Smart Digital Integration and Multi-Criteria Impact Assessment for Circular Economy Scenarios in Urban Development

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Abstract

Circular economy implementation typically requires multiple technologies to interact across infrastructures and stakeholders. However, digital planning and assessment solutions often assume extensive data centralization, increasing integration overhead and slowing decision-making. This paper presents the Circularity Optimizer, a digital framework for minimum-necessary data exchangeand multi-criteria impact assessment. It combines (i) participatory scenario development in a 3D environment, (ii) a technology catalogue with standardized factsheets and input/output flow descriptions, and (iii) an ESG-oriented indicator system enabling transparent evaluation across technical, ecological, economic, and social dimensions. A visual interface translates complex system configurations into comprehensible spatial scenarios for diverse stakeholders. The approach forwards only the information needed to assess selected circularity objectives, supporting interoperable integration of heterogeneous sources.

The method is demonstrated in an integrated workflow where a 3D-based system for visual stakeholder communication (URBAN MENUS) is linked to ESG data analysis (ESG-Cockpit) via API and combined with modelling of circular technologies. A prototype around a wastewater treatment plant in Gleisdorf (Austria) compares a baseline scenario (PV + heat pump) with an extended scenario (biogas CHP, membrane distillation, phosphorus recovery). Results show improved circular and energy performance, increasing circular output from 0% to 38.65% and electrical self-sufficiency from 1.44% to 26.19%, while making trade-offs in heat coverage and investment requirements explicit. The approach is designed for transferability and is briefly discussed for a follow-up application in a defined district in Kunshan (China).

Keywords

Circular economy, digital transformation, technology integration, data interoperability, impact assessment, ESG indicators, industrial–urban symbiosis, scenario planning, digital decision support, resource efficiency.