Assessing sustainability hotspots in the production of FR4 PCBs

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The world is experiencing significant electronification, driven by digital transformations and the rise of IoT, which are expected to keep rising in the upcoming years. This growth has seen a concomitant surge not only in the amount of e-waste — 62 billion kg of e-waste produced in 2022 [1]—but also in greenhouse gas emissions and diverse other environmental impacts. Printed circuit boards (PCB) form currently the basis of the electronics industry, and, as such, play a critical role in the sector's environmental footprint.

Investigating the quantification of the impacts of PCBs production is hence critical to sustaining this sector's longevity. In our study, we model the manufacturing of FR4 (Flame Retardants Class 4) PCBs in a facility located in Italy, through a life cycle assessment (LCA) approach. Primary results of the model will be discussed with a focus on the possible iterative strategies to mitigate disproportionately high environmental impacts, labeled as 'sustainability hotspots', from materials and processes used during production which are relevant for high-volume applications.

Challenges related to primary data collection and uncertainty will be discussed, as site-specific data and manufacturers' inputs may put into perspective certain conclusions. The study follows a cradle-to-gate LCA framework, thus integrating realities from raw materials extraction to factory output. The life cycle model, based firstly on a life cycle inventory, traces the flows of raw materials (laminated copper, epoxy and glass fiber pre-pregs, solder masks,...) through all process steps (comprising over 60 steps; drilling, hole conductive treatment, copper electroplating, etching, curing, routing, etc.) that are implemented when manufacturing a PCB. This mapping out of the network of materials and energy flows will be necessary to identify critical processes, but also alternative design and manufacturing strategies of the PCB itself.

Existing literature studies [2] have shown for example, that the majority of the contribution to freshwater aquatic ecotoxicity potential (FAETP) can be attributed to the disposal of copper-containing wastewater treatment sludge from etching operations to incineration, hence advising that etching operations are in the focus for environmental impact reduction. Our work seeks to improve the current knowledge of PCB manufacturing from an LCA point of view and explore potential improvements within the existing FR4-based system toward its will to commit to limiting environmental burdens.

Additionally, a parallel ongoing study will be addressed. Since PCBs are a technological waste of difficult disposal whose recycling is complex and expensive due to the diversity of materials and components and their difficult separation, the DESIRE4EU project is developing an alternative material to substitute current typical FR4 PCBs with a new substrate in certain applications. Towards its end-of-life, a PCB composed of such substrate would be compatible with a bioleaching treatment for copper recovery. The novel polylactic-acid/flax-composite substrate [3] is composed of biodegradable, reinforced, and flame-retarded pre-pegs with the motivation to present a working circuit in commercial complexity that can be implemented on such rigid substrate with a structure very similar to the widely FR4. The feasibility of manufacturing PCBs on this novel substrate is being tested at an early technological readiness level (TRL 2–3), with copper-clad pre-pregs processed using subtractive printed wiring technology and through-hole plating. Future research will focus on modeling this lab-scale emerging technology and later on, on assessing its potential for industrial adoption.

This work aims to establish a comprehensive LCA model of the full-market existing system FR4 PCB's production and a possible substitute under investigation, providing a foundation for reducing the sector's environmental burdens and informing sustainable innovation.

References:

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