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The Chartered Institute of Logistics and Transport

LRN Italy Forum 2023

Improving supply chain sustainability and resilience: the Italian way!

LOGISTICS RESEARCH NETWORK

Sustainable Food Packaging System Design through Optimized Reuse Networks

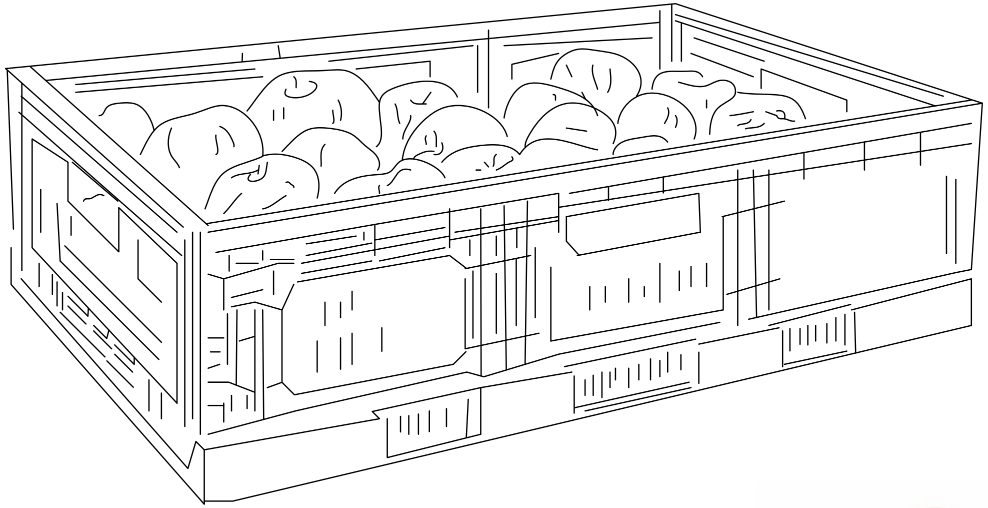
Prof. Riccardo Accorsi, Ph.D.
University of Bologna, Department of Industrial Engineering

Presenting Author:
Prof. Riccardo Accorsi, Ph.D.

22 SEPTEMBER 2023, **LIUC University**

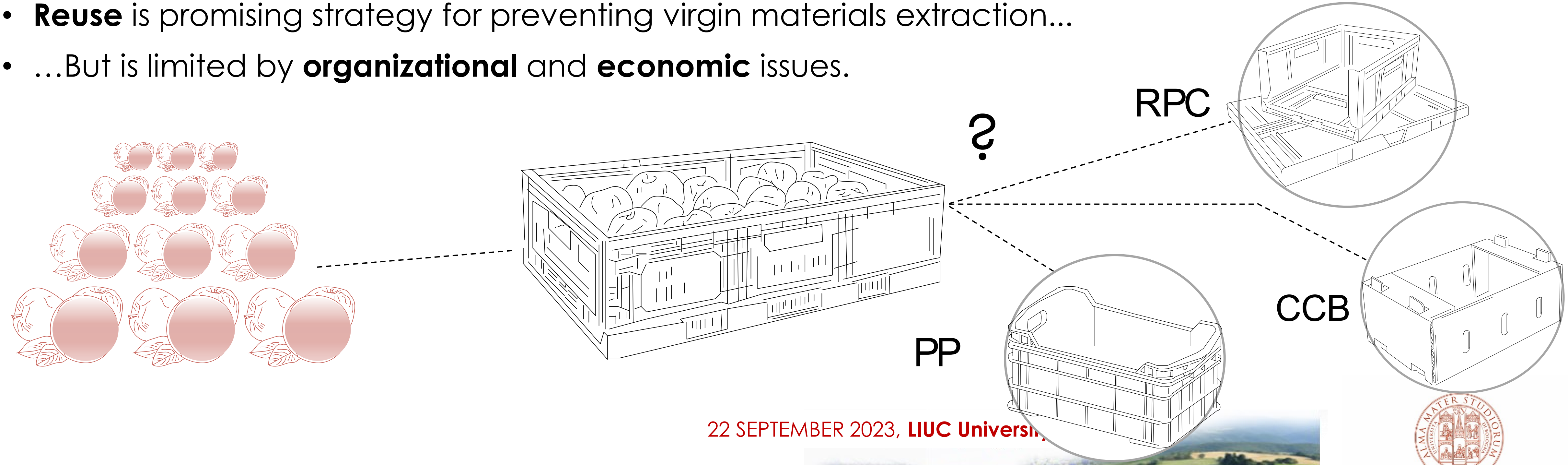
Agenda

- **Problem statement**
- **Optimisation to aid reuse network design and planning**
- **Industrial case study: CPR System**
    - Capacitated Location Problem
    - Managing washing operations
    - Trade-off cost vs transport emissions
- **Conclusions & Future developments**



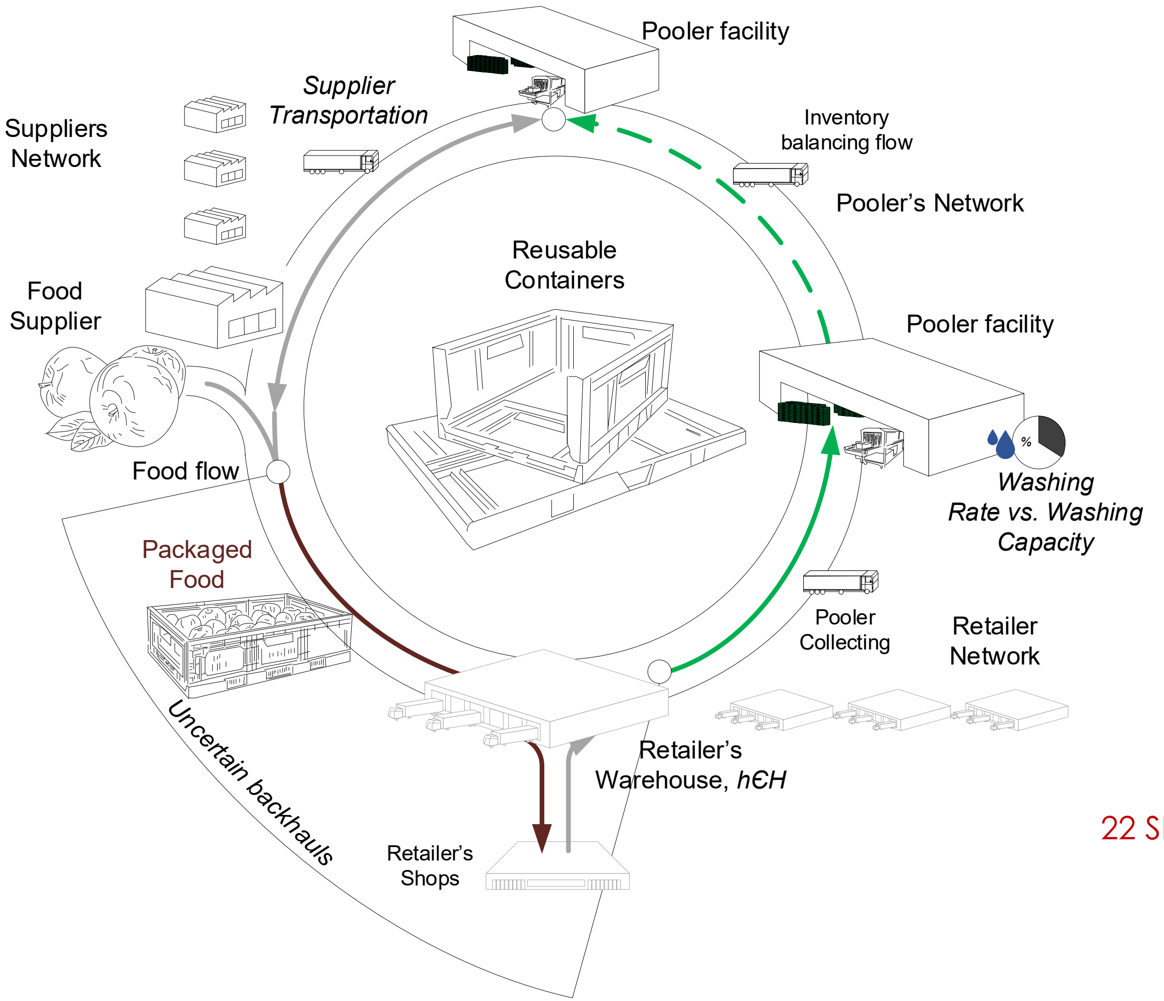
Problem statement

- **Packaging** plays a significant role in **FSC**, and its **management** affect overall **environmental sustainability**…
- Packaging accounts for 15% of the municipal solid waste with an increasing trend.
- For certain items, **packaging** contribute to almost **45% of food footprint** depending on product variety and package material.
- **Reuse** is promising strategy for preventing virgin materials extraction...
- …But is limited by **organizational** and **economic** issues.



Problem statement

- **Reuse** is promising strategy for preventing virgin materials extraction...
- …But is limited by **organizational** and **economic** issues:



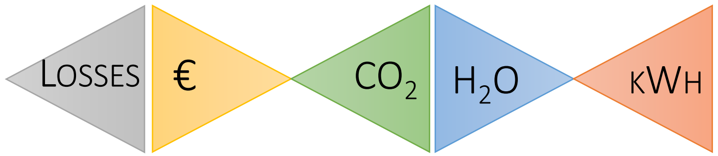
Managerial Issues:

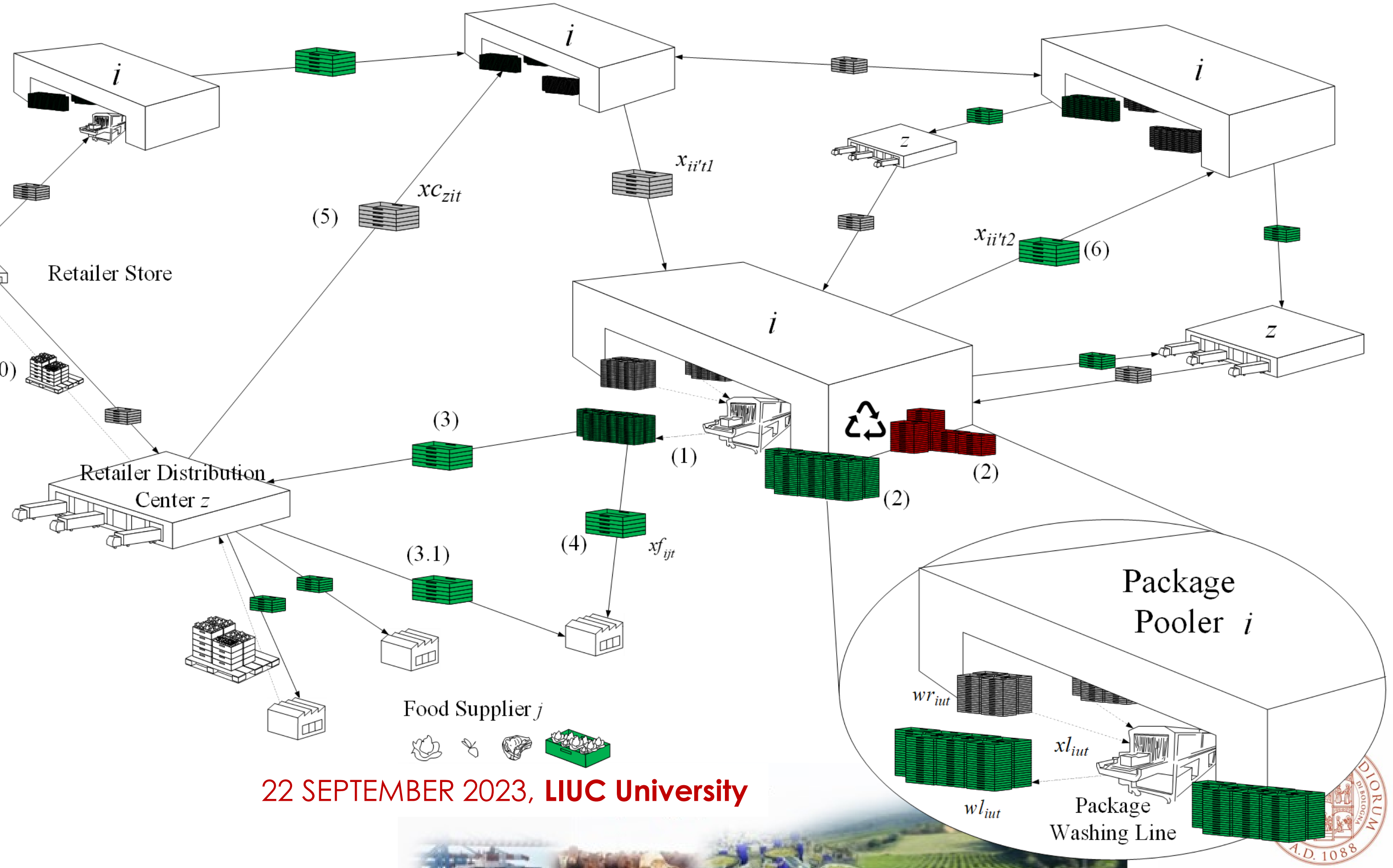
- Location of the **pooler's facilities** and intensity of transportation;
- **Geography** of **food vendors** and **distribution channels**;
- Material handling & **washing** operations;
- **Uncertain return** of containers;
- Containers inventory balancing;
- **Costs** raising;
- Transportation emissions;

Optimisation for reuse network design

- Given the broad set of **actors**, **entities**, **flows** involved, optimisation could aid cost and impacts minimization supporting network design:

- Food processors, growers, suppliers
- Retailers, distributors, shops
- Raw material suppliers
- Packaging maker
- Packaging and containers poolers
- Collectors, cleaning & disposal
- Logistics providers
- Consumers





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Optimisation for reuse network design

- Given the broad set of **actors**, **entities**, **flows** involved, **optimisation** could aid cost and impacts minimization supporting network design:

$$wr_{iut} + wl_{iut} \le stock_i \cdot y_{iut} \forall i \in P,\ t \in T,\ u \in U \quad (4)$$

$$\sum_{u=1}^{U} wr_{iut} = \sum_{u=1}^{U} wr_{iu(t-1)} + \sum_{i'=1}^{P} x_{i'itd} + \sum_{u=1}^{U} xl_{iut} + \sum_{u=1}^{U} xp_{iut} - \sum_{j=1}^{S} xf_{ijt} - \sum_{i'=1}^{P} x_{ii'td} \ \forall i \in P,\ t \in T,\ d = 2 \quad (5)$$

$$\sum_{u=1}^{U} wl_{iut} = \sum_{u=1}^{U} wl_{iu(t-1)} + \sum_{z=1}^{C} xc_{zit} + \sum_{i'=1}^{P} x_{i'itd} - \sum_{u=1}^{U} xl_{iut} - \sum_{i'=1}^{P} x_{ii'td} - \sum_{u=1}^{U} xp_{iut} \forall i \in P,\ t \in T,\ d = 1 \quad (6)$$

$$xl_{iut} \le lav_{iu} \cdot y_{iut} \forall i \in P,\ t \in T,\ u \in U \quad (7)$$

$$xp_{iut} \le prod_{iu} \cdot y_{iut} \forall i \in P,\ t \in T,\ u \in U \quad (8)$$

$$\sum_{i=1}^{P} xf_{ijt} = dom_{jt} \forall j \in S,\ t \in T \quad (9)$$

$$\sum_{i=1}^{P} xc_{zit} = cons_{zt} \forall z \in C,\ t \in T \quad (10)$$

$$\sum_{j=1}^{S} xf_{ijt} \le stock_i \cdot \sum_{u=1}^{U} y_{iut} \ \forall i \in P,\ t \in T \quad (11)$$

$$\sum_{z=1}^{C} xc_{zit} \le stock_i \cdot \sum_{u=1}^{U} y_{iut} \ \forall i \in P,\ t \in T \quad (12)$$

$$\sum_{i'=1}^{P} x_{ii'td} \le (stock_i + prod_{iu}) \cdot \sum_{u=1}^{U} y_{iut} \ \forall i \in P,\ t \in T,\ u \in U,\ d \in D \quad (13)$$

$$\sum_{i'=1}^{P} x_{i'itd} \le stock_i \cdot \sum_{u=1}^{U} y_{iut} \ \forall i \in P,\ t \in T,\ u \in U,\ d \in D \quad (14)$$

$$EOL_{ct} \le EOL_{c(t-1)} - 1 + M \cdot \varphi_{c(t-1)} \forall c \in K,\ t \in T \quad (15)$$

$$EOL_{ct} \ge EOL_{c(t-1)} - 1 - M \cdot \varphi_{c(t-1)} \forall c \in K,\ t \in T \quad (16)$$

$$EOL_{ct} \le 1 - \varphi_{c(t-1)} + L \forall c \in K,\ t \in T \quad (17)$$

$$EOL_{ct} \ge L \cdot \varphi_{c(t-1)} \forall c \in K,\ t \in T \quad (18)$$

$$\varphi_{ct} \le 1 - m \cdot EOL_{ct} \forall c \in K,\ t \in T \quad (19)$$

$$\varphi_{ct} \ge 1 - EOL_{ct} \forall c \in K,\ t \in T \quad (20)$$

$$\varphi_{ct} \ge \varphi_{c(t-1)} - 1 \forall c \in K,\ t \in T \quad (21)$$

$$\sum_{u=1}^{U} \sum_{i=1}^{P} xp_{iut} = \sum_{c=1}^{K} \varphi_{ct} \cdot n_c \forall t \in T \quad (22)$$

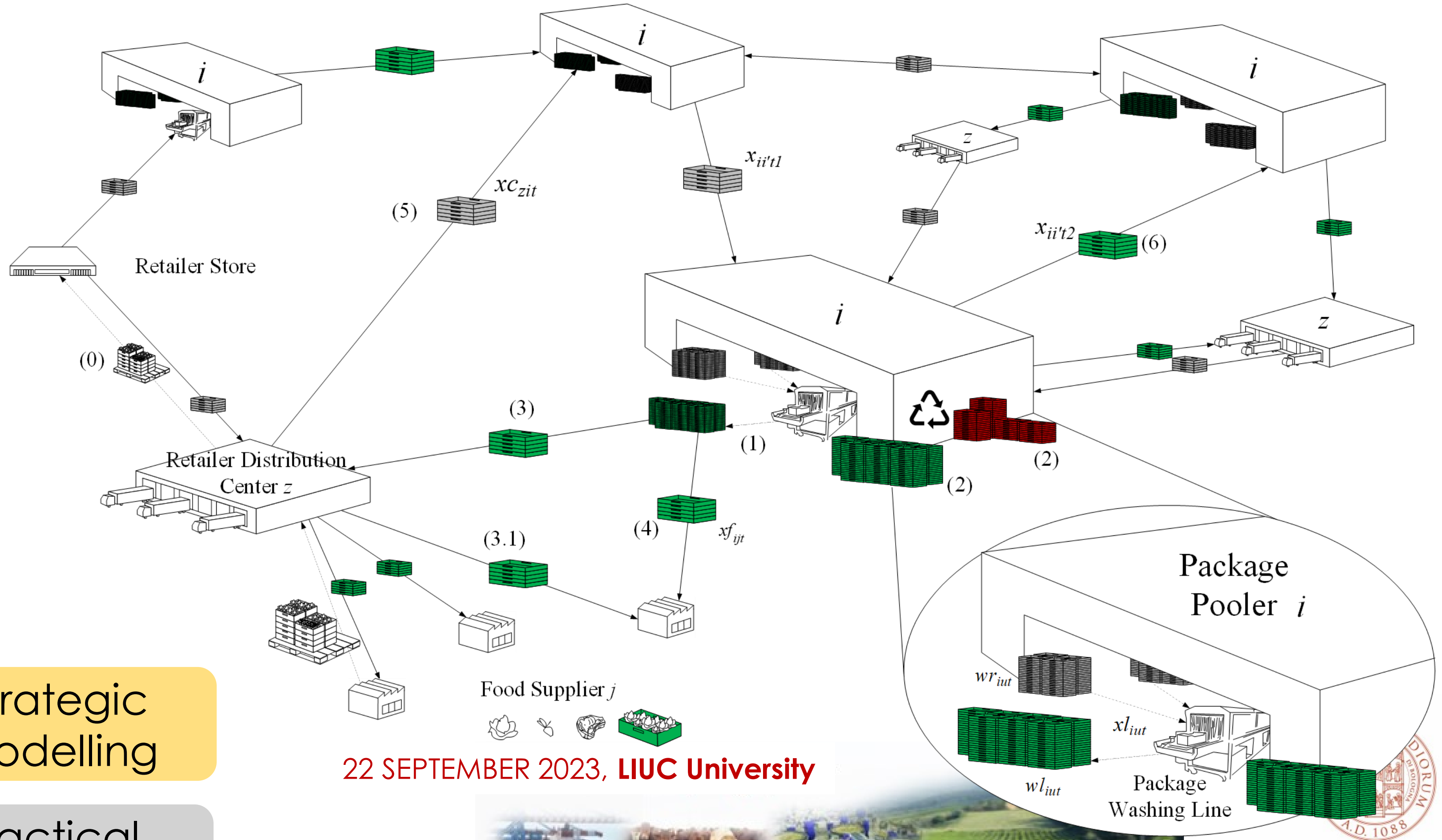
$$y_{iut} \in \{0, 1\} \forall i \in P,\ t \in T,\ u \in U \quad (23)$$

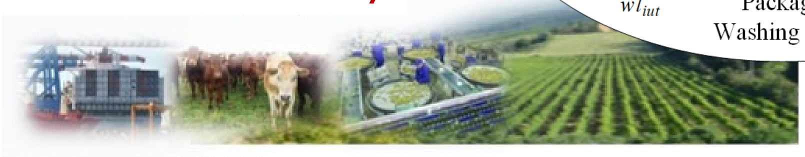
$$\varphi_{ct} \in \{0, 1\} \forall c \in K,\ t \in T \quad (24)$$

$$wr_{iut},\ wl_{iut},\ xp_{iut},\ xl_{iut} \ge 0 \forall i \in P,\ t \in T,\ u \in U \quad (25)$$

Strategic Modelling

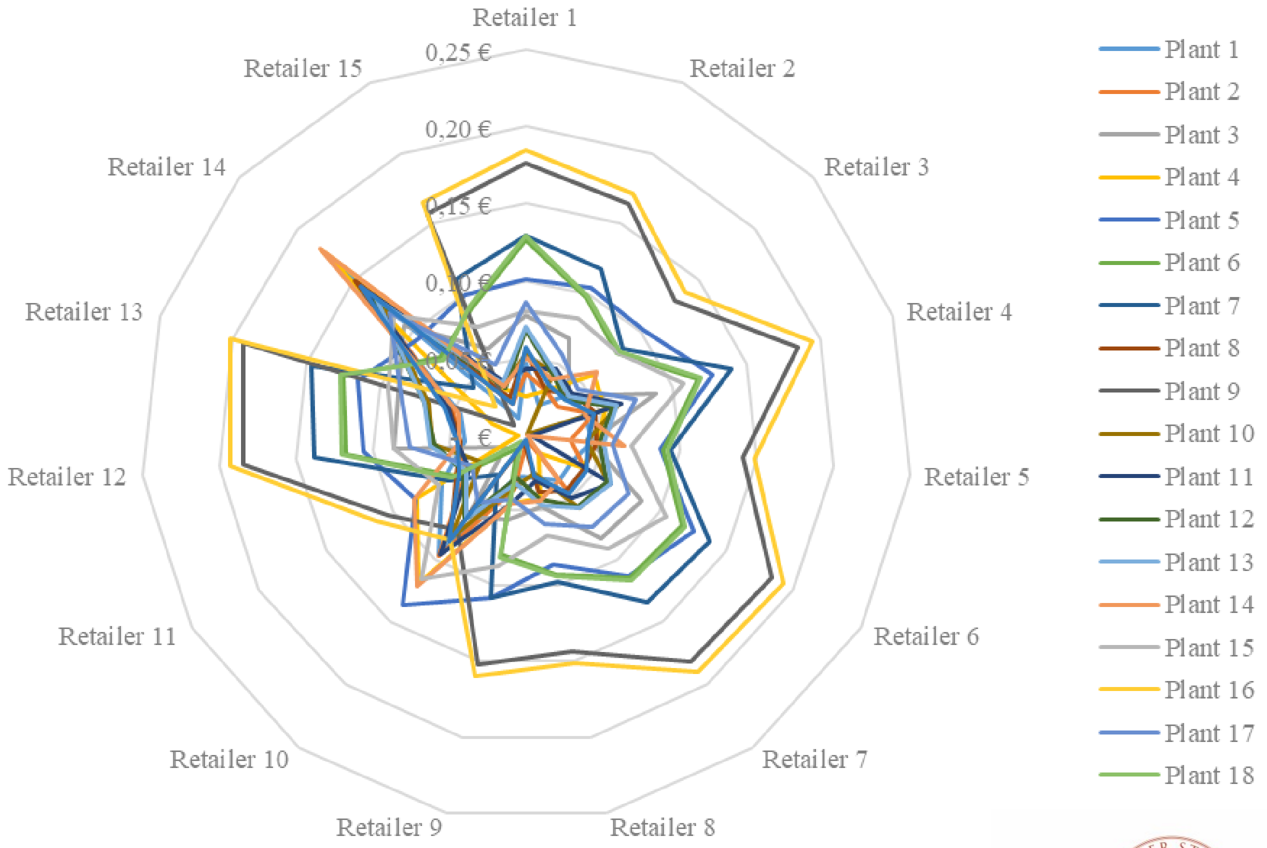
Tactical Modelling





Industrial case study: Location problem

- **Capacitated facility location problem** and network design to respond to retailers and food packers demand and requirements from the perspective of the pooler:



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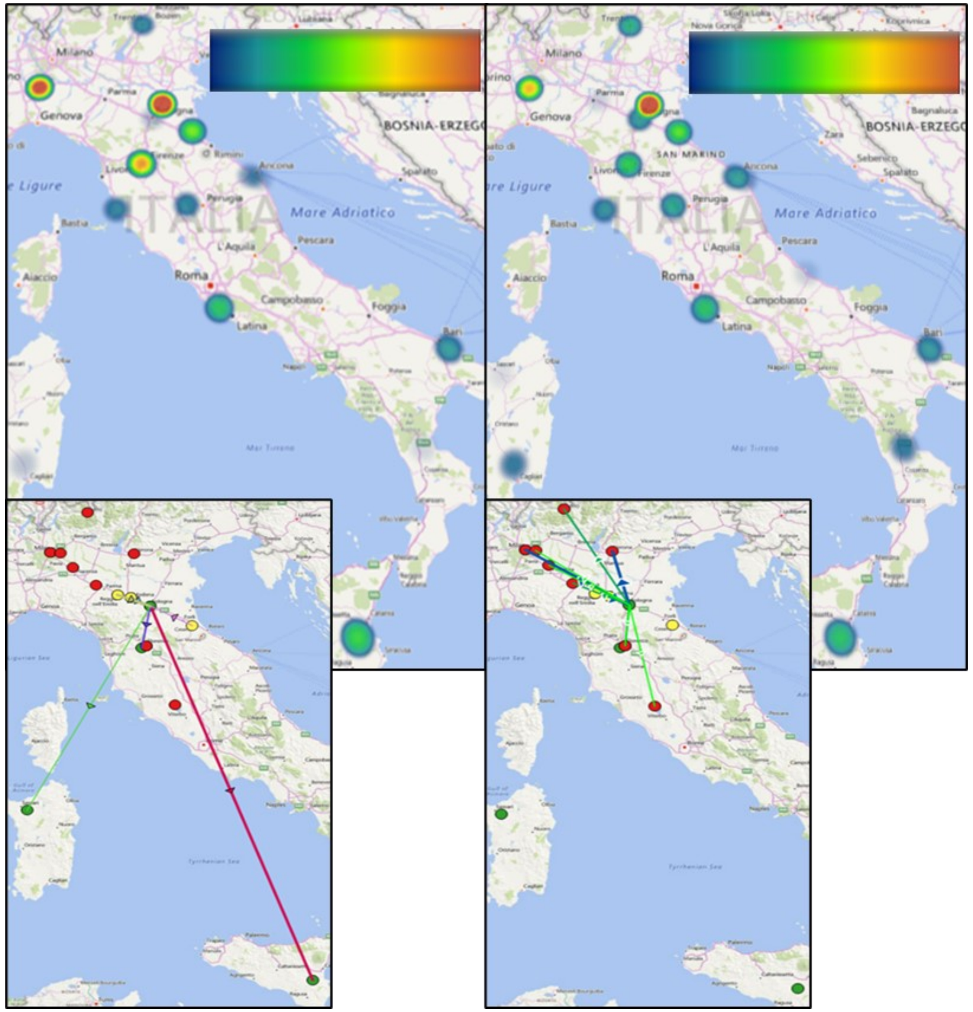
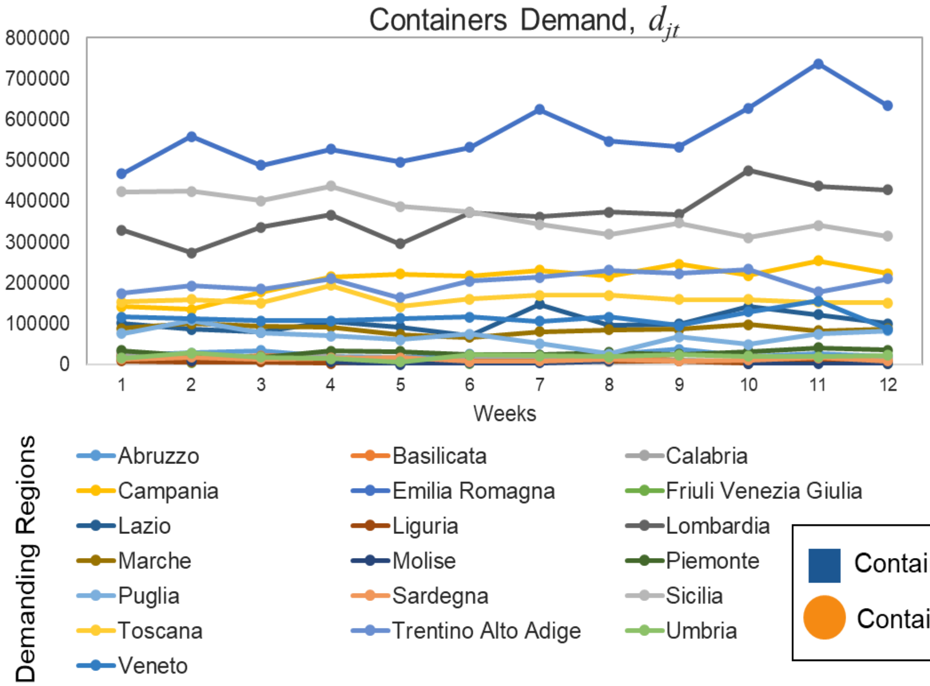
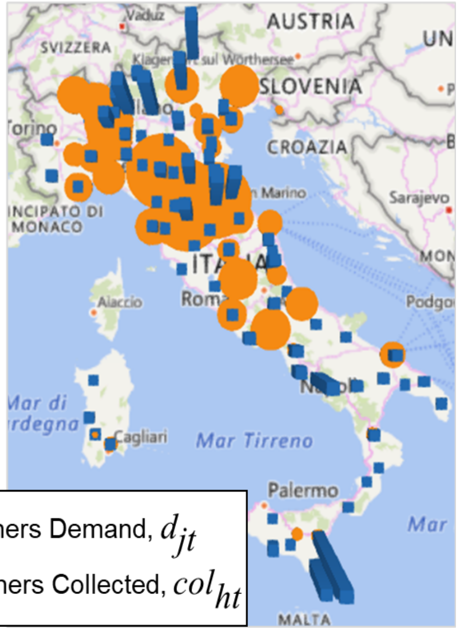
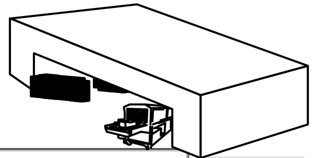


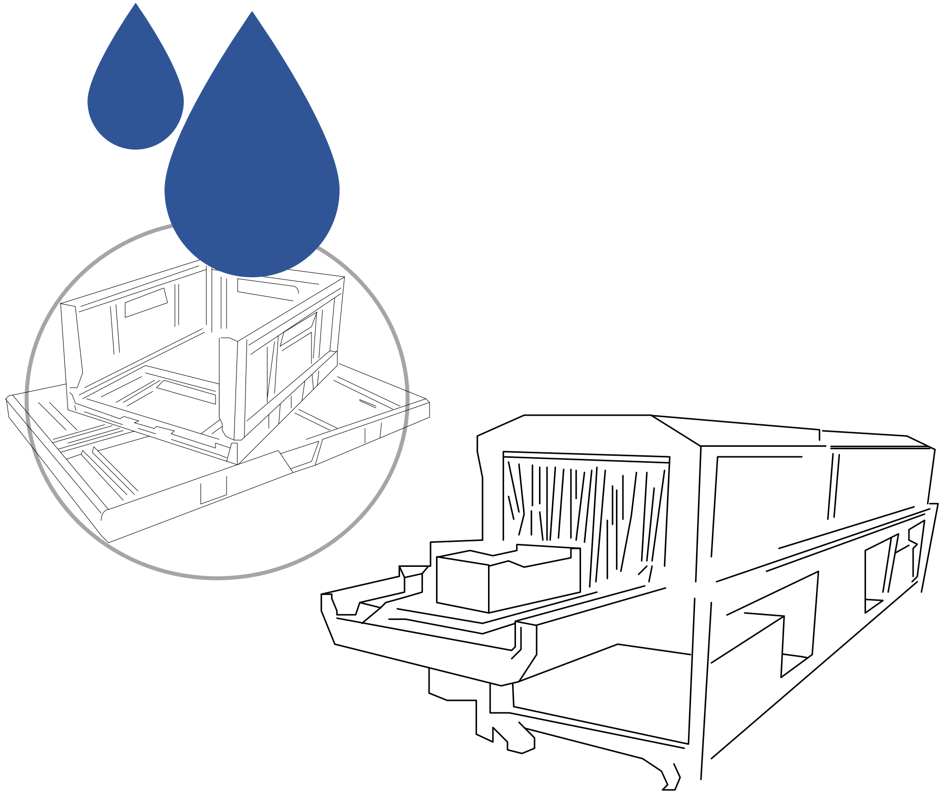




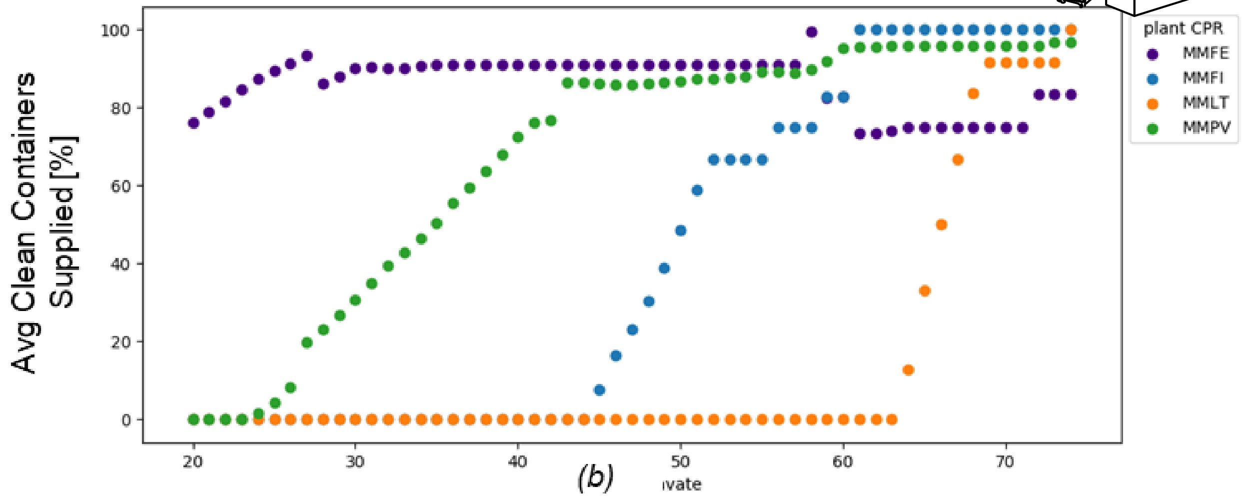
Industrial case study: Washing operations

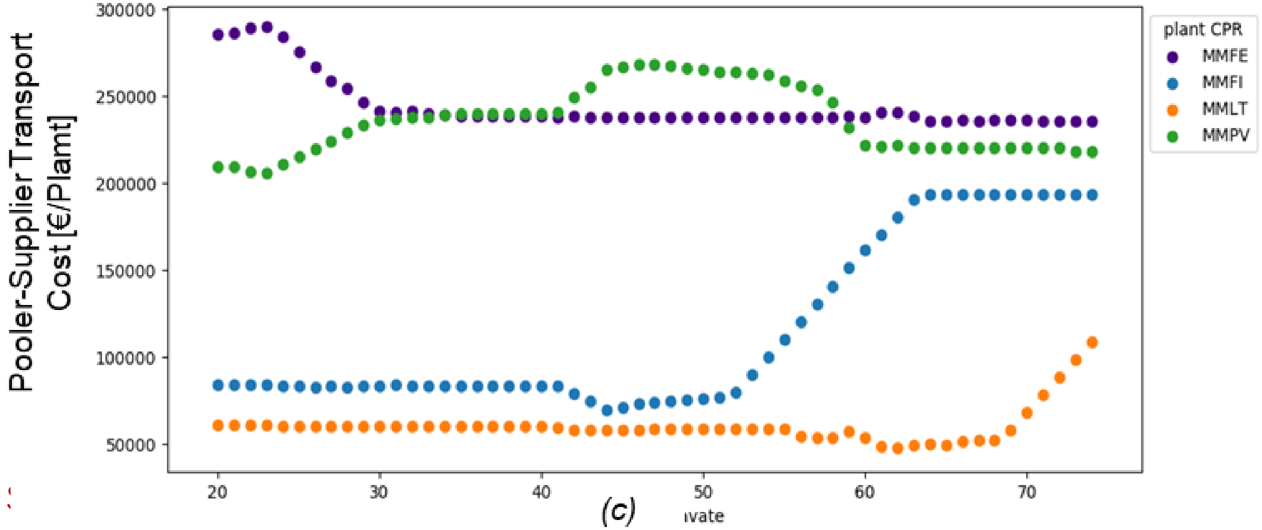


- From the pooler's perspective, **Service Level** is the percentage of containers washed at each return cycle.
- Increasing service % affect the operational costs of the network, as containers must be shipped to the washing facilities.



RPC





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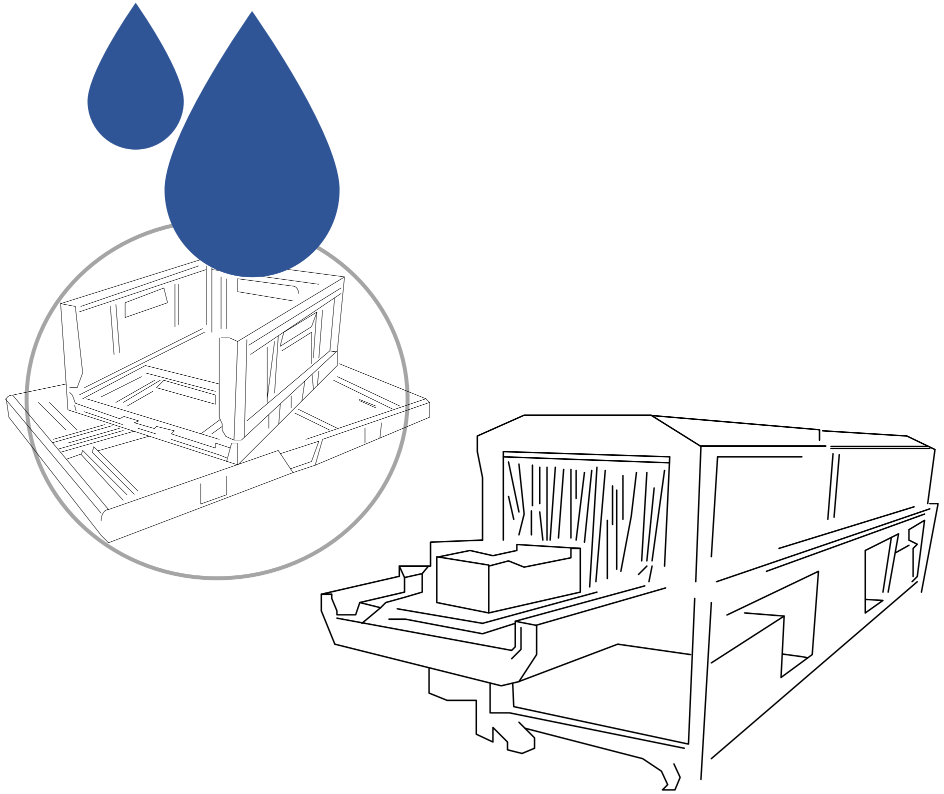
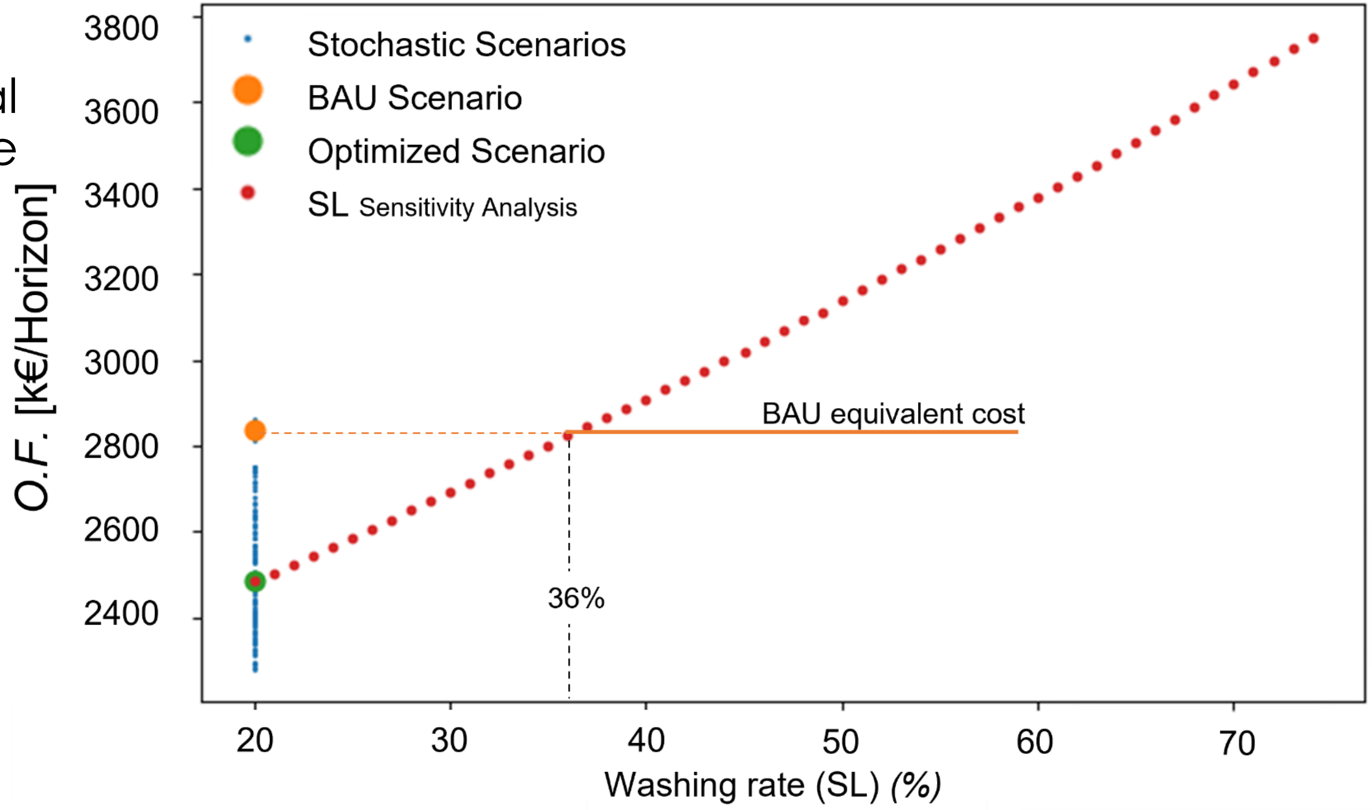
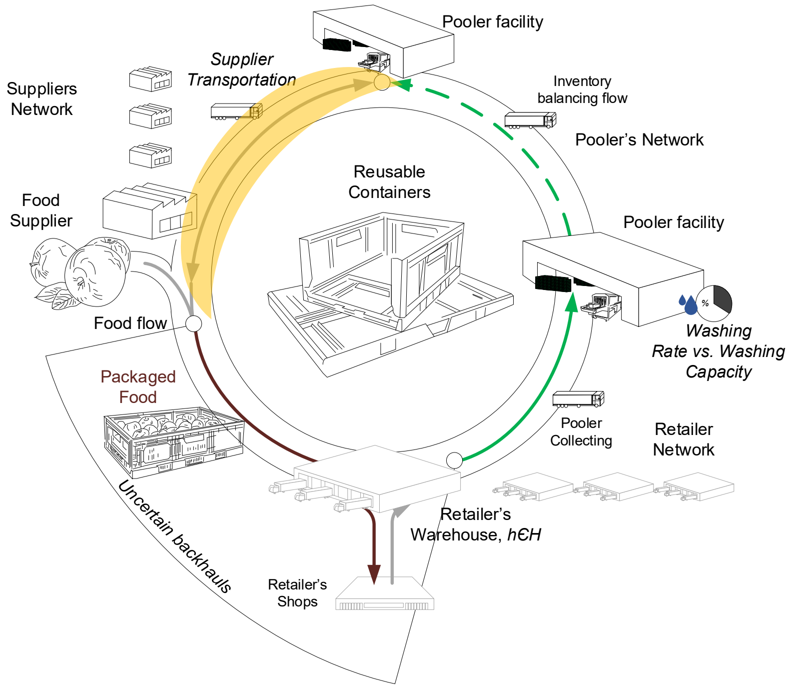
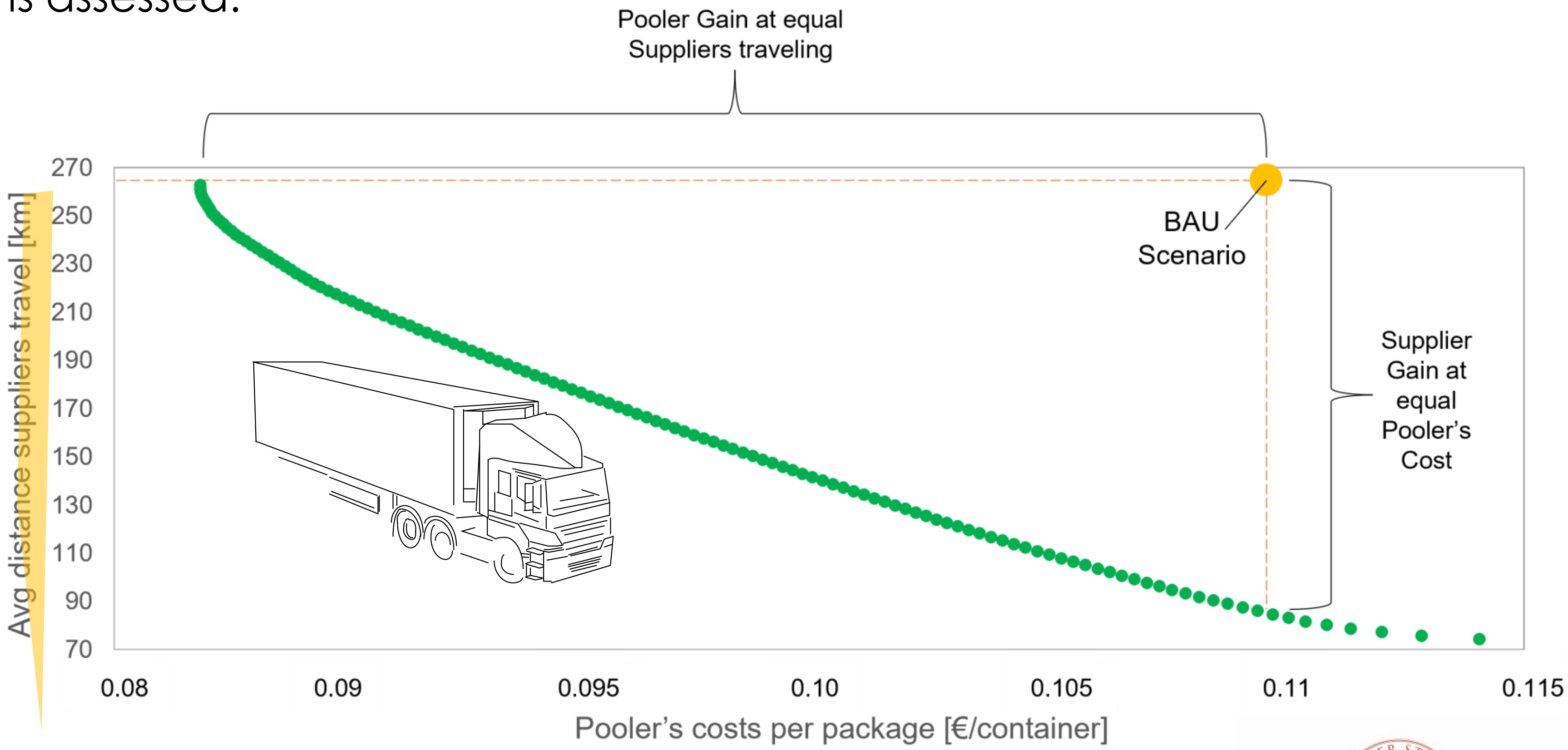




Industrial case study: Costs vs Transport Emissions

- While optimizing the network (strategically and tactically), the **trade-off** between **poolers costs** and **transport emissions** associated with containers supplies to the food vendors is assessed.





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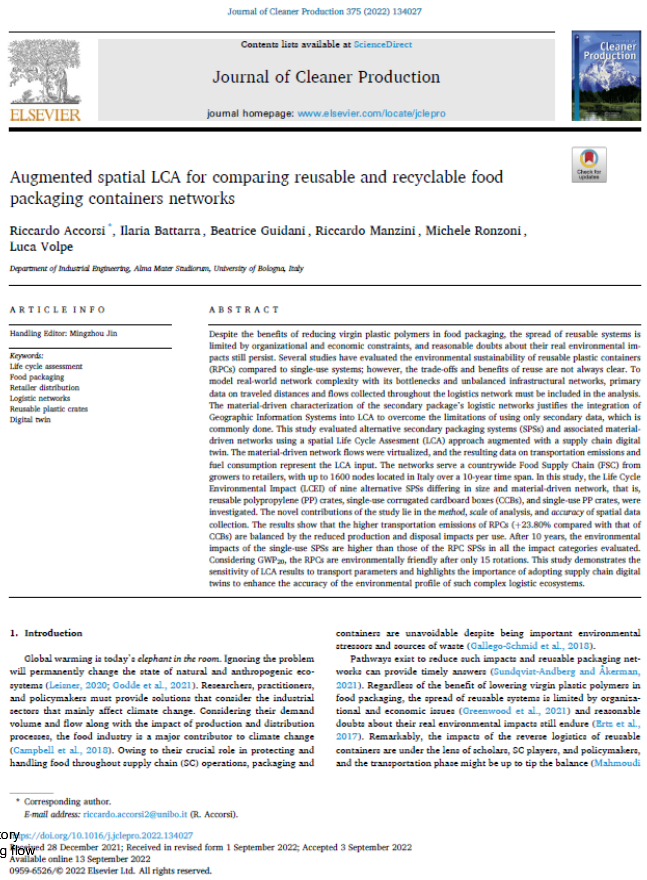

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Augmented spatial LCA for comparing reusable and recyclable food packaging containers networks

Riccardo Accorsi *, Ilaria Battarra, Beatrice Guidani, Riccardo Manzini, Michele Ronzoni, Luca Volpe

Department of Industrial Engineering, Alma Mater Studiorum, University of Bologna, Italy

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ABSTRACT

Despite the benefits of reducing virgin plastic polymers in food packaging, the spread of reusable systems is limited by organizational and economic constraints, and reasonable doubts about their real environmental impacts still persist. Several studies have evaluated the environmental sustainability of reusable plastic containers (RPCs) compared to single-use systems; however, the trade-offs and benefits of reuse are not always clear. To model real-world network complexity with its bottlenecks and unbalanced infrastructural networks, primary data on traveled distances and flows collected throughout the logistics network must be included in the analysis. The material-driven characterization of the secondary package's logistic networks justifies the integration of Geographic Information Systems into LCA to overcome the limitations of using only secondary data, which is commonly done. This study evaluated alternative secondary packaging systems (SPSs) and associated material-driven networks using a spatial Life Cycle Assesment (LCA) approach augmented with a supply chain digital twin. The material-driven network flows were virtualized, and the resulting data on transportation emissions and fuel consumption represent the LCA input. The networks serve a countrywide Food Supply Chain (FSC) from growers to retailers, with up to 1600 nodes located in Italy over a 10-year time span. In this study, the Life Cycle Environmental Impact (LCEI) of nine alternative SPSs differing in size and material-driven network, that is, reusable polypropylene (PP) crates, single-use corrugated cardboard boxes (CCBs), and single-use PP crates, were investigated. The novel contributions of the study lie in the *method*, *scale* of analysis, and *accuracy* of spatial data collection. The results show that the higher transportation emissions of RPCs (+23.80% compared with that of CCBs) are balanced by the reduced production and disposal impacts per use. After 10 years, the environmental impacts of the single-use SPSs are higher than those of the RPC SPSs in all the impact categories evaluated. Considering GWP_{20}, the RPCs are environmentally friendly after only 15 rotations. This study demonstrates the sensitivity of LCA results to transport parameters and highlights the importance of adopting supply chain digital twins to enhance the accuracy of the environmental profile of such complex logistic ecosystems.

1. Introduction

Global warming is today's *elephant in the room*. Ignoring the problem will permanently change the state of natural and anthropogenic ecosystems (Leisner, 2020; Godde et al., 2021). Researchers, practitioners, and policymakers must provide solutions that consider the industrial sectors that mainly affect climate change. Considering their demand volume and flow along with the impact of production and distribution processes, the food industry is a major contributor to climate change (Campbell et al., 2018). Owing to their crucial role in protecting and handling food throughout supply chain (SC) operations, packaging and containers are unavoidable despite being important environmental stressors and sources of waste (Gallego-Schmid et al., 2018).

Pathways exist to reduce such impacts and reusable packaging networks can provide timely answers (Sundqvist-Andberg and Åkerman, 2021). Regardless of the benefit of lowering virgin plastic polymers in food packaging, the spread of reusable systems is limited by organizational and economic issues (Greenwood et al., 2021) and reasonable doubts about their real environmental impacts still endure (Ertz et al., 2017). Remarkably, the impacts of the reverse logistics of reusable containers are under the lens of scholars, SC players, and policymakers, and the transportation phase might be up to tip the balance (Mahmoudi

* Corresponding author.
E-mail address: riccardo.accorsi2@unibo.it (R. Accorsi).

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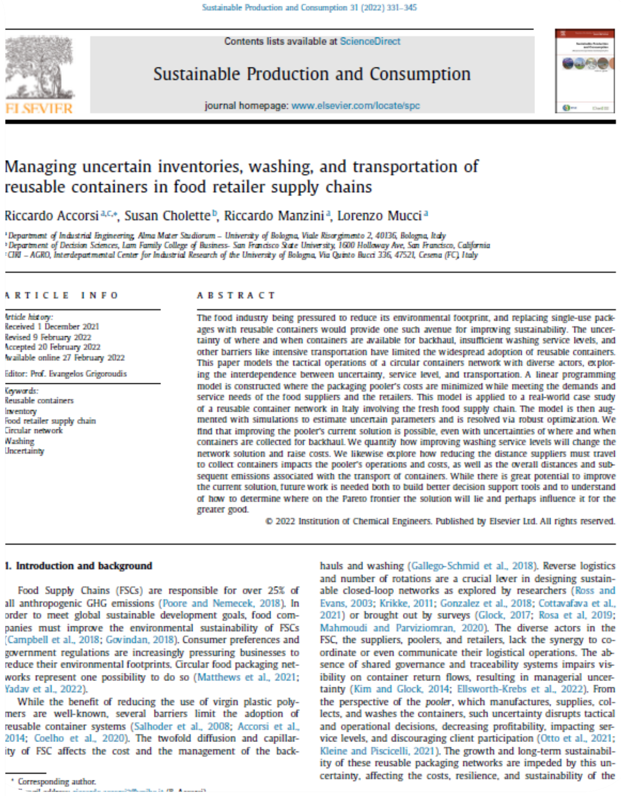

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Managing uncertain inventories, washing, and transportation of reusable containers in food retailer supply chains

Riccardo Accorsi [a,c,*], Susan Cholette [b], Riccardo Manzini [a], Lorenzo Mucci [a]

[a] Department of Industrial Engineering, Alma Mater Studiorum – University of Bologna, Viale Risorgimento 2, 40136, Bologna, Italy
[b] Department of Decision Sciences, Lam Family College of Business- San Francisco State University, 1600 Holloway Ave, San Francisco, California
[c] CIRI – AGRO, Interdepartmental Center for Industrial Research of the University of Bologna, Via Quinto Bucci 336, 47521, Cesena (FC), Italy

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ABSTRACT

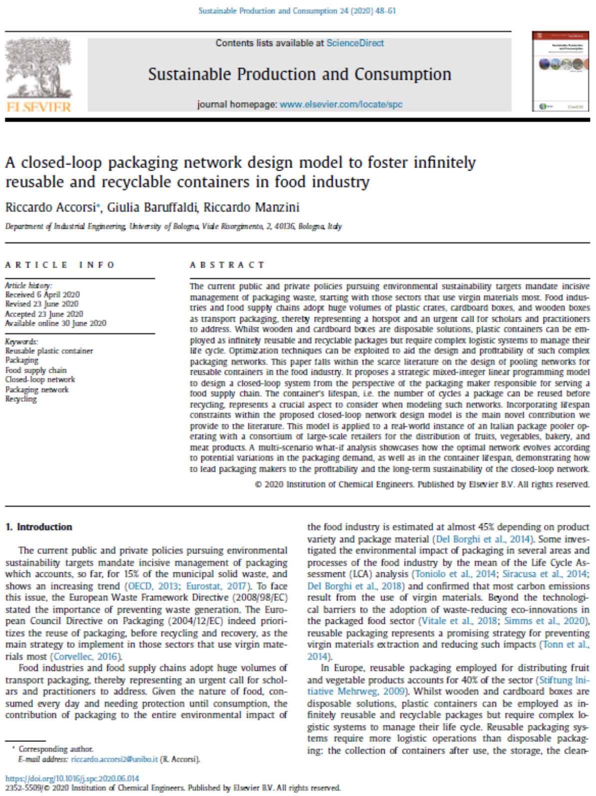
The food industry being pressured to reduce its environmental footprint, and replacing single-use packages with reusable containers would provide one such avenue for improving sustainability. The uncertainty of where and when containers are available for backhaul, insufficient washing service levels, and other barriers like intensive transportation have limited the widespread adoption of reusable containers. This paper models the tactical operations of a circular containers network with diverse actors, exploring the interdependence between uncertainty, service level, and transportation. A linear programming model is constructed where the packaging pooler's costs are minimized while meeting the demands and service needs of the food suppliers and the retailers. This model is applied to a real-world case study of a reusable container network in Italy involving the fresh food supply chain. The model is then augmented with simulations to estimate uncertain parameters and is resolved via robust optimization. We find that improving the pooler's current solution is possible, even with uncertainties of where and when containers are collected for backhaul. We quantify how improving washing service levels will change the network solution and raise costs. We likewise explore how reducing the distance suppliers must travel to collect containers impacts the pooler's operations and costs, as well as the overall distances and subsequent emissions associated with the transport of containers. While there is great potential to improve the current solution, future work is needed both to build better decision support tools and to understand of how to determine where on the Pareto frontier the solution will lie and perhaps influence it for the greater good.

1. Introduction and background

Food Supply Chains (FSCs) are responsible for over 25% of all anthropogenic GHG emissions (Poore and Nemecek, 2018). In order to meet global sustainable development goals, food companies must improve the environmental sustainability of FSCs (Campbell et al., 2018; Govindan, 2018). Consumer preferences and government regulations are increasingly pressuring businesses to reduce their environmental footprints. Circular food packaging networks represent one possibility to do so (Matthews et al., 2021; Yadav et al., 2022).

While the benefit of reducing the use of virgin plastic polymers are well-known, several barriers limit the adoption of reusable container systems (Salhoder et al., 2008; Accorsi et al., 2014; Coelho et al., 2020). The twofold diffusion and capillarity of FSC affects the cost and the management of the backhauls and washing (Gallego-Schmid et al., 2018). Reverse logistics and number of rotations are a crucial lever in designing sustainable closed-loop networks as explored by researchers (Ross and Evans, 2003; Krikke, 2011; Gonzalez et al., 2018; Cottavafava et al., 2021) or brought out by surveys (Glock, 2017; Rosa et al., 2019; Mahmoudi and Parviziomran, 2020). The diverse actors in the FSC, the suppliers, poolers, and retailers, lack the synergy to coordinate or even communicate their logistical operations. The absence of shared governance and traceability systems impairs visibility on container return flows, resulting in managerial uncertainty (Kim and Glock, 2014; Ellsworth-Krebs et al., 2022). From the perspective of the *pooler*, which manufactures, supplies, collects, and washes the containers, such uncertainty disrupts tactical and operational decisions, decreasing profitability, impacting service levels, and discouraging client participation (Otto et al., 2021; Kleine and Piscicelli, 2021). The growth and long-term sustainability of these reusable packaging networks are impeded by this uncertainty, affecting the costs, resilience, and sustainability of the

* Corresponding author.



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A closed-loop packaging network design model to foster infinitely reusable and recyclable containers in food industry

Riccardo Accorsi*, Giulia Baruffaldi, Riccardo Manzini

Department of Industrial Engineering, University of Bologna, Viale Risorgimento, 2, 40136, Bologna, Italy

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Recycling

ABSTRACT

The current public and private policies pursuing environmental sustainability targets mandate incisive management of packaging waste, starting with those sectors that use virgin materials most. Food industries and food supply chains adopt huge volumes of plastic crates, cardboard boxes, and wooden boxes as transport packaging, thereby representing a hotspot and an urgent call for scholars and practitioners to address. Whilst wooden and cardboard boxes are disposable solutions, plastic containers can be employed as infinitely reusable and recyclable packages but require complex logistic systems to manage their life cycle. Optimization techniques can be exploited to aid the design and profitability of such complex packaging networks. This paper falls within the scarce literature on the design of pooling networks for reusable containers in the food industry. It proposes a strategic mixed-integer linear programming model to design a closed-loop system from the perspective of the packaging maker responsible for serving a food supply chain. The container's lifespan, i.e. the number of cycles a package can be reused before recycling, represents a crucial aspect to consider when modeling such networks. Incorporating lifespan constraints within the proposed closed-loop network design model is the main novel contribution we provide to the literature. This model is applied to a real-world instance of an Italian package pooler operating with a consortium of large-scale retailers for the distribution of fruits, vegetables, bakery, and meat products. A multi-scenario what-if analysis showcases how the optimal network evolves according to potential variations in the packaging demand, as well as in the container lifespan, demonstrating how to lead packaging makers to the profitability and the long-term sustainability of the closed-loop network.

1. Introduction

The current public and private policies pursuing environmental sustainability targets mandate incisive management of packaging which accounts, so far, for 15% of the municipal solid waste, and shows an increasing trend (OECD, 2013; Eurostat, 2017). To face this issue, the European Waste Framework Directive (2008/98/EC) stated the importance of preventing waste generation. The European Council Directive on Packaging (2004/12/EC) indeed prioritizes the reuse of packaging, before recycling and recovery, as the main strategy to implement in those sectors that use virgin materials most (Corvellec, 2016).

Food industries and food supply chains adopt huge volumes of transport packaging, thereby representing an urgent call for scholars and practitioners to address. Given the nature of food, consumed every day and needing protection until consumption, the contribution of packaging to the entire environmental impact of the food industry is estimated at almost 45% depending on product variety and package material (Del Borghi et al., 2014). Some investigated the environmental impact of packaging in several areas and processes of the food industry by the mean of the Life Cycle Assessment (LCA) analysis (Toniolo et al., 2014; Siracusa et al., 2014; Del Borghi et al., 2018) and confirmed that most carbon emissions result from the use of virgin materials. Beyond the technological barriers to the adoption of waste-reducing eco-innovations in the packaged food sector (Vitale et al., 2018; Simms et al., 2020), reusable packaging represents a promising strategy for preventing virgin materials extraction and reducing such impacts (Tonn et al., 2014).

In Europe, reusable packaging employed for distributing fruit and vegetable products accounts for 40% of the sector (Stiftung Initiative Mehrweg, 2009). Whilst wooden and cardboard boxes are disposable solutions, plastic containers can be employed as infinitely reusable and recyclable packages but require complex logistic systems to manage their life cycle. Reusable packaging systems require more logistic operations than disposable packaging: the collection of containers after use, the storage, the clean-

* Corresponding author.
E-mail address: riccardo.accorsi2@unibo.it (R. Accorsi).

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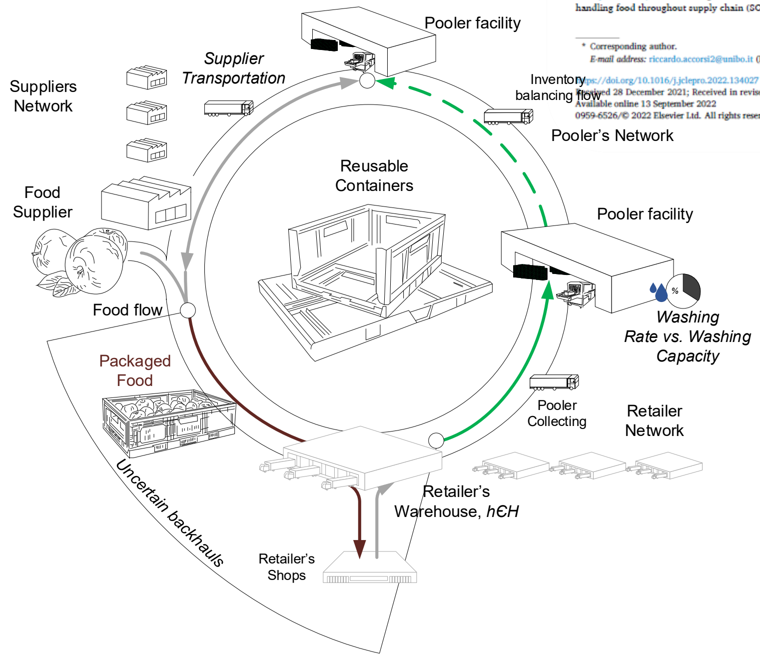

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Conclusions

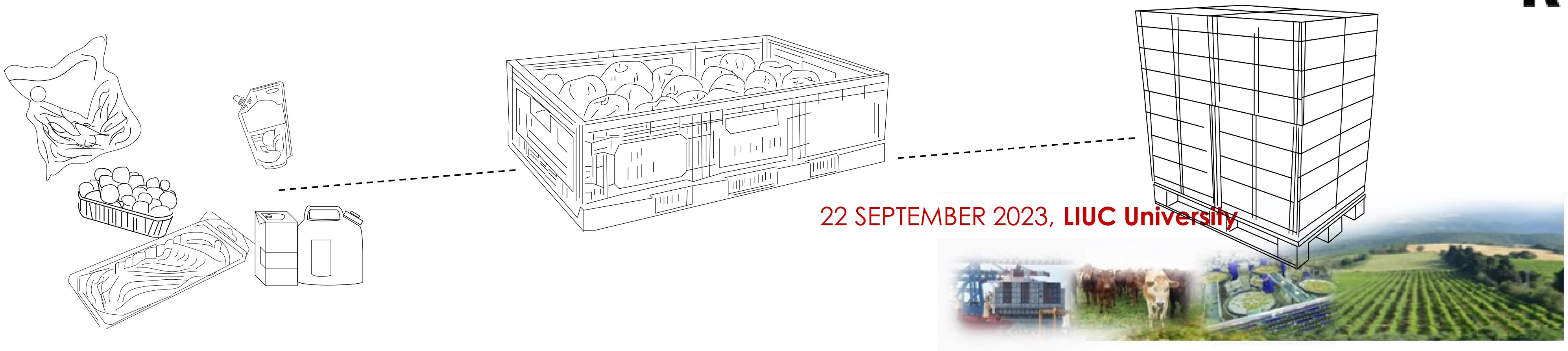
- **Reuse packaging system** are promising but the management of **circular logistics** is challenging.

- **Optimisation** comes to hand to provide support-decision and planning methods.

- **Addessable Issues** include the optimal location of the poolers facilities, the optimization of dirty and clean containers inventory, and the minimization of the overall environmental impacts associated with transportation.

- **Future developments** involve the design of circular networks for reusable primary packaging solution integrated with secondary and tertiary packaging (https://www.r3pack.eu/).

R3PACK



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Thanks for your Attention

Questions?

Prof. Riccardo Accorsi, Ph.D.

Department of Industrial Engineering

Alma Mater Studiorum – University of Bologna

riccardo.accorsi2@unibo.it