Doctoral Dissertation
Doctoral Program in Energy Engineering (37th Cycle)

Computational Model for the improved management of E-waste

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Abstract

This dissertation investigates critical challenges in the field of sustainable electronic waste (WEEE) management, with a particular focus on the fragmentation of knowledge across technological, material, and hazard domains, and the widespread reliance on generalized assumptions in material recovery processes. To address these issues, this research has investigated the possibility of developing a multi-domain ontology-based Decision Support System (DSS). The system scalable, reusable, and can be integrated to support informed decision-making aligned with green circular economy principles.

The developed ontology consolidates key knowledge by integrating information derived from scientific literature and industry practices, while keeping in mind the European Union legislative frameworks, particularly the WEEE and RoHS directives. As a result a proof of concept was initially established with a focus on the solar photovoltaic (PV) sector, to demonstrate the model's, flexibility, and capacity for expansion without compromising its foundational structure. To validate the ontology's scalability and broader applicability, some concepts from the printed circuit boards (PCBs) sector were incorporated.

Additionally, a comprehensive experimental study was conducted on different PCB categories extracted from personal computers, including motherboards, RAM modules, and CPUs/chipsets. This in-depth investigation has permitted to assess the variations in material compositions across categories and models, with particular attention to critical and valuable metals such as copper, gold, and silver. The results revealed significant differences within PCB categories. This underlined the importance of using precise, category-specific data in WEEE handling and highlighting the potential of the developed ontology to tackle this issue by capturing the variability through detailed and flexible data structures.

In parallel, experimental investigations were carried out to evaluate the effect of DMSO solvent pretreatment on the recovery efficiency of metals from PCB samples. Different particle size groups were analysed to determine their influence on the liberation and extraction of metals, particularly copper. The results were promising allowing to reach an optimised DMSO pretreatment applied to PCBs of particle size range between 5.6 mm to 2 mm, leading to a significant improvement in the metal recovery rates. The investigation also showed that a near-complete recovery was achieved without pretreatment for particles smaller than 400 µm, highlighting a trade-off between process complexity and material recovery optimization.

The developed ontology was validated using SPARQL queries which allowed to imitate a fully developed system. The validation process ensured the logical consistency, internal coherence, and responsiveness of the system to the different decision-making scenarios. Additionally, the dissertation gives a critical overview of the limitations encountered, including data quality challenges, integration complexity, and the need for dynamic updating mechanisms. Solutions are proposed to address these issues and to enable future expansions of the system. Collaboration Eni SpA as an industrial partner has ensured the practical relevance and multidisciplinary robustness of the developed solution.

In conclusion, this research delivers a comprehensive, ontology-driven decision support system

that not only bridges interdisciplinary gaps in e-waste management but also couples modelling with experimental validation through PCB material characterization and DMSO solvent pretreatment for metal recovery optimization. The DSS framework developed offers a powerful tool for sustainable e-waste management which is adaptable to different contexts and capable of supporting the evolving recovery strategies and techniques. It establishes a solid foundation for future research directions in the field of computational sustainability with the goal to integrate technical, environmental, economic, and social dimensions into circular economy practices and offer a simplified overview of the WEEE sector and its sound handling practices.