From Bottom-Up to Top-Down: Rethinking Approaches to Assessing ICT's Mineral Dependencies

The expansion of the *Information & Communication Technology* (ICT) sector is correlated with a growing production of hardware devices. According to Cisco [1], the number of digital devices *per capita* rose from 2.4 in 2018 to 3.6 in 2023, resulting in 29.3 billion connected digital devices globally. As such, the ICT sector significantly contributes to the immobilization of critical metals and minerals, both in quantity and diversity, due to its extensive material demands. For instance, Emsbo et al. state that manufacturing a smartphone requires up to 75 natural minerals [2].

However, achieving net-zero *greenhouse gas* (GHG) emissions by 2050 [3] necessitates a significant shift away from fossil fuels, resulting in most energy production sources becoming electrical. To achieve such energy transitions, substantial quantities of minerals are projected to be extracted, "*equivalent or exceed[ing] the cumulative amount produced from Antiquity to the present*" [4]. These minerals, such as copper, lithium, nickel, cobalt, rare earth elements, etc. are also essential for manufacturing ICT goods, forecasting a race for minerals between the energy and ICT sectors.

Given this context, should constraints will be imposed on the development of the ICT sector? How can researchers explore computing within mineral limits?

Shaping sustainable computing systems necessitates an understanding of the intricate relationship between the ICT and mineral industries. However, suitable data is not yet available, as existing studies mainly rely on the combination of bottom-up *Life Cycle Analysis* (LCA) data and top-down market data to assess the ICT sector's environmental footprint [5], which perpetuates the limitations of LCAs. Notably, publicly available LCAs of ICT goods (such as [6]) mainly address only GHG emissions. When mineral depletion is considered, it is typically measured through the *Abiotic resource Depletion Potential* (ADP), which aggregates various minerals into a single category, thus hindering detailed studies of individual minerals (e.g. their criticality, grades, recycling, etc.).

To overcome these limitations, we propose a shift from bottom-up to top-down approaches, which offers a global perspective that allows to incorporate limits, planet boundaries and sector dependencies.

By analyzing the embedded environmental footprint within monetary flows, *Environmentally Extended Input/Output analysis* (EEIO) enables the assessment of a sector's footprint across various categories—such as GHGs, water consumption, and mineral dependency—and can help in identifying emerging trends and critical areas. Consequently, the interdependent nature of EEIO facilitates the elucidation of critical links between the ICT sector, energy transitions, and the mineral industries.

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