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MAPPING AND COMPARATIVE ANALYSIS OF ARTIFICIAL INTELLIGENCE APPLICATIONS IN THE CIRCULAR ECONOMY

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Introduction and Background

The transition toward a Circular Economy (CE) requires intensive digital innovation, with Artificial Intelligence (AI) identified as a crucial accelerator for achieving sustainability in areas such as resource management and production. This study examines the global landscape of AI and Machine Learning (ML) applications in CE systems, addressing the complexity of material flows and the demand for real-time data. The specific objective is to map the latest trends, methodologies, and best practices in the integration of AI to enhance material circularity, resource efficiency, and production sustainability.

Methodology

The analyzed material consists of a benchmarking of a large corpus of publications produced between 2019 and 2025, including academic articles and technical reports from the fields of engineering, computer science, and environmental sciences. The study focuses on the application of advanced AI techniques, such as Deep Learning (DL), Computer Vision, and hybrid AI + Multi-Criteria Decision Analysis (MCDA) models. The data used range from large image datasets (e.g., 40K-sample datasets from industrial environments for plastic waste classification) and operational Life Cycle Assessment (LCA) data to SCOPUS-indexed bibliometric corpora (comprising 104 documents) used for thematic analyses.

Results

The results demonstrate a broad and robust application of AI across at least four critical domains:

1. **Waste Sorting:** Convolutional Neural Networks (CNNs) integrated with IoT technologies enable intelligent, real-time classification of municipal solid waste, plastics, and construction and demolition (C&D) waste. The performance of various DL architectures was compared to guide optimal selection for industrial-scale sorting applications.
2. **Environmental Assessment:** ML models are used as surrogates to automate and streamline LCA in circular production systems, enabling rapid scenario exploration and the direct integration of AI into decision-support tools.
3. **Circular Materials Design:** AI/ML facilitates materials property prediction and design-space exploration, embedding circularity criteria (recyclability/reusability) from the early stages of product development.
4. **Reverse Logistics:** Hybrid models combining AI and MCDA optimize reverse supply chains for solid waste, improving the efficiency of return flows. In addition, AI enables the assessment of CE maturity at the firm level through ML-based text analyses.

Conclusions and Implications

AI is an essential operational tool that transforms CE from theoretical concepts into scalable, data-driven solutions deployable under real-world operating conditions. The implications highlight the necessity of integrating AI best practices, including dual validation through rigorous LCA studies and aligning AI projects with governance and ethical objectives within socio-technical systems. AI-based solutions can support EU Member States in strengthening their circular economy agendas, particularly with regard to the enforcement of sorting regulations.

Keywords: *comparative analysis*, *machine learning*, *life cycle assessment*, *reverse logistics*, *waste sorting*, *sustainability*

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