Centre Génie Industriel

IMT Mines Albi
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Arts Sciences et Technologies et Métiers

PhD Thesis Proposal – Collaborative Information System for Recycling value chains

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

The present PhD will be mainly involved in the project on a task that deals with the design of a collaborative information system. The targeted Information system is distributed, manages the interoperability between partners, detects changes in the context and reconfigures itself accordingly. It must be agile, enabling data sharing, information synthesis, tracking products and supporting the coordination of the stakeholders' decisions.

State of the Art

The recycling chain is viewed as a collaborative ecosystem of heterogeneous and evolving entities. The definition and development of information systems is a recurring theme at the intersection of computer science and industrial engineering. Collaborative information systems aim to facilitate data sharing and the orchestration of processes among multiple partners, relying on services provided by various stakeholders involved in the collaboration. To address the need for agile configuration, model-driven and service-oriented architectures have been developed. A persistent challenge in this domain is ensuring the required interoperability among the various information systems.
The supervisory team has experience in the definition and management of collaborative information systems across diverse contexts requiring agile coordination among stakeholders: biomass valorisation (Houngbé et al., 2019), deduction of collaborative processes (Montarnal et al., 2018), Industry 4.0/5.0, and the enhancement of decision-making processes through new technologies (Rosin et al., 2022).

Scientific Challenges

Several gaps have been identified that will be studied during this PhD:

- Integrating agility on several levels: chain reconfiguration, partner changes, decision process changes, late flows adaptation to materials variability,
- Meta-modelling of minimal necessary information needs based on the required levels of collaboration, to ensure both process lifecycle management and situational awareness.
- Assessing data quality and strategies to address data gaps (e.g., data augmentation, synthetic data creation),
- Monitoring a data-driven model of the value chain that can trigger alerts and enable the reconfiguration of the recycling chain as needed,
- Identifying the technologies most suited to support the information system features.
- Defining a set of methods and tools that are generic enough to be applied to various recycling chains and support the required reconfigurations.

Action Plan

To define the collaborative Information systems, several steps have to be completed:

1. Conduct a literature review on collaborative information systems used in the management of recycling chains.
2. Model the distributed decision-making processes under study.
3. Assess opportunities to enhance this decision-making process with emerging technologies.
4. Identify precisely the data needed to support decision-making processes.
5. Address the various levels of required interoperability.
6. Orchestrate collaborative processes and ensure their agility on an illustrative use case.

References

1) Houngbé, M., Barthe-Delanoë, A. M., & Négny, S. (2019). Servitization of biomass processing for a virtual biorefinery: application to the lignocellulosic biomass in a French local territory. In 20th IFIP WG 5.5 Working Conference on Virtual Enterprises, PRO-VE 2019, Turin, Italy, September 23–25, 2019, pp. 477-486.
2) Rosin, F., Forget, P., Lamouri, S., Pellerin, R., (2022). “Enhancing the decision-making process through Industry 4.0 technologies”, Sustainability, 14(1), 461
3) Montarnal, A., Mu, W., Benaben, F., Lamothe, J., Lauras, M., & Salatge, N. (2018). Automated deduction of cross-organizational collaborative business processes. Information Sciences, 453, 30-49.

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Thesis Information

This PhD is part of a joint supervision between CGI (France) and LISPEN (France).
Location: Albi (main location) – Aix-en-Provence
Expected Start Date: September/October 2025
Please note that confirmation of funding for this project is expected in June or July 2025.

Desired Profile:

Professional skills: autonomy, strong English proficiency (min. B2), motivation for research in sustainable development.
Scientific Competencies and/or research experience: Enterprise modelling (business processes, data meta-models, etc.), Information systems design, Interoperability, Closed-loop supply chains management, AI for knowledge modelling.

Application materials: CV, cover letter, summary of Master's research work, transcripts, and any other documents supporting your motivation for this PhD.

Application Deadline: August 22, 2025, 12:00 PM
Notification for Interview: no later than August 29, 2025

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