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Artificial intelligence agents automate life-cycle assessment

Assessing the carbon emissions of an electronic device from raw material extraction to disposal requires time-intensive data collection for each component. Now, artificial intelligence agents autonomously generate life-cycle inventories for electronic devices in under a minute and estimate carbon emissions with less than 19% deviation from expert assessments.

This is a summary of:
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The problem

Electronic devices account for a rapidly growing share of global greenhouse gas emissions and decisive intervention is needed to meet the climate targets for 2030 and beyond[1]. An important step for reducing carbon emissions is to accurately quantify which components or processes they come from. The carbon emissions associated with a product are typically estimated through a life-cycle assessment (LCA), a rigorous methodology that traces environmental impacts across an entire supply chain — from raw material extraction through to end-of-life disposal[2]. The LCA of a single electronic device with hundreds of components can take weeks or months because expert analysts must manually gather data scattered across proprietary supplier documentation and disparate organizational silos. Methodological inconsistencies and sparse emission factor databases undermine reproducibility and cross-study benchmarking[2,3]. As public demand for environmental transparency grows[4] alongside mounting regulatory pressure, scalable tools that can assess the environmental impact of electronics and ultimately drive decarbonization are needed.

The solution

We designed two specialized multimodal artificial intelligence (AI) agents that automatically populate a life-cycle inventory (LCI) for a given product and calculate the carbon emissions throughout its life cycle. One AI agent — which we named the 'LCA agent' — decomposes a product into its constituent components and then identifies their relevant attributes. This LCA agent passes queries to a second AI agent — the 'stakeholders agent' — that iteratively searches publicly available online sources and runs custom software tools to extract information about the attributes of the components (such as grams of material or circuit board area). Optionally, proprietary supplier documentation can be provided by the user. The information is collected in a structured data abstraction (Fig. 1a). This process emulates how human LCA experts retrieve information from stakeholders. The LCA agent then completes a standard LCI assessment: it maps the LCI to carbon emissions by using emission factors from LCA databases (for instance, kilograms of carbon dioxide equivalent per gram of copper). The AI agents take only a product name as their input and complete the assessment in under 1 minute.

The resulting carbon emissions estimates deviate from estimates produced by experts by less than 19%. This deviation is comparable to the deviation arising from methodological differences, which can be 20% or more[3,5] (Fig. 1b). To accelerate the assessment further, we developed a complementary approach that bypasses the construction of LCIs for individual components. This approach exploits the observation that products with similar attributes often produce similar carbon emissions: we represented laptops, desktop computers and displays as weighted combinations of similar products with known carbon emissions. With this approach, we achieved an error of 12% relative to manufacturer-reported carbon footprint figures. To demonstrate that this approach can also be applied to materials, we estimated the emission factors of unknown plastics by representing them as a weighted combination of known materials. This approach achieved an error of 23% — much lower than the 143% error achieved by experts using search engines and AI chatbots to select the closest emission factor in a database.

The implications

By automating the most time-intensive stages of the LCA, our AI agents enable rapid carbon footprint estimation at a large scale. Our approach can guide low-emission design choices for components and materials early in the product development cycle and enables rapid environmental labelling of existing products. Beyond electronics, our approach can be adapted to other manufactured goods with complex and fragmented supply chains.

Unlike domains with objectively verifiable ground truth, the results from an LCA depend on system boundary choices, modelling assumptions and the granularity of the supply-chain representation. Our AI agents are intended as a tool for rapid iterative estimation controlled by LCA experts through methodological decisions. To minimize the energy consumption, our AI agents leverage caching, existing pre-trained models and custom lightweight algorithms. Nevertheless, the environmental cost should be considered if such AI tools are deployed at scale.

The decarbonization of electronics will require companies to use the carbon emission estimates to invest in sustainable products and supply chains. Similarly, consumers should make purchasing decisions based on the environmental impact of a product. Our AI agents could also inform government regulation, economic incentives and efforts to raise environmental awareness among the public to support decarbonization.

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EXPERT OPINION

"This work explores a timely and appealing topic of deploying AI agents for sustainability assessment. Such agents have the potential to considerably reduce both time and cost, while performing competitively with human experts."
An anonymous reviewer.

FIGURE

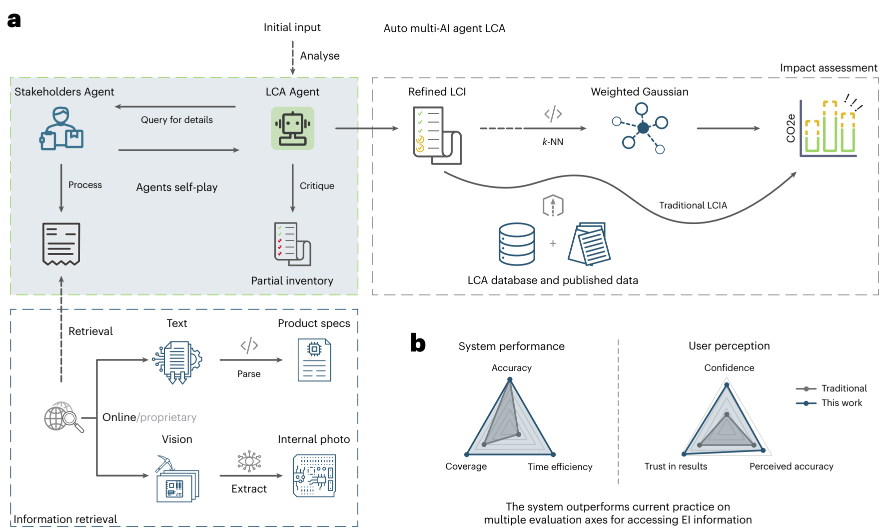

Fig. 1 | LCA automated by AI agents. a, The LCA agent takes a product name as input and decomposes it into a required LCI, querying the stakeholders agent. The stakeholders agent retrieves granular textual and visual component information from online or proprietary sources to construct a partial LCI. The LCA agent critiques and iteratively refines this output with the stakeholders agent (self-play). The refined LCI informs either traditional life-cycle impact assessment (LCIA) using databases and published emission factors, or a weighted nearest-neighbours (k-NN) approach, yielding an environmental impact (EI) assessment. **b**, Our approach outperforms current practice in both technical performance (left) and user perception (right) compared with traditional search by human agents. CO2e, carbon dioxide equivalent. Credit: icons in **a**, Noun Project under a Creative Commons license CC BY 3.0. © 2026, Zhang, Z. et al.

BEHIND THE PAPER

Our interest in automating LCAs grew naturally from earlier work on sustainable materials and electronics. About 3 years ago, we repeatedly found ourselves frustrated by the same bottleneck: we could design a component with sustainability in mind, but quantifying its environmental impact required weeks of painstaking manual work by specialist analysts. That disconnect prompted us to interview LCA experts about what part of their work consumed the most time.

We learned that an LCA is a distributed information retrieval challenge, which AI agents can tackle. Automating the full LCA end-to-end pipeline had always been our ambition, but it proved difficult. Along the way we developed intermediate tools, including methods for comparative analysis with incomplete information[5], each one bringing us closer to our goal. Getting the multi-agent system to perform reliably for real products, with no proprietary data, was the hardest problem we have faced as a group. **Z.Z. & V.I.**

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This article presents a computational tool for comparative LCA with incomplete information.

FROM THE EDITOR

"Assessing the emissions from electronic devices can be a complex, months-long process. Here, the authors develop an AI-driven workflow that collects information from various public sources, and, when emission factors for a specific material or process are unknown, uses knowledge about similar devices to make best-guess estimates of their environmental impact."
Matthew Parker, Associate Editor, *Nature Electronics*.