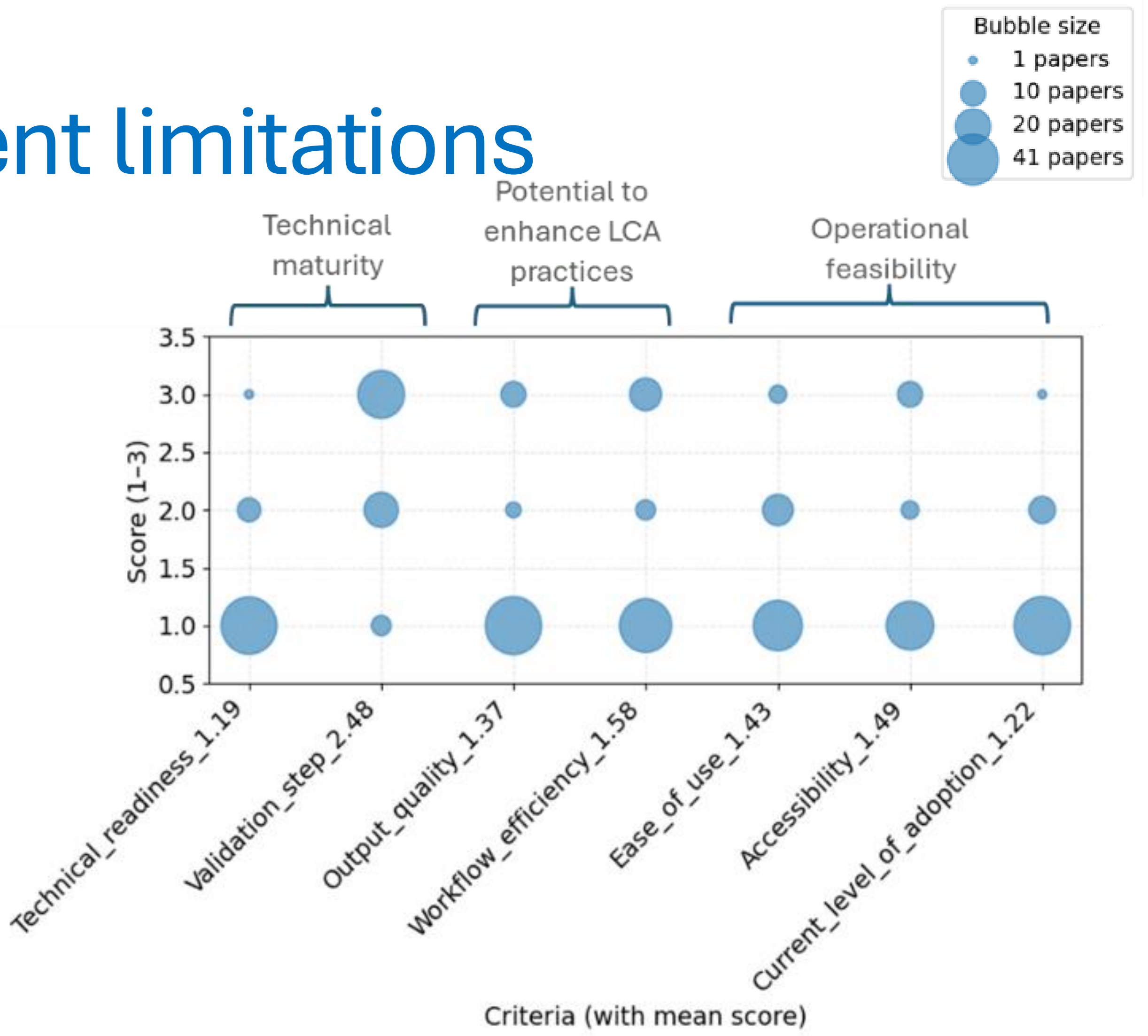


- 50% of the overall LCA workflow steps performed using AI
- Strong emphasis on filling data gaps, predicting and comparing impact scores, and hotspot identification in academic research
- Industrial applications focus on data collection, processes mapping, data verification
- Limited use of Generative AI (5%)

Source: [1]

AI-LCA applications: current limitations

- Mostly proof-of-concept, lacking full workflow integration
- Automatic validation of outputs is common, potential for full LCA automation
- Claimed benefits (faster LCAs, higher quality) are rarely quantified, limiting evidence of added value
- Operational feasibility is low and is a major barrier to inclusive adoption of AI in LCA: tools require coding skills, are not user-friendly, and often lack open access or documentation
- Adoption remains limited: most applications are research prototypes; only a few industrial tools show higher uptake



Preliminary Results of semi-quantitative scoring of AI-LCA applications against 14 criteria grouped into four categories (technical maturity, potential to enhance LCA practice, operational feasibility, and ethical risks) using a three-point scale for each criterion (from 1 to 3, 3 being the best or most desirable option)

Source: [1]

Ethical values of AI and LCA

	Ethical value	Simplified summary of ethical risks
AI	**Transparency**	Opaque models (black boxes) and undisclosed data or methods limit explainability, oversight, reproducibility and uncertainty analysis.
	Accountability	Algorithmic decision-making obscures responsibility: poor explainability, unclear liability, and few enforcement despite regulation.
	Fairness	Bias in training data and model design, combined with unequal access to AI, risks reinforcing exclusion and inequality.
	Privacy	Extensive data collection and profiling reduce individuals' control over personal information.
	Data protection	Inadequate protection of proprietary or copyrighted data may make AI systems unlawful.
	Safety and Security	Poor design or malicious attacks can cause harm, data breaches, misinformation, and reputational damage.
	Sustainability	AI poses environmental impacts and social risks, including labor exploitation, job displacement, and digital inequality.
LCA	**Transparency and Reproducibility**	Clearly report all assumptions, choices and data sources in a structured and detailed manner to ensure that results can be consistently reproduced under the same conditions
	Completeness	Being comprehensive to avoid problem shifting across life cycle stages and impact categories
	Coherence	Being consistent with the goal and scope
	Scientific Integrity	Ensure unbiased and accurate assessment to be as close as possible to the reality, while acknowledging limitations, uncertainties, and potential conflicts of interest
	Sustainable Responsibility	Guide toward decisions minimizing sustainability impacts
	Inclusivity and Fairness	Ensure a good representativeness by considering interests and point of views of all stakeholders

Source: [1]

Qualitative Risk Analysis

Ethical values of LCA / *Ethical values of AI*	**Transparency and reproducibility**	Completeness	Coherence	**Scientific integrity**	Sustainable responsibility	Inclusivity and fairness	Conformity	*Level of risk by AI value* *(deducted from Level of perceived risk by LCA value)*
Accountability	x			x	x			High*
Fairness				x	x	x		High*
Privacy							x	Low*
Data protection							x	Low(Medium)
Safety and security				x	x	x	x	High(Medium)
Transparency	x							High*
Sustainability					x	x		Medium*
Level of perceived risk by LCA value (source: survey of LCA community)	High	Low	Medium	High	Medium	Medium	Low	

LCA Ethical Values

- Most affected : Transparency, Reproducibility, and Scientific Integrity
- Medium Risk: Coherence, Sustainable Responsibility, and Inclusivity
- Low Risk : Completeness, Conformity

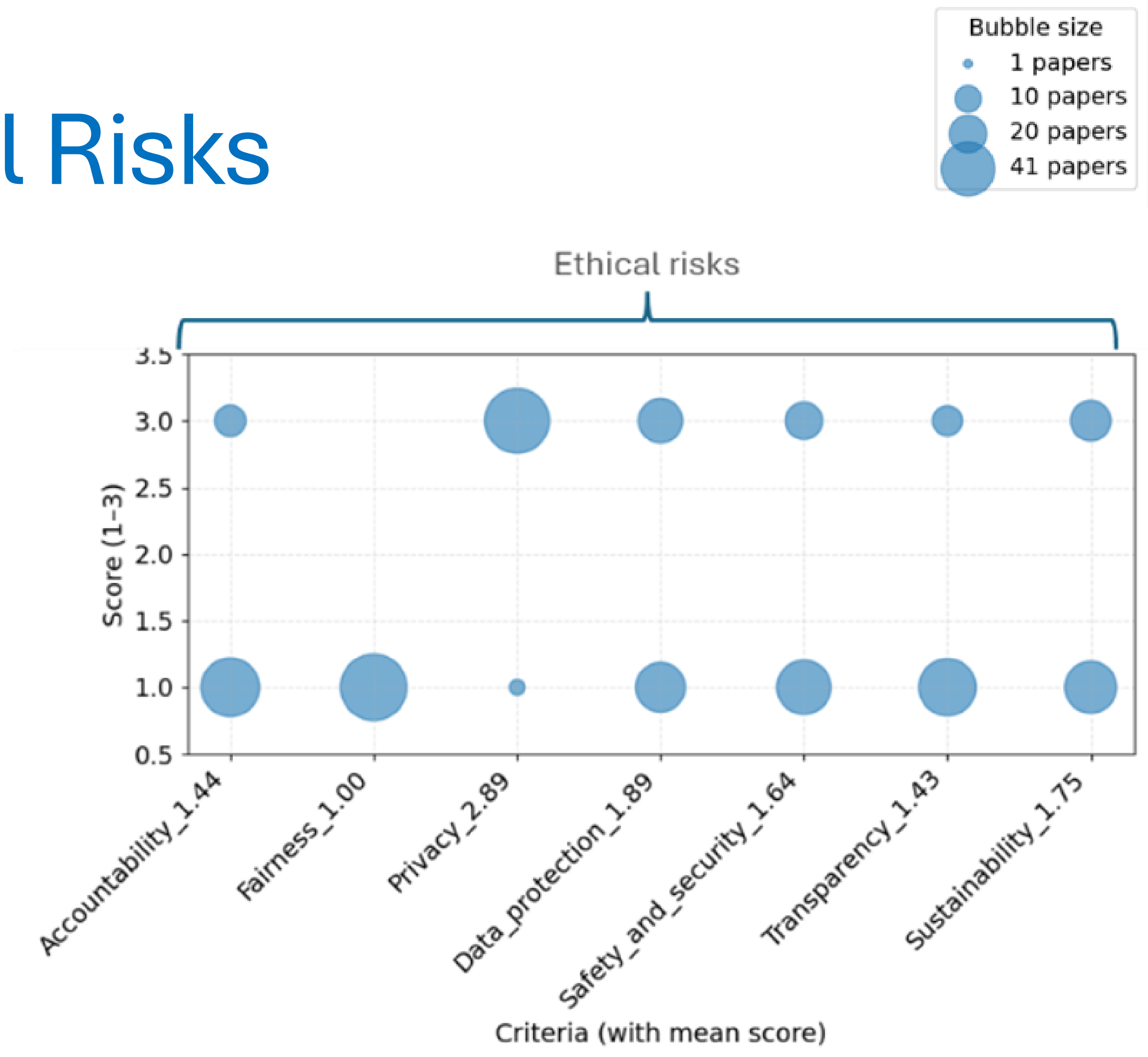
AI Ethical Values

- Most affected : Accountability, Fairness, Safety and security, and Transparency
- Medium Risk: Sustainability
- Low Risk : Privacy and Data protection

Source: [1]

AI-LCA applications: Ethical Risks

- Accountability (high): Weak explainability (transparency issues) and limited discussion of liability/enforceability
- Fairness (high): AI divide (English-only docs, closed code, non-accessible UX) + representation bias (training data skewed to high-income regions)
- Transparency (high): Black-box models; limited method/model documentation; missing performance metrics & uncertainty analysis
- Data protection (medium, bimodal): half transparent/licensed, half lacking transparency or using non-private AI platforms
- Safety & security (medium): Often missing protocols, access control, human review; exceptions for internally developed models
- Sustainability (medium, bimodal): Lower scores with LLMs/high compute; higher scores with lightweight ML and low computing needs
- Privacy (low risk): Personal data rarely used; few exceptions



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Organizational implications

- Expected Transformations
  - Short-term: Enhanced productivity, strategies for validating AI generated outputs
  - Long-term: Ethical concerns regarding AI autonomy
- Inequality Risks and Regional divide
  - Licencing costs, representation bias, limited regional focus
- Decision-making
  - Scalable, reduced human bias, risk of computational bias

Key Takeaways

- AI offers potential opportunities for efficiency improvements and scalability (automate repetitive tasks, fill data gaps, and quicker decision-making) and will deeply reshape our work practices
- Guardrails required
  - Highest AI ethical risks (accountability, transparency, fairness – threaten core LCA values (transparency and scientific integrity)
- Effectiveness must remain the priority
  - Transparency, scientific integrity, and ISO compliance cannot be compromised
- Responsible adoption is essential
  - Data standardization and rule-based automation
  - Use AI to augment expert judgment, not replace it

Future Directions

- Levels of automation
    - Standardized data collection, calculations
    - Rule-based automation integrating effectiveness measures (quality, transparency)
    - AI augmentation involving expert judgement
- Global roadmap for responsible adoption
    - Technical and Ethical guidelines and ISO standardization
    - Fairness ensuring equitable access to resources (open-source tools, trainings etc.)
    - Foster open access and global collaboration to avoid deepening the AI divide
- Standardized model evaluation
    - Benchmarking methodologies, performance testing consistent with LCA standards
- Extension to complementary LCA methodologies
    - Explore opportunities for S-LCA, Prospective LCA, and AESA

References

[1]. Kumar, M., Patouillard, L., Cornago, S., Bartocci, P., Qingshi, T., Donaldson, A., Hübner, N., De Wachter, H., Dumont, M., Coroama, V. C., Balaji, B., Peña, C., Martinez, E., Cullen, L., MacMaster, S., Ren, S., Chaudhary, A., Pechancová, V., Valdivia, S., Cecere, G., Yang, Q., Oriekezie, C., Datta, A. Artificial intelligence meets LCA: a critical analysis from technical, ethical, and organizational perspectives. International Journal of Life Cycle Assessment. *(In Preparation)*

[2]. Donaldson, A., Balaji, B., Oriekezie, C., Kumar, M., & Patouillard, L. (2025). An Expert-grounded benchmark of General Purpose LLMs in LCA. ArXiv Preprint ArXiv:2510.19886 *(under Review)*
https://doi.org/10.48550/arXiv.2510.19886

Thank you for your attention!