# Research Challenges In City Logistics For Circular Supply Chains Of E-Waste

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# RESEARCH CHALLENGES IN CITY LOGISTICS FOR CIRCULAR SUPPLY CHAINS OF E-WASTE

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**KEYWORDS:** circularity, circular economy, city logistics, collaboration, E-waste, urban circular supply chain, urban mining, WEEE

## ABSTRACT

This paper presents challenges in city logistics for circular supply chains of e-e-waste. Efficient e-waste management is one of the strategies to save materials, critical minerals, and precious metals. E-waste collection and recycling have gained attention recently due to lower collection and recycling rates. However, implementing circular urban supply chains is a significant economic transformation that can only work if coordination decisions are solved between the actors involved. On the one hand, this requires the implementation of efficient urban collection technologies, where waste collection companies collaborate with manufacturers, urban waste treatment specialists, and city logistics service providers supported by digital solutions for visibility and planning. On the other hand, it also requires implementing urban and regional ecosystems connected by innovative $CO_2$-neutral circular city logistics systems. These systems must smoothly and sustainably manage the urban and regional flow of resources and data, often at a large scale and with interfaces between industrial processes, private, and public actors. This paper presents future research questions from a city logistics perspective based on a European project aimed at developing a blueprint for systemic solutions for the circularity of plastics from applications of rigid PU foams used as insulation material in refrigerators.

## INTRODUCTION

This paper is one of the first results of the H2020-sponsored research project Circular Foam (https://circular-foam.eu/), in which Amsterdam University of Applied Sciences participates. The research project aims to develop a blueprint for circular urban regions, including the demonstration of a territorial cross-sectorial, large-scale and sustainable systemic solution for the circularity of plastics from diverse applications of rigid polyurethane (PU) foam. This PU foam is currently used as insulation material in refrigerators and construction elements. In the next three years, this research project will develop a blueprint for regional participative governance using an approach involving multiple actors from the public-, private-, academic-, and financial-sectors and civil society. Furthermore, the role of city logistics and collection services is to make these materials accessible for downstream sorting and recycling processes for the first time in a sustainable and economically viable way.

### Develop a Blueprint For a Circular Urban Region

Efficient electronic waste (e-waste) management is one of the strategies to save materials, critical minerals and precious metals that have limited global reserves or supplies. E-waste collection and recycling have gained attention recently due to lower collection and recycling rates. The European Union (EU) has legislated Waste Electrical and Electronic Equipment (WEEE) management since 2002. Between 2016 to 2020, the collection rate of e-waste dropped to from 50% to 44%. The Netherlands scored only 55% using the (certified) WEEE-generation approach to reporting and 33% using the EEE POM (Put on the Market) approach. One of the obstacles in reaching collection targets is that considerable amounts of WEEE are diverted to other undocumented WEEE flows. Unofficial or illegal WEEE flows must be minimized and steered into the formal WEEE management regime (WEEE, 2022). The exports for reuse and illegal exports are hardly monitored in most European countries due to the lack of trade codes for used WEEE. Stakeholders estimate 50% of undocumented WEEE flows are incinerated, and non-certified companies handle the other 50% (WEEE, 2022).

The literature review in this paper will explore what role urban collection has in lower collection and recycling rates of e-waste. Implementing urban circular supply chains is a major economic transformation that can only work if significant coordination decisions between the actors involved are solved. This paper presents research questions from a city logistics perspective. The next step in this research program is mapping the current supply chain and ecosystem of manufacturing companies, consumers, waste collection companies, recycling, government, etc.

### Challenges in Urban Circular Supply Chains

Circular Economy Business Models (CEBMs) are essential levers in transitioning to a circular economy. In recent years, a growing body of research has examined the barriers and enablers of these models. However, the available empirical evidence needs to be improved while sector-specific assessments are lacking (Rizos et al., 2022). Rizos et al. (2022) identified barriers and enablers to implementing a variety of CEBMs in the WEEE sector. Based on this analysis, they provide several policy insights.

Rizos et al. (2022) adopt a multi-case study approach using 31 cases developed through the CIRC4Life EU-funded project. This is the most significant case study sample used to examine circular economy approaches in the WEEE sector. Their findings show that key policy gaps require policy attention despite the various policy instruments in place to boost the transition towards circularity in this sector. These include a lack of rules for transparency across supply chains, weak enforcement of EU waste legislation rules, limited use of circularity criteria in public tenders, and lack of circular economy standards. In addition, inconsistent requirements stemming from different policy domains can also pose challenges for companies adopting circular economy practices. The suggested actions facilitating circular economy practices include knowledge-sharing platforms and business partnerships, R&D project grants, product labels, financial incentives, and awareness-raising campaigns.

From a supply chain perspective, Rizos et al. (2022) see difficulties in gaining access to spare parts and components, a lack of transparency regarding substances in WEEE, poor collection of WEEE, difficulties in influencing supply chain partners, complex reverse logistics systems, challenges in cooperating with international partners.

Enablers for change could be the establishment of partnerships and collaborations and developing a network of partners. Establishing partnerships and alliances was the single most crucial supply chain-related enabler raised by 11 companies (Rizos et al., 2022). For example, in two cases developing a collaboration with manufacturers helped two small companies offering repair and refurbishment services to gain access to original spare parts or software updates. In another case, a recycler could better anticipate demand for certain secondary raw materials through partnerships with manufacturers.

The analysis by Bressanelli et al. (2020) showed that servitized business models and supply chain management actions are widely used levers for circularity in WEEE. However, little attention is devoted to circular product design practices. The Internet of Things (IoT), Big Data, and Cloud emerged as powerful enablers of servitized business models. Two main patterns of Circular Economy adoption in the household appliance industry emerged from cases: incremental adoption patterns and radical adoption patterns. Incremental adoption patterns are based on design strategies focused on reducing and recycling, mainly led by manufacturers. Radical adoption patterns are instead focused on disruptive practices based on reuse, remanufacture, servitization, and sharing, where digital 4.0 technologies serve as enablers. Overall, this exploratory research lays the foundation for a more robust and more systemic understanding of the adoption of the circular economy in the WEEE industry.

Pollard et al. (2022) provide an agenda for a circular economy business model and offer perspectives for the ecosystem design based on case studies in washing machines and the telecom industry. The shift from product manufacturers' linear business model demonstrates a range of opportunities for circular value proposition by applying a CEBM, including product-service offerings, refurbished product sales, local take-back systems, and end-of-life product recycling. The findings show that the hierarchical resource loops of the circular economy provide manufacturers with opportunities for value creation and capture, namely through local repair, refurbishment, reuse, remanufacturing, and recycling activities. Implementing more resource-efficient CEBM also offers opportunities for manufacturers to reduce the costs associated with inputs to their manufacturing processes and local waste management. On a case-by-case basis, several publications about local initiatives and networks can be found (e.g., Lechner et al., 2020). The review of e-waste literature by Senna et al. (2022) concludes that reverse WEEE supply chains must deal with two different issues: how to regulate the recycling and disposal of these electronic wastes avoiding environmental and health hazards (Zhu and Li, 2020), and the design of supply chain processes that can recover materials, critical minerals, and precious metals with limited global reserves (Shevchenko et al., 2021).

According to Bressanelli et al. (2020), achieving potential environmental, social, and economic gains is still a significant challenge in implementing circularity within the WEEE industry. The literature is still generic in the context of manufacturing companies. Some key challenges and gaps are related to a lack of circular economy strategies for enhanced recovery of precious and special resources in WEEE, a lack of a sector-specific approach for circular implementation within the industry, and a lack of a more prescriptive research agenda focused on implementing circularity.

Most of the literature still discusses sustainability in the WEEE industry. To address these gaps, Bressanelli et al. (2020) aim to systematize the extensive scientific literature that exists about sustainability in the WEEE industry with a circular economy lens regarding what previous research has done in terms of objectives and how they have been achieved, where and how it has mainly geographically focused, who have been the actors primarily addressed and when the focus was put in terms of life cycle phases, and how circular economy has been implemented in the industry to achieve sustainability. The main goal is to gather and interpret the existing knowledge landscape to devise a research agenda and managerial implications for scholars and practitioners working in the circular economy and WEEE domains.

Shevchenko et al. (2021) searched for solutions in the local e-waste collection sphere with close-to-zero transport and infrastructure costs and minimizing consumers' efforts towards an enhanced local e-waste management efficiency and collection rate. Along these lines, they developed a smart reverse system of e-waste from end-of-life electronics holders to local recycling infrastructures based on intelligent information technology tools involving local delivery services to collect e-waste and connect with interactive online maps of users' requests. This system considers the vehicles of local delivery services as potential mobile collection points that collect and deliver e-waste to local recycling enterprises with a minimum deviation from the planned routes. Besides e-waste transport and infrastructure cost minimization, the proposed local e-waste reverse system supports the reduction of $CO_2$ through the optimal deployment of e-waste collection vehicles. Shevchenko et al. (2021) also advance a solid rationale for involving local e-waste operators as key smart reverse system stakeholders.

Dutch RLI (2013) analyzed the impact of a transition towards a circular economy (in general) and the consequences for strategic changes in logistics and the logistics industry. This report provides insight into the complexity of the circular economy. RLI acknowledges the importance that it is necessary for all stakeholders involved to move in the same direction. Institutional and economic barriers will therefore have to be eliminated. At the same time, consumers, producers, and logistics companies must be encouraged and supported in changing their social, personal, and corporate behaviors. However, the impact over reverse logistics on urban transport volumes is not clear. Most statistics are only available on a high level, e.g., tons per year. Research using geo-based information on e.g., sources and supply characteristics of urban waste is under development (Sileryte, 2022).

## Collaboration

Industrial symbiosis, in which companies exchange residuals for resource efficiency, is essential to the circular transition. However, many companies are hesitant to implement business models for industrial symbiosis because of the various roles, stakes, opinions, and resulting uncertainties for business continuity (De Lange, 2022). A circular supply chain system (or network) requires collaboration. Companies in the circular supply chain indicate that they see collaboration as a solution but do not know how to set it up. Therefore, networking plays a central role in building trust relationships between stakeholders working together on a shared platform. For supply chain collaboration, Barratt (2004) argues that different actors in a supply chain do not naturally act together through mutual distrust of stakeholders and their unfamiliarity with collaboration. Barratt distinguishes collaboration into other elements that can be grouped together in strategy, collaboration, and culture (see Figure 1).

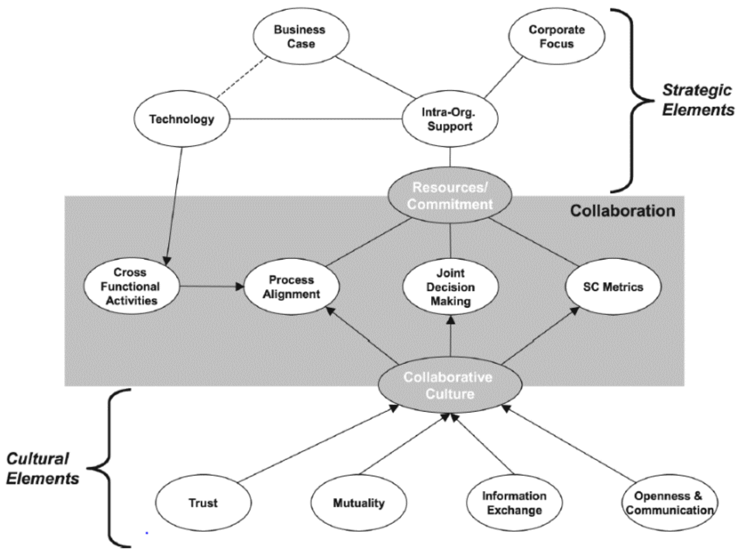

Figure 1: Elements of chain collaboration (Barratt, 2004)

- *Strategic Elements* are mainly about a joint business case for the circular supply chain: how are financial flows between stakeholders, which resources can be shared, and which technologies are available.
- *Collaborative Elements* are the results of the strategic and cultural elements: structures in which processes and decisions are taken together and progress is measured. These organizational elements form the basis for a functional design describing the collaborations.
- *Cultural Elements* are about the circular supply chain partners' attitudes and motivations. These elements serve the partners involved at a sufficient level to create a culture that stimulates collaboration.

Martinez-Olvera & Davizon-Castillo (2015) took value creation as a starting point for supply chain collaboration. In line with Barratt (2004), the synchronization of business processes is a prerequisite. In addition, they are setting a common goal and benefits when moving towards circular supply chain collaboration. In doing so, the actions and decisions of these stakeholders can be simultaneously driven to create shared value. Barratt (2004) and Martinez-Olvera & Davizon-Castillo (2015) propose stakeholder analysis to investigate strategic and organizational relationships between stakeholders. For example, in stakeholder analysis using Agent-Based Modelling (ABM) simulation, common and conflicting interests are identified, and the functioning of a shared resource and service can be tested (Dam et al., 2013). This is already applied in developing urban waste collection scenarios, such as for the collection of plastic in Singapore (Kerdlap et al., 2020), or for modeling the interactions between stakeholders in processing construction and demolition waste in China (Ding et al., 2016). Both studies underline the influence of stakeholder interaction on the results.

To map (common) relationships and motivations, the stakeholder model is enriched with mapped dependencies and value propositions of each stakeholder with the business model canvas (Osterwalder & Tucci, 2005). In research, this model is applied to test innovative collection models in China (Zuo et al., 2020) and in Santander (Díaz-Díaz et al., 2017). However, these canvases have not been used in published research to analyze further collaborations in a European context or context of appliances and construction waste. A SWOT analysis can help analyze where cultural risks and opportunities lie between stakeholders involved in the collaboration. This has already been applied to public participation in waste collection in Lucknow, India (Srivastava et al., 2005).

Past research on circular supply chain systems was not focused on an integrated approach; only on elements of collaboration. A systemic approach was not followed. The Circular Foam project will take this systemic approach to collaboration in circular supply chain systems (or networks) from a practical and scientific perspective, including networked business models looking for (economic) benefits.

## Supply Chains Versus Ecosystems

In developing (circular) city logistics innovations, we often discuss creating ecosystems to address systemic questions involving multiple stakeholders in these value chains. Innovating firms often need to rely on other actors in their innovation ecosystem to achieve a complex value proposition. This raises many challenges for the managers of these firms. However, a comprehensive approach is not yet to support managers in analysing and decision-making on ecosystem strategy.

Researchers suggest creating ecosystems to address systemic questions involving multiple stakeholders in developing urban circular supply chains. But how do ecosystems differ from and relate to supply chains? Legenvre et al. (2022) compared ecosystems to supply chains. While digital transformations are taking place, researchers and practitioners still have a limited understanding of how ecosystems and supply chains differ from a theoretical standpoint and how they relate practically.

Legenvre et al. (2022) studied the evolution of the concept of ecosystems through a systematic review of the literature to describe how the two concepts relate throughout this evolution. They use cases to investigate how ecosystems and supply chains relate practically. Legenvre et al. (2022) shows that non-contractual governance in a supply chain facilitates investment in specific assets by a few key suppliers. In contrast, non-contractual governance in an ecosystem facilitates the creation of collective shared assets by many ecosystem participants. They also show that at a practical level supply chains and ecosystems can either compete or complement each other and present some conditions for the emergence of such relations.

Ecosystems best suit dynamic business environments with complex and evolving technical systems. In contrast, supply chains are best suited for environments where firms can exert control of essential resources across multiple firms. Ecosystems support platforms built around a modular technical system with a sizable degree of openness, while supply chains support products characterized by proprietary resources and interfaces. Bilateral contracts in a supply chain govern the price, quantities, and risks associated with market transactions, whereas bilateral agreements in an ecosystem govern access conditions to shared resources. Non-contractual governance in supply chains facilitates investment in specific assets by suppliers.

In contrast, non-contractual governance in an ecosystem facilitates the creation of collective shared assets by many participants. Ecosystems and supply chains can coexist and complement each other within a product lifecycle. For example, an ecosystem can deliver services after a product is sold. This is possible as complementary capabilities provide the means to establish an ecosystem of partners.

**Research Programs in Europe**

In recent years, multiple European research projects have begun to address these city logistics research questions:

- Caircular Construction in Regenerative Cities (CIRCuIT) is a collaborative project from 2019-2023 and involves 31 partners across the built environment chain in Copenhagen, Hamburg, the Helsinki Region, and Greater London.
- The European Community of Practice for Hubs4Circularity (H4C) connects actors from industry, regions and cities, H4C initiatives, and research and development organizations are interested in sharing knowledge, experiences, tools, and materials to progress faster towards industrial and industrial-urban symbiosis and circular supply chains.
- The LINear to CIrcular Transition (LINCIT) project focuses on developing knowledge, insights, and tools to guide companies with linear supply chains to a circular business ecosystem and organize logistics and operational processes.
- In the Urban Upcycling project, the Amsterdam University of Applied Sciences (AUS), together with local SMEs and non-profit companies, municipalities, industry association CBM, IKEA, and various knowledge partners, is investigating how upcycling of waste streams can take shape in an urban context.
- The Dutch Logistics in the Circular Economy Living Lab (LogiCELL) project aims to specify further and address the logistics challenges for reuse and recycling operations.
- The CINDERELA project aims to develop a new Circular Economy Business Model (CEBM) for using secondary raw materials (SRM) in urban areas.

- REFLOW is an EU H2020-funded project from 2019 to 2022 that seeks to understand and transform urban material flows and to co-create and test circular and regenerative solutions at the business, governance, and citizen levels.
- geoFluxus BV., a spin-off company of Delft University of Technology that works with urban regions in the Netherlands to build a Circular Economy Monitor.

## CONCLUSION

The research carried out in this project has raised a number of questions which must be answered to design and develop effective and efficient future circular supply chain blueprint models and reverse logistic processes in the urban environments. Developing answers and solutions to these research questions will aid in developing a blueprint for systemic solutions for the circularity of plastics from applications of rigid PU foams, and gaining alignment of governments and regulators, industry partners, and public.

### Future Research Questions

The impact over reverse logistics on urban transport volumes is not clear. Most statistics is only available on a high level, e.g., tons per year. Research using geo-based information on e.g., sources and supply characteristics of urban waste is under development. Recent data mapping and analysis in Amsterdam has revealed several limitations present in the waste data collection and a number of gaps present in current circular economy research and data analysis. At the same time, the available data already supports significant insights into the status quo of the current waste system and provides opportunities for circular economy monitoring (Sileryte, 2022).

The functional design of local circular supply chains serves as a blueprint for the distribution and coordination of the different roles of the direct stakeholders in future urban waste collection systems in which (common) goals and societal goals serve as motivation. A functional design includes a set of (cross) functional activities, mutual data exchange, urban and regional logistics nodes (and cost-modelling the network), a method of planning and control (and supporting AI-ICT systems for managing the network), and the governance structure as building blocks for collaboration. These result from different stakeholders' intentions, opportunities, risks, and mutual relationships in a new system, which emerge in stakeholder analyses (e.g., using Agent-Based Modelling (ABM) or fuzzy logic to simulate and identify common and conflicting interests).

A higher value use of secondary materials requires improvements in product design, proper separate collection points or facilities, opportunities for high-value application, and steering for that. Some parts of the products are currently designed in ways that recycling for application as a secondary material is difficult, or it takes a lot of energy to recover some materials. Therefore, it is necessary to establish closed-loop (urban) supply chains to recover the materials needed for recycling or upcycling. Circular supply chains must be designed to retrieve these values and mitigate the risks.

Furthermore, urban collection points and repair centers must be strategically positioned to make this feasible and, very significantly, attractive for consumers (with the right incentives) and integrate the concept of smart cities. How can city logistics (cost) modeling support the development of these urban collection points and repair networks? What are the planning and control (including ICT-support and control towers) concepts to support operational excellence, and tactical and strategic planning?

Besides e-waste transport (both urban and long haul) and infrastructure cost minimization for urban collection points and urban hubs, future smart e-waste reverse systems must support the reduction of CO2 through the efficient deployment of zero-emission e-waste collection vehicles. New urban waste collection initiatives and the new roles of stakeholders in collaboration form an integrated design for collaboration (or maybe only for collection as a first step). The functional design serves as a blueprint for the distribution and coordination of the different roles of the direct stakeholders in future urban waste collection systems in which (common) goals and societal goals serve as motivation. Relationships between the circular economy and space requirements are critical in the network's design for land-use planning.

Collaboration results from intentions, opportunities, risks, and mutual relationships of different public and private stakeholders in a new system, which emerge in stakeholder analyses. How can we use stakeholder analysis, e.g., Agent-Based Modelling (ABM), to identify common and conflicting interests? How can a collaboration framework (e.g., Barratt, 2004) support the needed systemic approach? How can we link city logistics concept to ecosystem development?

Circular supply chains will 'feed' downstream large recycling and upcycling 'factories' that often require large and predictable volumes for many years. How do we organize for reverse 'sales and operations planning' and the resulting strategic, tactical, and operation capacity planning of partners in the circular supply chain to secure resilience in 'feeding' recycling and upcycling downstream?

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