

	<b>Postdoctoral Research Project – Multi-Agent Modeling and Stochastic Optimization for Strategic Waste Management</b>			CGI
				

### Context

Recycling value chains in France and Europe face significant challenges due to the diversity of actors involved, the fragmentation of management systems, the heterogeneity of material flows, and increasing economic and regulatory constraints. This structural complexity is further amplified by the interdependence of processes, variability in available resources, and the growing need for industrial and technological sovereignty. While the literature on the circular economy is extensive, much of the existing research remains focused on local process optimization (e.g., energy efficiency, waste reduction, yield improvement) or on individual actors, without fully addressing the systemic dynamics and multi-scale interactions required to build robust and resilient recycling networks.

To address these challenges, recent studies emphasize the need to move beyond siloed approaches and develop systemic models capable of integrating the entire product life cycle, delayed decision feedback, sector-specific constraints, and multi-level governance mechanisms. These approaches must consider not only the physical and economic characteristics of materials but also the collaborative dynamics between heterogeneous actors, the uncertainty of material flows, market unpredictability, and the rapid evolution of technologies and regulations.

### Problem Statement

This work proposes an innovative approach to structuring and managing recycling value chains as dynamic, interconnected, and territorially embedded networks. Based on Systems of Systems (SoS) engineering, the project aims to overcome the limitations of local optimization by integrating multi-level interactions, complex feedback loops, and sector-specific constraints. This vision facilitates the coordination of actors with potentially divergent goals, while providing the flexibility needed to respond to the uncertainties of material flows and the rapid changes in market and regulatory conditions. Digital sciences play a central role in this approach, providing the methods and tools needed to model, simulate, analyse, and orchestrate these complex networks while integrating technical, economic, environmental, and social constraints. The main research axes of the project include:

- Multi-scale control: Integrating decision-making from the nano (material, product) to the macro (territorial or national strategy) levels, accounting for complex interactions and delayed impacts.
- Flow traceability: Using digital twins to model and monitor material flows throughout their life cycle, providing increased transparency for industrial stakeholders.
- Uncertainty management: Developing robust tools based on artificial intelligence, machine learning, and data fusion to handle heterogeneous, incomplete, and uncertain information.
- Flexibility and adaptability: Leveraging digital platforms and simulation tools to enable rapid adjustments to market, regulatory, or material availability changes.
- Dynamic orchestration: Coordinating data flows and real-time decision-making to optimize the overall performance of value chains.
- Subsystem autonomy and coordination: Ensuring interoperability between actors while maintaining their autonomy through distributed, reconfigurable architectures.
- Hyperspectral analysis and material sorting: Developing advanced material characterization technologies, such as hyperspectral imaging and deep learning, to improve sorting, separation, and regeneration of complex materials.

### Research Problem Addressed in this Thesis

This postdoctoral research will address the development of a multi-agent modeling framework integrated with robust and stochastic optimization techniques for dynamic waste management. The project specifically requires hands-on engagement with real-world waste management operations to model complex interactions between multiple stakeholders—households, municipalities, waste collection contractors, recycling facilities, and regional authorities—

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who make decisions under uncertainty and potentially conflicting objectives. The candidate will need to work directly with these stakeholders to understand their operational constraints, decision-making processes, and strategic concerns. The research will build tools to simulate emergent behaviors in waste flows based on stakeholder interactions and field observations, assess the impact of territorial and regulatory constraints through empirical data collection, and guide equilibrium strategies that align stakeholder incentives with circular economy goals. This work demands deep practical understanding of waste management systems, proven ability to establish rapport with industry professionals, and demonstrated experience in translating real-world operational challenges into quantitative models.

### **State of the Art**

Despite notable advances in applying data-driven techniques to urban systems, current models in waste management often fall short on behavioral realism and their ability to respond to uncertainty. A critical gap exists in the disconnect between academic models and the practical realities faced by waste management practitioners. Traditional statistical models and static optimization methods typically lack the flexibility needed to capture the adaptive strategies and complex interactions inherent in multi-stakeholder environments, largely because they are developed without sufficient input from industry professionals and operational experience. While the integration of agent-based simulation with robust optimization has shown promise in various fields like supply chain management and energy systems, its application for strategic waste governance remains largely unexplored, particularly in terms of models that accurately reflect the behavioral patterns and constraints observed in real waste management operations. This research aims to bridge this critical gap by designing scalable hybrid models grounded in empirical observations and stakeholder engagement. These models will effectively combine machine learning for predictive capabilities, agent-based modeling to simulate intricate behavioral dynamics based on actual stakeholder interviews and operational data, and optimization techniques to find robust solutions for waste management challenges that have been validated through industry collaboration.

### **Scientific Challenges**

The research will address several open scientific challenges:

- Designing and validating agent-based models that reflect the behavioral heterogeneity of real-world stakeholders in waste systems through extensive fieldwork and stakeholder interviews
- Integrating these models into a decision-support environment that accommodates multi-level uncertainties based on actual operational variability observed in waste management practice
- Incorporating dynamic feedback mechanisms and adaptive responses to regulation, pricing, and policy changes through direct collaboration with waste management professionals and regulatory bodies
- Developing equilibrium strategies that balance efficiency, compliance, and stakeholder autonomy while accounting for the practical constraints and preferences identified through stakeholder engagement
- Producing transferable tools applicable across different territories and waste types, validated through real-world case studies and industry partnerships
- Bridging the gap between theoretical optimization frameworks and the operational realities of waste management systems through sustained engagement with industry practitioners

### **Action Plan**

To achieve the objectives of this postdoctoral project, the following steps will be pursued:

1. Stakeholder Mapping and Engagement: Identify and establish working relationships with key waste management stakeholders across different territorial scales, conduct interviews to understand operational constraints, decision-making processes, and strategic priorities.

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2. Modeling Framework Development: Develop a modular architecture combining agent-based simulations with optimization algorithms, grounded in empirical observations from stakeholder interactions and operational data.
3. Behavioral Modeling: Calibrate agent behaviors using historical data, expert knowledge, and direct observations from stakeholder engagement, incorporating responses to regulations and incentives.
4. Optimization Integration: Embed robust/stochastic optimization techniques to enable scenario evaluation under uncertainty.
5. Prototype Testing: Apply the model to selected case studies representing territorial variability in France’s waste system.
6. Dissemination and Tool Development: Publish results in peer-reviewed journals and develop a prototype decision-support interface for stakeholders.

### References

- 1) Ogbolumani, O. A., & Adekoya, M. (2025). Intelligent Waste Management Optimization Through Machine Learning Analytics. *Journal of Science Research and Reviews*, 2(1), 7-26.
- 2) Sauvageau, G., & Frayret, J. M. (2015). Waste paper procurement optimization: An agent-based simulation approach. *European Journal of Operational Research*, 242(3), 987-998.
- 3) Tian, X., Peng, F., Wei, G., Xiao, C., Ma, Q., Hu, Z., & Liu, Y. (2025). Agent-based modeling in solid waste management: Advantages, progress, challenges and prospects. *Environmental Impact Assessment Review*, 110, 107723.

### Postdoctoral Project Information

This postdoc is part of a joint collaboration between LEM (IÉSEG School of Management) and CGI (IMT Mines Albi).

Location: Paris (main location) and Albi

Expected Start Date: October 2025

Please note that the confirmation of funding for this project is expected in July 2025.

### Desired Profile:

Background: PhD (or near completion) in Operations Management, Industrial Engineering, Applied Mathematics, Economics, Computer Science, or a closely related field (PhD earned no later than October 2022)

Professional skills:

- Autonomy and motivation for research in sustainability and applied modeling
- Strong English proficiency and at least basic French language skills
- Demonstrated ability to engage with diverse stakeholders and conduct structured interviews with industry professionals

Scientific competencies: Proven expertise in at least two of the following areas—stochastic optimization, agent-based modeling, machine learning, or game theory.

Additional assets:

- Practical waste management experience through research projects, industry collaboration, or professional practice
- Experience in developing Decision Support System (DSS) tools or computational platforms

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- Knowledge of EU and French waste management regulations, policy frameworks, and circular economy principles in European contexts

Application materials: CV, cover letter, three representative publications or working papers, two letters of recommendation, and any other documents supporting your motivation for this project.

**Application Deadline: August 22, 2025, 12:00 PM**

**Notification for Interview: no late than August 29, 2025**

**Contacts:**

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