D4.1 – Circular Supply/Value Chains Development

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Table of contents

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

List of figures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

List of tables

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

List of abbreviations

Abbreviation	*Explanation*
AA	Automotive Aftermarket
BAU	Business-As-Usual
BiB	Back-in-Box
BX	Bosch eXchange product
CE	Circular Economy
CLSC	Closed-Loop Supply Chain
CMS	Circular Manufacturing Systems
DC	Distribution Centre
EoL	End of Life
IAM	Independent Aftermarket
ICT	Information and Communication Technology
KPI	Key Performance Indicator
OEM	Original Equipment Manufacturer
OES	Original Equipment Services
PPU	Pay-Per-Use
PRM	Product Recovery Management
PSS	Product Service System
ResCoM	Resource Conservative Manufacturing
RL	Reverse Logistics
SBU	Sales and Business Unit
TL	Trade-Level
WEEE	Waste Electrical and Electronic Equipment
WM	Washing Machine

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Executive summary

The purpose of this deliverable is to analyse best practices in industry and state-of-the-art supply chain design methodologies (task 4.1) and develop circular supply network design and optimization of multiple reverse flows and re-distribution for both demonstrators (task 4.2).

Firstly, an overview of the state-of-the-art in supply chain design methodologies that can contribute to the definition, development, and implementation of circular supply chains is presented. Conventional approach of closed-loop systems typically addresses reuse, remanufacturing, or recycling only when products reach their end of life (i.e. reactive approach). In the ReCiPSS context, circular supply chains refer to closing the loop intentionally by design in a systemic manner where the forward and reverse flows are integrated and optimized for multiple product lifecycles (i.e. proactive approach).

Secondly, industrial best practices in closed-loop supply chains are identified to enhance the understanding and knowledge about practical aspects of circular supply/value chains and to benchmark the current state of the supply chains of the ReCiPSS demonstrators against the best practices. Prominent examples include companies like Ricoh, Hewlett-Packard, IBM, Caterpillar, Xerox, Renault and Komatsu. These companies are OEMs that have full control of their product throughout the entire lifecycle including design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities and re-distribution.

Thirdly, a baseline analysis is conducted through field visits and interviews with the company representatives to understand critical success factors for circular supply chain design and development. For white goods demonstrator the purpose is to understand the preconditions in terms of supply chain when transitioning from a product sales business model to a product as a service business model whereas for the automotive spare parts demonstrator, the focus is to understand the current logistics set-up, how is it designed and operated for the current business. However, the potential critical success factors for both the demonstrators converge around the aspects of geographical locations of facilities, lead times for delivery or collection of products as well as the logistical network design.

Building upon the learnings of the analysis of the state-of-the-art, industrial best practices and baseline of the two demonstrators, simulation models of the demonstrators supply chains are developed and what-if analysis is performed to explore the aspect of centralized and decentralized supply chains scenarios while keeping the aspect of economic and environmental performance in focus. Based on the simulation modelling results, trade-off analysis has been created for both demonstrators to aid in decision making for implementation of circular supply chains in line with the business model and product design.

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1. Introduction

Deliverable *D4.1 Circular Supply/Value Chains Development Report* consists of two sub-tasks with the purpose to analyse best practices in industry and state-of-the-art supply chain design methodologies (task 4.1) and to develop circular supply network design and optimization methods for multiple reverse flows and re-distribution of products, modules, and components (task 4.2).

By presenting a comprehensive review of the state-of-the-art in supply chain methods, this work is meant to contribute to the definition, development, and implementation of circular supply chains. Furthermore, the current state of supply chains of the two project demonstrators namely Gorenje and Bosch, is also thoroughly investigated and presented for comparison and learnings. Moreover, this deliverable includes company-specific supply chains for circular system implementation while considering supply chain-specific design aspects of both demonstrators, including forward and reverse flows of products, taking into account product design and business model in line with the work in WP2 and WP3.

Key objectives of this deliverable are:

1. State-of-the-art in supply chain methods that can contribute towards the definition, development, and implementation of the circular supply chains.
2. An analysis of the best practices from industry in closed-loop supply chain design, as well as relevant concepts, methodologies, and standards.
3. Identify critical success factors in implementing circular value chains.
4. Explore the operational supply chain processes and elaborate feasible forward and reverse supply chain networks for the white goods and the automotive parts demonstrators.
5. Identify supply chains performance criteria, such as materials management, forecasting, lot sizing, inventory levels, and transportation routes.
6. Analyze the impact of business model and product design configurations on circular supply chain design and performance through the criteria of end-of-life design strategies (reuse, remanufacturing, recycling) on component, module, and/or product level, length of product use phases, customer service-level agreements and product collection cost.

This deliverable serves as input to infrastructure requirements of circular supply chains in D4.3 as well as for evaluation efforts in D4.4.

1.1. Methodology

The methodological approach used to carry out the tasks in this deliverable consists of a combination of literature review, case-study research, and simulation modelling.

A thorough literature review is conducted to highlight concepts that are relevant to circular supply chains, primarily focusing on the manufacturing industry. In addition to that, performance analysis criteria of state-of-the-art supply chains that are contributive to the circular supply chain implementation are highlighted. Moreover, industrial best practices in supply chain with potential in contributing to circular systems implementation and current state of the demonstrators' supply chains are identified.

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To establish a baseline for the two case studies, field visits, interviews and discussions with the representatives of both demonstrators are carried out.

Based on the literature review, industrial best practices, and current description of the supply chains in project demonstrators, a set of critical factors is identified which is used to create the simulation models to measure the economic and environmental performance of circular supply/value chains. These simulation models are designed and developed to provide a sound basis for decision making as they allow to experiment with different scenarios for different cases. The simulation models are developed using agent-based, system dynamics, and discrete event modelling techniques. Anylogic simulation platform is used to develop the models as it allows multi-method modelling with a high degree of flexibility and features.

1.2. **Scope**

This document presents the concept of circular supply chain and its relevance to closed-loop supply chain. It also describes key processes in reverse flows/logistics, relevant performance indicators, and standards for measuring the performance of supply chains. Furthermore, industrial best practices are explored and presented. Case study baseline for Gorenje and Bosch is outlined, and critical success factors in implementing circular value chains are highlighted. Through simulation modelling, a circular supply chain decision-support tool is designed to analyse the integration of forward and reverse flows and to understand the underlying supply chain design attributes that can enhance the economic and environmental performance of the current supply chain of the two demonstrators.

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2. State-of-the-art research in supply chains - from closed loop to circular

There is no denying of the fact that the Circular Economy (CE) transition is underway. Both research and industry are emphasizing a coherent concept of CE implementation. However, the nomenclature of CE and the relevant concepts are highly fragmented. Similar is the case when it comes to concepts relevant to supply chains that are contributing towards the implementation of Circular Manufacturing Systems (CMS). Circular supply chains is an emerging concept; efforts in research are ongoing to conceptualize the circular supply chains and their relevance to the existing concepts of closed-loop supply chain and green supply chain.

Conventional concepts in closed-loop supply chains deal primarily with reverse flows of products or components where neither business models nor the design of the products are intended for closing the loop. From a business point of view, this means dealing with uncertain product returns with no control over quality, quantity or timing of the returns. The concept of circular supply chains on the other hand refers to the seamless integration of forward and reverse flows where both the business models and the products are designed for closing the loop. In addition, economic and environmental performance indicators are embedded in the design of circular supply chains.

Supply chain is a well-researched field, where a large body of work deals with the design of supply chains, supply chain networks, performance measures, optimization and modelling. However, the focus of mainstream supply chain research has been mostly the linear businesses i.e. highly focused on the forward flows. Closed-loop supply chain is an important area of this field and research in this area has evolved over the past three decades. Due to its strong relevance with the concept of CE and CMS the topic needs serious attention, especially if the discussion and development are directed toward circular value and supply chains. Circular value chains include the phases of value creation, delivery, use, recovery and reuse in a systemic perspective. The literature review is structured around the following questions:

1. What are the relevant concepts in supply chain discipline that may contribute in implementing circular supply/value chains?
2. How can we measure the performance of the circular supply chains?

2.1. Closed-loop supply chains – definition and concepts

Closed-Loop Supply Chains (CLSC) as defined by Guide and VanWassenhove refer to "*the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time*" [1], and addition to this the definition also includes *"product return management, leasing and remanufacturing"* [2].

CLSC intend to integrate both the forward and reverse flows of products as depicted by a typical example in Figure 1.

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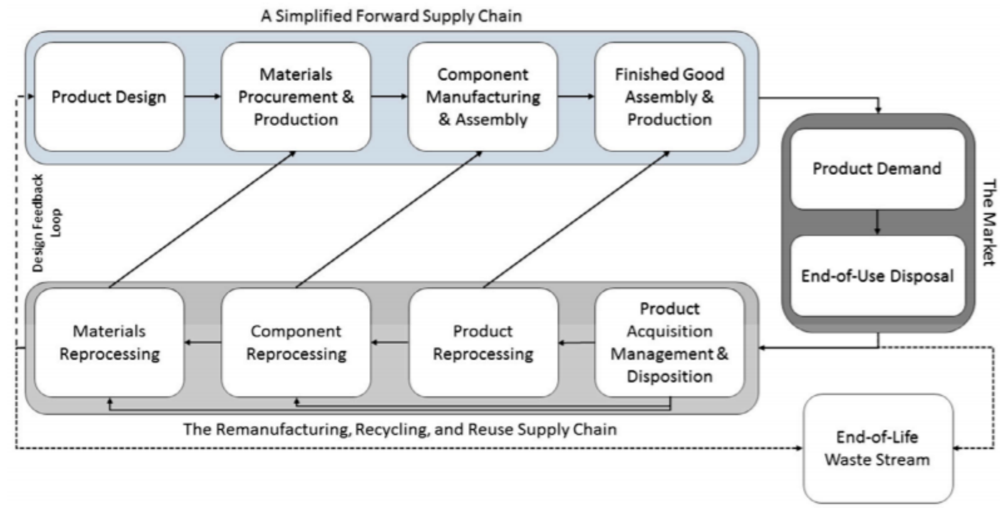

Figure 1: Process flow of closed-loop supply chain activities by Abbey et al (2018) [3]

Businesses may close the loop due to perceived indirect or direct economic gains such as increased market share, reduced costs for input materials, cost savings in production, shorter delivery times for materials and distributions, or to explore new markets [4]. Closing the loop may impact design, sales, purchasing, production, distribution, after-sales services, and accounting departments [5]. The classical drivers of CLSC system design are the volume of returns, the timing of returns [6], and the quality of returned products which determines the recovery activities and residual value in the products. To achieve business profitability in CLSC an integrated perspective is required from the design of the products and analyzing the lifecycle and end of use strategies to the collection of products [7]. Higher rate of returns can be achieved through investments in mechanisms for acquisition of products [8]. Complexities associated with CLSC revolve around management of material inventories, streamlining return flows, transportation planning, management of production facilities as well as uncertain information flows regarding return processes [9].

CLSC can be analyzed from three levels of decision-making, which are strategic, tactical, and operational. The strategic level refers to the high level of decision-making in the supply chain, including pricing and network design. The tactical level entails activities such as product acquisition and planning, inventory planning, and dealing with product returns. The operational level refers to day-to-day activities such as disassembly planning, lot sizing, priority dispatching, and scheduling [10].

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Table 1 highlights the levels of decision making in CLSC:

Table 1: Examples of strategic, tactical and operational issues in CLSC by Souza et al (2013) [11]

Strategic, tactical and operational issues in CLSC	
Level	**Decisions and issues**
Strategic	• Network design: location and size of collection centres, remanufacturing facilities, etc. • Collection strategy: should customers return products to retailers or directly to OEMs? • Should the OEM remanufacture? • Leasing or selling? • Trade-in and buy backs programs • Supply chain coordination: contracts and incentives • Response to take-back legislation • Impact of recovery activities in new product design
Tactical	• Acquisition of product returns – how many, when, and of which quality? • Returns disposition: remanufacturing, dismantling for spare parts, or recycling?
Operational	• Disassembly pplanning: sequence and depth of disassembly • Scheduling: priority rules, lot sizing and routing for the remanufacturing

A forward supply chain includes enterprise entities such as suppliers, manufacturers, transporters, warehouses, retailers, and customers themselves and is highly focused on fulfilling customers' requests [12]. The strategic perspective of CLSC requires an effective reverse logistics infrastructure for product recovery management. Product Recovery Management (PRM) refers to the management of all used and discarded products, components, and materials by a manufacturer [13]. In CLSC, reverse logistics is integral for both forward and reverse flow of products. Hence it assumed to be the nucleus of CLSC [14].

"Reverse logistics is the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal" [15].

Reverse logistics process enables to effectively use resources, which were not utilized or considered in earlier phases of production. Through effective reverse logistics processes, the flow of parts or products can be managed by remanufacturing operations, recycling or disposal [16]. Reverse logistics is practiced in several industries, including: commercial aircrafts, computers, automobiles, chemicals, appliances, apparel, and medical items. Companies with reverse logistics profile include 3M, Aurora, BMW, Chrysler, DEC, Ford, General Motors (Delphi), Hewlett-Packard, DuPont, IBM UK, IBM, Mercedes-Benz, Opel, Peugeot-Talbot, Philips, Shape, Volkswagen, Xerox, Storage Tek, TRW, and many other [17]. Several issues can be attributed to the effectiveness of reverse logistics such as the functions, the channels, the differences

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between forward and reverse operations and the cost of operations [18]. The typical reverse logistics process begins with a returned product that is inspected and sorted into different categories. Followed by a repurposing strategy, i.e. reuse, remanufacturing or recycling.

Key processes in reverse logistics are product acquisition, collection, inspection, sorting, and disposition are explained in detail in Table 2

Table 2: Reverse logistics key processes literature review by Agrawal et.al [19]

Reverse logistics key processes	
Process	**Key activities**
Product acquisition	Product acquisition is the first and critical aspect of the profitability of reverse logistics. It is the process of acquisition of used products, components or materials from the end-users for further processing. Since product returns are uncertain in terms of time, quantity and quality, their acquisition is important for the success of reverse logistics.
Collection	Collection methods can range from manufacturers directly collecting from customers, manufacturers collecting via retailers or manufactures collecting through third-party logistics. Two alternative take back methods are considered for collection which are distinguished by the "degree of control" on product returns which includes collective take back in which the manufacturer has no control over returns while second method is individual collection which gives complete control to the manufacturer. Moreover, the collection method depends on the cost structure and collection quantity decisions.
Inspection and sorting	Product returns may be commercial returns, service returns, distribution returns or end of life returns. Individual assessment of the products is required since customers can return the products for various reasons and in unpredictable condition.
Disposition	Once the products are inspected, the next step is to take disposition decisions for further processing. There are different disposition alternatives: product reuse, product upgrade, material recovery, and waste management. Firms mostly have five recovery options including sell as new; repair or repackage and resell as new; repair or repackage and resell as used; resell at a lower value to a salvage house; and sell by the material weight to a salvage house.

Reverse logistics network design is based on several elements, including product return management, collection channels structure, collection strategy and inventory management. Product return management impacts the profitability of the business, hence requires collaboration between the manufacturer and retailer [21]. The reverse channel can be handled by either the manufacturers, the retailer or third-party suppliers. The party who manages the reverse channel determines the collection quantity [22]. Reverse channel structure can be organized in three formats namely (1) producer collects directly from the end customers, (2) producer contracts the collection to the retailer, and (3) producer contracts the collection to a third party [23]. Furthermore, collection strategy might include setting up drop-off facilities serving small zones or assigned pick up locations from where the products can be transported

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to consolidation or recovery facilities, a hybrid strategy involving both pickup and drop-off is likely approach towards product collection. Subsequently, effective reverse logistics network requires inventory buffers to ensure reliability and a better control over products' availability for remanufacturing.

2.2. Performance measurement of closed-loop supply chains

In the systemic view of circular systems, it is imperative to understand the complexities associated with the performance of supply chains in the perspective of business model and product design. Changes in either the business model or the product design will require an adaptation in supply chain configuration. A cohesive picture of a potential circular supply network can only be obtained by addressing which parameters of supply chain performance shall be measured and what are the possible key performance indicators. Since the concept of circular supply chains is in its infancy where the development of circular performance criteria is at a conceptual stage. Therefore, a standard performance measurement criteria or matrix does not exist currently. To identify relevant performance criteria for circular supply/value chains, we will look into the existing performance indicators in linear supply chains. Linear supply chains are typically focused on business performance alone whereas CLSC consider the environmental performance aspects as well. Reverse logistics design still leans towards profit maximization and lesser on environmental impact [24]. The overarching key performance indicators for supply chains are reliability, responsiveness, flexibility, cost and time [25]. Performance measurement criteria can be further subdivided into functional criteria such as planning performance, sourcing performance, production performance, delivery performance, customer service performance [26]. These measures can fall in the category of strategic, tactical or operational. Strategic level measures include lead time against industry norm, quality level, cost-saving initiatives, and supplier pricing against the market. Tactical level measures include the efficiency of purchase order cycle time, cash flow, quality assurance methodology, and capacity flexibility. Operational level measures include the ability in day-to-day technical representation, adherence to developed schedule, ability to avoid complaints and achievement of defect free deliveries [27].

Table 3 presents a list of business performance KPIs for the linear supply chains as found in literature.

Table 3: List of strategic, tactical and operational KPIs for linear supply chain [27]

Strategic, tactical and operational KPIs in linear supply chain	
Level	**Performance metrics**
Strategic	• Total supply chain cycle time • Total cash flow time • Customer query time • Level of customer perceived value of product • Net profit vs. productivity ratio • Rate of return on investment • Range of product and services • Variations against budget • Order lead time • Flexibility of service systems to meet particular customer needs

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	• Buyer-supplier partnership level • Supplier lead time against industry norm • Level of supplier's defect free deliveries • Delivery lead time • Delivery performance
Tactical	• Tactical accuracy of forecasting techniques • Product development cycle time • Order entry methods • Effectiveness of delivery invoice methods • Purchase order cycle time • Planned process cycle time • Effectiveness of master production schedule • Supplier assistance in solving technical problems • Supplier ability to respond to quality problems • Supplier cost saving initiatives • Supplier's booking in procedures • Delivery reliability • Responsiveness to urgent deliveries • Effectiveness of distribution planning schedule
Operational	• Operational cost per operation hour • Information carrying cost • Capacity utilisation • Total inventory as: incoming stock level, work-in-progress , scrap level, ffinished goods in transit • Supplier rejection rate • Quality of delivery documentation • Efficiency of purchase order cycle time • Frequency of delivery • Driver reliability for performance • Quality of delivered goods • Achievement of defect free deliveries

The standard performance measurement framework in supply chain design is the Supply Chain Operations Reference (SCOR) model which is considered by some scholars as the standard employed in academia and industry in the supply chain management area [28]. The SCOR model maximizes supply chain visibility including efficiency, measurable and actionable outcomes when the visibility strategy of the supply chain is aligned with the model [29]. SCOR combines elements of business process engineering, metrics, benchmarking, leading practices, and people skills into a single framework. Within the SCOR framework, supply chain management is defined as the integrated processes of PLAN, SOURCE, MAKE, DELIVER, and RETURN—from the supplier's supplier to the customer's customer [30]. SCOR identifies five core supply chain performance attributes: reliability, responsiveness, agility, costs and asset management [31].

2.3. State-of-the-art research in ReCiPSS context

In the current Circular Economy scenario, circular material flows are in focus with efforts being put forward to close the loops. The notion of closing the loop has a multi-dimensional focus,

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which spans from reuse and remanufacturing of components or products to recycling for material recovery.

Conventional approach of closed-loop systems typically addresses reuse, remanufacturing, or recycling only when products reach their end of life . This is considered a reactive approach in comparison to a proactive approach, as proposed in the concept of Resource Conservative Manufacturing (ResCoM)[1]. In this concept, business models, product design, supply chains and supporting ICT for circular value management are developed with loop-closure in mind from the beginning [32]. The ResCoM concept includes the idea of multiple product lifecycles along with conservation of energy, material and added value with waste prevention and environmental protection has integrated components of the product design and development strategy. Studies highlighted that closed-loop system according to the ResCoM concept are more robust in terms of operations and face less uncertainty in terms of timing, quantity and quality of product returns as well as the mismatch between the supply and demand of product returns in remanufacturing scenarios [33].

Designing and managing supply chains to ensure collection of used products (also referred as cores) for value recovery are two essentials of products multiple lifecycles. The efficient collection of cores is a prerequisite for remanufacturing operations. Since the cores act as input to value recovery part in a closed-loop system, factors such as product variety, return time, quality of the cores, product life cycle, technology life cycle, cost of collection become challenging yet vital for remanufacturing operations. Several reasons from the literature have been highlighted for the uncertainty of core returns, for example including cores returning for different reasons and different timings, geographical dispersion of products where returns are not economically feasible, the product information is lost and the products are not being designed for efficient recovery [33]. For efficient product retrieval, ownership and buy-back business models have been proposed. These two business models, while addressing the challenge of return timing and quantity, do not address the aspect of core return quality. The return flow issues can anyhow be mitigated via closer customer relations [34] and retained ownership of the products by the OEM [35].

Hence, in the ReCiPSS context, circular supply chains refer to closing the loop by design in a systemic manner where the forward and reverse flows are integrated and optimized for multiple product lifecycles. These supply chains would be contributive in the implementation of circular manufacturing systems. CMS refers to the recovery of value (i.e., material, embedded energy and value that are added to products during manufacturing processes) through reusing, remanufacturing and recycling in a systematic way [36]. The rationale to explore circular value chains lies in the fact that an efficient circular supply chain network cannot be designed without considering the interconnections between the business model,product design, and the supporting ICT infrastructure.

[1] ResCoM, which stands for Resource Conservative Manufacturing, is a research initiative developed at the department of Production Engineering at KTH Royal Institute of Technology with the vision to conserve resources in the context of manufacturing systems [70]. This initiative was funded by the European Commission (EC) FP7 framework (website: www.rescoms.eu).

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3. Relevant industrial best practices

This section brings forward the industrial examples that are relevant from the point of view of implementing a circular supply/value chain. These examples will help in enhancing our understanding and knowledge about practical aspects of circular supply/value chains and at the same time support in benchmarking the current state of the supply chains of the ReCiPSS demonstrators against the best practices.

The selection of industrial best practices in the supply chain for ReCiPSS is performed in the context of value chains. Value chain concept here implies that the OEM is in full control or at least has a clear view of entire product life throughout all stages including design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities, and re-distribution. In simpler terms, the selected OEMs have enabled reverse flows of their products with a focus on remanufacturing, refurbishment or reuse. Partial control or no control of the value chains entails that the OEM does not have full control of the product throughout all stages; third party remanufacturing typically falls under this definition.

However, it is difficult to obtain a full and clear picture of the total supply chain and especially of reverse logistics flow from a company's websites and grey literature, as most often the information about supply chain and logistics is strategically confidential. However, a serious effort is made in understanding and highlighting appropriate supply chain elements of the relevant industrial cases such as inventory management, warehouse facility location, predictive maintenance or buy-back model where replicability to ReCiPSS cases is possible.

3.1. **Ricoh**

Ricoh Ltd is a Japanese multinational imaging and electronics company producing electronic products, primarily cameras and office equipment such as printers, photocopiers, and fax machines. The Group introduced in 1994 the Comet Circle oncept (Figure 2) to represent a sustainable society that recirculates resources. The circles in the diagram represent partners in the recycling-based society. *"Resources taken from the natural environment by materials suppliers shown at the upper right are processed into products, moving from right to left along the upper route, and are finally delivered to users (customers*)"[37]. Whereas the end -of-life products move from left to right along the lower route. To promote recirculation of products, it is necessary to recycle products through the inner loops of the Comet Circle. The Ricoh Group emphasizes the following activities that make the Comet Circle more effective [37]:

- **Reducing environmental impact at all stages**: The Ricoh Group uses a sustainable environmental management information system for its suppliers, customers, and recycling companies to determine the degree of environmental impact at all stages of operations. The sustainable environmental management information system guides to use the latest environmental conservation technologies and helps in promoting the recycling and collection systems all over the world.
- **Inner loop recycling**: By focusing on the inner loops, the Ricoh Group is minimizing the resources input, cost and energy usage that in turns results in higher rate of reuse and recycling of products.
- **Partnership at every stage of product lifecycle**: In order to reduce the environmental impact effectively, partnerships are essential. The Ricoh Group is striving to reduce their environmental impact in all business areas by establishing partnerships with stakeholders at all stages of the product lifecycle.

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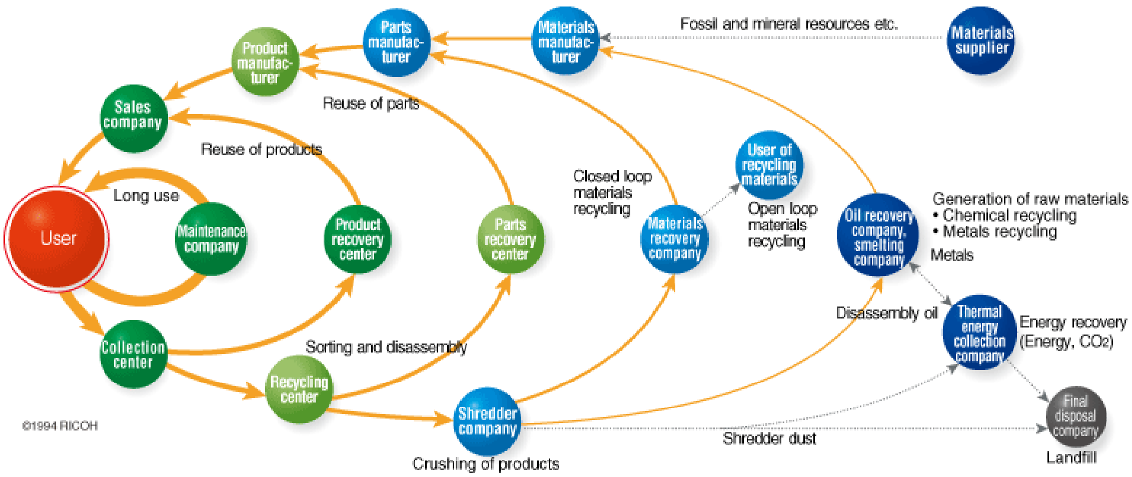

Figure 2: The Comet Circle of Ricoh (source: Ricoh website) [38].

Supply chain management

The Ricoh Group has 21 major production bases across Japan, the Americas, Europe, the Asia-Pacific region and China. Ricoh has reorganized its supply chain management across the Group, coordinating design, information systems and more with functions covering everything from procurement to collection and recycling [39].

The Ricoh Group is simultaneously lowering logistics costs and environmental impact by reducing waste in five areas: packaging, transportation, space utilization, transshipment and storage. Detailed initiatives include improved space utilization of containers, modal shifts in transportation among warehouses, direct deliveries to customers and optimizing transportation routes through milk run system, which entails that a single truck collects parts from multiple suppliers which improves the efficiency by reducing the distance the truck has to travel. In addition, to minimize the costs incurred in logistics to end-user delivery, parts and packaging materials, the Group is investing in the product design and development stage.

The logistics system integrates both arterial flows that deliver products to the customers and venous flows that collect used products (see Figure 3). The arterial logistic flows consist of:

- A direct transportation system from plants to customers
- A modal shift in transportation
- Usage of reusable packaging materials

While the venous logistic flows consist of:

- A direct collection system for used products
- The expansion and improvement of infrastructure such as collection centers

In the reverse logistics of the collection process, the data retrieved from the product recycling database which is read through the product's bar code showing the number and ratio of products recovered. The product recycling data is further used to estimate the sales of recycled products and parts.

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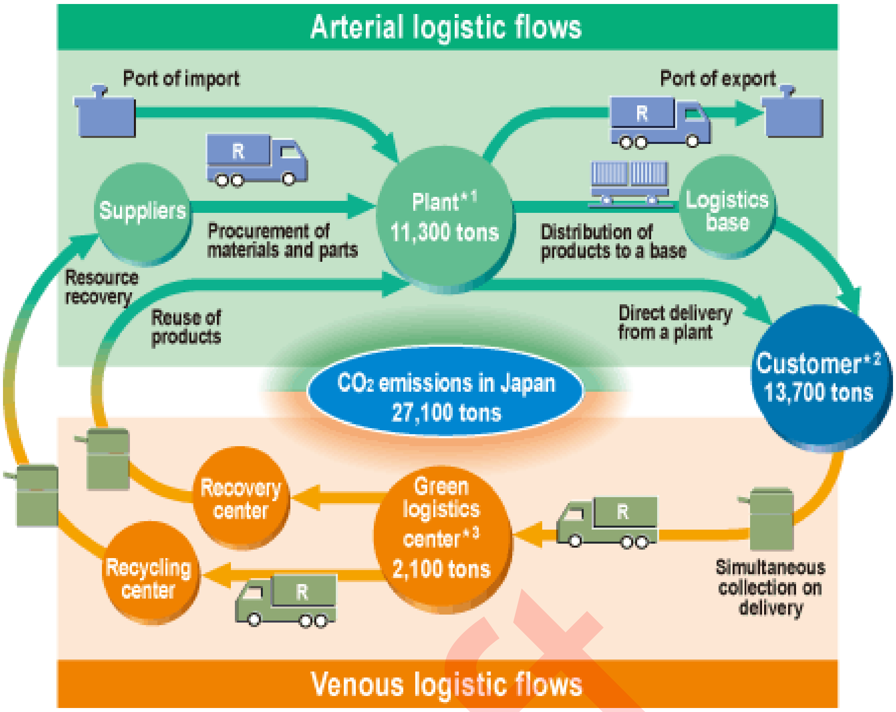

Figure 3: Arterial and venous logistic flows at Ricoh (source: Ricoh website) [40].

The Ricoh Group's design and development process is integrated with the supply chain to satisfy the diverse customer needs while in parallel improving the development efficiency and lowering product costs. Ricoh is extracting value from used products by employing an upgraded design of products, an established system to reuse parts repeatedly in production as well as effective partnerships with recycling companies and improved efficiency in transportation.

3.2. **Hewlett-Packard**

Hewlett-Packard, commonly referred to as HP, is a US-based multinational technology development and electronics company with a portfolio of printers, PCs, mobile devices and services. HP is shifting its business model and operations towards materials- and energy-efficient circular economy by investing in product design, production and reuse of recovered products (see Figure 4).

Materials cycle is a key concept at HP, where plastics, metals and other durable materials are continuously being used and reused for high-grade applications, without being down-cycled into lower-grade uses that eventually become waste. HP is working towards efficient use of materials thereby reducing the product-related environmental impact. Moreover HP is developing product recycling systems, designs for upgradeability and repairability [41].

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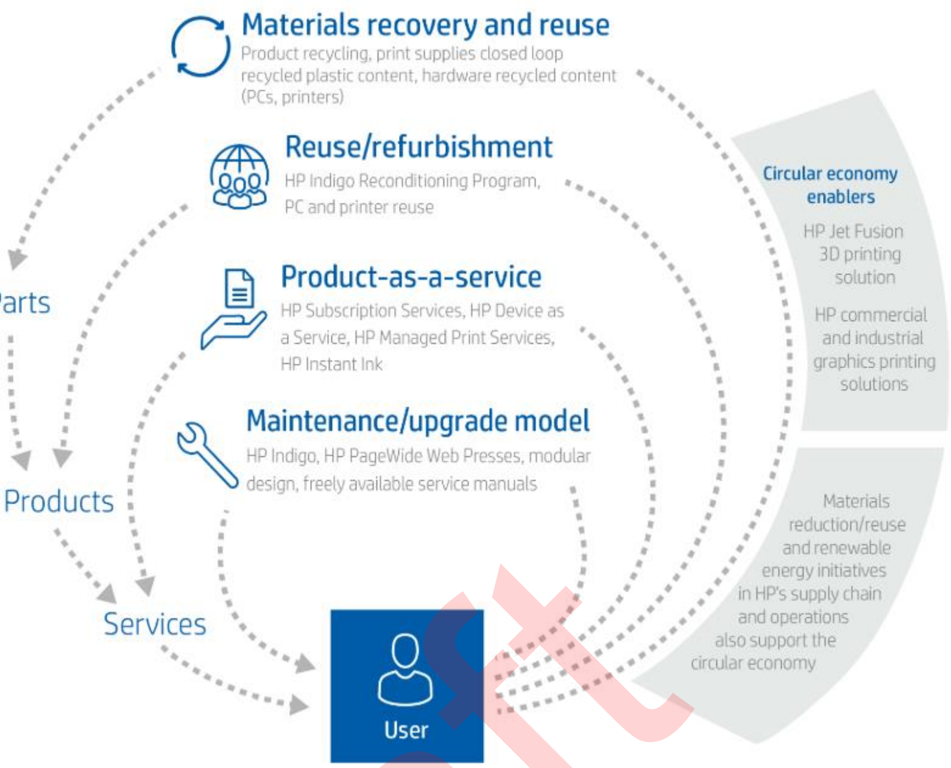

Figure 4: HP and Circular Economy (source: HP website) [42].

The rapid pace of innovation in electronics and technology products is increasing the urgency to move towards a circular economy model in which products are repurposed and kept in use for as long as possible. HP implements design for sustainability at every stage of the product life cycle— from use to servicing and maintenance, and end-of-service. Considerations include the availability of spare parts, ease of disassembly, materials identification, and ability to separate materials for higher recycling yields. When the products reach the end of their useful life, repair, reuse, and recycling programs support responsible collection and processing to recover and re-use as much material as possible. Through these activities, HP is helping to grow the supply chain and market for recycled materials, and make progress toward a circular business model [43].

HP has the following circular business models in place [41]:

- **Resource recovery**: Resource recovery and recycling recovers useful resources out of disposed products or by-products. HP recycles plastic content in its ink and toner cartridges and is committed to incorporating more recycled materials into its products to support the material recovery market and reduce the need for future resource extraction. To be effective in doing this, the company focuses on removing substances of concern from its product materials to facilitate their reuse into new products. HP also participates in end-of-life component harvesting by reusing PC and printer hardware components in refurbished products.
- **Product life extension**: Product life extension relies on remanufacturing, repairing or upgrading and reselling used products and components to give them a longer life with existing or new customers. This approach keeps products in use longer. A key HP material conservation priority is modular product design to support repairability and aid eventual refurbishment and upgrading to extend the life of its product lines. It is increasingly focused on designing products to be easily serviced and is ramping up the incorporation of smart

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technology to enable prompt servicing and repair. HP finds that modular design provides customers upgradeable capability as their needs evolve, eliminating the need for costly equipment replacement and the related resource impacts. For example, HP offers a reconditioning program for its digital presses in which units sourced from customer trade-in undergo refurbishing at company factories and are resold.

- **Product as a service**: Product as a service replaces ownership-based models with usage-based services. These encourage companies to maintain products for longer and offer new services, such as predictive maintenance. HP is moving into the product as a service business model by focusing on leasing, renting and other service contracts for ink, print and PC services. For example, HP's ink subscription service, HP Instant Ink, has more than 1 million subscribers in six countries. The service ensures customers never run out of ink when they need it, and that they can recycle used cartridges more efficiently (returned cartridges are fed into HP's closed-loop recycling program). Through the service, an internet-connected printer notifies HP when it is running low on ink, and a replacement cartridge is automatically delivered. Compared with conventional business models, printers using this service generate up to 67% less materials consumption per printed page. With its print and PC subscription services, commercial customers can access the latest and most energy-efficient IT products without the up-front costs of purchase. Every two to three years, HP commercial customers can upgrade to the newest hardware and software, supported by a service relationship that keeps products running smoothly. For example, its Managed Print Services offer a customizable set of solutions—including devices, network print management software, supplies, support, and end-of-life hardware options—that reduce customers' printing-related energy usage up to 40%, decrease costs up to 30% , and lower paper waste 25% or more.

Controlling reverse logistics routes and developing pure material streams are considered as important pre-conditions for HP to scale up its circular solutions. HP has considerable manufacturing operations in Brazil with an ambition for a zero waste landfill through the adoption of a circular economy strategy. To achieve this ambition, HP has partnered with Sinctronics to develop processes for recycled materials into new products and packaging. This collaboration has enabled HP to make better design decisions and identify timely opportunities for closed-loop systems [44].

3.3. **IBM**

International Business Machines Corporation (IBM) is an American multinational information technology company that manufactures and markets computer hardware, middleware and software, and provides hosting and consulting services in areas of mainframe computers and nanotechnology. IBM founded 35 years ago the IBM Global Asset Recovery Services (GARS) with the mission to recover the value of IT assets. As a global player in the asset disposition and remarketing industry, GARS specialize in pre-owned equipment, asset buyback, and recycling. The aim is to recover the maximum value of assets, find second uses and lives for assets, and minimize disposition. As a leader in product recovery and reuse, IBM remanufacturing and demanufacturing combined operations processed an average of over 41,482 IT assets per week in 2016. The total worldwide remanufacturing and demanufacturing combined operations processed 26,626 metric tons or 58,700,000 pounds of products parts and materials. Over 1,036,000 IT units were processed through their remanufacturing and refurbishment operations. More than 99% of all IT equipment and IT product waste returned to IBM at the end of IT asset lifecycle was either reused, remanufactured or recycled. IBM certified pre-owned

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equipment is updated to current engineering standards, fully tested using IBM original manufacturing specifications, and comes with a product guarantee [45].

Reverse logistics practice at IBM [46]:

- **The supply side reverse product flows**: IBM operates its reverse logistics processes for components that can be repaired or used as a service. IBM offers its customers the option to return end-of-life used equipment.
- **The demand side – remarketing**: IBM's asset recovery operations runs under GARS label which prioritizes the reselling of equipment as a whole with minor reconfigurations adapted to the customer requirement. These products are sold as IBM certified remanufactured equipment through the regular sales organization. Nonetheless, IBM is able to resell some 80% of the PCs returned from the business market.
- **Take-back strategies**: Through the lease portfolio, the product returns are known in advance by IBM recovery organization since they stem from expiring leases. However, actual return dates and quantities deviate because the customers might request for contract extension or the customers buy the product at the end of lease expiration.
- **Grading and disposition**: IBM's asset recovery is a two-step grading process with the selection criteria updated based on market needs and development. The selected products are tested at the central recovery facility of IBM.
- **Location and network design of reverse logistics**: GARS operate two major recovery facilities in the Europe, Middle East and Africa (EMEA) region, for a specific product range with locations in Montpellier, France, for the server equipment and in Mainz, Germany, for all other product ranges. These facilities perform the reverse logistics operations including the final grading, component disassembly, material separation, remanufacturing and subsequent storage. The PC operations are subcontracted to a service provider, whereas the other operations are carried out in-house. To be economically effective the transportation operations are subcontracted to a single provider which is responsible for the 'forward' distribution shipments. GARS operates two product-specific facilities in the United States of America (USA), in addition to central facilities in Canada, Brazil, Japan and Australia. However, the number of facilities in each region, and the aspect of centralization of the recovery operations are largely dependent on available competencies and infrastructure.
- **Inventory management and value of information**: IBM uses supply forecasts mainly on a medium-term aggregated level to adjust capacities. Furthermore, IBM's supply of service parts from dismantled machines is push-driven where the available parts which correspond to the projected future demand are moved through their specific recovery process and are then stored until deployed in the service network.

3.4. **Caterpillar**

Caterpillar is an American corporation which designs, develops, engineers, manufactures, markets and sells machinery, engines, financial products and insurances to customers via a worldwide dealer network. It is the world's largest construction equipment manufacturer.

Caterpillar remanufactures and rebuilds products and components that results in life cycles extension and material efficiency. Through the rebuild programs the lifespan of equipment is increased and the customer receives a restored part at less cost. A complete Caterpillar "*Certified Rebuild includes more than 350 tests and inspections, automatic replacement of*

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approximately 7,000 parts and a like-new machine warranty. Caterpillar provides information, data, training and service tools to help dealers make the most appropriate decisions on which parts to reuse in order to achieve expected longevity of rebuilt components" [47]. By reusing the components Caterpillar uses materials and energy more efficiently.

Caterpillar takes a systemic view of the product lifecycle. The products are designed and manufactured for multiple lives. The dealers support and service them to maximize their value to the customer. Products are remanufactured at the end of useful life to deliver the next generation of value. This total life cycle approach allows to provide sustainable solutions [47].

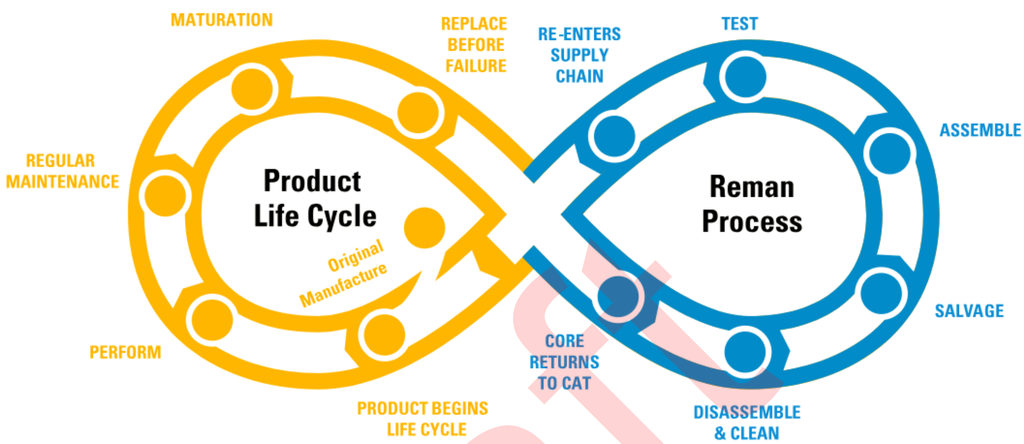

Figure 5: Extending product life at Caterpillar (source: Caterpillar website) [48]

Caterpillar Reman returns products at the end of their lives (called 'core') to same-as-new condition. Through remanufacturing, Caterpillar reduces waste, lowers greenhouse gas production and minimizes the need for raw materials. Over the past 45 years, Caterpillar´s remanufacturing activity has been improved and expanded. Caterpillar Reman takes back about 75,000 tons of end of serviceable life material every year and employs around 4,000 people worldwide.

Once a returned core arrives at a remanufacturing facility, it is disassembled, cleaned and inspected against strict engineering specifications to determine if it can be remanufactured. These components are then converted into production ready material through advanced salvage techniques which use the same rigorous engineering process that goes into new Caterpillar machines [48].

The product portfolio of Reman and rebuild opportunities comprise components, engines, turbines and rail as shown in Figure 6.

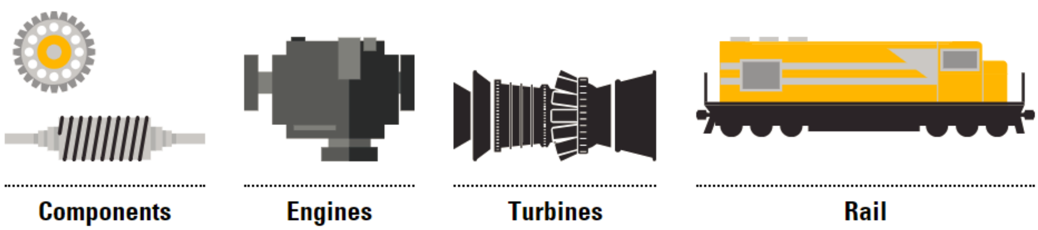

Figure 6: Reman & rebuild opportunities at Caterpillar (source: Caterpillar website) [47].

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The Caterpillar example shows that combining the manufacturing and remanufacturing does increase the product stewardship. The engines and parts remanufactured by Caterpillar are sold exclusively through the Caterpillar parts distribution network (Caterpillar dealers).Caterpillar offers its dealers a variety of product take-back incentives that ensures a larger volume of parts are returned by the dealers to Caterpillar.

These incentives include [49]:

- A buy-back guarantee for unused (unsold) parts inventory
- A deposit scheme on remanufactured parts and engines (a core deposit fee) as an incentive for dealers to return used parts to Caterpillar
- A voluntary take-back of surplus used products at a price above the scrap value.

Caterpillar already applies a policy of an **extended producer responsibility**, 'from cradle back to cradle', to parts and engines.

3.5. Xerox

Xerox Corporation is an American global corporation offering products and services for printing, publishing, copying, storing and sharing documents. Xerox recovered used equipment since the 1960s but developed a more formal remanufacturing system in the late 1980s and early 1990s to maximize the profitability of remanufacturing operations. Xerox remanufactures photocopiers and print and toner cartridges through its facilities in the USA, the United Kingdom, The Netherlands, Australia, Mexico, Brazil and Japan. By remanufacturing used photocopiers, Xerox has saved on raw material and waste disposal costs [50].

Xerox applies the following three main principles to reach their circular economy goals [51]:

- **Use "waste" as a resource**: In the early 1990s, Xerox pioneered the practice of converting end-of-life electronic equipment into products and parts that contain reused parts while meeting new-product specifications for quality and performance. Xerox take-back system for end-of-life product facilitates effective assets processing through remanufacturing, refurbishment, parts reuse and recycling.
- **Design for the future**: Xerox designs the products while keeping the aspect of reuse, end-of-life management processes while being customer centered at the same time.
- **Adaptive business model**: The Xerox business model offers its customers the option of leasing the products. Through the leased equipment program, it is guaranteed that the equipment is returned for optimized end-of-life processing. This model also ensures the design process prioritizes equipment longevity, re-use and allows for ultimate recycling. Since the customers can flexibly update the software and refresh the hardware, this business model is able to avoid premature obsolescence of their products

Xerox products are classified as Newly Manufactured Equipment, while a few products are classified as Factory Produced New Equipment [52]:

- **Newly Manufactured Equipment**: The newly manufactured equipment includes products with new parts as well as a few reused parts such as internal frames, covers or glass used inside the imaging unit of a device.
- **Factory Produced New Equipment**: This classification for equipment contains parts from a device previously used by a customer and then restored to meet product specifications prescribed by the company. The reverse logistics process includes the evaluation of

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equipment for its potential to be in a “like new” condition, the disassembly and upgrade into the next generation product with updated software. This equipment might also be a mix of new and reused components.

3.6. Renault

Groupe Renault is a French multinational automobile manufacturer that produces passenger cars and light commercial vehicles. Renault’s approach to circular implementation is by transforming the end-of-life parts and vehicles throughout the various stages of the products life cycle, to transform end-of-life parts and vehicles into a resource for the production and maintenance of vehicles, with a view to reducing its consumption of raw materials (see Figure 7). Renault uses the following circular economy principles [53]:

- **Eco-conception of vehicles**: Renault’s eco-design policy is to create vehicles which are easy to dismantle and contain recyclable or recoverable materials. The company also prioritizes the use of secondary material.
- **The end of automotive life**: Renault Environment (Renault’s own subsidiary) was created in 2008, which maintains the economic and technical control over the flow of automotive waste materials and parts. Renault Environment encompasses three subsidiaries: Indra (collects and handles end-of-life vehicles), Boone Comenor (metal waste), and Gaïa (end-of-life waste).
- **The reusable vehicles parts:** Renault reconditions or remanufactures used parts collected through their sales network. The process involves complete dismantling, cleaning, sorting, refurbishment and replacement of faulty or worn parts, reassembly and inspection. The parts used in the reconditioning and remanufacturing comes from their end-of-life vehicles and after sales network. This service is particularly attractive for customers with vehicles which are not economically repairable using only new parts.
- **The recycling loop:** Renault aims for “short recycling loops” by using secondary materials into the car manufacturing process with a precondition of product availability and quality. By using secondary materials Renault gains material efficiency.

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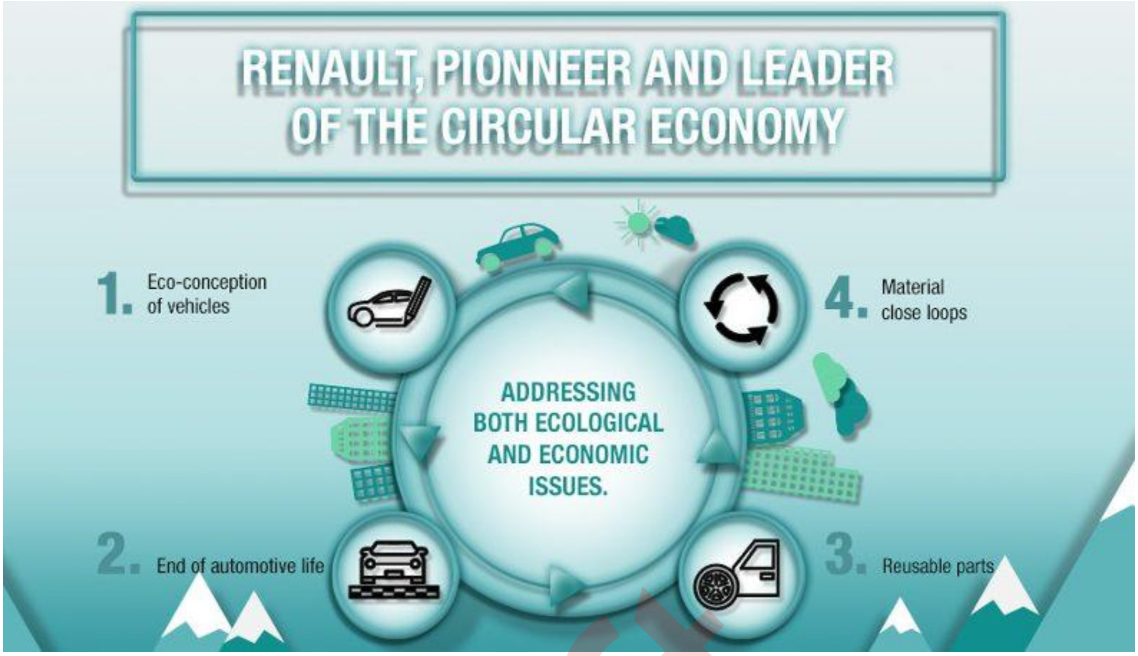

Figure 7: Circular economy at Renault (source: Renault website) [53].

The remanufacturing of Renault's automobiles parts started in 1949 at Choisy-le-Roifrom then onwards, the factory has been diversifying its output: injection pumps (1989), gearboxes (2003), injectors (2010) and turbo compressors (2013). The damaged parts (scraps) from vehicles currently in use are being collected through the commercial reverse logistic network (see Figure 8).

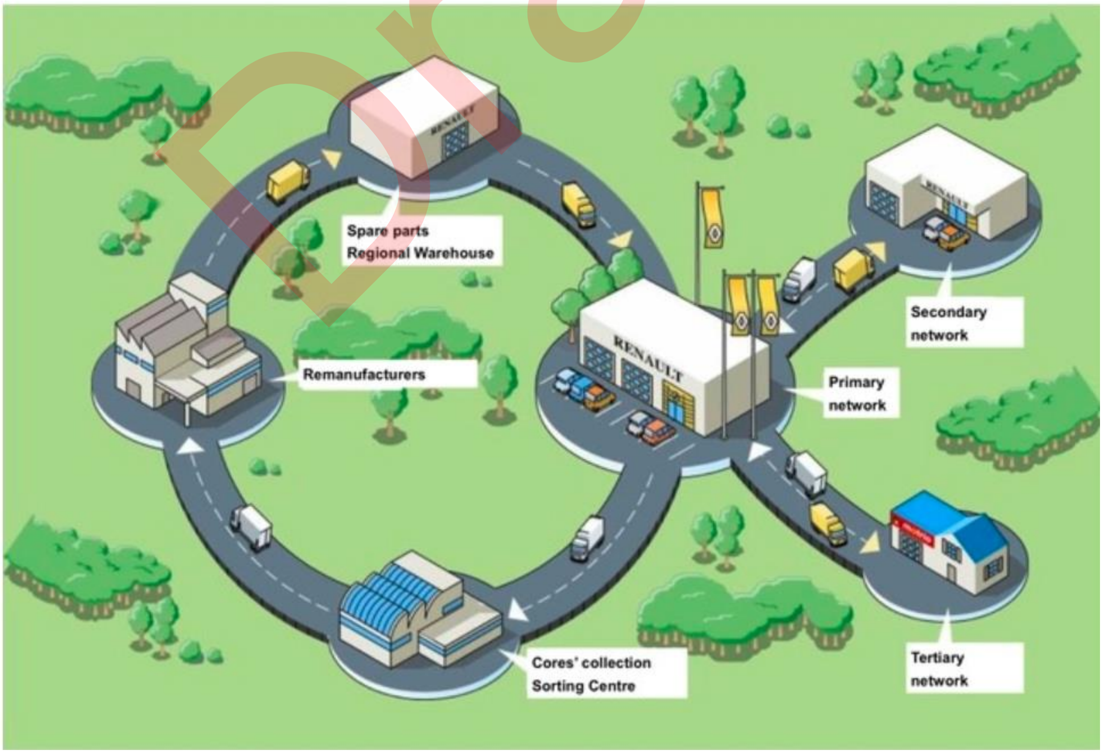

Figure 8: Reverse logistics network of Renault(source: Renault website) [54].

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Spare parts supply

In the aftermarket and spare parts business, logistics is a major focus for improving material flows from suppliers to the carmakers' global network. It is also critically essential to achieve better service rates to dealers worldwide. Renault has also been moving increasingly towards shared aftermarket logistics functions and operations with its alliance partner, Nissan, including combined warehousing, common transport tenders and administration, and joint expansions in new markets. These combinations follow other successful examples where Renault and Nissan have combined supply chain and logistics operations, notably across Europe for inbound and outbound logistics with its Alliance Logistics Europe function. Renault has invested in tools to generate procurement requests automatically and has succeeded in decreasing its stock level drastically without affecting the service rate in comparison to other carmakers. Renault's aftersales logistics organization is responsible for the procurement, storage, and delivery of aftersales parts for the multi-brand Renault Group, which includes Renault and Dacia, as well as Renault Samsung in South Korea. The department also serves Renault's wider vehicle and engine production partners, which along with Nissan includes General Motors, with which Renault shares van production, and Daimler, which has a variety of cross-production and supply agreements with Renault Nissan, including assembly in France and Slovenia. Renault's aftersales logistics department covers forecasting, procurement, stock management, warehousing, transport management, customer service and documentation. Spare parts are shipped from distribution centers to dealerships as well as to 100 importers in the countries in which Renault does not have subsidiaries. It supports dealer performance by ensuring parts availability to customers, providing dead-stock management and other functions. IT systems will play a further role in improving spare parts logistics. Renault has recently launched a renewal programme for its systems together with Nissan, which helps to optimize procurement and stock management [55].

3.7. Komatsu

Komatsu Ltd. is a Japanese multinational corporation that manufactures construction, mining, forestry, and military equipment, as well as industrial equipment like press machines, lasers and thermoelectric generators. The company has manufacturing operations in Japan, Asia, America and Europe. Komatsu has fitted all standard equipment with sensors that send data to a central platform. The platform is able to compile and analyze data on equipment location and condition, allowing Komatsu to quantify the cost and benefits of various reverse logistics options, including reusing, remanufacturing or refurbishing. It also allows the company to better plan maintenance operations [56]. Komatsu has introduced KOMTRAX Vehicle Management System (see Figure 9), a remote management system that uses on-board Global Positioning System (GPS) and wireless communications technology to monitor the operational state and "health" of Komatsu construction equipment operating anywhere in the world. The system can collect information on the equipment, such as how many hours the machine operates in a day and the amount of fuel it consumes, regardless of the equipment model or its location. This allows service personnel to plan timely inspections and part replacements, as well as to take preventative maintenance measures. As a result, maintenance-related waste is steadily reduced, together with the maintenance costs that are associated with this waste. It is also possible to use the information obtained from KOMTRAX to propose more efficient ways of using the equipment based on the characteristics of the customer's worksite. Selecting more appropriate equipment models and using the equipment more efficiently leads to a decrease in fuel consumption and less environmental impact for the customer [57].

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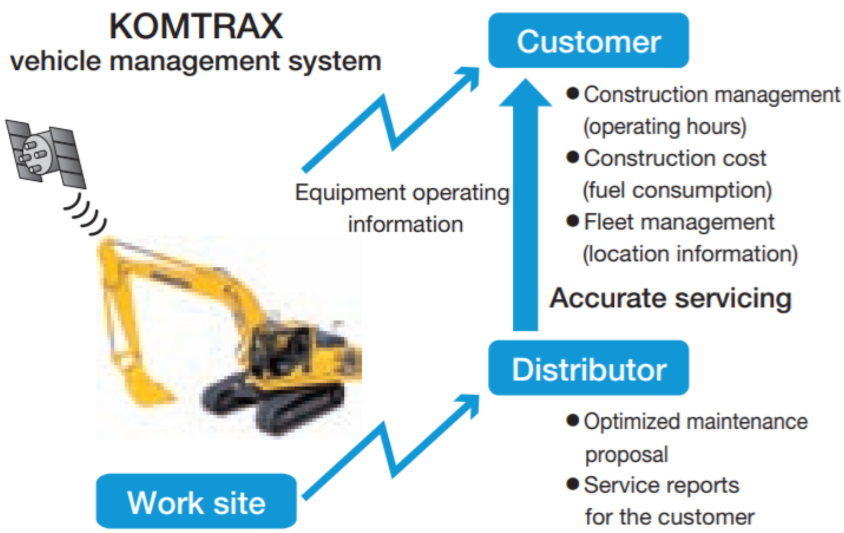

Figure 9: Vehicle information management system (source: Komatsu website) [57].

3.8. Learnings from industrial best practices

By analysing the industrial cases presented above, it can be concluded that OEMs have full control of their product throughout the entire lifecycle including design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities and re-distribution. Furthermore, these OEMs recover value through reuse, remanufacturing/refurbishment, and recycling (see Table 4).

Table 4: Best practices catalogue

Cases	Value chain aspects							Best practices in supply chains for		
	Design	Manufacturing	Forward supply chain	Customer use phase	Reverse supply chain	Recovery activities	Re-distribution	Reuse	Remanufacturing / Refurbishment	Recycling
Ricoh	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
HP	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
IBM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Caterpillar	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Xerox	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Renault	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Komatsu	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

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These companies represent leading examples of circular manufacturing systems where successful implementation is a result of a dynamic interaction among business model, product design, supply chain, and information and technology infrastructure. The products are designed and manufactured for multiple lifecycles. Modular product design is commonly employed to support repairability, remanufacturing and upgrading to extend the life of the products. Moreover, there is an increased focus on designing products to be easily serviced by incorporating smart technology to enable prompt servicing, repair, and predictive maintenance. Buy-back and product as a service including leasing, renting and other service contracts are the most employed business models by these companies to take the products back after use for the purpose of value recovery and redistribution. The companies have reverse logistics activities that lead to the recovery of value through either remanufacturing, reuse or recycling.

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4. Current state of the supply chain of the ReCiPSS demonstrators

This chapter provides an overview of the current state of the supply chains of the two demonstrators. It summarizes the supply chain operations of Gorenje and Bosch. This creates a baseline for analysis that eventually will be used to develop models to design and optimize circular supply networks. Before going into further details, it is useful to get an overview of the two demonstrators in ReCiPSS.

The overall goal of ReCiPSS is to explore key success factors for circular manufacturing systems in two cases where OEMs have different control levels over their value chains: one case with full control, and one case with partial control.

Value chains spans from sourcing, manufacturing, product use phase, repair, reuse, and recovery. A value chain with full control entails that the OEM is in full control of the entire product throughout all stages (i.e. design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities and re-distribution). Whereas a partial control of the value chains means that the OEM does not have full control of the product throughout all stages.

4.1. Demonstrator overview

The **white goods demonstrator** relates to a tightly connected value chain and will demonstrate the successful implementation of circular manufacturing systems where the OEM (Gorenje) is in full control of the entire product throughout all stages (i.e. design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities and redistribution).

The demonstrator will develop and implement a pay-per-wash offering for 300 washing machines, using co-creation methods in four markets namely Denmark, Austria, Slovenia and the Netherlands. The four markets for the ReCiPSS project have been chosen based on sales volume and existing supporting infrastructure. The washing machine model relevant for the study is ASKO85, a domestic professional built-to last model that is produced in Velenje. Each washing machine will be refurbished twice and serve over 3 life cycles of 5 years.

To support a new business model for washing machines based on multiple use cycles and product refurbishing, Gorenje will need to develop a new system for reverse logistics.

The **automotive spare parts demonstrator** relates to a more complex value chain where the OEM (Bosch) does not have full control of the product throughout all stages and needs to involve third-party logistics, remanufacturing, etc. In order to demonstrate how third-party automotive remanufacturers can be effectively integrated in circular supply chains while keeping their independence from the OEM, the demonstrator will streamline the reverse logistics flow, enabling aftermarket stakeholders to close the loop by using a single service provider for reverse logistics. Cores will be identified and evaluated only once (which is currently done arbitrarily) and then directly shipped to the final destination (remanufacturer), allowing cost savings of at least 50%. Moreover, by sharing core return information transparently between stakeholders, the quality, quantity and timing of core returns can be estimated accurately to manage a fully circular manufacturing operation.

In accordance with the project description (Annex 1) the demonstrator will process 80,000 cores (Bosch cores and non-Bosch cores) in France and Germany, which are the two largest European markets for automotive parts. Bosch cores will be sent to the Bosch remanufacturing facilities.

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The trade levels will continue to operate normally in the forward logistics segment (i.e. selling remanufacturing parts throughout the trade network). Since the cores will be shipped directly from the workshop to the remanufacturer, bypassing trade levels, the overall system is more efficient and transparent. All stakeholders will benefit from increased transparency, reduced lead times, increased efficiency of the reverse logistics supply chain and reliable financial transactions.

The baseline analysis was conducted to understand the prerequisites for the development of supply chain network. For white goods demonstrator the purpose was to understand their current business model and preconditions for transformation from product sales business model to service based business model whereas for the automotive spare parts demonstrator, the focus was to understand their current logistics set-up, how is it designed and operated for the current business. However, the potential critical key success factors for both the demonstrators were converging around the aspects of geographical locations of facilities, lead times for delivery or collection of products as well as the logistical network design.

4.2. **White goods demonstrator baseline**

4.2.1. Gorenje focus

Gorenje strategic focus is to be the leading design-driven manufacturer of home products with an increased market share of premium products. Gorenje's commitment to environmental sustainability is evident from the eco-cycle, which comprises of sourcing, production, use, and recovery with a strong focus on environmental sustainability. According to Gorenje's sustainability report, the product planning stage is very important as up to 80% of all of the environmental impact of a product is determined at the design phase of the product and the company invests in environmentally sound and degradable materials. Moreover, by investing in advanced production processes the company has been able to reduce the amount of hazardous waste by 91% per product, amount of disposed waste by 76% per product, water consumption by 86% per product, and use of natural gas by 32% per product between 1997 and 2013.

Furthermore, the products are planned and produced for easy disassembly and recycling. This is done by incorporating as few versions of the same material as possible which reduces the need for waste separation in the recycling process. The products are made of materials and components that are at least 80% recyclable.

Gorenje wants to achieve excellence in after-sales with an emphasis on predictive maintenance during the use-phase and upgradeability of products after the use-phase. To gain traction in the predictive maintenance landscape and have a competitive advantage, Gorenje is exploring the option of connectivity in their washing machines.

Reverse logistics seems to be a challenge for Gorenje, since the logistics cost is a big issue. Critical factors for reverse logistics are the location of dismantling facilities, the warranty processes of second-hand spare parts, the issue of geographical dispersion of the customers, which increases the logistics costs, and lack of quality information from the supplier's internal processes.

4.2.2. Refurbishment/ Remanufacturing

Refurbishment and remanufacturing is not currently practiced in the company due to higher perceived cost for remanufacturing set-up. Therefore, Gorenje's current strategy is to produce long lasting appliances. The only exception is moving the operations to a low-cost country, e.g. Czech Republic to save on fixed costs in the current business context. Also due to legislative barriers, it is not allowed to use a used part in a new washing machine. Moreover, higher legal

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cost is anticipated, if products are not returned in a service-based model as per contract. Therefore, technical safeguards are needed, e.g., "automatic break down" if bills are not paid.

The production team has demand cannibalization concerns. If ReCiPSS proves the feasibility, the team proposed that a special model will be launched only for the pay-per-wash market to avoid cannibalization. Another challenge is that long-lasting products require less maintenance and repair, which is perceived as an obstacle to the growth of service organization. Therefore, Gorenje wants to explore the refurbishment option with the upgradeability of machines after the use phase as a future strategy. Furthermore, specific safety regulations must also be considered in remanufactured washing machines.

4.2.3. ASKO 85 Professional / sourcing

The washing machine model relevant for the study is ASKO85 professional. ASKO models are produced with a standard interface. However, the professional models are more durable compared to the domestic models. Besides durability, ASKO professional comes with additional features in the software, integrated Wifi, and a coin inlet.

To implement a pay-per-wash offering for 300 washing machines, Gorenje wants to use the best product, i.e. ASKO domestic professional (built-to-last) model. Each washing machine will be refurbished twice and serve over three life cycles of 5 years. ASKO washing machine is assembled with 33 sets, has a volume of 0,306 m^3 with an approximate weight of 100 kg.

4.2.4. Delivery

The overall delivery process begins with the production of washing machines in the factories, and then the machines move on to the main warehouse. The products are then sent to the distribution centres (DCs) and then further to the wholesalers and retailers. The main warehouse is in Velenje (Slovenia) with distribution centre in Celje, Vienna, Duiven, and Brabrand for Slovenia, Austria, the Netherlands, and Denmark, respectively. The wholesalers and retailers have various locations in the chosen four markets.

4.2.5. Inventory policy

Gorenje's inventory policy is "on-demand". The distribution centre is not supposed to keep products in stock. The required number of products are ordered only after receiving an order from a customer/factory or another distribution centre. Exceptions for keeping safety stock for unanticipated sudden sales are possible but need to be approved by the management. In practice, the order quantities may be increased/adjusted based on seasonal demand (past experience). Gorenje DCs can purchase each other's stock (multi-channel sourcing) based on the rule "closest available"- Backlog orders need to be fulfilled and penalties may apply if orders are not delivered on time.

4.2.6. Logistics

Gorenje uses their local train station in Velenje to transport goods to their DCs (Slovenia and Denmark). Transportation cost is volume-based (m^3) and truck transportation policy is based on Full Truck Load (FTL), which means orders will not be shipped until at least one vehicle is fully loaded. For Gorenje, the minimum load of a vehicle is 90%. The container types for truck and railway are assumed to be the same and intermodal transport is possible. The mode of transportation is decided on a case-to-case basis by the corresponding DC/Sales Business Unit (SBU) and made dependent on the cost minimum option. The largest truck capacity is 120 m^3.

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The largest train capacity is 180 m^3 (valid for Slovenia) and the large truck capacity is 216 m^3 (valid for Denmark). The share of transportation modes is shown in Table 5.

Table 5: Transportation modes for logistics.

Share of transportation mode		
Relevant markets	***Train***	***Truck***
Slovenia	90%	10%
Austria	0	100%
The Netherlands	0	100%
Denmark	50%	50%

4.2.7. Service and repair

Service network includes SBUs led by a regional service manager. The spare parts are mostly delivered by Velenje warehouse to avoid using any other distribution centre's stock and to minimize bureaucracy and cost. In addition to this, Gorenje has the obligation to take back outdated parts. The spare parts are delivered regularly to DCs/SBUs almost daily. Gorenje is developing a system for warranty management, where all customer warranties are registered in the system. Generally, in Europe the warranty period for white goods is 2 years whereas in Slovenia it is 5 years.

The service and repair process begins with call centre or service partner receiving customer calls. Diagnosis is made on the phone, and the customers fill out a form to register the claim. Spare part management sources spare part(s); Gorenje provides suggestive stock level on spare parts. Technicians take over and plan the visit at the customer site. Depending on whether the washing machine breakdown has occurred within the warranty time, the customer will be charged or not. The repairs mostly are carried out within 25 km travel distance on average, cost depend on salary in the market (Netherlands/Denmark higher than Slovenia). Delivery cost is part of the spare part price. A minivan is used for transportation in service and repair activities. For Slovenian market, there are 8 service units in 8 major Slovenian cities with a team of technicians. In Austria, the service network is divided into 4 areas (Vienna, Salzburg, Linz, Graz). In the Netherlands, Gorenje has access to independently owned service network through ATAG, which a leading supplier of kitchen appliances in the Dutch market. The Danish market is catered through the service technicians in Copenhagen.

4.2.8. End-of-life (EoL)

For the four markets of relevance, the principles of EoL are the same. i.e., Gorenje will pay an authorized representative to collect and process their washing machine according to EoL processes.

ZEOS is handling the EoL of Gorenje's white goods (95% Gorenje-owned). Municipalities have to collect appliances from the household (by legislation) through the collection yards. New WEEE gives full responsibility/obligation to producers to account for their products (collection, logistics, treatment, etc.), i.e. all associated costs with the EoL are put on producers. In current appliances, these environmental costs are included in the price (the customer pays upfront for

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the EoL processes). ZEOS is an authorized representative to finance the collection of white goods in Slovenia. In the case of other countries (e.g. Spain) Gorenje can pay the local authorized representative in charge for the EoL processes to take care of their white goods. In return, these fees can be subtracted from the price. Operational responsibilities (”PRO” system) of ZEOS includes the collection, treatment, recovery and environmentally sound disposal of e-waste.

For ASKO (white goods) Slovenia has collection yards. The parties involved in the EoL processes are public services and collectors for profit. The fee for ASKO is 1,67€ per washing machine which is included in the sales price. Due to the higher metal value, the recovery has become more profitable recently. The treatment process (WEEE standard) comprises of dismantling, sorting of hazardous materials and residuals, and incineration or other for energy recovery.

4.3. **Automotive parts demonstrator baseline**

4.3.1. Automotive aftermarket structure

The automotive aftermarket is the part of the automotive industry sector comprising the automotive services and parts businesses to vehicles that are already sold. The service business (maintenance and repair of vehicles) generates about 45% of total aftermarket revenues in Europe, while retail and wholesale of vehicle parts make up the remaining around 55% [58]. Remanufacturing in this sector is worth €8-10 billion of retail sales, with circa. 30 product groups able to be remanufactured [59].

The automotive aftermarket is split into the OEM network (i.e. OES Original Equipment Services) and the Independent AfterMarket (IAM). Multiple types of stakeholders interact with each other along the value chain. Up to six distinct stakeholders can be distinguished in the automotive aftermarket (see Figure 10):

- **Car manufacturers** such as OEMs (e.g. BMW, Daimler)
- **Automotive part manufacturers** (e.g. Bosch, ZF), and generic manufacturers that produce aftermarket parts and offer services
- **Part distributors**, including buying groups (e.g. Affiliated Distributors), independent distributors (e.g. Stahlgruber, LKQ), online retailers (e.g. Amazon, eBay), and OEMs with their affiliated distributor network
- **Workshops**, including the OEM workshop networks, auto centers, and small garages
- **Intermediaries**, in particular insurances, automobile clubs, leasing companies, and routing portals
- **End customers**, consisting of the private, business and fleet market

Aftermarket business is conducted via several business models, including OEM/OES, the independent aftermarket, workshops, and a range of other business models or channels (e.g. e-commerce). While most aftermarket suppliers are currently operating in the independent aftermarket and via the OEM/OES channel, a shift towards direct distribution models and partnerships (in particular e-commerce businesses and workshops) will characterize the future evolution of the aftermarket [58].

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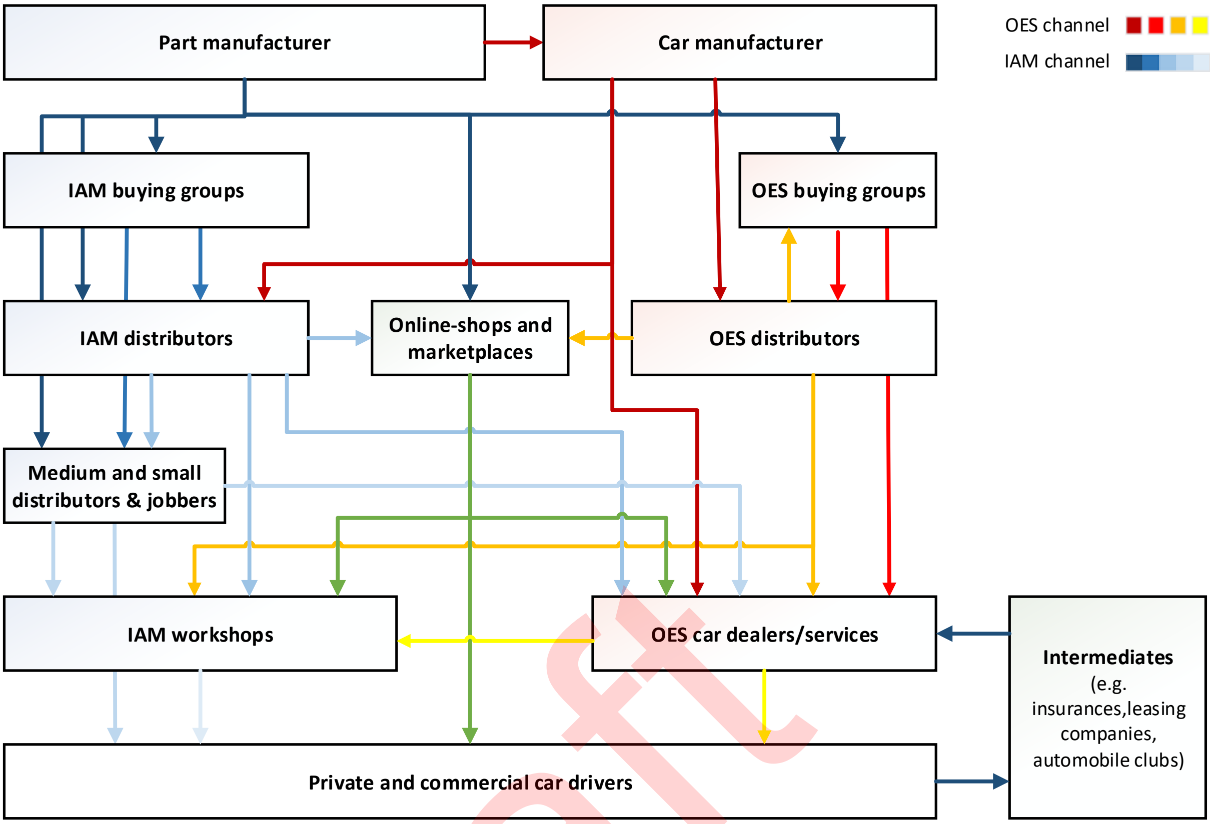

Figure 10: The EU car aftermarket structure (adapted from Wolk after sales experts [60]).

4.3.2. Automotive spare parts demonstrator

Bosch is the world's largest automotive supplier and is active in various sub segments. The business sector comprises the following divisions [61]:

- Powertrain solutions
- Chassis systems control
- Electrical drives
- Car multimedia
- Automotive electronics
- **Automotive aftermarket**
- Automotive steering
- Connected mobility solutions

The Automotive aftermarket division offers a comprehensive range of automotive spare parts for the aftermarket and repair shops worldwide – from new parts to remanufactured spares and repair solutions – as well as diagnostic and repair-shop solutions. The product portfolio consists of Bosch original-equipment products, as well as services and products developed and manufactured in-house specifically for the aftermarket.

Bosch has implemented the Bosch eXchange program for remanufactured parts. The reman product portfolio comprises electrical rotating machines (i.e. starters and alternators), diesel systems, braking systems, steering systems, and gasoline systems. Products within the eXchange program have the same warranty as new products and are offered around 30% cheaper than new alternative parts. Compared with new unit production, remanufactured units allow for

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material savings up to 90%, and energy and CO_2 savings of approximately 50%. The eXchange program ensures the availability of products after the end of the series production [62].

Efficient core management is a precondition for a successful remanufacturing. Core management consists in the collection of used parts from the market, core identification and evaluation, core sorting, core stocking, delivery to the remanufacturing plant (

Figure 11), and the commercial system behind that managing the financial incentives for core-returns between the business partners. Bosch processes the core return with the help of the service CoremanNet that offers core return solutions for the automotive aftermarket. CoremanNet is the service brand of Circular Economy Solutions GmbH (C-ECO), offering a variety of services for circular economy including reverse logistics and consulting.

The “back-in-box” process of returning the core in the original packaging provided with the exchange part is implemented. The used part is placed in the exchange part´s box and send from the workshop via the wholesaler to CoremanNet. By using the same original packaging, the core is protected against transit damage. Moreover, it allows for easier identification of the cores and therefore speeds up the return process. Upon request, CoremanNet picks up the cores at the wholesaler and sends them to the selection station where the cores are identified and evaluated. It is checked whether the core complies with the return criteria. The technical inspection consists in a minimum of checking whether the core is complete, not dismantled and not mechanically damaged. Depending on the type of product additional inspections or testing will be conducted. If the core meets the return criteria, Bosch refunds the wholesaler with the core surcharge paid upfront. The results of the identification are reported in the core selection report. With this report, each single part number, condition and value for cores received is documented. The cores are then labeled, sorted and stored at different warehouses operated by C-ECO´s service providers. Upon request, the cores are delivered to the remanufacturing plant.

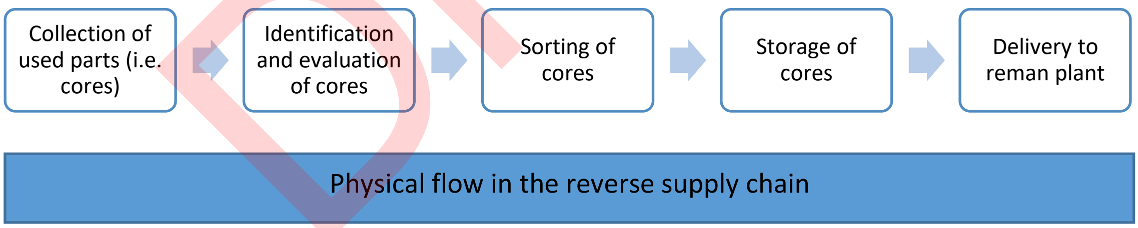

Figure 11: Core management.

4.3.3. Reverse logistics flow

The trade channel structure within the automotive aftermarket is complex, as it consists of multiple part dealers (i.e. trade levels) between the remanufacturer and the workshop (Figure 12). Automotive aftermarket repair and maintenance is carried out either through approved OES car dealers/services or through the independent aftermarket workshops. However, the structure of OES network is leaner and less complex than IAM network in terms of distribution. The majority of vehicles younger than three years are serviced in the OEM network. This is due to the fact that the vehicles are still under warranty. This number decreases to around 10% for vehicles older than eight years. The remaining 90% of older vehicles are then serviced in the IAM network.

When a vehicle with a defective part is brought to a workshop for repair, the workshop orders a replacement part via its local distributor. In the case of exchange-parts, the distributor will also

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collect the defective part at the workshop level. This dealer sorts and evaluates the part before "selling" it to the wholesaler (IAM or OES distributors), who buys parts from its customer, a broad number of medium and small distributors and jobbers. Upon request, the wholesaler delivers the cores to the part manufacturers after having identified and evaluated them once again.

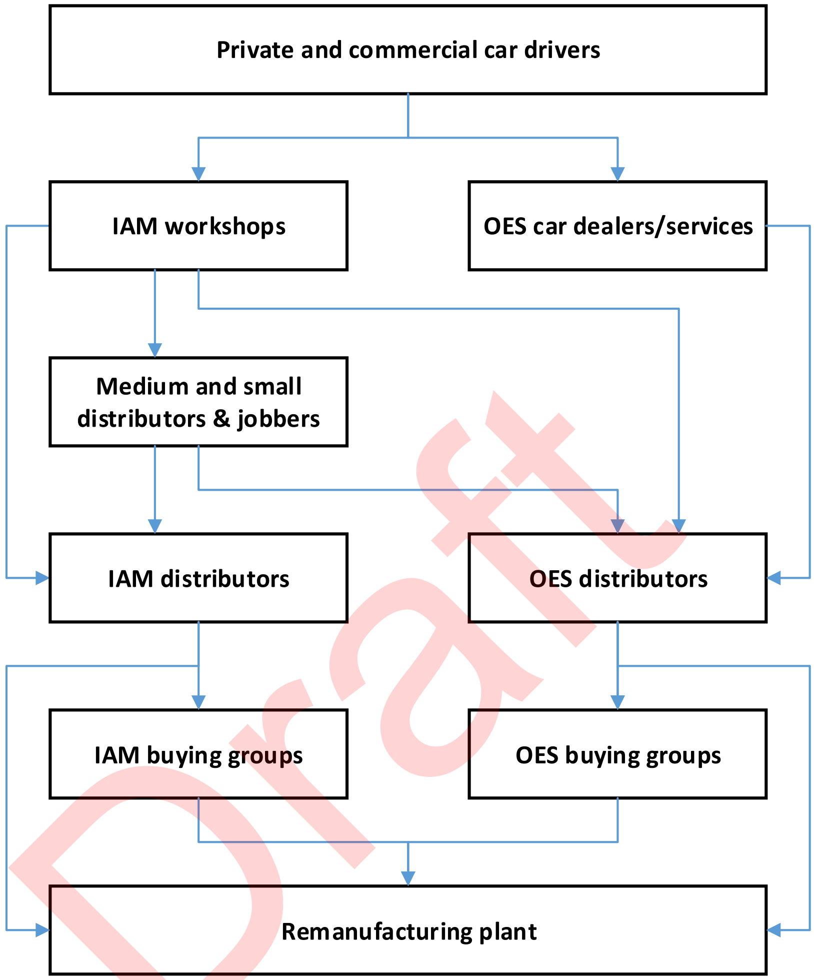

Figure 12: Core flow process.

Currently, the trade levels operate independently and share little information with each other. The main reason is the commercial interest to protect the individual business relation. Therefore, the same core is identified and evaluated several times, creating inefficiencies, additional costs and the risk for a trade-level to decide differently from the one before resulting in loss of the core-surcharge. By streamlining the reverse logistics flow, enabling aftermarket stakeholders to close the loop by using a single service provider for reverse logistics, cores will be identified and evaluated only once and then directly shipped to the remanufacturer. By shipping the cores directly from the workshop to the remanufacturer, logistically bypassing trade levels, the overall system can be more efficient. By the usage of intelligent digital data exchange, it will not be necessary anymore to transport the used parts back via the same way the remanufactured parts have been delivered just to ensure the crediting between all trade-levels. All stakeholders will benefit from increased transparency, reduced lead times, increased efficiency of the reverse logistics supply chain and reliable financial transactions. For the wholesaler, for example, outsourcing core management would bring several benefits as core management represents a non-value-added activity that brings only complexity. The aim is to

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reach a critical mass of parts and leverage economies of scale (e.g. size of customer access and purchasing volumes). Different part manufacturers have different selection criteria and different business models with which the distributors/wholesalers have to deal. By outsourcing core management, the wholesaler will benefit from a reduced complexity. Having one standard process for all reman suppliers will allow the wholesaler to achieve better service levels (e.g. efficiency, transparency), offer additional services (e.g. better reporting), have free capacity in the warehouse (only new parts), and reduce financial risk.

By subcontracting reverse logistics within the wholesale network that supports complete core collection, identification, evaluation, sorting, and return of cores in one step, the supply chain efficiency will increase substantially. This will create transparency for all stakeholders by providing accurate information about the current whereabouts, surcharges, legal information, and return option as well as part history and changes in ownership and increase the acceptance of remanufactured products.

4.3.4. Reverse logistic flow in the German aftermarket

The Bosch Automotive Aftermarket (AA) headquarter is located in Karlsruhe, Germany. The wholesaler, IAM is the direct customer of Bosch AA. When the wholesaler buys a Bosch eXchange product (i.e. BX-product), Bosch invoices the product price plus a core value (deposit, core surcharge). Upon request, the wholesaler sends the BX-products to the medium and small distributors and jobbers (i.e. outlets). When a vehicle with a defective part is brought to a workshop for repair, the workshop orders an exchange part via the outlets and returns the defective part back in the original packaging provided with the exchange part. There are approximately 38,000 workshops in Germany, where 30,000 belong to the IAM network and 8,000 to the OES network. The wholesaler collects the cores from the outlets and sends them back to Bosch for core selection. Bosch processes the core return with the help of core return service CoremanNet that offers core return solutions for the automotive aftermarket. Upon request, CoremanNet picks up the cores at the wholesaler and sends them to the selection stations where the cores are identified and evaluated. The transportation and core selection is done by the service providers of CoremanNet (e.g. Striebig in France or Bosch Aftermarket solutions GmBH in Germany). CoremanNet checks whether the core is part of the eXchange programme, if the core meets the requested return criteria and if the Bosch-customer has purchased the respective exchange-part upfront. If this applies, Bosch refunds the customer (i.e. wholesaler) with the core value. From the selection station, the cores are sent to the warehouse and stocked. Upon request, the cores are delivered to the remanufacturing plant. Bosch has 30 remanufacturing plants in Europe, of which six are located in Germany (see Figure 13).

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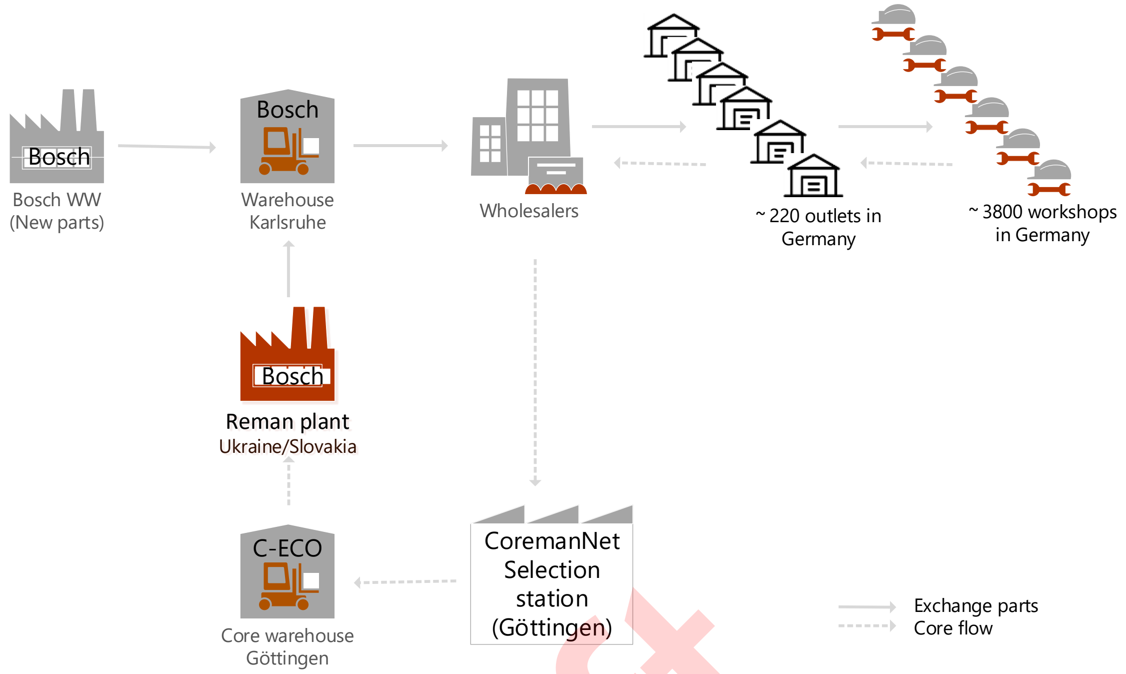

Figure 13: Example of reverse logistics flow in the German IAM

4.3.5. Reverse logistic flow in the French aftermarket

While in the German aftermarket there is a clear logistical flow of parts between the trade levels, in the French aftermarket the logistical flow is less stringent. All stakeholders are purchasing parts from various sources. The wholesaler can purchase parts directly from Bosch and at the same time be part of a buying group where it purchases parts that can also be originally from Bosch. The buying group is an entity created by independent aftermarket distributors who want to combine their purchasing power towards the parts-manufacturers to achieve better purchasing conditions. The functional range of operations for the buying groups can vary from “an office with a purchaser” to providing financial logistic services for their members. The main difference to a wholesaler is that the outlets of a wholesaler are his subsidiaries or legal entities over which he has economic control. Usually, the decision to buy directly from Bosch or via the buying group depends on the availability and the price of the parts. This is not a problem for forward logistics. However, for reverse-logistics, it is hard or even impossible for the wholesalers to keep track of reman-sales and therefore control to where they have to deliver cores matching to those exchange-parts. This results in loss of money for the wholesalers in case they return cores to the wrong destination (see Figure 14).

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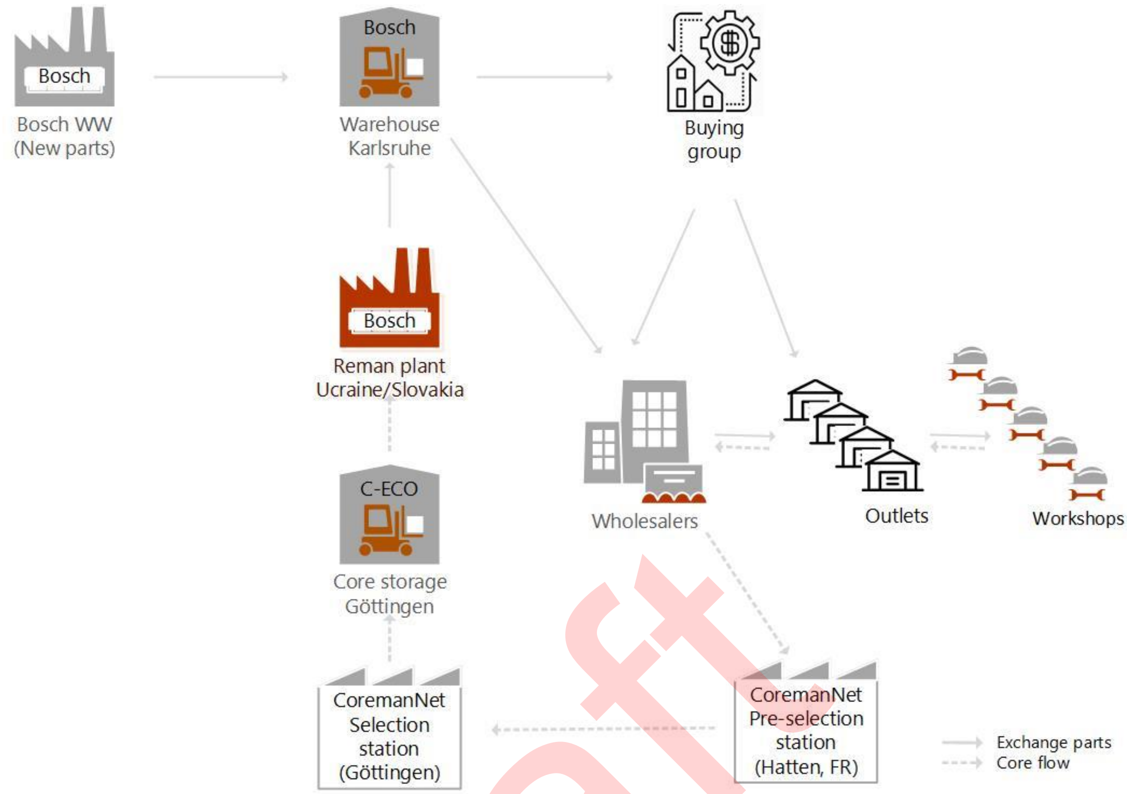

Figure 14: Example of reverse logistics flow in the French IAM

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5. Modelling and simulation of the supply chains

This chapter provides an overview of the modelling and simulation of the supply chain of the two demonstrators. Based on the baseline created for both demonstrators, simulation models are developed to design and highlight circular supply chain attributes that encompass the aspects of transportation routes, materials management, length of product use phases and product collection cost.

Implementation of the circular manufacturing systems calls for studying the mutual interaction of product design, which supports a business model that delivers through a closed-loop supply chain network while creating efficiency and transparency in the operations through ICT.

The most significant aspect in the design of circular supply chains lies in the fact that there should be a balance between the economic and environmental performance of the supply chains to be called circular in real sense i.e. the business model in place supports the product take-back in an economically feasible and environmentally friendly manner. Environmental impact in current cases is calculated based on product weight, transportation distance, and the consequent cost.

Transportation cost is considered as a decisive element in the economic performance measurement as one of the major costs in the logistics expenditure as compared to the linear supply chains. Transportation cost is accounted mostly in terms of economic feasibility in the literature; however, its effect in terms of environmental impact is rarely acknowledged and an unexplored area within supply chain studies, particularly the environmental impact of distance travelled by products.

To assess the complex and dynamic behaviour of supply chains, multi-method modelling comprising of agent-based, system dynamics and discrete event modelling techniques have been employed. The objective of simulation modelling is to create what-if scenarios that analyse and evaluate the overall economic and environmental performance of the system. It serves as decision support both in the design phase of reverse operations as well as the improvement of existing reverse operations.

5.1. Significance of modelling and simulation

Models can be used to come up with the best possible solutions in different scenarios. They provide a possibility to envisage real-world problems in a simplified manner to establish a sound basis for decision support with measurable parameters and indicators. A simulation model is an extended version of reality where the results and analysis can be simulated and forecasted over a period of time. Modelling and simulation help in understanding the dynamics of complex systems and how the underlying attributes behave over time. The choice of modelling method depends on the questions to be answered, the underlying phenomenon to be studied or to test different scenarios in a simulation and find out the best solution to be implemented in the real world. The major benefit of simulation models is the aspect of scalability, flexibility in introducing the levels of abstraction and modularity i.e. the system can be analysed as part or as a whole [63].

There are three approaches in simulation modelling namely System Dynamics, Discrete Event Modelling and Agent-based Modelling. Each approach is different in terms of its level of abstraction. System Dynamics employs the concept of stocks and flows and their interdependencies, which is useful in understanding the tendencies and phenomena in a given environment. Discrete Event Modelling focusses on the operational aspects and on how entities

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pass through a network of queues and activities. Agent-based Modelling stresses on the agents and their relationships with each other and their environment [64].

The above mentioned three approaches distinguish themselves on the range of abstraction levels. System dynamics operate at a high abstraction level and is mostly used for strategic modelling. Discrete event modelling with the underlying process-centric approach supports medium and medium-low abstraction. Agent-based models can vary from very detailed where agents are physical objects to highly abstract where agents are competing companies or governments [63].

Multi-method approach comprising of agent-based, system dynamics and discrete event has been adopted to develop circular supply/value chain design and optimization for both demonstrators. Discrete event is used for processes occurring at facilities, system dynamics for the aggregated effect of the of product flows between facilities in the supply chain network and agents-based approach to monitor a system behavior evolving from agents with a set of rules acting independently in a predefined system

The agents considered in the model are the physical entities, products, vehicles for transport, technicians, and customers. The multi-method approach is needed to capture the complexity and dynamic behavior of supply chain as different levels of abstraction need to be considered. However, the model is primarily built using agent-based modelling approach. As mentioned earlier, an agent is an object/entity with particular properties, actions, and target behaviours. These agents move and interact in a specific environment which can be geographic, network-based, or based on real data. The interactions between these agents are usually complex with changing behaviour over time. The agents, their environments and relationship dependences with inputs and outputs together form a system with a particular behaviour, phenomenon to be studied over the course of time [65]. Moreover, agent-based modelling provides the flexibility of going from high to low level of abstraction and representation. Since this modelling task is related to the implementation and design of the supply chains from the location and allocation of facilities perspective, it is necessary to adopt the medium level of abstraction where the costs and environmental attributes can be highlighted without going in-depth with the capacity optimization questions. This approach particularly helps in building the what-if scenarios and is useful for visualization and analysis of non-linear behavior in complex systems. For building the model, a bottom-up approach is used where a domain or phenomenon of interest is chosen with or without specifying a formal question. With this approach, the user/modeler can build the conceptual model from the bottom up, accumulating the necessary mechanisms, properties and entities, and eventually formulating some formal research questions along the way. In doing so the chances of introducing ambiguities, redundancies, and inconsistencies into the model are greatly reduced [65].

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5.2. Methodology

To model the supply chain of the two demonstrators, first, a baseline with the current state of the supply chain of the demonstrators was established. Based on the As-Is scenario several To-Be scenarios were developed. Potential questions for the economic and environmental performance of the demonstrators' supply chain were outlined and a list of parameters was generated to be able to prototype the scenarios in the modelling platform. Finally, analysis was conducted based on future scenarios and their related parameters.

Inspired by and adapted from Balci and Ormsby's conceptual modelling [66] [67] the simulation model was initiated by developing a conceptual model of supply chain structure including the interactions and potential questions to be explored, followed by data collection and data synthesis. Next to that, the logic was developed for the interactions of agents in the simulation platform. Once the model was formed, the analysis was made for what-if conditions and interactions. The model was verified and validated for discrepancies and finally results with comparative scenarios were presented. Figure 15 illustrates the methodology employed. The agent-based models were developed from an object-oriented perspective using AnyLogic 8 University 8.5.0; a Java-based simulation development platform.

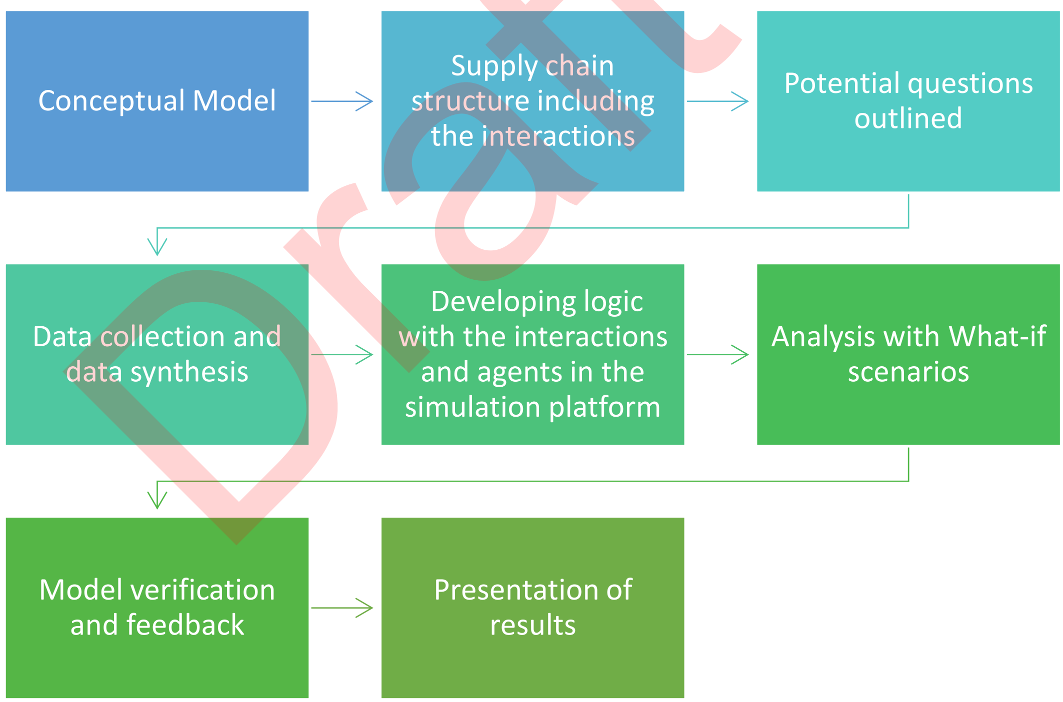

Figure 15: Modelling methodology

5.3. Overarching questions for the simulation modelling

The questions outlined for the system model are the aggregated economic performance and environmental performance attributes of the system over a period of time. The high-level cost and environment attributes for both the models are approximately similar.

To provide reliable decision support and identify effects on cost and CO_2 emissions from the supply chain perspective, the model focusses on product collection cost, product life cycle, and

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transport routes. The model is constructed on a strategic and tactical level rather than an operational level as the purpose is to formulate a broad picture of cost and CO_2 impact of the reverse operations. Hence, the overall economic and environmental performance is calculated based on the following:

- Economic performance is the aggregated cost of operations including product transport cost, product acquisition or collection cost and processing cost.
- Environmental performance is the aggregated environmental impact, including CO_2 equivalent emissions during transportation, product acquisition or collection and processing of products.

The efficiency and effectiveness of supply chains are generally affected by complex factors, including warehousing, inventory management, and transportation frequency. Traditionally the reverse logistics operations have stressed the importance of transport costs, modes of transport, fleet sizes and their impacts on delivery. In this model, the underlying focus of the simulation model is on reverse logistics where transportation cost specifically due to distance travelled, is one of the major points of focus for economic performance and environmental effectiveness of the operations.

The economic performance spans over the costs incurred during the reverse logistics that includes the costs of collection, transportation, inspection, sorting, storage and shipping costs within the supply chain structure. As mentioned earlier in reverse logistics, collection constitutes the first stage where used products originating from multiple sources are brought to a product recovery facility for refurbishing or remanufacturing. The second stage is the inspection or sorting, which can be carried out either at the collection points or at recovery facilities. In addition, the collection can be combined with pre-processing such as sorting, segregation, partial or complete disassembly or minor repair and refurbishing activities at the collection centres or service facilities depending upon various technological and economic factors [68].

There are several environmental sustainability indicators for energy usage, water consumption and pollutions that could be considered such as energy footprint (i.e. the demand for non-renewable energy resources), water footprint (i.e. total volume of direct and indirect freshwater used, consumed and/or polluted), and water pollution footprint (i.e. the amount of substances emitted to water in the environment) [69]. However, for the purpose of this task, the environmental performance is based on the consequent CO_2 emissions during the product acquisition and redistribution processes. The environmental performance is evaluated at a system level which is measured in kg CO_2eq. It is an aggregation (under a given time period) of the amount of CO_2 emitted during the collection of products, return management and remanufacturing. If the carbon footprint per product decreases, the environmental performance of the system will improve[70].

Although, social indicators of sustainability such as job creation and installing facilities in low GDP locations [71] could also be part of the systemic view, in this task this aspect is beyond the scope of work.

Despite having similar overarching questions for economic and environmental performance, the focus of simulation modelling differs for both demonstrators. Having reverse logistics as point of departure, the focus of the automotive spare parts demonstrators is mainly on optimizing the operations through changing the business dynamics in terms of trade-levels whereas white goods demonstrator leans towards expansion in the area of service and maintenance with an aligned take-back business strategy pertaining to the development of refurbishing and repair centres. Studies have highlighted that the effective configuration of the reverse logistics network has a direct impact on the economic viability of the business in the long run [72].

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Moreover, the model is developed on the assumption that both the demonstrators have a business model in place which is leasing and pay-per-wash respectively.

Automotive operational aspects in reverse logistics can be explored either from location-allocation perspective or inventory optimization questions. For the modelling and simulation, the task will focus on location-allocation aspects with additional focus on the environmental impact created due to the transportation of products through several entities in the supply chain network.

The white goods operational aspects are explored in light of service innovation and maintenance. It is an expansion of their current after-sales and logistics network and deals with the questions on the location of repair centers and the required operational functions such as inspection, repair, availability of spare parts, etc.

The data used in the model has been gathered through interviews and discussions with the company representatives specifically functions operating in the areas of logistics, purchasing, after-sales, and business development. The starting values for the parameters were assumed based on the company information and when the data was missing, own assumptions are used based on literature review and field surveys. Besides, Ecoinvent version 3.1 lifecycle inventory database (LCI) was used as a reference source for environmental impact values [73].

5.4. Automotive spare parts demonstrator modelling

The boundary of the model is focused on the reverse supply chain including the collection channels, core selection stations, warehouses, remanufacturing plants and redistribution through wholesalers.

The selection station occupies a pivotal position in the reverse supply chain, as its functional-units initiate and control the interactions with the external entities such as the wholesaler outlets, third-party logistics providers and other storage and warehousing entities.

Typically, the operation of the reverse logistics flow requires various decisions for instance what mix of cores to collect, what are the contractual conditions, state of the cores, how to identify, where to collect, where to sort, where to store. Automotive spare parts demonstrator' current reverse network is heavily decentralized which means that the operations i.e. sorting is done on each single location (the wholesaler outlets) which leads to a lot of uncertainty in delivery times, lack of transparency and high transportation costs as highlighted in Figure 16

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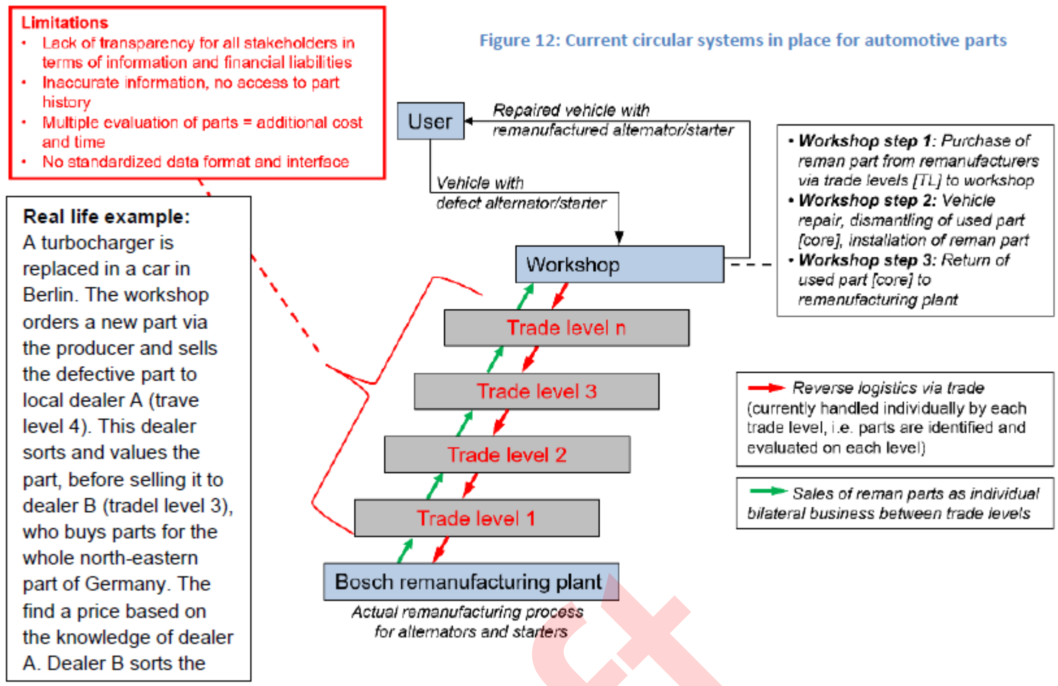

Figure 16: Current reverse logistics flow (source: ReCiPSS DoW)

As part of a new intended business strategy, which aims to have a more efficient reverse supply chain network and anticipate future market needs, the company has ambition to consolidate the operations by collecting cores in batches and then inspecting and sorting them instead of decentralized collection, inspection and sorting currently happening through different trade-levels in the reverse supply chain network. One can argue that the decentralized collection creates more environmental burden in terms of logistics costs as well as uncertainty in terms of quantity and quality of cores and redundant work processes in terms of inspection and sorting of cores.

Cost factors at each node will make up total cost of operations as illustrated in Figure 17.

Figure 17: Total cost of reverse operations automotive demonstrator

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The environmental performance of the reverse operations is based on the CO_2 emissions of process and transportation (see Figure 18).

Figure 18: Total environmental impact of reverse operations automotive demonstrator

From wholesaler outlets in Germany and France, C-ECO is receiving a mix of cores ranging from diesel parts such as high-pressure injectors, pistons to non-diesel parts such as starts, alternator and other product group for e.g. brake calipers etc. However, following the complete lifecycle of different core types was not possible both due to the unavailability of data and confidentiality concerns. The core flow mapped in the model is mainly based on the volume coming from the independent aftermarket. To be able to create the model, the **product** is assumed to be an aggregation of core types, which are referred to as cores throughout the model. Therefore, the cores are assumed as an aggregated category with an average weight of 2 kg. Cores are assumed as a product to be remanufactured with identical efforts in handling, inspection, sorting, and storage. It is also assumed that the cores are available in storage managed by C-ECO at any given time when the remanufacturing plants request the cores. Moreover, there is a steady supply of cores from the market with the selection stations receiving the products once a week with an average weight of 7 tonnes.

5.4.1. Automotive demonstrators description, assumptions and scenarios

The following section details the actors, assumptions, and input parameters used in the model.

5.4.1.1 Actors

The actors involved in the model are shown in Figure 19 and detailed below:

a) **Customers/ wholesalers outlets**: The reverse flow of cores begins with the wholesalers receiving the cores from the customers. The wholesalers accept the cores and inform the selection stations to arrange the pick-up. In ReCiPSS scope, French and German markets are considered with approximately 100 geographical locations for wholesaler outlets in respective markets.

b) **Sorting station/ selection station**: At the selection station the cores received from the wholesalers are inspected, evaluated and sorted.

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c) **Remanufacturing plants**: At the remanufacturing plants, the cores are inspected, cleaned, disassembled and assembled as remanufactured products, ready to be sent back to the market.

d) **Warehouse**: Warehouses are vital both for the storage of cores as well as remanufactured products.

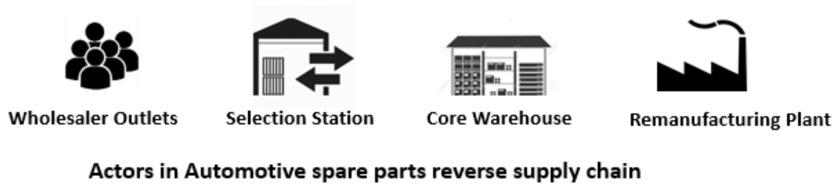

Figure 19: Actors considered in reverse logistics flow

5.4.1.2 Model boundary and assumptions

Following assumptions are made to create the basis for the model and the boundary assumed is shown in Figure 20:

i. Two remanufacturing plants at different geographical locations in Europe are considered (i.e. Ukraine and Slovakia)

ii. Both French and German markets are assumed as one market in the model

iii. The core collection is assumed in weight (tonnes) for the model

iv. Distance (km) from the Geographical Information System (GIS) maps to calculate the total distance travelled by cores

v. The market boundary is assumed until wholesaler outlets, 50 geographical locations for each French and German market are assumed.

vi. The CO_2 equivalent is assumed for road freight transport for a truck with 24-ton container for a partially loaded vehicle

vii. The CO_2 equivalent for remanufacturing processes is considered for steel metal processing since predominantly the cores are made of steel. To make a conservative assumption the remanufacturing emissions are assumed to be 50% of the manufacturing process emissions.

viii. The core collection is assumed to be requested once per week by the wholesaler outlets to C-ECO for collection

ix. The average pallet weight is assumed as 500 kg, expressed as tonnes in the model.

x. Between 4-10% leakage of cores is assumed for the system

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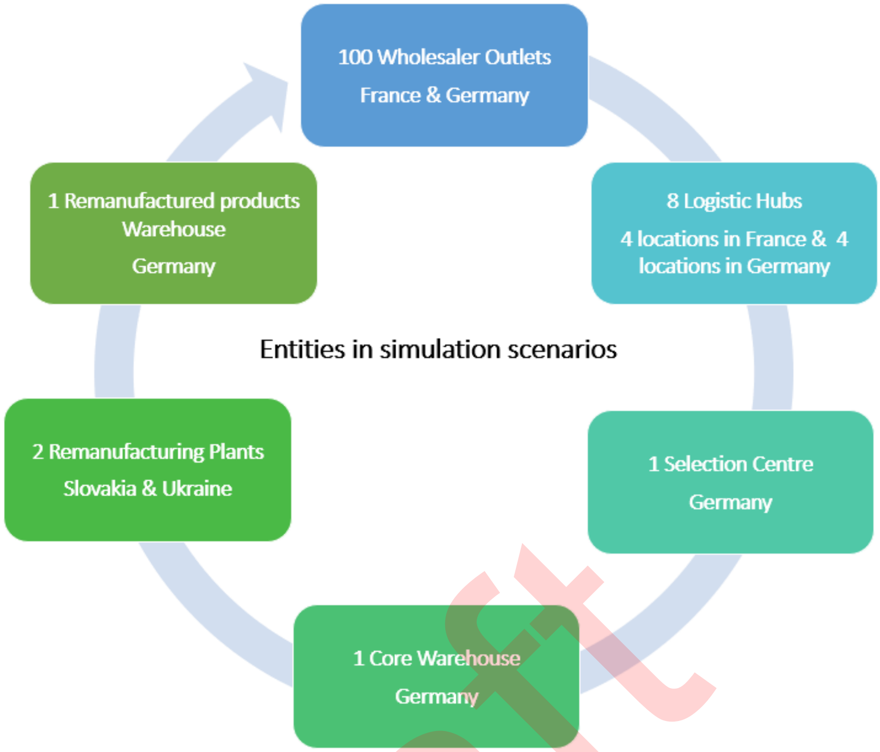

Figure 20: Automotive spare parts demonstrator modelling boundary

5.4.1.3 Automotive spare parts demonstrator scenarios

The reverse operations of the automotive spare parts demonstrator are complex, from the physical supply chain point of view with the major hindrance in terms of redundant processes which increase the overall cost of the operations when a systemic perspective of the supply chain is assumed.

To make a comparative analysis of the reverse operations and create a feasible scenario for optimal reverse flows of cores, two scenarios are considered: an As-Is scenario to create a baseline with current supply chain set-up of the reverse operations and a Hubs scenario aiming at integrating trade levels for the intended business strategy for reverse operations.

A. *As-Is scenario - current business with decentralized operations*

This scenario depicts the current decentralized system of core collection and will focus on the closed-loop system by showing the flow of cores from trade-levels to remanufacturing plant and back in the market as remanufactured components. Since the exact data for trade levels was not available, for As-Is model trade-level differentiation has been created from the given data, by sorting the cores into low (workshops), medium (wholesaler outlets) and high volume (wholesalers).

Within the proposed boundary, the economic and environmental performance of the system is calculated while focusing on the logistics costs, i.e. the environmental impact of transportation. For economic performance, cost implications can range from the cost of core purchase, transportation cost, inspection cost, cleaning/sorting cost and remanufacturing cost. The operational costs for a period of one year in As-Is scenarios is obtained by adding the costs

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associated with the handling of products entering/leaving entities such as wholesaler outlets, selection stations, the transportation costs, storage costs and remanufacturing costs.

In decentralized scenario, the cores are being sorted at each trade level which in this model are the wholesaler outlets comprising of 50 geographical locations in each market. An inspection and sorting cost is assigned for each location. From each facility, there will be shipping cost, assumed to be reverse cost. The products are shipped at an interval of one week with a fluctuating amount, as the wholesalers are receiving the cores sometimes on daily basis, but the amount is random.

To create this scenario, C-ECO Warehouse, Bosch Remanufacturing plants and Bosch Warehouse are considered as entities. C-ECO is receiving the cores, sorting/evaluating and getting them ready to be transferred to Bosch Remanufacturing plant. This part of the model will be deterministic as we assume that all cores received by C-ECO will move to the next entity in the reverse supply chain.

B. Hubs scenario - integrating trade levels with centralized operations

This scenario will depict the impact of centralized collection of cores on the overall economic and environmental performance of the system. This impact will be calculated by rationalizing the flow of cores by jumping or integrating the trade levels i.e. skipping the collection of cores from smaller outlets and collection happening through outlets with a larger capacity. For this scenario, regional logistics hubs that can either be a logistics node or serve as regional sorting stations replace wholesaler outlet locations collecting cores. They can switch flexibly, depending on the current volume of cores in the respective region.

The location of hubs has been provided by C-ECO based on PSIglobal software[2]. C-ECO generated 8 scenarios with a number of hubs in France and Germany in order to find the optimal number of hubs from an economic feasibility perspective. In three of these scenarios, Germany and France were modelled as two separate markets that each one needs a certain number of hubs. In the remaining five scenarios these two markets were considered as one integrated market. Based on data provided by C-ECO French and German markets were modelled as one market with 8 regional logistics hubs acting as sorting centres.

Hubs scenario consists of four sub-scenarios, which are described in the following section.

B.1 Hubs scenario 1

In the first scenario, 100 wholesalers at 50 geographical locations in each market send products to their assigned regional logistic hubs. These hubs collect and bundle the products and ship them to the selection station in Germany without any further processing. The selection station inspects, sorts and stores the products in the warehouse. Upon request, these products are transported to the two remanufacturing plants.

B.2 Hubs scenario 2

In the second scenario, 8 regional logistics hubs will carry out the inspection, sorting, collection and bundling of the products. After receiving the products from all 100 wholesalers, regional logistic hubs will process the cores, discard the ones not suitable for remanufacturing and send the rest to the warehouse in Germany which covers the remanufacturing plants requests.

[2] PSIglobal software is an analysis instrument to plan and optimize procurement and distribution logistics network. (website: www.psi.de/en/home/)

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B.3 Hubs scenario 3

The third scenario considers the 4 regional logistics hubs in Germany as both collection and selection stations. Products come pre-sorted from German market to the selection station in Germany directly into the storage warehouse. Regional logistics hubs at the French market only collect and bundle the products received from wholesalers and send them to the selection station in Germany to be handled i.e. sorting and storage.

B.4 Hubs scenario 4

In this scenario, French regional logistics hubs are the ones that both collect and handle the products and send processed ones to Germany for storage. In German market, regional logistics hubs only collect and bundle the products and send them to the selection station to process them.

The overall objective of simulating the above-mentioned scenarios is to create a what-if analysis of the inspection and sorting process in different scenarios while comparing the aspect of economic feasibility and environmental impact of the system. Economic performance of decentralized sorting at wholesaler outlets in the As-Is scenario will be compared to centralized sorting at hubs in the Hubs scenarios. Whereas the environmental impact (i.e. CO_2) in decentralized sorting and centralized sorting will also be compared.

5.4.2. Model building

The model simulates the arrival of cores from wholesaler outlets. In German, and French markets the wholesaler outlets generate an order for pick-up of cores. C-ECO receives the order and requests the logistics company to pick-up the cores and bring it to the C-ECO selection station where the cores are inspected, sorted and stored. The stage of inspection and sorting is also modelled as a process. The next order is generated by the remanufacturing plants, where the cores are transported. By order of Bosch, the requested stored cores will be transported from the C-ECO warehouse to the Bosch remanufacturing plant.

The explanation given below is not exhaustive but only representative of the complexity of the modelling logic.

Step 1: Creating model boundary with agents

Based on the data provided by C-ECO, a boundary for the model was created consisting of the geographical location of entities (i.e. wholesaler outlets, C-ECO selection station/warehouse, regional logistics hubs and remanufacturing plants), as shown in Figure 21.

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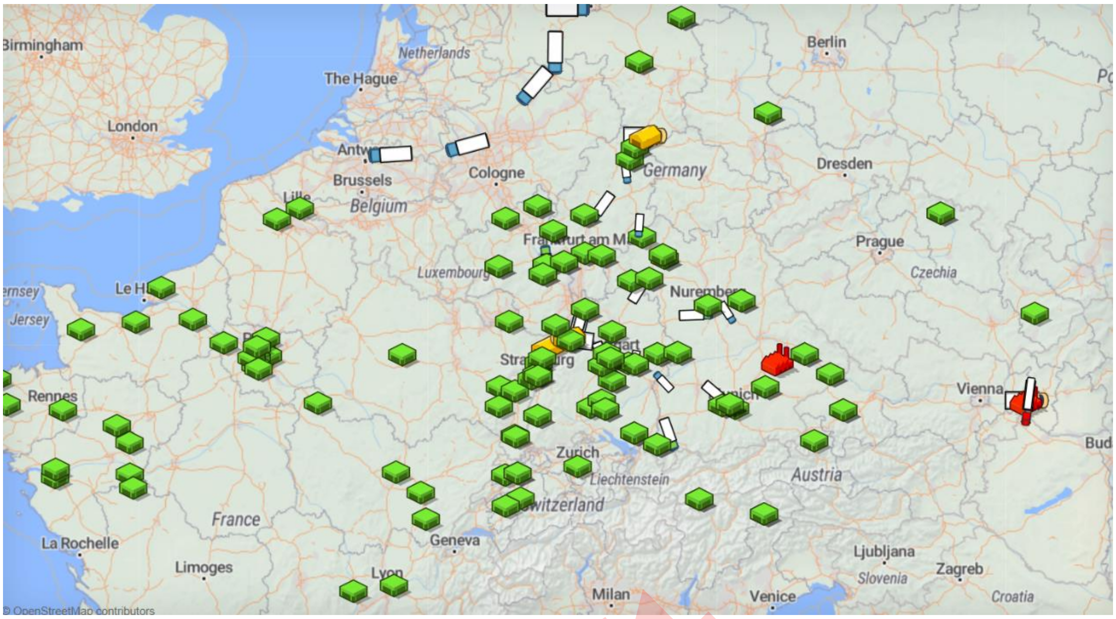

Figure 21: Geographical location of entities in the model

Figure 22 represents these entities and vehicles, which were created as agents in the model. The behavior of each agent may vary depending on the chosen scenario

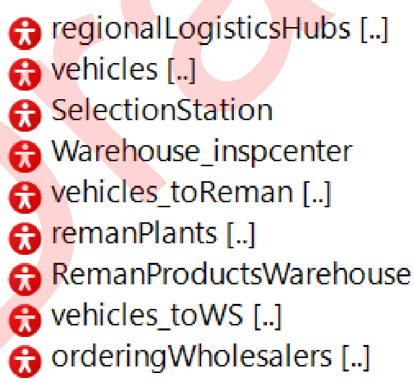

Figure 22: Example of agents in the model

Step 2: Defining parameters and variables

For arranging the experiment settings, design parameters pertaining to the economic and environmental performance are created with an input value based on company data and discussions with the company representatives.

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Detailed information on the parameters used in the model is illustrated in Table 6.

Table 6: Input parameters automotive demonstrator model

Parameter Type	Parameter Description	Parameter name in model	Unit
Operational	**Number of cores in storage**: *the amount of cores avaialble at selection stations to move to next entity in supply chain*	coresInStorage	tonne
	Core supply rate: *the supply rate of cores available for remanufacturing*	supplyRate	tonne/week
	Number of cores collected: *cores collected from trade-levels in weight*	weightPerStation	tonne
	Leakage: a *certain amount of cores will be discarded during inspection and remanufacturing*	leakage	%
	Lead time: *time spent from core collection to core processing*	leadtime	days
	Location of entities: *geographical locations of supply chain entitites*	location	GIS points
Cost	**Reverse transport cost** : *cost of transport spanning from trade-levels to remanufacturing plant*	revTransportCost	€/tkm
	Forward transport cost: *cost of transport from remanufacturing plant to market*	fwdTransportCost	€/tkm
	Handling cost: *costs including inspection, sorting and storage of cores*	handlingCost	€/t
	Sorting cost: *costs occuring at logistic hubs and selection stations*	sortingCost	€/t
	Inspection cost: *costs occuring at logistic hubs and selection stations*	inspectionCost	€/t
	Remanufacturing process cost: *cost including the testing, disassembly and assembly processes*	remanCost	€/t
Environment	CO_2 emission factor transport : CO_2 equivalent emission of 0.082 kg is considered for a truck with 24 tonne container partially loaded	CO2emissionfactor_transport	kg/tkm
	CO_2 emission factor handling : CO_2 equivalent emission during handling process with a value of 0.36 kg	CO2emissionfactor_handling	kg/t
	CO_2 emission factor remanufacturing: includes process emissions during remanufacturing with a value of 1.30 kg of CO_2 equivalent emissions for metal working and auxillary enery inputs for steel manufacturing. (Note: the remanufacturing emission is based on the assumption that it is 50% of the new manufacturing on steel based products. This is the most conservative figure as reduction of more than 80% are reported in the literature)*	CO2emissionfactor_reman	kg/t
	** Reference: IRP (2018). Re-defining Value – The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy. Nabil Nasr, Jennifer Russell, Stefan Bringezu, Stefanie Hellweg, Brian Hilton, Cory Kreiss, and Nadia von Gries. A Report of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya.*		

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Step 3: Defining rules for products and transport

The next step was to define the amount of products to be shipped from one entity to another and the frequency of vehicles movement. The vehicle movement logic has been created using a series of state charts, as shown in Figure 23. The vehicles in the model initially wait for orders at the selection station. The orders are initiated once per week by the regional logistics hubs. At regional logistics hubs, the vehicle loads the cores from the storage and moves to the selection station. Upon arrival at the selection station, the vehicle begins the unloading process and then moves back to the selection station to await the next order.

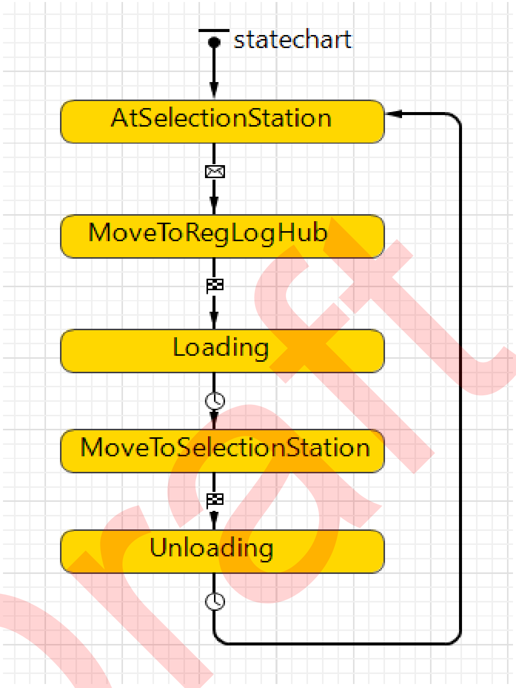

Figure 23: Vehicle state chart representing movement from regional logistics hubs to selection station

Step 4: Defining entities activities

The selection station is responsible to inspect and sort the received products from wholesalers (in As-Is scenario) or regional logistics hubs (in Hubs scenarios). Figure 24 shows exemplary activities at the selection station in the model.

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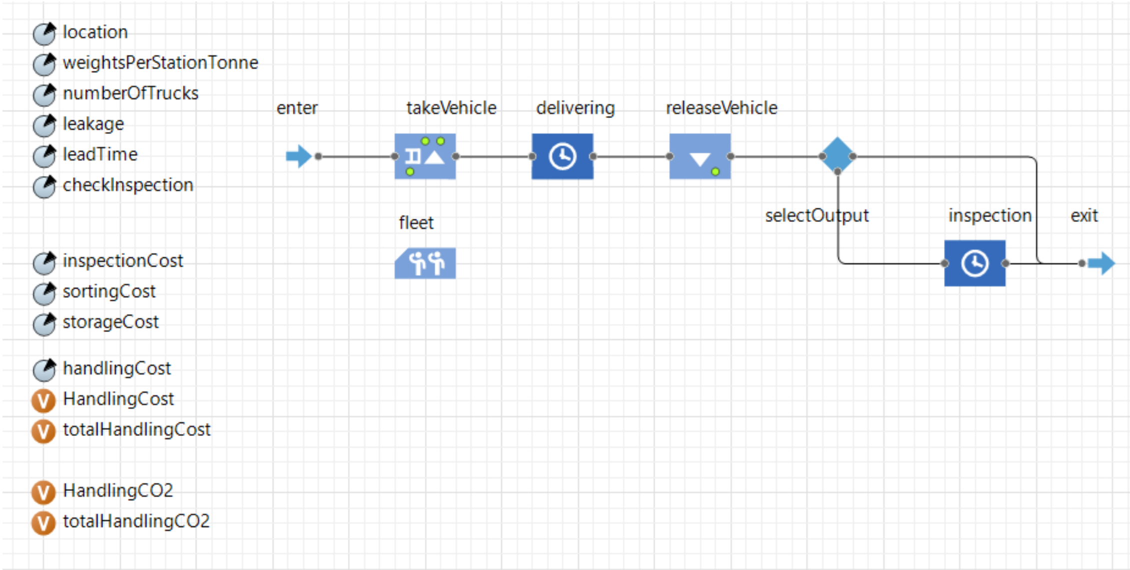

Figure 24: Example of activities at selection station in the model

Regional logistic hubs are another example of entities that can fulfill different roles, depending on the corresponding scenario. Figure 25 depicts the parameters that can be used to flexibly change activities at the hubs between collection/bundling and inspection/sorting.

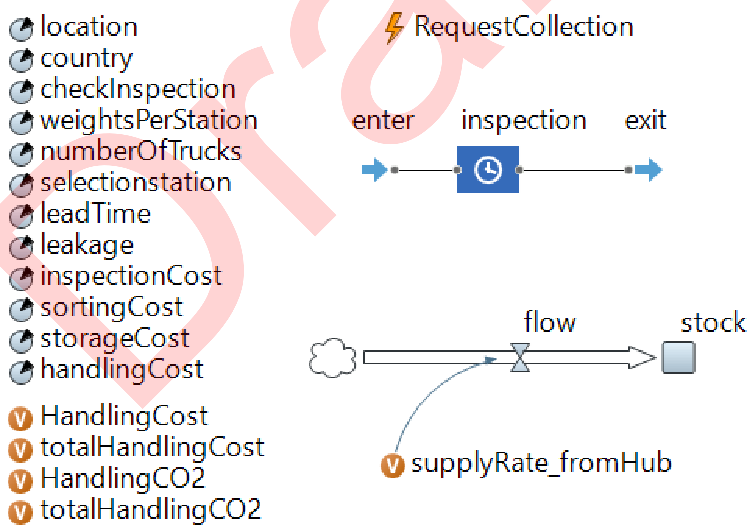

Figure 25: Example of activities at regional logistic hubs in the model

Step 4: Model visualization and results

After creating the logic for movements and products and entering the initial values for the parameters, the visualization was created both with the agents moving on the GIS map as well as the KPIs dashboard highlighting the economic and environmental performance indicators. As mentioned before, scenarios were generated by assigning the inspection and sorting process at different facilities such as in regional logistics hubs or selection stations. Table 7 summarizes the simulated scenarios.

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Table 7: Simulated scenarios automotive demonstrator

Scenario	Entities	Description
As–Is scenario	• 100 wholesalers in Germany and France • 2 selection stations in Göttingen and Hatten • 2 remanufacturing plants in Slovakia and Ukraine • 2 warehouses in Germany (for handled and remanufactured products)	1. Wholesalers in Germany and France collect, inspect, sort, and store the cores and send them to selection stations Göttingen and Hatten, respectively. 2. Cores will be inspected and sorted at each selection station and send for storage in the core warehouse in Göttingen. 3. Core warehouse sends the cores to the remanufacturing plants in Slovakia and Ukraine. 4. Remanufactured products will be sent to Germany to be stored at Bosch warehouse in Karlsruhe and then distributed to the market
Hubs scenario 1	• 100 wholesalers in Germany and France • 8 regional logistics hubs in Germany and France (one of the hubs in Germany is the selection station) • 2 remanufacturing plants in Slovakia and Ukraine • 2 warehouses in Germany (for handled and remanufactured products)	5. Wholesalers in Germany and France collect and send the cores to their assigned regional logistic hubs 6. Hubs will collect and bundle the cores and send them to the selection station in Germany 7. Selection station will inspect and sort the cores and store them in the warehouse 8. Warehouse send the cores to the remanufacturing plants 9. Remanufactured products will be sent to Germany to be stored and then distributed to the market
Hubs scenario 2	• 100 wholesalers in Germany and France • 8 regional logistics hubs in Germany and France (one of the hubs in Germany is the selection station) • 2 remanufacturing plants in Slovakia and Ukraine	10. Wholesalers in Germany and France collect and send the cores to their assigned regional logistic hubs 11. Hubs will collect, bundle, inspect and sort the products and send them to the warehouse in Germany 12. Warehouse send the cores to the remanufacturing plants

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	• 2 warehouses in Germany (for handled and remanufactured products)	13. Remanufactured products will be sent to Germany to be stored and then distributed to the market
Hubs scenario 3	• 100 wholesalers in Germany and France • 8 regional logistics hubs in Germany and France (one of the hubs in Germany is the selection station) • 2 remanufacturing plants in Slovakia and Ukraine • 2 warehouses in Germany (for handled and remanufactured products)	14. Wholesalers in Germany and France collect and send the cores to their assigned regional logistic hubs 15. German hubs will collect, bundle, inspect and sort the products and send them to the warehouse 16. French hubs only collect and bundle the products and send them to the selection station 17. Selection station will inspect and sort the products come from France and send them to the warehouse 18. Warehouse send the cores to the remanufacturing plants 19. Remanufactured products will be sent to Germany to be stored and then distributed to the market
Hubs scenario 4	• 100 wholesalers in Germany and France • 8 regional logistics hubs in Germany and France (one of the hubs in Germany is the selection station) • 2 remanufacturing plants in Slovakia and Ukraine • 2 warehouses in Germany (for handled and remanufactured products)	20. Wholesalers in Germany and France collect and send the cores to their assigned regional logistic hubs 21. French hubs will collect, bundle, inspect and sort the products and send them to the warehouse 22. German hubs only collect and bundle the products and send them to the selection station 23. Selection station will inspect and sort the products come from Germany and send them to the warehouse 24. Warehouse send the cores to the remanufacturing plants 25. Remanufactured products will be sent to Germany to be stored and then distributed to the market

The economic and environmental performance of each scenario is calculated for one year based on Equation 1 and Equation 2, respectively.

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$$Total\ Cost = \left[\left(reverese\ transport\ cost\left[\frac{€}{t.km}\right].reverse\ transport\ distance\ [km]\right) + \left(forward\ transport\ cost\ \left[\frac{€}{t.km}\right].forward\ transport\ distance\ [km]\right) + \left(handling\ cost\ \left[\frac{€}{t}\right] + remanufacturing\ cost\ \left[\frac{€}{t}\right]\right)\right].weight[t] \quad \text{Equation (1)}$$

$$Total\ CO2 = \left[\left(reverese\ transport\ CO2\left[\frac{kg}{t.km}\right].reverse\ transport\ distance\ [km]\right) + \left(forward\ transport\ CO2\ \left[\frac{kg}{t.km}\right].forward\ transport\ distance\ [km]\right) + \left(handling\ CO2\ \left[\frac{kg}{t}\right] + remanufacturing\ CO2\ \left[\frac{kg}{t}\right]\right)\right].weight[t] \quad \text{Equation (2)}$$

Please note that the numbers provided in the results are representative and may not depict the actual costs.

The results of the simulated scenarios are as follows

As-Is scenario shows the flow of cores of current business from 100 wholesaler outlets to remanufacturing plants and back in the loop as remanufactured components through the wholesalers. Total costs and CO2eq. emissions are shown in Figure 26 and Figure 27. In this scenario, inspection and sorting of cores, which is happening in all trade levels, has a major contribution to the total costs of operations. The most environmental impact in the whole system caused by remanufacturing the products, since CO2eq. emission factor of this process is considerably more than transportation and product handling.

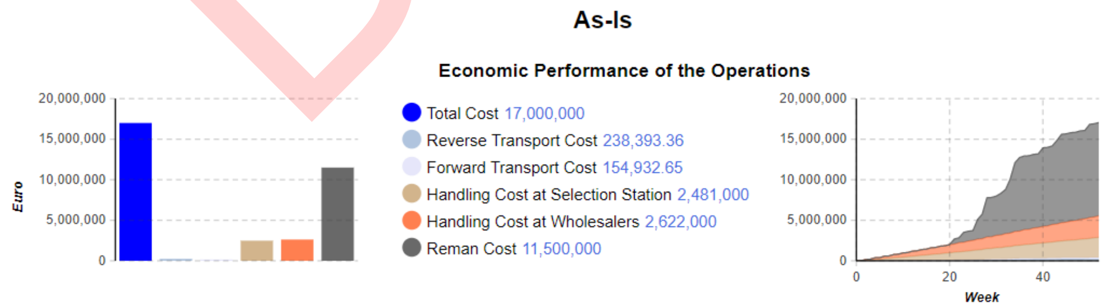

Figure 26: As-Is scenario – economic performance

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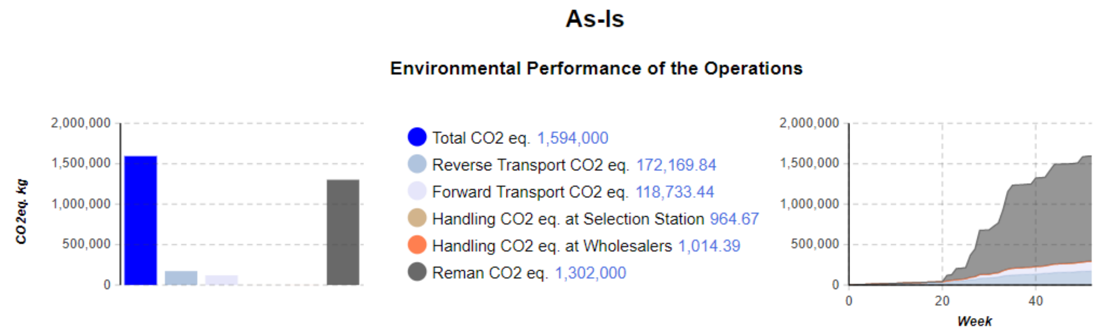

Figure 27: As-Is scenario – environmental performance

Hubs scenario 1 illustrates the consolidated collection of cores from 100 wholesaler outlets in both markets through bundling at the 4 regional logistics hubs in each market i.e. inspection and sorting will be done at the selection station in Germany. The results are shown in Figure 28 and Figure 29. Consolidating the inspection and sorting trade levels resulted in lower total costs and CO_2 emissions comparing to the As-Is scenario. It should be noted that in the model the total remanufacturing cost and environmental impact are different for each scenario because the core supply rate from hubs or Selection station is different, which in turn affects the number of cores that remanufacturing plants can process.

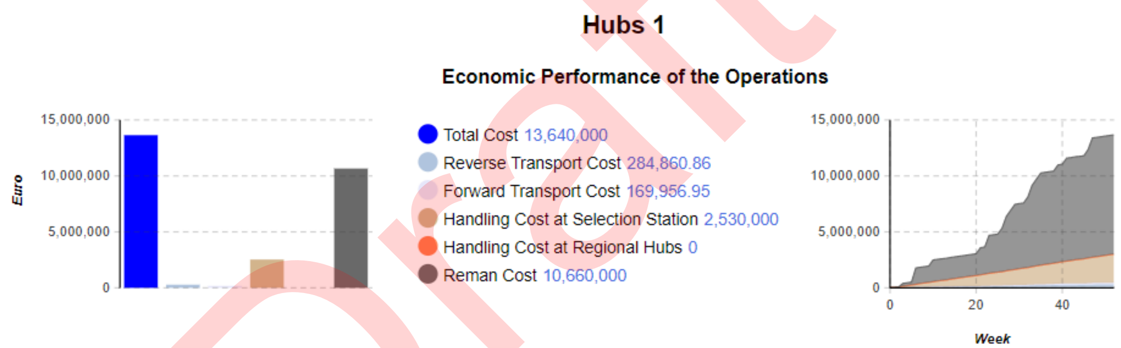

Figure 28: Hubs scenario 1 – economic performance

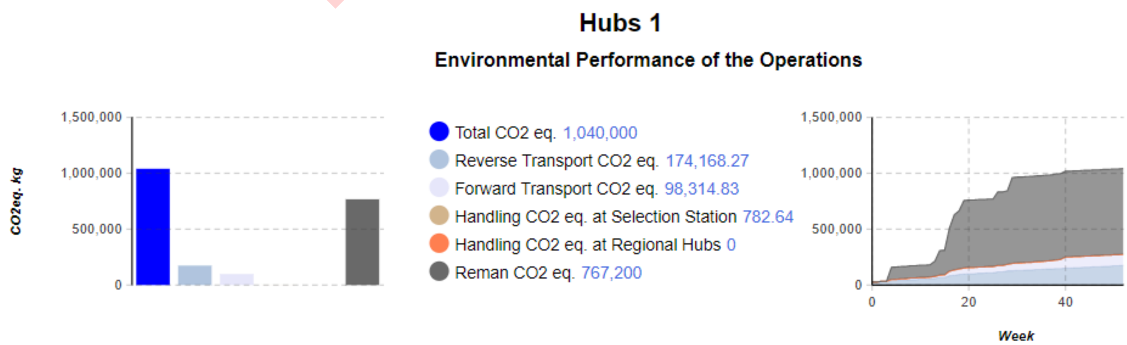

Figure 29: Hubs scenario 1 – environmental performance

Hubs scenario 2 considers the inspection and sorting of products that are collected from 100 wholesaler outlets at the regional logistics hubs in 8 locations while the selection station in

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Germany acts as a core storage warehouse. As shown in Figure 30 and Figure 31 the economic and environmental performance is better than hubs scenario 1. The main reason is that the handling cost in French market is lower than the German market. In hubs scenario 1 inspection and sorting of all cores is accumulated in Germany, whereas in hubs scenario 2 French market is also contributing to this process. The reason for better environmental performance is that due to the pre-sorting of cores at the hubs, a specific proportion of cores will be discarded and the amount of cores being transported from regional logistics hubs to the selection station in Germany will be reduced in number.

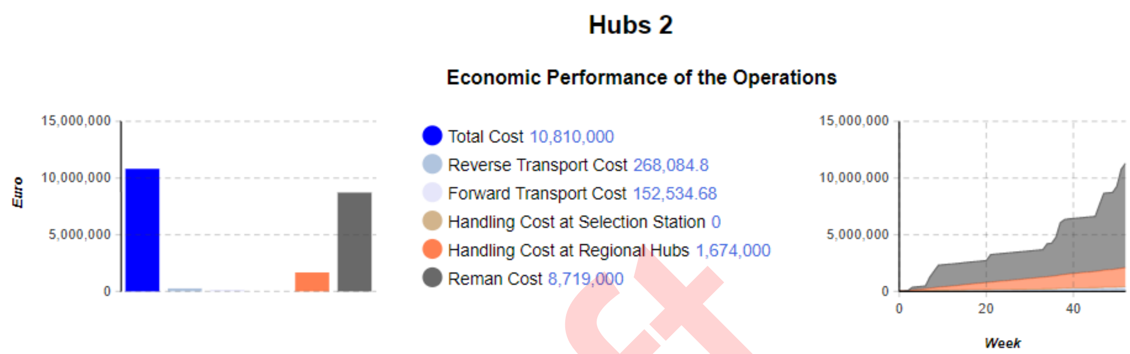

Figure 30: Hubs scenario 2 – economic performance

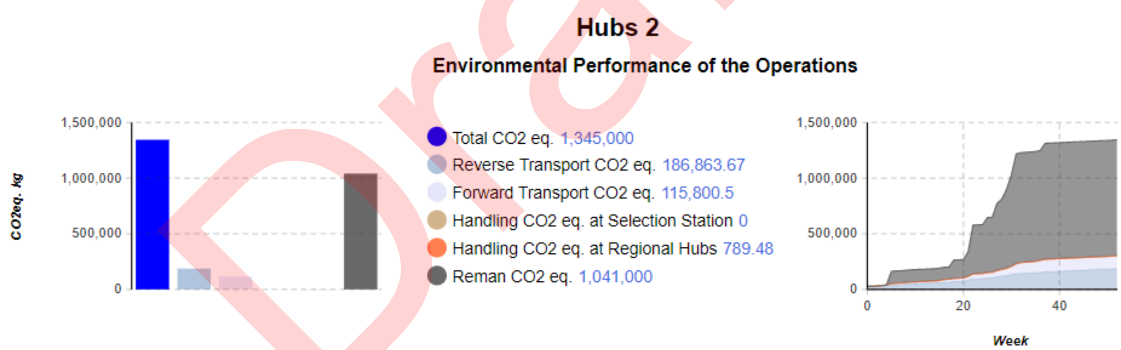

Figure 31: Hubs scenario 2 –environmental performance

Hubs Scenario 3 presents the results for bundling the cores at the 4 logistics hubs in France whereas the German hubs are responsible for sorting the cores at their respective locations. For French hubs, the cores are sorted at the selection station in Germany, which results in higher total handling cost as compared to hubs scenario 2. In addition to that, cores inspection and sorting are more expensive in Germany than in France. The economic and environmental performance of this scenario is shown in Figure 32 and Figure 33. Handling cost at selection station is more than regional logistics hubs for the reason that the selection station will handle cores from 5 hubs in total, from which 4 are located in France and 1 in Germany.

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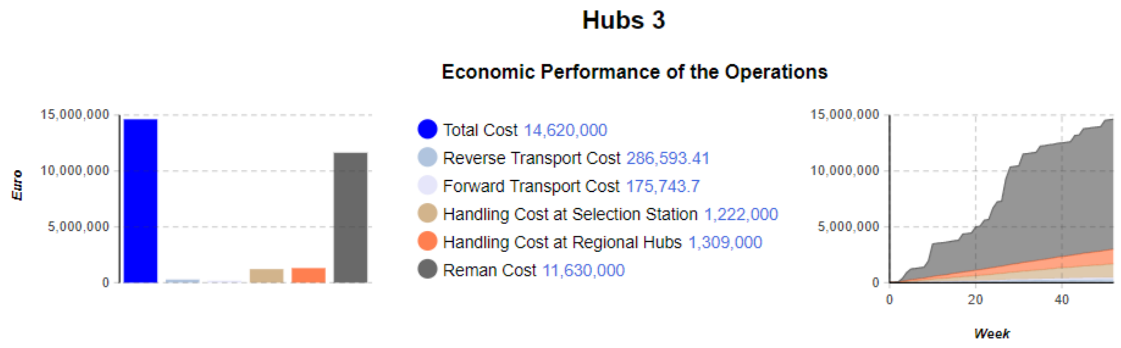

Figure 32: Hubs scenario 3 – economic performance

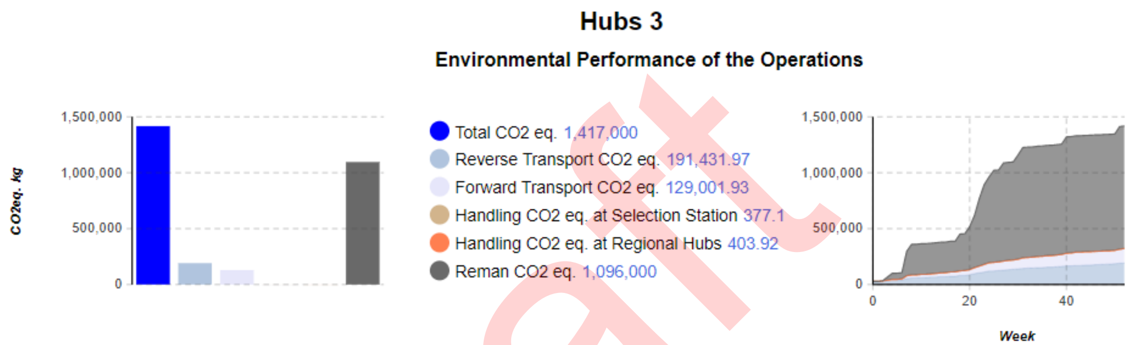

Figure 33: Hubs scenario 3 – environmental performance

Hubs scenario 4 represents the bundling of cores at the 4 logistics hubs in Germany and sorting at the selection station while the French hubs are sorting the cores at their respective locations. The results are shown in Figure 34 and Figure 35. Despite all similarities, this scenario performs better than hubs scenario 3, because in French market the cores are pre-sorted and available for storage in Germany resulting in lower handling costs and reverse transportation costs as well as consequent emissions.

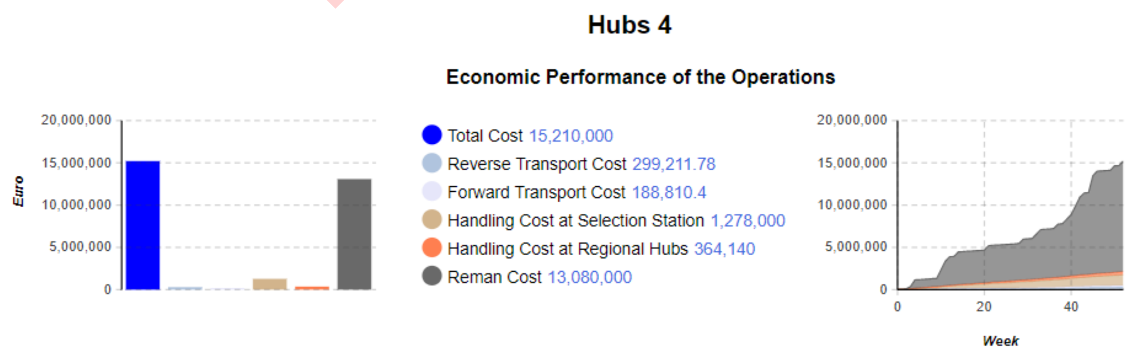

Figure 34: Hubs scenario 4 – economic performance

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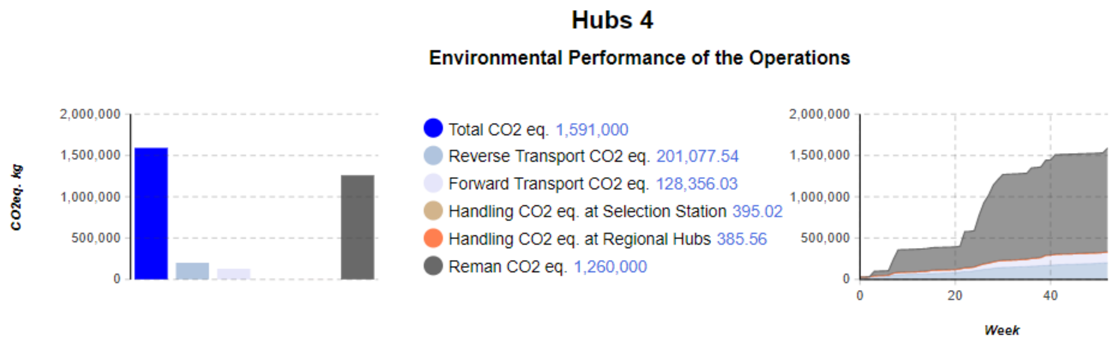

Figure 35: Hubs scenario 4 – environmental performance

5.4.3. Results analysis

The results for all scenarios were compared for trade-offs between the cost changes at the different physical entities and the environmental impact of the process and transportation activities. To compare the scenarios, the aspect of centralized and decentralized sorting and inspection was assigned at different entities as explained in Table 7. A comparison of the total economic and environmental performance of the different scenarios is shown in Figure 36 and Figure 37 respectively.

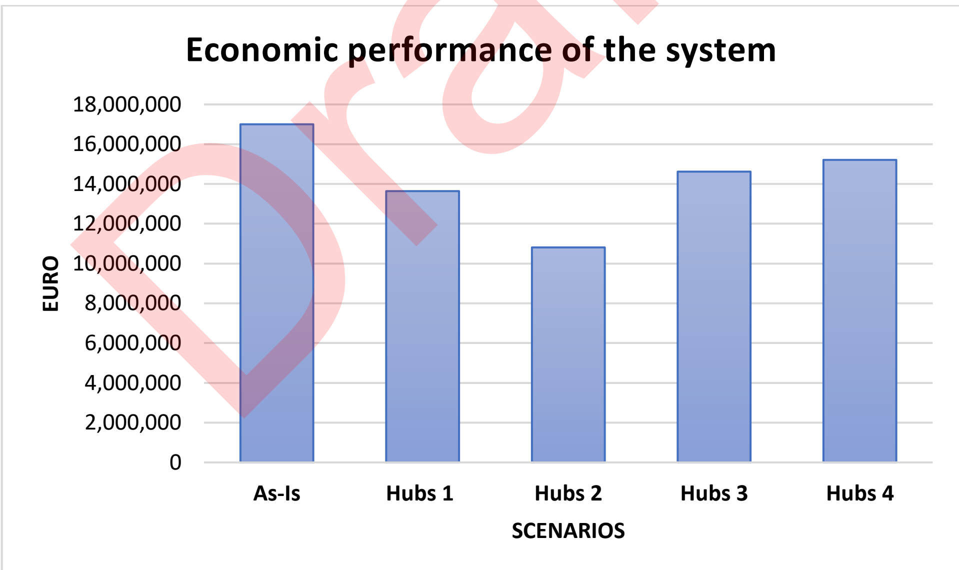

Figure 36: Economic performance of automotive demonstrator scenarios

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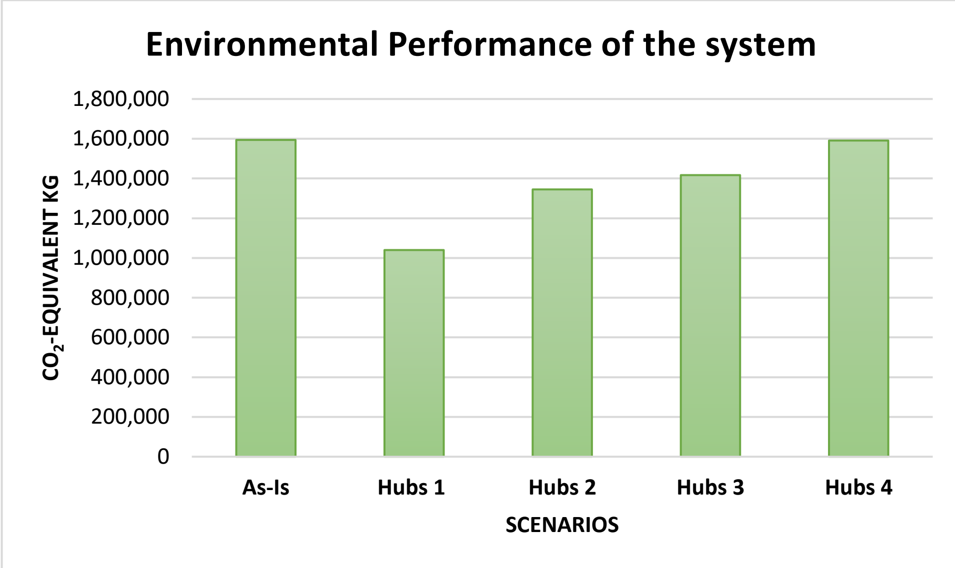

Figure 37: Environmental performance of automotive demonstrator scenarios

To evaluate the trade-offs between the economic and environmental performance of the scenarios, as shown in Figure 38, we can deduce that by inspection and sorting of products at the regional logistics hubs and storage at selection station in Germany acting as a core warehouse, the overall cost will be reduced as compared to the existing As-Is scenario. The reason is that in As-Is scenario inspection and sorting happen at all trade levels whereas in Hubs scenario 2, regional logistics hubs carry out the handling process and send only the remanufacturable products to Germany. It implies that the number of products transferred to Germany will decrease resulting in lesser transportation costs.

The handling cost in the German market is more expensive than in the French market, which results in less favorable economic performance of Hubs scenario 3 among all 4 Hubs scenarios. As in this scenario, all the inspection and sorting of products are accumulated in Germany and French regional logistics hubs are bundling the products only. The same reason applies for Hubs scenario 1, in which only German hubs do the inspection and sorting and regional logistics hubs only bundle the products.

Comparing the environmental performance of Hubs scenarios and As-Is scenario, it can be concluded that Hubs scenarios generally perform better due to consolidating the handling process and number of cores transported. However, among the Hubs scenarios, Hubs 1 shows the least environmental impact, since in this scenario only the remanufacturable products are transported from regional logistics hubs to the selection station in Germany. As mentioned in section 5.4.2, requests fulfillment by the remanufacturing plants depends on the inspection and sorting rate in hubs or selection station, which means that the remanufacturing costs will vary in different scenarios. Moreover, CO_2 emission factor for remanufacturing process emissions is also higher in comparison to other attributes for environmental performance evaluation in the model.

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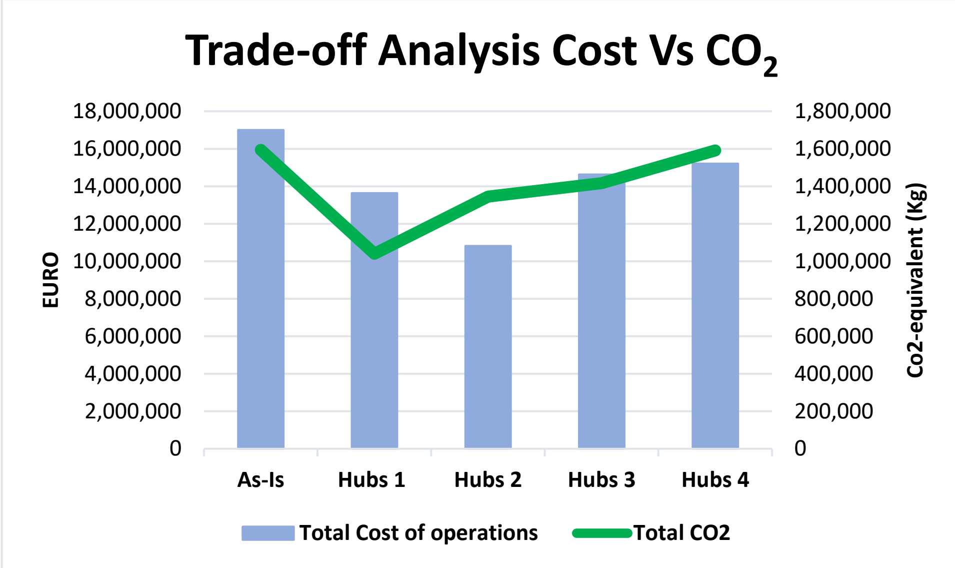

Figure 38: Trade-off between economic and environmental performance for automotive demonstrator

For the future state of the automotive demonstrator in terms of economic performance, the Hubs 2 scenario is most feasible. In Hubs 2 scenario, the cores arriving from wholesalers outlets would be sorted at the regional logistics hubs in respective markets and then shipped to the selection station in Germany to make them available for remanufacturing.

Moreover, in terms of environmental performance, the Hubs 2 scenario aligns with the initial assumption of integrating trade levels where instead of collection and sorting happening at the individual outlets, it is converged into a bundled collection and sorting at the regional logistic hubs

It can also be noted that the economic performance of Hubs 2 scenario is 36% better than As-Is scenario. It is also noteworthy that the handling costs are lower at the hubs in this scenario as compared to As-Is scenario.

5.5. White goods demonstrator modelling

In ReCiPSS, Gorenje has planned to exploit the potential of service-oriented offers, where the customers will pay-per-wash. The demonstrator will develop and implement a pay-per-wash offering for 300 washing machines, using co-creation methods in four markets namely Denmark, Austria, Slovenia and the Netherlands. The four markets for the ReCiPSS project have been chosen based on sales volume and existing supporting infrastructure. The washing machine model relevant for the study is ASKO85, a domestic professional built-to-last model that is produced in Velenje. The case washing machine weighs approximately 100 kg. Each washing machine will be refurbished twice and serve over three life cycles of five years each.

To support a new business model for washing machines based on multiple-use cycles and product refurbishing, Gorenje will need to develop a new system for reverse logistics. According to studies, the aftersales services primarily operate on the notion that the products are returned due to functional problems, recalls or reaching the end-of-life. There are many fully functional products, ending up in the warehouses, which can be potentially redistributed through new customer streams and sales channels [74]. The simulation-based decision support will help in understanding the systemic effects of Gorenje's intended business strategy to explore the

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refurbishment in combination with the pay-per-wash business model. Moreover, it will also guide in identifying underlying environmental and economic performance trade-offs in choosing the level of service, the supply chain configuration as well as the impact of the service-based business model.

The actors involved in the model are shown in Figure 39 and detailed below:

i. **Production**: The supply chain begins with the production of washing machines in Velenje which are further distributed in the respective markets through local distribution centres.

ii. **Distribution centre / sales and business units**: This is the second stage of operations and the pay-per-wash contracts will be managed through the SBUs in the respective markets. The function of sales and business units will be to distribute and deploy the machines or sell the contracts, provide services and collect the used washing machine at the end of its lifecycle. In the ReCiPSS scope, this means that the local distribution centres will act as a hybrid facility and double-up as a sales and business organization.

iii. **PSS costumers**: Gorenje customers will be distributed in the chosen four markets. The customer segmentation is done as “premium”, “economy “and “budget.” The premium customer will be served with a brand-new washing machine whereas the economic or budget customer will be served either by a refurbished or washing machine.

Figure 39: Actors in white goods service supply chain

This model will help in decision making for the development of the service supply chain when Gorenje moves from selling products to Product-as-a-Service (PSS). The model is developed incrementally from current service and sales set-up, as shown in Figure 40, towards the location of repair and refurbish facilities. What-if analysis can help in finding out the best locations for the potential refurbishment facilities.

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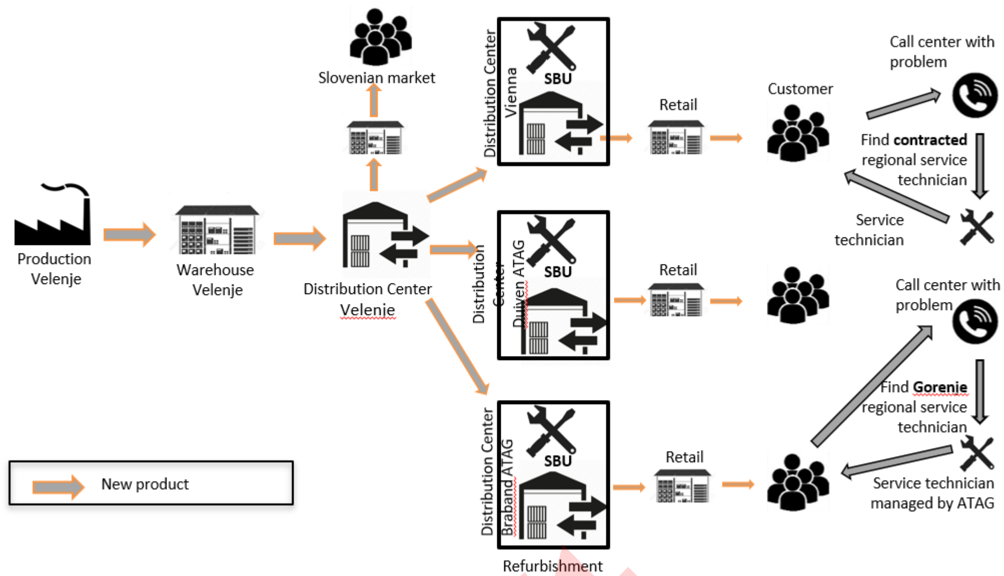

Figure 40: Conceptual model of Gorenje current supply chain

5.5.1. White goods demonstrator description, assumptions, and scenarios

Since Gorenje intends to exploit its currently established service network, the focus of the demonstrator is on service innovation. Within the ReCiPSS scope, owned networks are considered in Slovenian markets whereas in other markets a mix of partially owned and independently owned service network are considered. Salient features of a service network are the number of technicians, the available facilities for service and repair in case of repairs, the service cost per washing machine, the fixed costs incurred in terms of storage facilities, the availability of spare parts, and the level of customer service available. Additionally, the analysis of the supply chain will include the total cost of the service supply chain including repair and refurbishment cost at different stages and different lifecycles of the product. It will also include transportation costs and their associated environmental impacts as well as the repair and refurbishing infrastructures.

5.5.2. Model boundary and assumptions

To create a representative of major supply chain attributes of the white goods demonstrator, following assumptions were made based on the baseline analysis, interviews with the company representatives:

i. Four SBUs at four geographical locations in Europe are considered.

ii. At the end of the first life cycle, washing machines are collected and brought for refurbishment.

iii. Products which are at the end of the second and third life cycle will be sent to Slovenia for advanced processing. In this document advanced processing refers to any processing beyond refurbishing to complete remanufacturing. Advanced processing is assumed due to the uncertainty that the white goods demonstrator has in terms of the future strategy of refurbishment or remanufacturing.

iv. The washing machine's weight is assumed as 100 kg including packaging.

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v. Distance (km) from the GIS maps calculate the total distance travelled by service technicians

vi. The market boundary is assumed from the deployment of washing machines through SBUs until the customers within the chosen 4 markets

vii. A random population of 75 customers is assigned in each market respectively

viii. The CO_2 equivalent is assumed for road freight transport i.e.0.229 kg/ tonne-km CO_2 for truck with 7.5- 16 tonne less than load capacity.

ix. For service transport, CO_2 for light commercial vehicles is assumed.

x. Breakdown rate or mean time to failure (MTTF) for machines is assumed for the system.

xi. Based on Gorenje current after-sales set-up both owned and independent service networks are considered in different markets.

xii. Customers can terminate their contract before the product reaches the end of life cycle and order a new type of product (premium, economy or budget). The probability of a contract termination is assumed to be 10%.

xiii. Premium and budget products will be supplied to SBUs by Slovenia's main production facility, and economy products, depending on the scenario can be provided by a) SBUs, b) Slovenia or c) central collection and service hub.

xiv. In order to meet customers' requests, it is assumed that if the economy or budget product is not available, it will be provided from upper-level products (premium instead of economy, economy or premium instead of budget).

xv. The probability of buying a new product (premium, economy or budget) after contract termination or end of life cycle is 70%.

xvi. Each SBU should have 25 (one-third of 75) premium products available in its stock initially whereas Economy and budget products will be added to the stock during the model run time.

5.5.3. White goods demonstrator scenarios

Two main scenarios are considered for the white goods demonstrator supply chain: decentralized and centralized refurbishment. Decentralized scenario means that the SBUs are responsible for refurbishment in the respective markets whereas in centralized scenario the machines will be refurbished in a central service hub. The role of the SBUs can extend from contract management, machine deployment, providing maintenance and service, carrying out refurbishment and storage of machines. The central service hubs can have the functionality of larger capacity for refurbishment processes as well as spare parts stocking and machines storage capacity. The supply chain attributes of the service-based business model being considered are environmental impacts (CO_2eq.), cost of service and transport.

The maintenance and repair service procedure, which is similar for all scenarios, is elaborated in the following section. The organization of maintenance and repair activities operates through the sales and business units (SBUs). The frequency of these services at the customer site by the service technicians are shown in the scenarios. Service and maintenance requests will be triggered by active tracking of machine usage. Two types of service will be considered at different intervals of time: repair and schedule service. The intention of service and maintenance is to keep the machine in running condition at the customer and avoid the transport of the washing machine from the customer to the sales and business unit.

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Potential situations in service and maintenance can be:

- The service technician visits the customer for regular maintenance of the washing machine (no triggers from the customer, the machine is monitored through the app)
- The service technician visits the customer for repair (triggered from customer and app, this step might require spare parts replacement)

The service technician is called for machine breakdown triggered by the customer through the mobile application. The machine will either require repair on customers-site with available spare parts at the SBUs or replaced with an ad hoc machine.

To create a decision support tool for Gorenje following scenarios have been sketched and modelled:

A) Repair and maintenance scenario with decentralized refurbishment in SBUs

In this scenario, repair and maintenance will be carried out through SBUs at the customer site. However, it will mainly focus on the decentralized collection and refurbishing of washing machines through the SBUs in the respective markets. In this scenario, the washing machines will be taken back to SBUs when a customer terminates their contract or when the machine reaches the end of life cycle. SBUs will act as hybrid facilities with refurbishing capabilities. Therefore, the refurbishment will be done in each market's SBU and refurbished products will be distributed to the respective markets. That means SBUs would be able to partially fulfill customer demand for economy type washing machines. However, premium and budget products will be supplied to SBUs upon request by the main production facility in Slovenia.

B) Repair and maintenance scenario with centralized refurbishment in central service hubs

Repair and maintenance service is similar to scenario A, but here the focus will be on centralized refurbishment of products. It depicts the return of washing machines by the service technicians to the SBUs. At SBUs the machines will be collected and bundled to be sent to a refurbishing facility.

Therefore, this scenario will simulate the collection of machines from the customers to the sales and business units. Moreover, it will also simulate the travel distance, processes for refurbishment and the associated costs during the collection and service intervals. Refurbishment, in this case, means inspection of the appliance after usage by the first customer and putting returned appliance in a reusable condition by the functional and aesthetical repair and cleaning proposed by white goods demonstrators Research and Development (R&D) department instruction protocols. This scenario will focus on the centralized collection of machines through a central service hub serving all the four markets. The service hub with a potential location in Germany, can either act as a collection center to move the machines for refurbishing and remanufacturing at the production site or with the extended functionality of refurbishment. The potential location of Germany is explored because of being geographically in the middle of the other 4 markets. The aspect of centralized collection is explored through two sub scenarios:

B.1 Centralized collection in the central service hub and refurbishment in the main production plant

In this scenario, SBUs will send the collected and bundled products to the central service hub in Germany. There, the washing machines from all four considered markets are collected and

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bundled again and then send to the main production plant in Slovenia. Therefore, refurbishment or any other required advanced process will be done in Slovenia. These refurbished products will be sent back to the market from Slovenia.

B.2 Centralized collection and refurbishment in the central service hub

Unlike the previous sub scenario B.1, the central service hub is able to act as both a collection and refurbishment center. Consequently, refurbished products will be supplied by this center to the 4 markets.

These two scenarios deal with the potential location of collection centers, the available capacities/capabilities of the facility and spare-part stocks to be able to refurbish the machines. The scenarios explore the aspect of the centralized collection of machines as well.

The cost and environmental factors considered for both scenarios are shown in Figure 41 and Figure 42

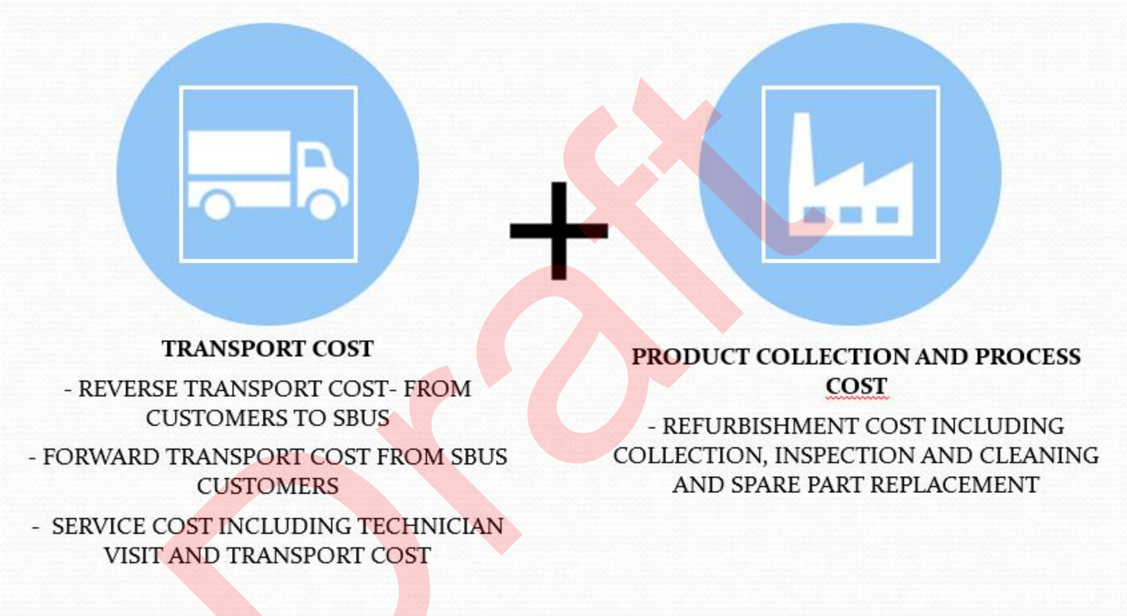

Figure 41: Total cost of service operations white goods demonstrator

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Figure 42: Total environmental impact of service operations white goods demonstrator

5.5.4. Model building

The model simulates the installation, de-installation and refurbishment of washing machines from the SBUs to the customers in respective markets. When a customer signs a contract for a washing machine, SBUs deploy the washing machine through the service technicians at the customers' site. At the end of lifecycle the washing machines are collected from the customers and brought back to the SBUs for repair and refurbishment. Moreover, in the case of contract termination, the product take-back requests will be generated by customers to SBUs. At SBUs the machines can be bundled, inspected, cleaned and refurbished, depending on the simulated scenario. The stages of collection and refurbishment are modelled as a process. The repair and service requests are generated by the customers from the SBUs on intervals defined in the model.

The explanation given below is not exhaustive, but representative of the complexity of the modelling logic.

Step 1: Creating model boundary with agents

Based on the data provided by the white goods demonstrator representatives, a boundary for the model was created consisting of the geographical location of entities (i.e. production in Slovenia, SBUs in Austria, Denmark, Netherlands, and Slovenia). These entities were created as agents in AnyLogic software, along with other agents as shown in Figure 43.

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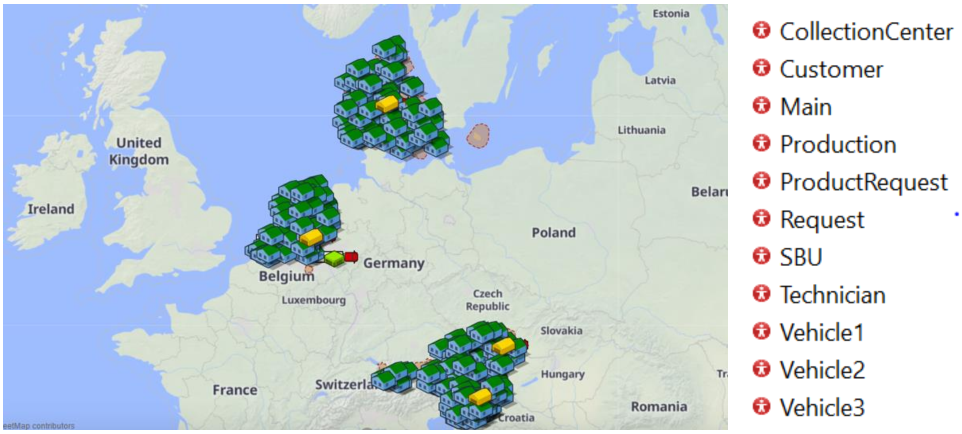

Figure 43: Geographical location of entities in the model and agents

Step 2: Defining parameters and variables

For arranging the experiment settings, design parameters pertaining to the economic and environmental performance are created with an input value based on company data and discussions with representatives of the company. A detailed description of the parameters used in the model is illustrated in Table 8.

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Table 8: Input parameters white goods demonstrators model

Parameter Type	Parameter Description	Parameter name in model	Unit
Operational	**Service interval:** *frequency of service*	serviceTimeout	months
	Contract termination: *propotion of customers ending the contract*	avgTerminationprobablity	%
	Machine breakdown: *mean time to machine repair or failure*	MTTF	year
	Product: *product category*	product	-
	Service Type : *maintainence or repair*	type	-
	Location of entities: *geographical locations of supply chain entitites*	location	GIS points
Cost	**Transport cost** : includes forward *transport cost from production to SBUs and customers i.e. machine installation. Plus r* everse transport cost from SBUs to Service Hubs/ Production includes deinstallation of machines	transportCost	€/km
	Service transport cost: *cost of service including* technicians travel to customers site excluding labor cost	servicetransportCost	€/km
	Service cost: *includes maintainence and repair service plus labor cost per hour and spare part price.*	ServiceCost	€/h
	Warehouse cost: storage *costs at central service hubs and SBUs*	warehouseCost	€/product
	Refurbishing cost: *cost including the cost of labor for cleaning, testing and sparepart replacement processes (e.g., motor, bearings, front panel, printed circuit board, or pump) and some cosmetic changes*	refurbishCost	€/product
Environment	CO_2 emission factor transport : CO_2 equivalent emission of a road freight lorry 7.5-16 tonnes with 0.229 CO_2-eq. kg emissions	CO2_transport	kg/tkm
	CO_2 emission factor service transport : CO_2 equivalent emission of a light commericial vehicle amount to 1.944 kg CO_2-eq. emissions	CO2_servicetransport	kg/tkm
	CO_2 emission factor refurbishing: includes process emissions during refurbishing (cleaning,testing and sparepart replacement) with a value of 0.6 kg of CO_2 equivalent emissions for metal working and auxillary enery inputs for steel manufacturing.(Note: the refurbishing emission is based on the assumption that it is 90% less of the new manufacturing on steel based products, which may be compared to the figures of 80% or higher for remanufacturing reported ften in the literature*)	CO2emissionfactor_refurb	kg/kg
	** Reference: IRP (2018). Re-defining Value – The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy. Nabil Nasr, Jennifer Russell, Stefan Bringezu, Stefanie Hellweg, Brian Hilton, Cory Kreiss, and Nadia von Gries. A Report of the International Resource Panel. United Nations Environment Programme, Nairobi, Kenya.*		

Step 3: Defining rules for products and transport

Next step was to define the movement of washing machines among the different agents and the frequency of service trips. The washing machine movement logic has been created using the state chart in Figure 44. It should be noted that this figure only shows the movement of products

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or technicians inside each market between SBUs and customers. In this case, the vehicles in the model initially wait for requests at SBUs. There are different types of the request made by customers, repair service, contract termination or ordering a new type of product. The customers initiate the repair service requests approximately every 1.5 - 4 years.

Upon arrival at the customers, depending on the type of request, the technician either unloads the machine, services or collects the machine and then moves back to the SBU to await the next request. At SBUs, the vehicle loads the washing machines from the storage and moves to the customers, if they ordered a product. The service, repair, and collection of washing machines is triggered by the customers in the model.

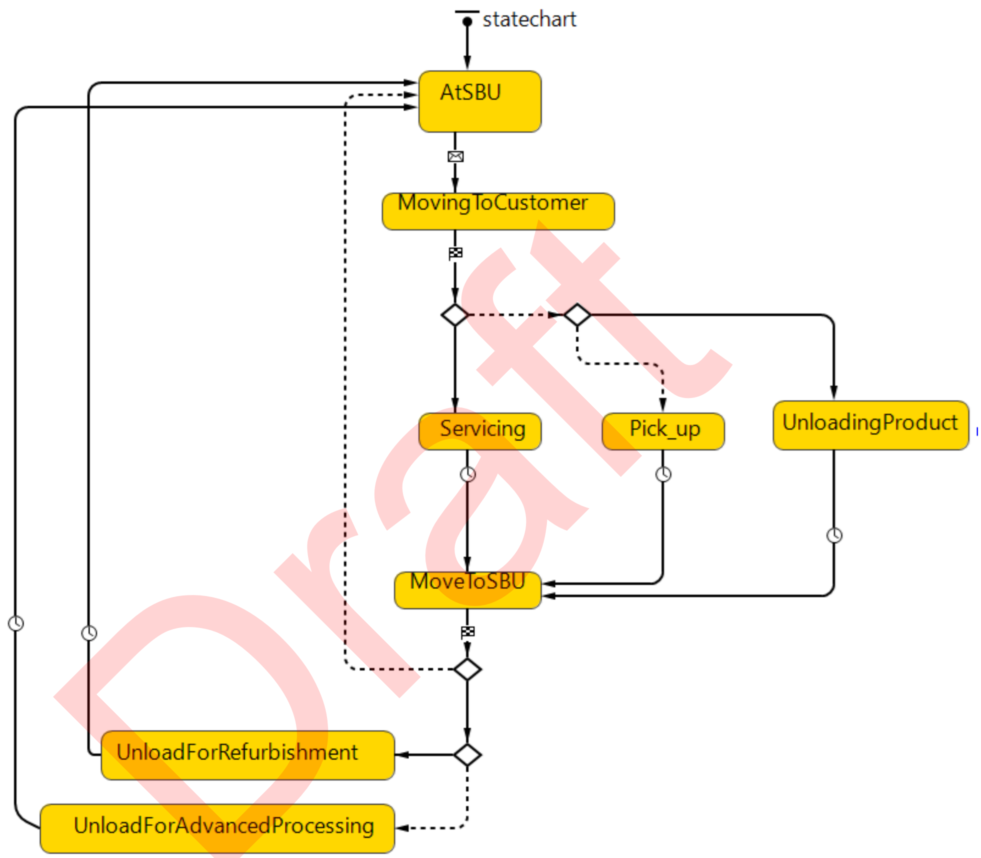

Figure 44: State chart showing movement of washing machines

Step 4: Defining entities activities

As mentioned in step 3, repair service, collection and delivery of washing machines is triggered by customers' requests. Figure 45 shows customers possible states only for premium type, the economy and budget products are similar to this one as well. Depending on the type of washing machine deployed at the customer site, this state would be premium, economy or budget operating. Inside this state, predictive service and maintenance and unplanned failure are considered. Contract termination states indicate situations where the customer decides to end the contract before the end of the five-year contract period. If this is not the case, the washing machine will be taken to the SBUs after each life cycle of five years. Additionally, if the customer is still willing to utilize the product after contract termination or product's end of life cycle, there is a possibility to order a new product.

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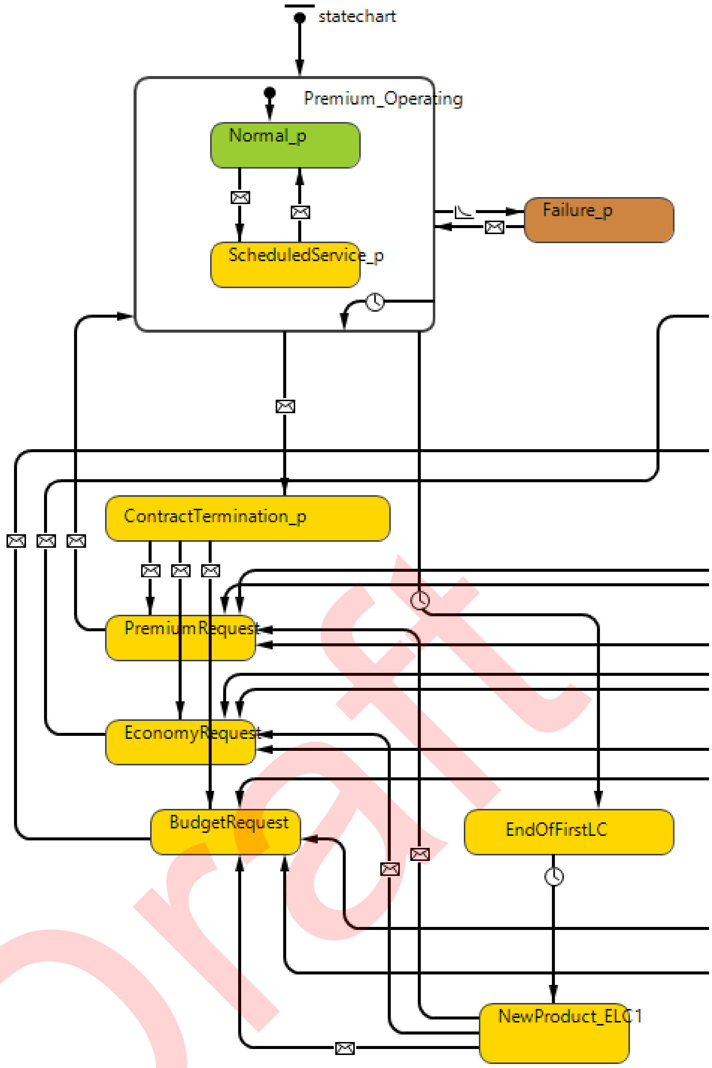

Figure 45: State chart showing customers activities in the model

SBUs responsibility on providing repair service, collecting and delivering products is shown in Figure 44. Moreover, Figure 46 shows that SBUs can flexibly act as a refurbishment facility or collection and bundling station in each market depending on the scenario.

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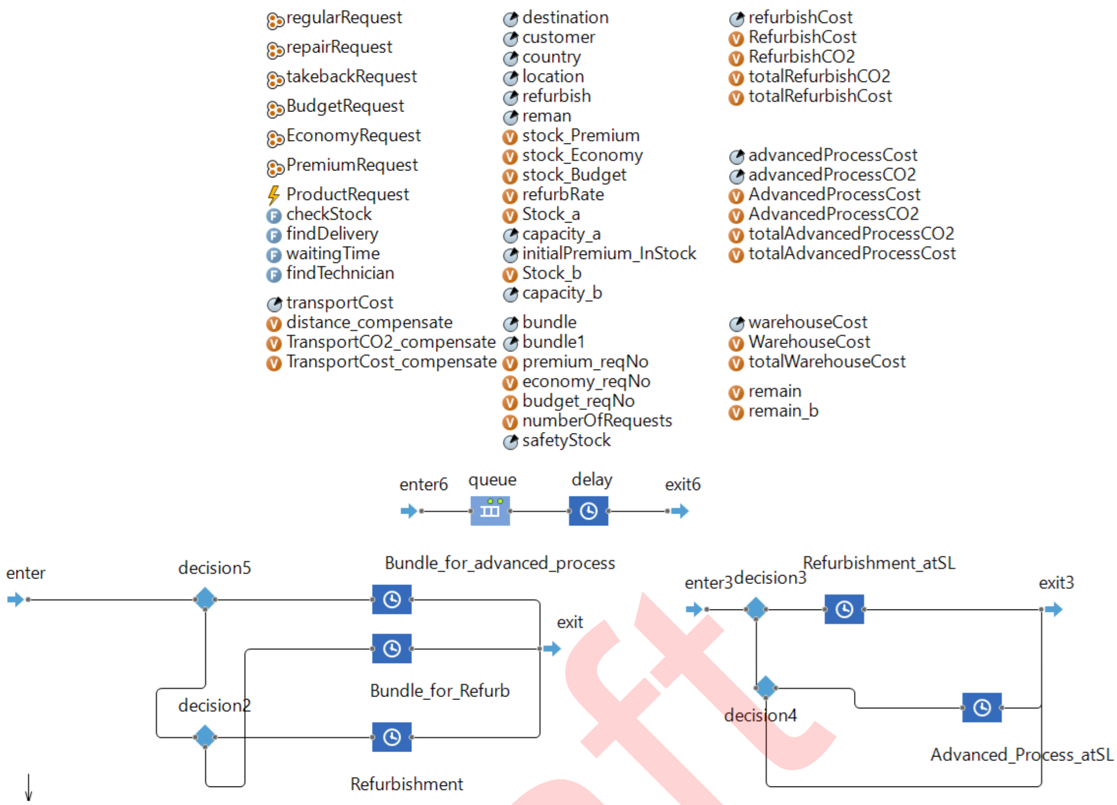

Figure 46: SBUs activities in the model

Like SBUs, the central service hub can function as a central collection center or central refurbishment center, shown in Figure 47

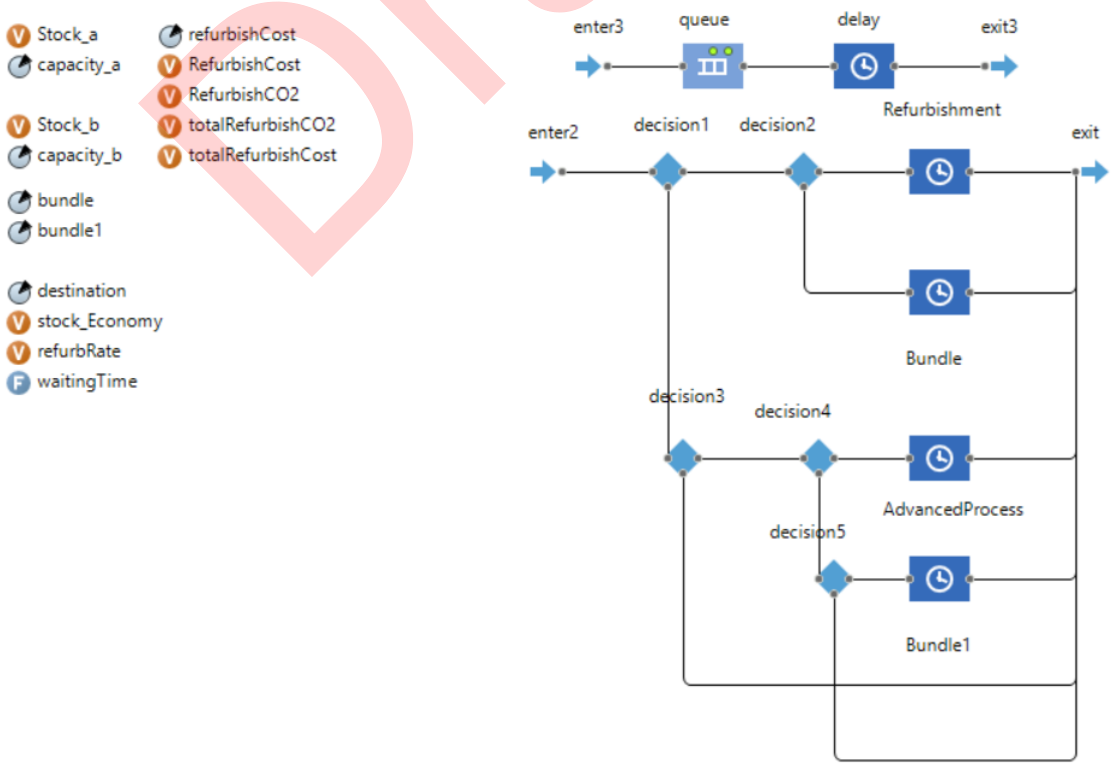

Figure 47: Central service hub activities in the model

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Step 5: Model visualization and results

After creating the logic for movements and products and entering the initial values for the parameters, the visualization was created both with the agents moving on the GIS map as well as KPIs dashboard highlighting the economic and environmental performance indicators. As mentioned above, scenarios are generated by assigning different functions at the SBUs and central service hub in Germany. The scenarios are illustrated in Table 9.

Table 9: Simulated scenarios white goods demonstrator

Scenario	*Entities*	*Description*
A. Decentralized refurbishment	• 4 SBUs • Production (Slovenia)	Washing machines will be refurbished in SBUs in respective markets and circulated back in the markets. Washing machines requiring advanced processing will be bundled in SBUs and shipped to Slovenia.
B.1 Centralized refurbishment (Slovenia)	• 4 SBUs • Central service hub (Germany) • Production (Slovenia)	SBUs collect and bundle the washing machines and send them to the central service hub. Central service hub, that only acts as a collection centre will send them to Slovenia for refurbishment at Velenje.
B.2 Centralized refurbishment central service hub (Germany)	• 4 SBUs • Central service hub (Germany) • Production (Slovenia)	Washing machines will be bundled at SBUs and transported to the central service hub for refurbishment and refurbished machines will be circulated back in the respective markets.

The economic and environmental performance for each scenario is calculated for 15 years (i.e. 3 lifecycles of 5 years each) based on Equation 3 and Equation 4, respectively.

$$\begin{aligned} Total\ Cost &= \left(transport\ cost\ \left[\frac{€}{km}\right].transport\ distance\ [km]\right) \\ &+ \left(service\ transport\ cost\ \left[\frac{€}{km}\right].service\ transport\ distance\ [km]\right) \\ &+ \left(service\ cost\ \left[\frac{€}{h}\right].service\ time\ [h]\right) \\ &+ \left(refurbish\ cost\ \left[\frac{€}{product}\right].number\ of\ products\right) \end{aligned} \quad \text{Equation (3)}$$

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$$Total\ CO2 = \left[\left(transport\ CO2 \left[\frac{kg}{t.km}\right] . transport\ distance\ [km] \right) + \left(service\ transport\ CO2 \left[\frac{kg}{t.km}\right] . service\ transport\ distance\ [km] \right) + refurbish\ CO2 \left[\frac{kg}{t}\right] \right] . weight[t] \qquad \text{Equation (4)}$$

Please note that the numbers provided in the results are representative and may not depict the actual costs. The results of the simulated scenarios are as follows:

A. Decentralized refurbishment

Figure 48 and Figure 49 respectively shows that the main element of both economic and environmental performance is the service transport. Service transport refers to the transporting machines within the markets, while reverse and forward transport refer to the washing machines movement from Slovenia or central service hub to the market which may include the installation and de-installation of machines. Since in this scenario washing machines will not be moved to Slovenia and SBUs do the refurbishment, service transport cost and CO_2eq. is more than reverse and forward transport.

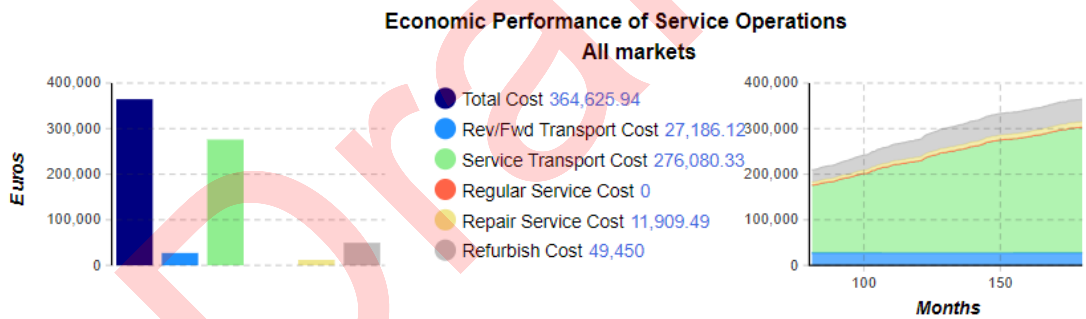

Figure 48: Scenario decentralized refurbishment - economic performance

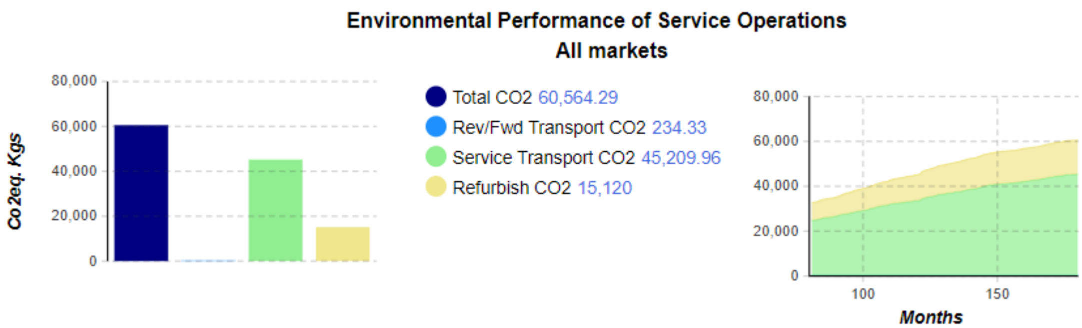

Figure 49: Scenario decentralized refurbishment - environmental performance

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B.1 Centralized refurbishment in Slovenia

In this scenario the machines are deployed through SBUs in Slovenia, Austria, Denmark, Netherlands. The washing machines are brought back to the SBUs after contract termination and at the end of a product's life cycle. The machines are bundled at the respective SBU in the four chosen markets and sent to Slovenia for refurbishing or advanced processing. The economic and environmental performance of this scenario is shown in Figure 50 and Figure 51 respectively.

As mentioned in the model assumptions, customers contract termination and a new type of product request is triggered by probability functions, which results in fluctuations in the amount of refurbished or delivered products to customers in different scenarios. The decentralized refurbishment scenario shows more service transport costs and CO_2eq. emissions compared to the centralized refurbishment in Slovenia, which means that based on the probability functions more customers in this scenario would be making requests for repair, contract termination or renewal.

Although Figure 51 shows that the environmental performance of centralized refurbishment in Slovenia is better than decentralized refurbishment. It should be emphasized that reverse and forward transport emissions are still higher compared to the decentralized scenario because the products are travelling long distances for refurbishment in Slovenia.

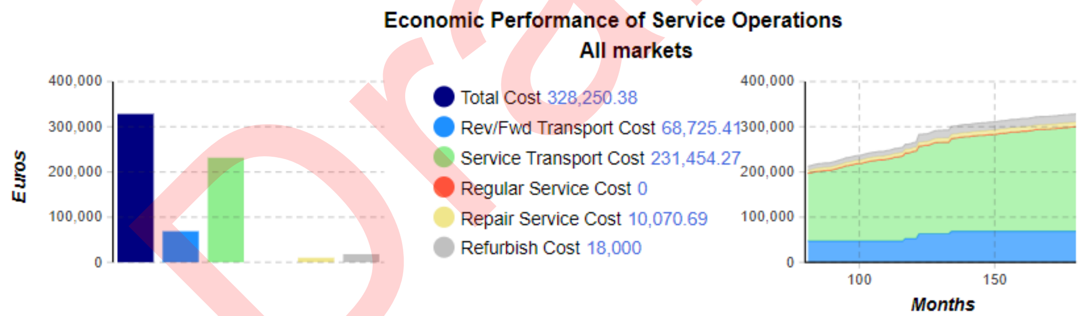

Figure 50: Scenario centralized refurbishment in Slovenia - economic performance

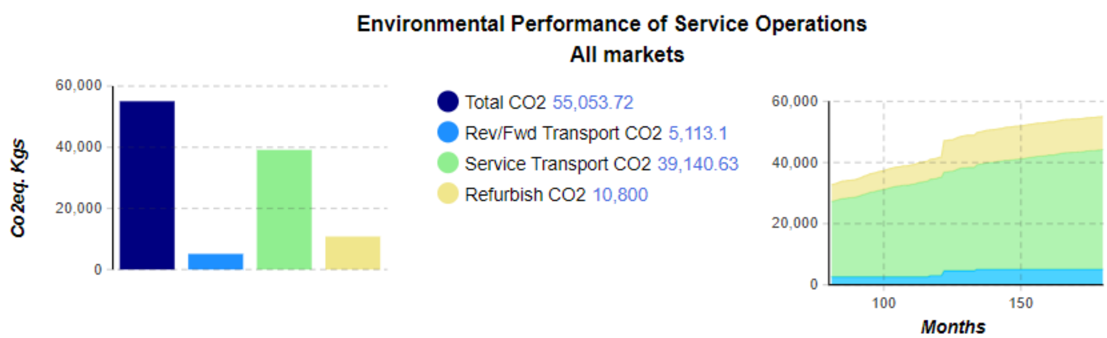

Figure 51: Scenario centralized refurbishment in Slovenia - environmental performance

B.2 Centralized refurbishment in Germany

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This scenario shows that the machines are deployed through SBUs in SL, AU, DK, NL. The machines are brought back to the SBUs after contract termination and at the end of the product life cycle. The machines are bundled at the respective SBUs in the chosen 4 markets and sent to the central service hub for refurbishment. The service hub can act as a central unit with a larger capacity for refurbishment operations or a node for the collection and bundling of machines. Total costs and CO_2eq. emissions are shown in Figure 52 and Figure 53 respectively.

Figure 52 indicates that centralized refurbishment in Germany will be costly since it covers reverse cost from the 4 SBUs to central service hub as well as higher refurbishment cost than the Slovenian market.

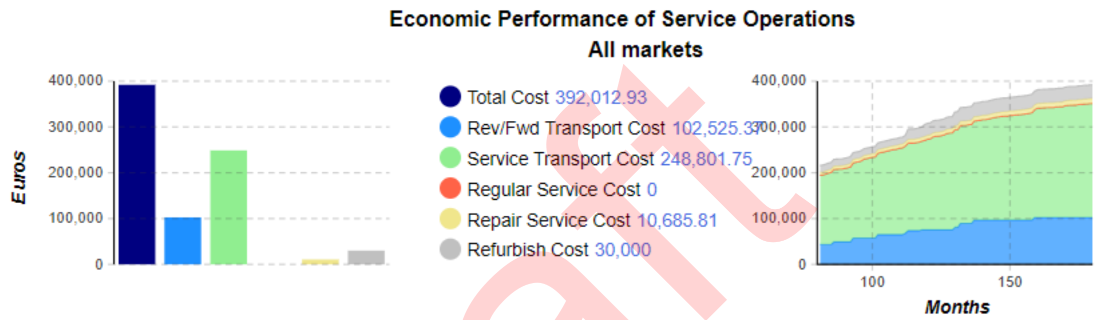

Figure 52: Scenario centralized refurbishment in Germany - economic performance

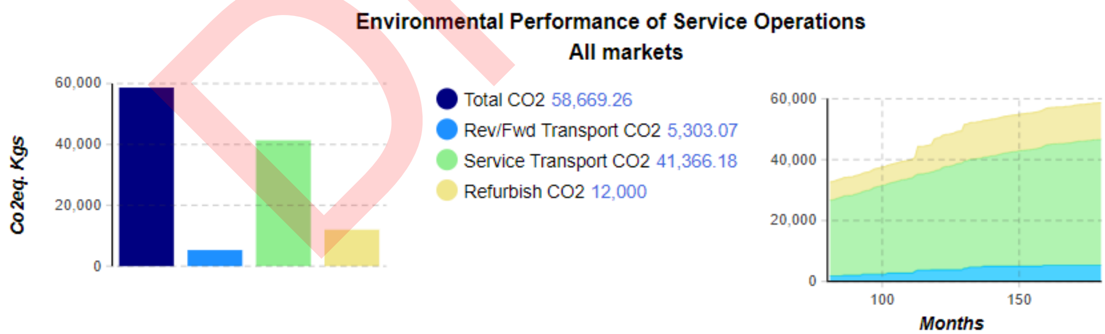

Figure 53: Scenario centralized refurbishment in Germany- environmental performance

5.5.5. Results analysis

The total economic and environmental performance of simulated scenarios is shown in Figure 54 and Figure 55, respectively.

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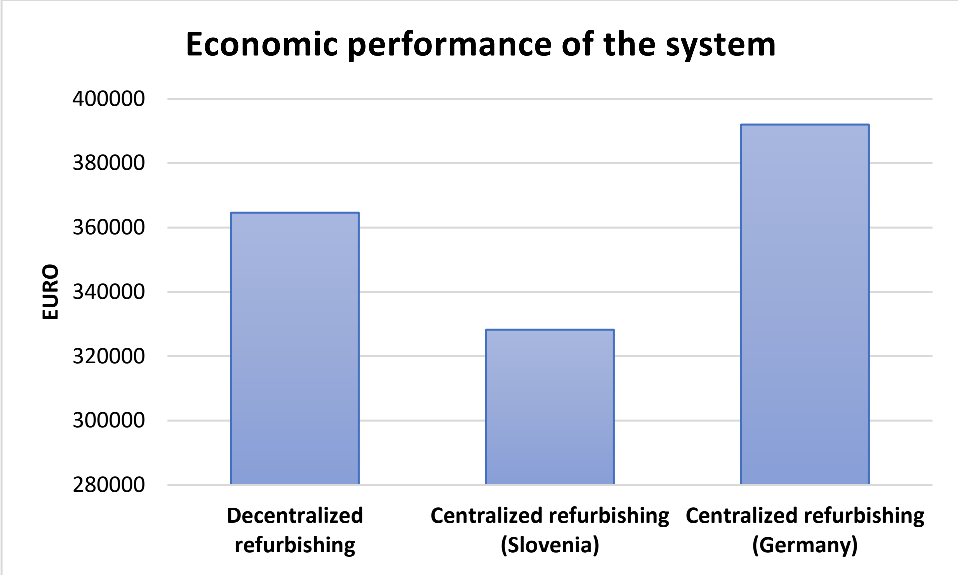

Figure 54: Economic performance of white goods demonstrator scenarios

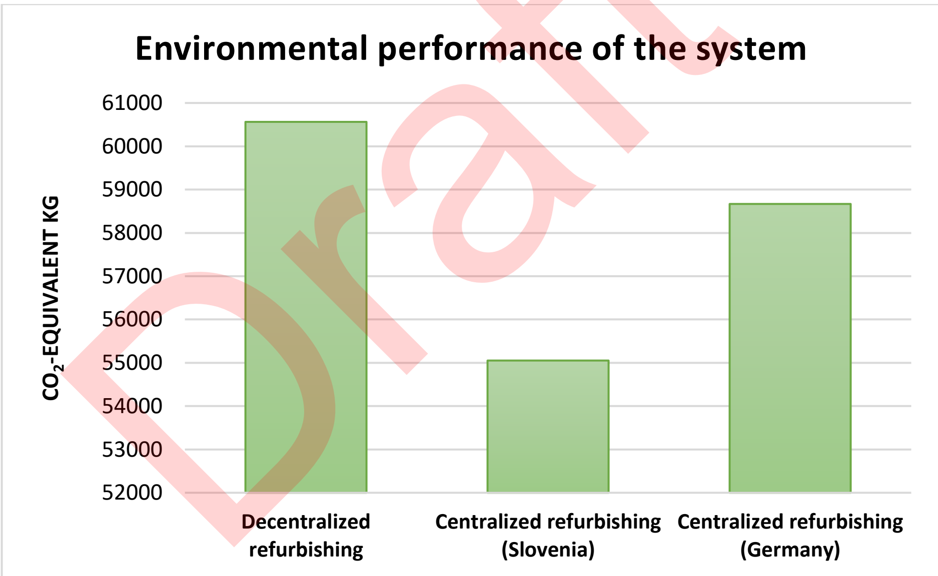

Figure 55: Environmental performance of white goods demonstrator scenarios

To make an effective comparison of economic and environmental trade-offs, the following results can be seen in Figure 56.

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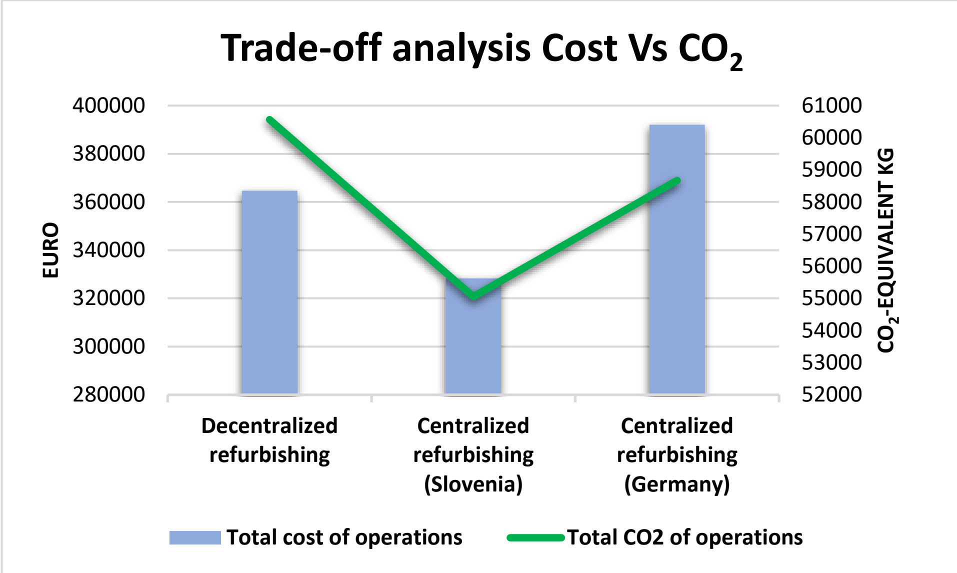

Figure 56: Trade-off between economic and environmental performance of white goods demonstrator

From the trade-off analysis, shown in Figure 56, and the economic and environmental performance shown in Figure 54 and Figure 55, it can be concluded that centralized refurbishing at the Slovenia is the most feasible scenario from both economic and environmental aspects. The reason being that the refurbishing process cost is cheaper in Slovenia as compared to the other 3 markets and Germany. Moreover, the transportation cost will also be lower for centralized refurbishment in Slovenia in comparison with centralizing in Germany.

It can be noted from the results that for economic performance the decentralized refurbishment scenario performs better than refurbishing in Germany due to decreasing washing machines movement from each SBU to Germany. However, in terms of environmental performance, decentralization scenario does not show the feasibility because for decentralized refurbishment, there are more service trips which amounts to higher CO_2 equivalent emissions. Therefore, these currently existing facilities in Slovenia, have the potential to improve the total operations.

5.6. Model verification and validation

The models are built adopting the bottom-up approach which means at first a conceptual model was created which is a simplified version of the existing system. The logic was incorporated step by step to reduce discrepancies and ambiguities and inconsistencies. Modelling is a context specific task where the conceptual level forms a basis for the potential outcomes of the model. However, there is room for subjective interpretation in modelling, which rests upon the modellers view and understanding of the conceptual model. To minimize bias and develop fairly comprehensive models representative of the demonstrators' individual characteristics, the conceptual models have been discussed in groups and verified by the demonstrators' representatives. Scientific literature has been consulted to understand the industry-specific questions and connect those with the current demonstrators intended business approach. Based on the agreed-upon scenarios, the logic was developed iteratively with continuous input of data from the demonstrators. Moreover, internal validation of the models has been conducted using techniques such as dimensional consistency and agent-behaviour testing by using specific parameter settings to verify expected outcomes.

Furthermore, with the agent-based modelling approach, by adopting the bottom-up principle, the model is kept simple and easier to verify. The model was further validated by verifying the

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numerically calculated solutions in parallel while building the model as well as the testing of the model. The most important metrics were cost parameters in different markets which were rigorously tested in different scenarios

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6. Discussion and conclusions

At a glance, the demonstrators seem to have more differences than similarities, but they have the same ambition of implementing a circular supply/value chain. Nevertheless, as the details of the demonstrators are being investigated, more and more synergies can be found. Some of the differences, similarities, and possible synergies are highlighted below.

The main motivation for both companies to implement circular approach is driven by economic interests, environmental well-being, better services and value proposition for their customers as well as be a forerunner for transitioning towards circular economy in these two traditional sectors.

As mentioned earlier, ReCiPSS deals with two demonstrators in entirely different sectors. Gorenje has full control over their value chains, but the current state analysis shows that there is nearly no reverse logistics infrastructure available to establish a circular supply chain. However, Gorenje has a well-established service organization that can play a major role in building up the reverse logistics network.

Bosch has a relatively well functioning reverse logistics network but due to the complexity of the business structure of the aftermarket as well as a large number of product variants (both Bosch and non-Bosch parts), there is a margin for improvement when it comes to the efficiency of reverse logistics. Furthermore, Bosch is one of the actors among many competitors in the aftermarket holds a major market share in this business. However, for the long-term sustainability of the remanufacturing business sourcing of cores both from the OES providers and other service organizations need to be integrated within the Bosch service organization.

From the product design point of view, both demonstrators deal with long-lasting products and take product life extension as one of the main product design and development strategies. The main reason for focusing on product life extension is that drastic design change is challenging in both sectors for various reasons. For example, automotive components are highly standardized and need to follow the strict requirements of car manufacturers. While Bosch automotive parts are already remanufactured several times, Gorenje is going to extend the life of washing machines so that minimum refurbishment operations are needed to put the products back again in service.

Furthermore, Bosch has a well-functioning remanufacturing process infrastructure of their own which has the capacity of remanufacturing a wide range of automotive parts. On the other hand, Gorenje has the infrastructure for service and repair which is mostly outsourced to independent local service providers. Bosch has a solid knowledge base and experience with remanufacturing whereas Gorenje has started to gather knowledge and experience.

Both demonstrators have well-functioning IT infrastructures for the forward flow of materials and have an initial platform with basic functionalities to fulfill some purposes of the value recovery. In the case of Gorenje the initial platform is designed to implement pay-per-wash scheme with real-time condition monitoring of washing machines that will provide better maintenance and service to their customers. On the other hand, Bosch is testing a solution developed by C-ECO for efficient presorting of cores for minimizing the complexity of trade levels to some extent. C-ECO is also running the reverse logistic supply chain for Bosch basing on financial incentives, which motivates the customers to return the used products.

From the theoretical point of view circular supply chains development necessitates looking into related concepts such as linear supply chains sourcing, production, distribution and sales of the product. On the other hand, closed-loop supply chains focus on capturing value from products

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after their use-phase through product return management and repurposing as well as redistribution. There is a wealth of knowledge supporting the notion of value recovery and the efficiency measures for forward supply chain performance and reverse logistics infrastructure design. Circular supply chain development, however, emphasizes the notion of systemic view where the design of a supply chain network is dependent on the corresponding business model, product design and supporting IT infrastructure. Hence, circular supply chains should not be developed in silos.

A prerequisite for circular supply chain implementation is to re-feed the products back in the loop for repurposing. On the conceptual level, this means that the consideration of interdependencies between the design, business model and supporting ICT infrastructure is vital. On the operational level, this translates into the need for an efficient reverse logistics infrastructure. For efficient reverse logistics process management, several aspects are important, for instance, the appropriate channel for the collection of cores, the process of acquisition through either an own service network or a third-party supplier directly from the users or dropped–off at the facilities. Moreover, detailed questions pertaining to reverse logistics network design can be based on facilities location for collection, inspection, remanufacturing and recycling.

Further considerations might include the pricing decisions for acquiring cores, the levels of inventory required to maintain stocks for remanufacturing operations as well as the seamless integration with the forward network. Several performance measurement indicators have been found in the literature for the linear supply chain. Some of these performance indicators may be directly relevant and some might need to be adapted for circular supply chains. This will be explored through further work on circular supply/value chains development.

In the context of this deliverable, the best practices are selected based on the value chain concept in supply chain which implies that the OEM is in full control of entire product throughout all stages (i.e. design, manufacturing, forward supply chain, customer use phase, reverse supply chain, recovery activities, and re-distribution). This consideration made the list brief despite the fact that there are many success stories of implementing CE approach circulating in scientific publications, grey publications and websites promoting the CE approach. As mentioned earlier, in the proactive approach of implementing circular manufacturing systems simultaneous consideration of business models, product design, supply chains and supporting ICT infrastructure is necessary. This will ensure long term sustainability of CMS which is both economically and environmentally better than linear manufacturing systems. Furthermore, if the best practices are analysed carefully simultaneous consideration of business models, product design, supply chains and supporting ICT infrastructure can be found as the common denominator. All the best practices that are described in this report have intentionally adopted a business model that differs from conventional sales model, which ranges from buy-back to selling product as service to ensure product return and value recovery.

Similarly, nearly all companies have talked about adapting their product design approach including special packaging, product life extension, ease of disassembly/recovery/rebuild and adding conditions monitoring devices etc. to make value recovery easier and efficient. In case of supply chain integration, companies in the examples have used both their own logistics networks and the networks of the service providers to ensure timely and efficient supply. Furthermore, all companies have mentioned the use of ICT infrastructure to collect online/offline data for various reasons such as condition monitoring for efficient maintenance and service support, measuring the environmental performance of the supply chain and inventory management etc. In the light of the best practices, the industrial demonstrators are not very far from the most favourable precondition of designing a CMS. Some of the elements

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of the business models, product design, supply chains, and ICT infrastructure aspects are already in place and some of the elements need to be developed integrated as well as improved within the frame of the ReCiPSS project. In terms of development of the circular supply/value chain both demonstrators have the basic infrastructures in place which need to be developed further.

Building upon the learnings of the analysis of the state-of-the-art, industrial best practices and baseline of the two demonstrators, simulation models were developed to assess the economic and environmental performance of the two demonstrators supply/value chains. As part of a new intended business strategy, which aims at streamlining the reverse logistics flow, the modelling for the automotive demonstrator is focused on the reverse supply chain including the collection channels, core selection stations, warehouses, remanufacturing plants and redistribution through wholesalers. In order to make a comparative analysis of the reverse operations and identify optimal reverse flow of cores, two main scenarios are considered: As-Is scenario and hubs scenario. The As-Is scenario simulates the current decentralized system of the core collection, where the cores are sorted at each trade level which in this model are the wholesaler outlets. The hubs scenario, on the other hand, simulates the impact of centralized collection of cores by integrating the trade levels. For this scenario, wholesaler outlet locations collecting cores are replaced by regional logistics hubs that can either be a logistics node or serve as regional sorting stations. The overall economic and environmental performance of the scenarios is calculated as an aggregated cost and CO_2eq. respectively of operations including product transport, collection, and processing. By evaluating the trade-offs between the economic and environmental performance of the scenarios, it can be concluded that a centralized scenario with 8 regional logistics hubs where the inspection, sorting as well as collection and bundling of cores take place is the most feasible scenario.

The white goods demonstrator is exploring a new circular business model for washing machines based on multiple-use cycles and product refurbishing. Therefore, the simulation modelling is focused on identifying environmental and economic performance trade-offs in choosing the level of service, the supply chain configuration as well as the impact of a service-based business model. In order to identify the best locations for the repair centers and potential refurbish facilities two main scenarios are considered: 1) repair and maintenance scenario with decentralized refurbishing and 2) centralized refurbishing in service hubs scenario. The decentralized refurbishing scenario considers the current set-up of the service network where the collection and refurbishing of washing machines take place through the sales and business units. In the centralized scenario, the collection of washing machines takes place through a central service hub. The service hub can either act as a collection center to move the washing machines for advanced processing at the production site or with extended functionality of refurbishment. By analyzing the economic and environmental performance of both scenarios, it can be concluded that a centralized scenario where the cores are first bundled in SBUs then sent to Slovenia for either refurbishment or advanced processing is the most feasible scenario.

Simulation modelling is very useful to come up with possible future scenarios. However, the major purpose of simulation modelling is not to predict but rather provide potential decision-making solutions especially in complex systems where minor fluctuations could lead to systemic effects. The automotive and white goods supply chain models presented in the deliverable are intended to be a decision support platform which implies that the same supply chain model can be replicated for any number of geographical locations with varying operational costs and environmental performance indicators. Cost and CO_2 calculations in the model are primarily suggestive and aggregated which necessitates external validation to improve the simulation results. A point to note is that a robust design of a simulation model is very dependent on the quality of input data; however data quality and uncertainty is inherent in any multi-objective supply chain design model. It has been consciously ensured that subjectivity is minimized, by

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using data provided by the case companies and calculated assumptions based on relevant and available peer-reviewed literature. The robustness of the model can be tested against more assumptions as well. Nonetheless, the basic model will remain useful and applicable for any supply chain network in the service innovation as well as in streamlining the reverse logistics flows.

The simulation model is a representative of the complex supply chain structure and enables developing insights by introducing incrementally further attributes such as financial flows, pricing strategies, customer demand, and service levels. With white goods demonstrators moving towards servitization, the patterns of customer demand are also changing, which calls for a high level of customer satisfaction and requires more active customer engagement. This aspect will be explored further while creating the simulation model for business encompassing service pricing, cost of operations, and the influence of time leading to a breakeven in profits. Furthermore, the fine level impact of local service operations shall be considered for instance for efficient operations at the local facilities what would be the optimal stock levels. The supply and demand of end-of-life products is very critical for an effective reverse logistics network. From a multiple lifecycle perspective, a steady supply of products at different lifecycle stages is vital to retain the customers and for the viability of the service business model. Accumulation of inventory is another challenge of an unplanned and unresponsive reverse logistics system not designed and developed for redistributable products. This will require an investment of a new inventory policy with stocks of spare parts as well as an inventory management system. Furthermore, decision pertaining to the location of repair centres, product warehouses and proximity to remanufacturing facilities also plays a role in making the reverse operations effective. Since the optimal reverse logistics design depends on factors such as collection rate, reverse logistics operational costs, the quantity of products collected, and cost paid to the wholesalers/retailers. It is advisable to consider the aspect of supply and demand balancing through forecasting product volumes and analyzing the storage and processing capacity at the logistics hubs. Additionally, inventory and stocking aspects shall cover the unequal accumulation of spare parts and availability of the required spare parts only, meaning that there are certain spare parts with a higher demand than others. Logistical planning should include the aspects of throughput planning to rationalize the costs for transport volumes and warehousing, as well as looking into buffer stocks. For both demonstrators, the knowledge and development of maintenance and a repair knowledge repository, including activities, methods, processes, resources for materials, spare parts, energy, and operational facilities are instrumental for the implementation of circular supply/value chains.

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7. References

[1] V. D. R. Guide Jr. and L. N. Van Wassenhove, "The Evolution of Closed-Loop Supply Chain Research," *Operations Research*, vol. 57, no. 1. pp. 10–18, 2009.

[2] J. L. Mishra, P. G. Hopkinson, and G. Tidridge, "Value creation from circular economy-led closed loop supply chains: a case study of fast-moving consumer goods," *Prod. Plan. Control*, vol. 29, no. 6, pp. 509–521, Apr. 2018.

[3] J. D. Abbey, & V Daniel, and R. Guide, "A typology of remanufacturing in closed-loop supply chains," *Int. J. Prod. Res.*, vol. 56, pp. 374–384, 2018.

[4] V. D. R. Guide, T. P. Harrison, and L. N. Van Wassenhove, "The Challenge of Closed-Loop Supply Chains," 2003.

[5] S. D. P. Flapper, J. A. E. E. Van Nunen, and L. N. Van Wassenhove, "Managing closed-loop supply chains," 2005.

[6] H. Krikke, D. Hofenk, and Y. Wang, "Revealing an invisible giant: A comprehensive survey into return practices within original (closed-loop) supply chains," *"Resources, Conserv. Recycl.*, vol. 73, pp. 239–250, 2013.

[7] D. Guide and L. N. Van Wassenhove, "The Evolution of Closed-Loop Supply Chain Research," *Indep. Rev.*, vol. 14, no. 3, pp. 363–375, 2009.

[8] Z.-S. Huang and J.-J. Nie, "Dynamic closed-loop supply chain model with product remanufacturing," in *ICLEM 2012: Logistics for Sustained Economic Development - Technology and Management for Efficiency - Proceedings of the 2012 International Conference of Logistics Engineering and Management*, 2012, pp. 1039–1045.

[9] D. Battini, M. Bogataj, and A. Choudhary, "Closed Loop Supply Chain (CLSC)_ Economics, Modelling, Management and Control," 2016.

[10] N. S. Chari, "Thematic Development of Recovery , Remanufacturing , and Support Models for Sustainable Supply Chains," no. March, 2015.

[11] G. C. Souza, "Closed-Loop Supply Chains: A Critical Review, and Future Research*," *Decis. Sci.*, vol. 44, no. 1, pp. 7–38, 2013.

[12] S. Chopra and P. Meindl, *Supply Chain Management: Strategy, Planning, and Operation*. 2015.

[13] M. Salomon, "Strategic issues in product recovery management," *Long Range Plann.*, vol. 28, no. 3, p. 120, 1995.

[14] N. Kazemi, N. M. Modak, and K. Govindan, "A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis," *Int. J. Prod. Res.*, pp. 1–24, 2018.

[15] D. S. Rogers and R. Tibben-lembke, "JOURNAL OF BUSINESS LOGISTICS, Vol.22, No. 2, 2001 129," vol. 22, no. 2, pp. 129–148, 2001.

[16] S. Dowlatshahi, "Developing a theory of reverse logistics," *Interfaces (Providence).*, vol. 30, no. 3, pp. 143–155, 2000.

[17] S. Dowlatshahi, "A strategic framework for the design and implementation of remanufacturing operations in reverse logistics," *Int. J. Prod. Res.*, vol. 43, no. 16, pp. 3455–3480, 2005.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[18] S. Dowlatshahi, “A strategic framework for the design and implementation of remanufacturing operations in reverse logistics,” *Int. J. Prod. Res.*, vol. 43, no. 16, pp. 3455–3480, 2005.

[19] S. Agrawal, R. K. Singh, and Q. Murtaza, “A literature review and perspectives in reverse logistics,” pp. 76–92, 2015.

[20] S. Kumar and V. Putnam, “Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors.”

[21] J. D. Shulman, A. T. Coughlan, and R. Canan Savaskan, “Optimal Reverse Channel Structure for Consumer Product Returns.pdf,” *Source Mark. Sci.*, vol. 29, no. 6, pp. 1071–1085, 2010.

[22] A. Atasu, L. B. Toktay, and L. N. Van Wassenhove, “How collection cost structure drives a manufacturer’s reverse channel choice,” *Prod. Oper. Manag.*, vol. 22, no. 5, pp. 1089–1102, 2013.

[23] R. Canan Savaskan, S. Bhattacharya, and L. N. Van Wassenhove, “Closed-Loop Supply Chain Models with Product Remanufacturing,” *Manage. Sci.*, vol. 50, no. 2, pp. 239–252, 2004.

[24] N. Aras, T. Boyacı, and V. Verter, “Designing the Reverse Logistics Network,” *Closed-Loop Supply Chain. New Dev. to Improv. Sustain. Bus. Pract.*, pp. 67–97, 2010.

[25] 2015 Stadtler, H., Kilger, C., Meyr, H. (Eds.), *Supply Chain Management and Advanced Planning (Fourth Edition): Concepts, Models, Software, and Case Studies*, Stadtler,. 2008.

[26] A. Gunasekaran, C. Patel, and E. Tirtiroglu, “Performance measures and metrics in a supply chain environment,” *Int. J. Oper. Prod. Manag.*, vol. 21, no. 1–2, pp. 71–87, Jan. 2001.

[27] A. Gunasekaran, C. Patel, and R. E. Mcgaughey, “A framework for supply chain performance measurement,” *Int. J. Prod. Econ.*, vol. 87, pp. 333–347, 2004.

[28] E. N. Ntabe, L. LeBel, A. D. Munson, and L. A. Santa-Eulalia, “A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues,” *Int. J. Prod. Econ.*, vol. 169, pp. 310–332, Nov. 2015.

[29] E. N. Ntabe, L. LeBel, A. D. Munson, and L. A. Santa-Eulalia, “A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues,” *Int. J. Prod. Econ.*, vol. 169, pp. 310–332, Nov. 2015.

[30] L. Li, Q. Su, and X. Chen, “Ensuring supply chain quality performance through applying the SCOR model,” *Int. J. Prod. Res.*, vol. 49, no. 1, pp. 33–57, Jan. 2011.

[31] P. J. Z. G. Dwayne Whitten, Kenneth W. Green Jr, “Triple-A supply chain performance,” *Int. J. Oper. Prod. Manag. An Int. J. Iss Int. J. Oper. &amp Prod. Manag. Iss Int. J. Oper. Prod. Manag.*, vol. 19, no. 3, pp. 275–292, 2012.

[32] A. Rashid, F. M. A. Asif, P. Krajnik, and C. M. Nicolescu, “Resource Conservative Manufacturing: an essential change in business and technology paradigm for sustainable manufacturing,” *J. Clean. Prod.*, vol. 57, pp. 166–177, Oct. 2013.

[33] F. M. Asif, C. Bianchi, A. Rashid, and C. M. Nicolescu, “Performance analysis of the closed loop supply chain,” *J. Remanufacturing*, vol. 2, no. 1, p. 1, 2012.

[34] J. Östlin, E. Sundin, and M. Björkman, “Importance of closed-loop supply chain

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 776577-2

relationships for product remanufacturing," *Int. J. Prod. Econ.*, 2008.

[35] M. Linder and M. Williander, "Circular Business Model Innovation: Inherent Uncertainties," *Bus. Strateg. Environ.*, vol. 26, no. 2, pp. 182–196, 2017.

[36] F. M. A. Asif *et al.*, "A practical ICT framework for transition to circular manufacturing systems," in *Procedia CIRP*, 2018, vol. 72, pp. 598–602.

[37] Ricoh, "More Economically Rational Recycling," 1994.

[38] "Vision -The Comet CircleTM- | Global | Ricoh." [Online]. Available: https://www.ricoh.com/environment/management/concept.html. [Accessed: 01-Nov-2018].

[39] "Supply Chain Management | Global | Ricoh." [Online]. Available: https://www.ricoh.com/sustainability/report/action/supplychain.html. [Accessed: 01-Nov-2018].

[40] "Business Sites:Energy Conservati... | Global | Ricoh." [Online]. Available: https://www.ricoh.com/environment/office/energy/06_01.html. [Accessed: 01-Nov-2018].

[41] WRAP, "WRAP and the circular economy," *Wrap*, p. 1, 2016.

[42] "Circular economy | HP® Official Site." [Online]. Available: http://www8.hp.com/us/en/hp-information/environment/design-for-environment.html. [Accessed: 01-Nov-2018].

[43] HP, "2017 Sustainable Impact Report Contents," 2017.

[44] "Creating a reverse logistics ecosystem." [Online]. Available: https://www.ellenmacarthurfoundation.org/case-studies/creating-a-reverse-logistics-ecosystem. [Accessed: 01-Nov-2018].

[45] "IBM Global Asset Recovery Services (GARS) - IBM Global Financing | IBM." [Online]. Available: https://www.ibm.com/financing/asset-buyback/global-asset-recovery-services. [Accessed: 02-Nov-2018].

[46] M. Fleischmann, J. Van Nunen, B. Gräve, and R. Gapp, "Reverse logistics - Capturing value in the extended supply chain," in *Supply Chain Management on Demand: Strategies, Technologies, Applications*, 2005.

[47] "Caterpillar," *Extending product life*. [Online]. Available: http://reports.caterpillar.com/sr/report/remanufacturing.php.

[48] "Caterpillar," *CAT REMAN PROCESS*. [Online]. Available: https://www.caterpillar.com/en/company/sustainability/remanufacturing/process.html.

[49] "The Product-Life Institute," *Caterpillar Remanufactured Products Group*. [Online]. Available: http://www.product-life.org/ru/node/50.

[50] W. Kerr and C. Ryan, "Eco-efficiency gains from remanufacturing: A case study of photocopier remanufacturing at Fuji Xerox Australia," *J. Clean. Prod.*, vol. 9, no. 1, pp. 75–81, Feb. 2001.

[51] "How Xerox Succeeds in the Circular Economy - Xerox Connect." [Online]. Available: https://connect.blogs.xerox.com/2018/05/02/circular-economy-remanufacturing-xerox-ewaste/. [Accessed: 29-Oct-2018].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[52] "You and Xerox: Enabling a Circular Economy."

[53] "Renault, actively developing circular economy throughout vehicles life cycle - Groupe Renault." [Online]. Available: https://group.renault.com/en/news/blog-renault/renault-actively-developing-circular-economy-throughout-vehicles-life-cycle/. [Accessed: 02-Nov-2018].

[54] Ellen MacArthur Foundation, "The Circular Economy Applied to the Automotive Industry." .

[55] "Renault: A new direction for parts supply - Automotive Logistics." [Online]. Available: https://automotivelogistics.media/intelligence/renault-a-new-direction-for-parts-supply. [Accessed: 30-Oct-2018].

[56] "Why reverse logistics is an essential part of a circular economy | Circulate." .

[57] "KOMATSU : Enhancing Quality of Life -Special Story: Reducing CO2 Emissions from Construction Equipment-." [Online]. Available: http://www.komatsu.com/CompanyInfo/csr/environment/2015/02.html. [Accessed: 01-Nov-2018].

[58] D. Breitschwerdt, A. Cornel, S. Kempf, L. Michor, and M. Schmidt, "The changing aftermarket game–and how automotive suppliers can benefit from arising opportunities," *Adv. Ind.*, no. June, pp. 1–36, 2017.

[59] D. Parker *et al.*, "Remanufacturing Market Study," *Eur. Remanufacturing Netw.*, no. 645984, p. 145, 2015.

[60] "wolk after sales experts." [Online]. Available: http://www.wolk-aftersales.com/the-european-car-aftermarket-structure.html.

[61] "Bosch Annual Report," 2017.

[62] "Bosch eXchange." [Online]. Available: https://hr.bosch-automotive.com/en/parts_and_accessories_8/specials_11/bosch_exchange_12/overview_boschexchange_special.

[63] Andrei Borshchev, *The big book of simulation modeling*. 2013.

[64] S. Taylor, *Agent-based modeling and simulation*. .

[65] W. and W. U. Rand, *An introduction to agent-based modeling Modeling Natural, Social, and Engineered Complex Systems with NetLogo*, no. January. 2013.

[66] O. Balci and W. F. Ormsby, "Conceptual modelling for designing large-scale simulations," *J. Simul.*, vol. 1, no. 3, pp. 175–186, Aug. 2007.

[67] G. Jetly, C. L. Rossetti, and R. Handfield, "A multi-agent simulation of the pharmaceutical supply chain," *J. Simul.*, vol. 6, pp. 215–226, 2012.

[68] G. Elmas, "The importance of reverse logistics," *Int. J. Bus. Manag. Stud.*, vol. 3, no. 1, pp. 161–171, 2011.

[69] L. Čuček, P. S. Varbanov, J. J. Klemeš, and Z. Kravanja, "Total footprints-based multi-criteria optimisation of regional biomass energy supply chains," *Energy*, vol. 44, no. 1, pp. 135–145, 2012.

[70] F. M. A. Asif, "Circular Manufacturing Systems: A development framework with analysis methods and tools for implementation," KTH Royal Institute of Technology, Stockholm, 2017.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776577-2

[71] D. J. Garcia and F. You, “Supply chain design and optimization: Challenges and opportunities,” *Comput. Chem. Eng.*, vol. 81, pp. 153–170, 2015.

[72] H. Dai and Q. Wang, “Reverse logistics network design for the collection of end-oflife vehicles,” in *Proceedings of the ASME Design Engineering Technical Conference*, 2012, vol. 5, pp. 541–548.

[73] G. Wernet, C. Bauer, B. Steubing, J. Reinhard, E. Moreno-Ruiz, and B. Weidema, “The ecoinvent database version 3 (part I): overview and methodology,” *Int. J. Life Cycle Assess.*, vol. 21, no. 9, pp. 1218–1230, Sep. 2016.

[74] M. Granlie, H.-H. Hvolby, R. A. Cassel, I. C. De Paula, and C. Soosay, “A Taxonomy of Current Literature on Reverse Logistics,” *IFAC Proc. Vol.*, vol. 46, no. 7, pp. 275–280, May 2013.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 776577-2