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A hybrid optimization-simulation framework for sustainable closed-loop supply chains design and planning

Sustainability challenges have become a central concern in supply chain design and planning, requiring effective decision-support methods that address economic, environmental, and social objectives. This work proposes a hybrid optimization–simulation framework that combines a mixed-integer linear programming model, used to optimize sustainability goals through a novel practically oriented objective function, with a discrete-event simulation model to assess the solution under uncertain conditions. A closed-loop supply chain design, inspired by the case of a chemical manufacturer, is optimized and subsequently simulated under realistic variability scenarios to yield more feasible sustainable solutions. Results demonstrate how operational decisions, such as workforce expansion, enhance demand fulfillment, while strategies like order consolidation contribute to environmental improvements. The proposed framework provides a structured methodology for evaluating strategic trade-offs across the triple bottom line, offering actionable insights for supply chain managers aiming to align operations with long-term sustainability objectives.

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