Makersite

The AI tightrope in sustainability: Balancing automation, accuracy, and trust in LCA/EPD

Executive summary

Life Cycle Assessments (LCAs) and Environmental Product Declarations (EPDs) are critical for making informed, sustainable decisions, but traditional methods are too slow and data-intensive to scale. AI can help meet these challenges, but only if we use it wisely, understanding its potential, its boundaries, and what makes it effective.

This white paper serves as a practical guide for sustainability professionals to understand where AI can truly add value in LCA workflows and where it can introduce risk. Drawing on Makersite's expertise, it explores how to combine automation with data integrity and expert oversight to deliver faster, more trustworthy environmental insights.

Here are three key takeaways:

- **Trustworthy AI starts with trusted data:** Generic AI tools lack the scientific rigor for credible LCA. Reliable automation depends on curated data foundations and expert oversight.
- **AI can enhance, not replace, expertise:** Purpose-built AI can accelerate LCA workflows and improve data quality, but sustainability decisions still require human judgment.
- **Transparency is essential for credibility:** To meet regulatory and stakeholder demands, LCA tools must offer auditable, compliant, and explainable results, not black-box outputs.

A comparison of typical AI approaches in LCA

	Generic AI model approach	Purpose-built AI-LCA framework
Core engine	General purpose LLMs, opaque algorithms	Specific ML and purpose-built AI Models, transparent methodology
Data handling	Unverified gap filling relies on web scraping/LLMs output	Starts with customer data, uses curated premium databases not accessible by LLMs
Expert role	Minimal, overlooked, replaced	Central: Training, validation, interpretation
Transparency	Low - "black box"	High - auditable data lineage
Outcome	Fast but mostly inaccurate, non-compliant risk	Scalable, credible, compliant, actionable insights
Trust	Eroding	Accurate and transparent

Introduction

More and more companies seeking a deeper understanding of their products conduct Life Cycle Assessments (LCAs) to identify improvement opportunities across the entire product lifecycle and make data-driven decisions for more sustainable and efficient design, sourcing, and production.

Also the demand for Environmental Product Declarations (EPDs) is rising rapidly as regulators, customers, and value chain partners increasingly require transparent, standardized, and credible data of the environmental impact of products that support sustainable procurement decisions.

On top of all regulations like ESPR-DPP and CPR, alongside customer mandates and corporate sustainability commitments, drive the need for environmental insights at scale and this demand has outpaced traditional, manual methods. Naturally, Artificial Intelligence (AI) has emerged as a powerful technology supporting the necessary speed and automation across complex value chains.

However, this rush towards AI-driven solutions requires closer examination. Seasoned practitioners are rightly concerned as we witness faster outputs potentially sacrificing rigor, leading to a 'quality slipping' perception. Materials and fuels in LCI databases come with defined physical properties such as moisture content, lower heating value (LHV), and combustion emission factors for fuels. Relying on a "best match" without verifying these critical specifics can lead to wildly inaccurate results, with environmental impacts potentially miscalculated by devastating margins—sometimes by tens of thousands of percent.

While AI, particularly large language models, excels at rapid data processing and retrieval, it often lacks the nuanced, context-specific judgment and problem-solving creativity essential for rigorous LCA methodology. As prominent AI researchers like Yann LeCun (Meta)[1] have noted, while current LLMs excel at processing known information, it generally lacks inherent capabilities for novel problem-solving and validated reasoning, skills essential when navigating the complexities of LCA. Relying solely on unchecked automation risks amplifying errors or creating plausible but inaccurate outputs.

Achieving both scale and scientific integrity, therefore requires a balanced, collaborative approach, one that bridges automation with essential human expertise and oversight. The critical challenge for our field is clear: How do we leverage AI's power for scale without sacrificing the trustworthiness vital for credible environmental assessment?

AI potential and risk in Life Cycle Assessments

Today's LCA tools are increasingly integrating AI to automate key processes, aiming to address the scalability bottleneck created by traditional methods.

- **Elaborate complex supply chains:** One of the key promises of AI integration into LCA tools is to model multi-tier supply chains beyond simple material matching. However, current "automation" often relies on superficial string-matching, ignoring crucial details like upstream processing steps, specific manufacturing technologies, logistics routes, supplier practices, and regional variations that heavily influence environmental impacts. True elaboration requires AI capable of contextual reasoning over diverse data to reflect how products are actually made.

[1] "Why Can't AI Make Its Own Discoveries?" - Big Technology Podcast (2025)

- **Enrichment of data without explicit matching:** AI has the potential to intelligently connect disparate data sources (BOMs, supplier declarations, material specs) without manual mapping, surfacing overlooked connections for more complete LCAs. Yet, today's general-purpose LLMs often lack the domain knowledge, structure awareness, and trust layers for sensitive supply chain data. Without robust semantic understanding and enterprise-grade data integration, AI enrichment remains unreliable. The opportunity is in domain-trained models combining AI with structured product intelligence.

- **Interrogation – simplifying data input via AI prompts**: Another key benefit AI could bring to LCA is improved user interaction. Instead of filling in rigid, complex forms, users could be guided through conversational “prompts” that feel more intuitive. This would reduce friction in data collection and onboarding. But while this improves usability, it does not solve the scalability issue most organizations face. Companies that are mature enough to perform LCAs typically need to assess thousands of products across diverse regions, suppliers, and configurations. Manually “prompting” for every product variant or component becomes a bottleneck of its own.

- **Report writing & interactive output:** AI can summarize complex results, answer queries, and draft compliance documents (EPDs, PEF reports), saving time. However, this assumes accurate, complete, and structured underlying data. Without solving upstream data complexity, AI-generated reports risk being superficial or misleading. The true value lies in AI systems that also automate data preparation and validation.

But a Life Cycle Assessment is only as good as the data and methodology behind it. While LCA automation holds revolutionary potential, significant roadblocks remain concerning data quality, availability, integration, and crucially, the responsible application of AI itself.

Before leveraging AI at scale, data maturity is key, but even with good data, the AI approach matters immensely. A recently published research article in the Journal of Industrial Ecology[1] stated that data quality, structure, and completeness are more critical than model complexity when applying ML to LCI gap-filling.

Early attempts at AI-driven LCA/EF mapping often fell short due to domain-specific data limitations, poor contextual understanding, and lack of interpretability. Now, while advanced techniques like Large Language Models (LLMs) with the utilization of Retrieval-Augmented Generation (RAG), a method that enhances model outputs by dynamically retrieving relevant external data, offer more sophisticated capabilities for parsing information and suggesting connections, applying them without rigorous expert oversight and grounding in validated data creates substantial risks.

[1]A data-centric investigation on the challenges of machine learning methods for bridging life cycle inventory data gaps (2025)

Not all AI is created equal, and applying generic AI tools (like standalone LLMs and wrappers) directly to LCA/EPD creation is not the way:

- **The "garbage in, garbage out" amplifier**: LLMs trained on the vast, uncurated internet lack the validated, context-specific data essential for LCA. They risk embedding biases, using outdated information, or simply "hallucinating" plausible but wrong environmental impacts.

- **Ignoring LCA nuance**: Creating a credible LCA/EPD requires deep understanding of specific standards (ISO 14040/44 etc.), allocation rules, system boundaries, and impact methods. General-purpose LLMs models don't inherently possess or reliably apply.

- **The dangerous fallacy of unverified gap filling**: Some vendors claim AI can simply predict data to fill gaps in your BOM or supplier information. This is irresponsible. Real data gaps require conservative assumptions, use of verified secondary data from scientific databases, or direct supplier engagement, but not AI fabrication. Relying on invented data yields meaningless results that can't be verified and constitutes greenwashing.

- **The black box problem**: When an AI system lacks transparency, failing to disclose its data sources, the assumptions it makes, or the steps behind its calculations, its outputs become unverifiable and inherently untrustworthy. Without clear traceability and interpretability, stakeholders cannot assess the quality or reliability of the results, undermining confidence in any sustainability claims derived from them.

Why purely LLM-based LCAs can't meet ISO standards

ISO standards (14040/44, 14067, 21930, etc.) provide the essential framework for LCA/EPD process (goal/scope, inventory, impact assessment, interpretation). Adherence ensures procedural rigor. However, **ISO compliance alone doesn't guarantee the accuracy or reliability of the underlying data or models,** especially when complex AI is involved. An LCA can follow the ISO steps perfectly but produce misleading results if built on flawed data or opaque, unvalidated AI assumptions. In the age of AI, scrutiny must go beyond procedural checklists.

Moreover, given the ISO standards' emphasis on transparency, data quality, and justifiable assumptions, a reputable certification body will not verify results derived exclusively from an unexamined 'black box' AI model. This lack of transparency prevents the necessary validation required by the standards. LCAs based on generic LLM predictions lead to wrong or misleading results even if the ISO-compliant process was rigorously followed.

Benchmark: LLM outputs vs. verified data

To illustrate this risk, the following table directly compares weight and CO2e estimates for a range of standard electronic components. Results from a leading general-purpose AI (OpenAI) are contrasted with verified supply chain data, revealing significant potential discrepancies. This represents a sample of our findings; please contact Makersite to learn more.

MPN	Weight			CO_2e		
	ChatGPT[1]	Primary Data	Delta	ChatGPT[1]	Primary Data	Delta
MAX4534EUD+	0.140	0.055	**-61%**	0.335	0.181	**-46%**
SN74ALS20ADR	0.129	0.151	**17%**	0.309	0.119	**-62%**
BQ294705DSGR	0.008	0.012	**47%**	0.019	0.027	**41%**
STL24N60M2	0.180	0.180	**0%**	0.430	0.454	**6%**
ULN2003D1013TR	0.290	0.150	**-48%**	0.693	0.158	**-77%**
5962-1620701VXC	0.008	2.119	**26406%**	0.019	5.915	**30866%**
1-1871468-2	50.000	0.608	**-99%**	119.459	0.014	**-100%**
SIMX8DX5AVLF1BB	3.082	3.081	**0%**	7.362	6.973	**-5%**
6609047-3	0.008	1381.385	**17278961%**	0.019	97.222	**508903%**
EP20K1500EFC33-2	0.008	10.933	**136654%**	0.019	24.617	**128783%**

[1]ChatGPT results represent the best outputs achieved via multiple iterative prompts using the latest available OpenAI models (Q2 2025, accessed via Microsoft's Copilot). The stark deviations highlight the unreliability of using generalized, probabilistic models for precise technical data compared to structured, verifiable sources and validated EF mappings essential for credible LCAs.

The path to scale with trust: AI powered by curated data & expert validation

The responsible path forward leverages AI as a powerful tool for sustainability experts to augment their expertise. As you explore AI-driven LCA solutions, keep these elements in mind:

1. **Ground yourself with the data you already have**: Start with the actual data in your existing systems (BOMs, FMDs, transaction, supplier inputs). Here AI's initial role is to help you structure and understand this specific information. This credible approach in automation ensures that costs and resources don't increase over time or with expanding product coverage.

2. **Save time with targeted AI for defined tasks:** Let specifically trained machine learning models handle the LCA-relevant tasks for you

    - **Smart matching & enrichment**: Linking your parts, materials, substances, and suppliers to entries in curated scientific databases (materials, processes, energy grids, EFs). This is intelligent mapping, not fabrication.
    - **Accurate classification**: Assigning manufacturing processes, materials, and other LCA-critical attributes on patterns based on your actual product data.
    - **Responsible gap filling**: AI can significantly improve gap filling by systematically evaluating and selecting the most appropriate proxies from curated databases, guided by a framework of established LCA rules and expert-defined constraints. This ensures AI contributes to data completeness responsibly, and gives you full traceability and transparency of the chosen proxies and the logic applied.
    - **Controlled use of GenAI**: Generative AI has specific, limited roles, such as helping interpret cryptic part descriptions or suggesting potential manufacturing routes for expert review. It is not capable of generating core impact factors or fill primary data gaps for you.

3. **Stay in control:** Ensure models are refined by LCA experts, and AI-generated suggestions on mappings, classifications and compositions are validated. Also make sure the underlying models themselves are trained and refined based on expert feedback through strict QA processes.

4. **Experts interpret & strategize**: The expert remains in control, defining the study, validating inputs, interpreting AI-generated results in context, and deriving strategic insights. This will shift your focus from number-crunching to change-making.

    - **Transparency by design**: Ensure clear data auditability. Can you see where the data came from? What factors were applied? And what assumptions were made? For example, automatically generated EPDs undergo a multi-stage quality check. To ensure successful verification, not only the model is checked, but samples of the EPDs are also regularly manually reviewed.

With routine tasks automated, sustainability professionals can focus on:

- **Scenario modeling and hotspot identification.**
- **Strategy development for decarbonization.**
- **Explaining and defending LCA/EPD outcomes with confidence.**

Conclusion: Scaling LCAs with trust – the Makersite standard

The future of scalable, credible LCA lies in using AI not as a replacement for expertise, but as an enabler of it. By grounding automation in curated, transparent data and embedding expert oversight into every step, organizations can unlock speed and efficiency—without compromising scientific integrity.

A best practice example is the partnership between Microsoft and Makersite[1]. Makersite automates and scales the modeling of Microsoft's complex electronic products with an unprecedented level of primary data coverage. The key differentiation from common practices is that Makersite's AI analyzes the bill of material (BOM) of each device and the material composition from primary data collected from suppliers to automatically model each part, component, and sub-assembly down to its actual chemical composition.

A model of a representative manufacturing process is associated with each part in the BOM using data from Makersite's world's largest supply chain database with 150+ data sources, cutting out much of the manual effort and providing Microsoft's LCA practitioners a running start.

To succeed, sustainability teams must focus on responsible AI deployment: starting with trusted internal data, applying targeted and explainable models, and ensuring that all outputs are verifiable and auditable. This approach doesn't just meet compliance, it empowers experts to lead change, translating complex environmental data into strategic action.

When done right, AI helps sustainability professionals shift from data wrangling to strategic impact, accelerating better decisions, faster innovation, and more credible product claims. That's the real opportunity: scaling sustainability with trust.

[1]Microsoft Consumer Devices Life Cycle Assessment Methodology Overview (2024)