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A qualitative assessment tool for innovative waste logistics scenarios: a case study for Flanders

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Abstract

With new, innovative logistics tools and frameworks coming to the market rather quickly, developing a decision support framework to assess its value before carrying out extensive, quantitative economic assessment studies and large-scale implementation is necessary. This paper focuses on developing a qualitative decision support framework—aiding the deployment of successful tools in the logistics landscape and avoiding high sunk costs without added value. Resulting in a qualitative tool based on a literature review and industry expert interviews. The derived parameter impact model assesses the importance of different parameters, allowing to find opportunities without the need for extensive information and/or investments. Therefore, the parameter impact model was applied to three different cases of waste logistics located in Flanders: (1) the use of telemetry (i.e., the use of sensors to identify the filling rate of waste collection points remotely), (2) small waste compactors on the business side, and (3) inland waterways to transport waste to treatment centers. The qualitative results can vary depending on the specific case, establishing the fundament for future innovations.

Keywords: Waste logistics, Decision support tool, Parameter impact model, Reverse logistics

Introduction

There is a scarcity of primary raw materials and its associated energy needs leading to rising and volatile prices on the world market (Milios et al. 2019). However, secondary material flows are not being optimally used today, and *we,* as a consumer society, are throwing away products at the end of its life cycle—i.e. so-called linear production and consumption. The challenge lies in evolving into a sustainable and circular production and consumption process. Products would not just be thrown away but instead recycled or reused within specific production processes. Its roll-out implies that products/waste must be collected to maximize the recovery of raw materials. Although these *product life expansion* initiatives contain good ideas, the various stakeholders within the supply chain need to be aligned (Milios et al. 2019). Ultimately, society aims to evolve into a circular economy in which no or as few goods

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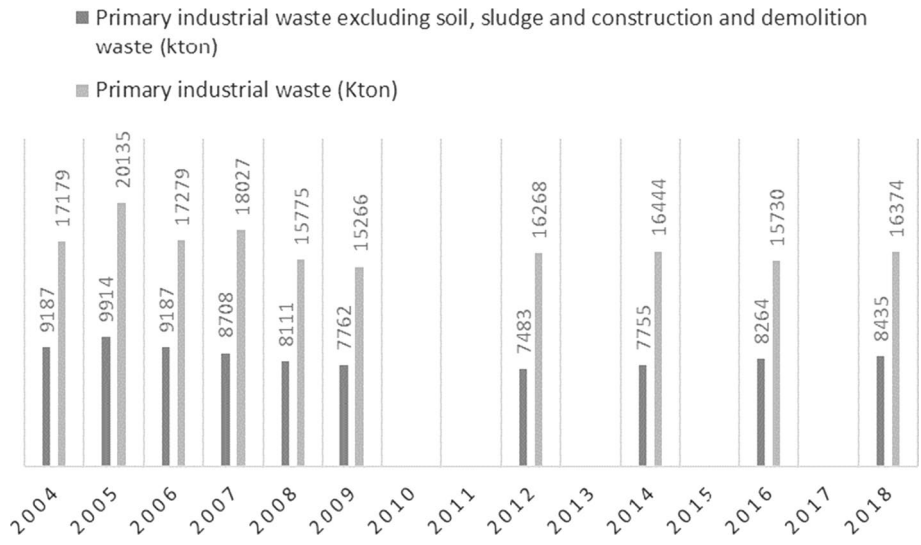


Fig. 1 evolution of primary industrial waste (2004–2018). Source: OVAM (2019)

as possible find its way to an incinerator or landfills and can be used in the production process as secondary raw materials—leading to less waste and a cleaner planet.

Companies are increasingly aware of the problems surrounding waste and often no longer only operate from a business point of view. This business ethos is emphasized by the strategy that many companies already maintain today—Corporate Social Responsibility (CSR). These strategies attempt to maximize profits with the environment in mind, reflecting itself in the logistics involved in all the supply chain steps. Even though no attention used to be paid to goods that are located at the end of the life cycle, companies are increasingly paying attention to this phase. One reason may be the implementation of an *extended producer responsibility* (EPR) in which the producer is held partly responsible for the indirect waste the latter causes. A legislative framework can enforce EPR. Examples are product passports where the origin of the materials is tracked (van den Bergh 2020). Another reason may be that the goods produced are increasingly difficult to recycle. More and more, goods are optimized for (long-term) use. In order to achieve this, for example, different types of polyesters are woven with cotton in clothing to obtain the appropriate characteristics. Making recycling difficult due to the necessity to separate the different types of fabric that need a separate recycling program resulting in greater costs. (Visser 2018; VIL 2020).

What becomes clear from Fig. 1 is that the number of kilotons of waste produced by Flemish companies has remained more or less constant over time. The three R's—Reuse, Recycle, Reduce—can influence the amount of waste produced on the one hand and the recycling of the waste produced on the other (Seroka-Stolka and Ociepa-Kubicka 2018). Figure 2 shows how the industrial waste in Flanders is processed. Only a relatively small proportion (4%) of all waste is incinerated directly. Nevertheless, 10 percent of all waste is incinerated after certain pre-treatments and other processes. In addition, 9 percent is deposited (i.e. landfill), 13 percent further

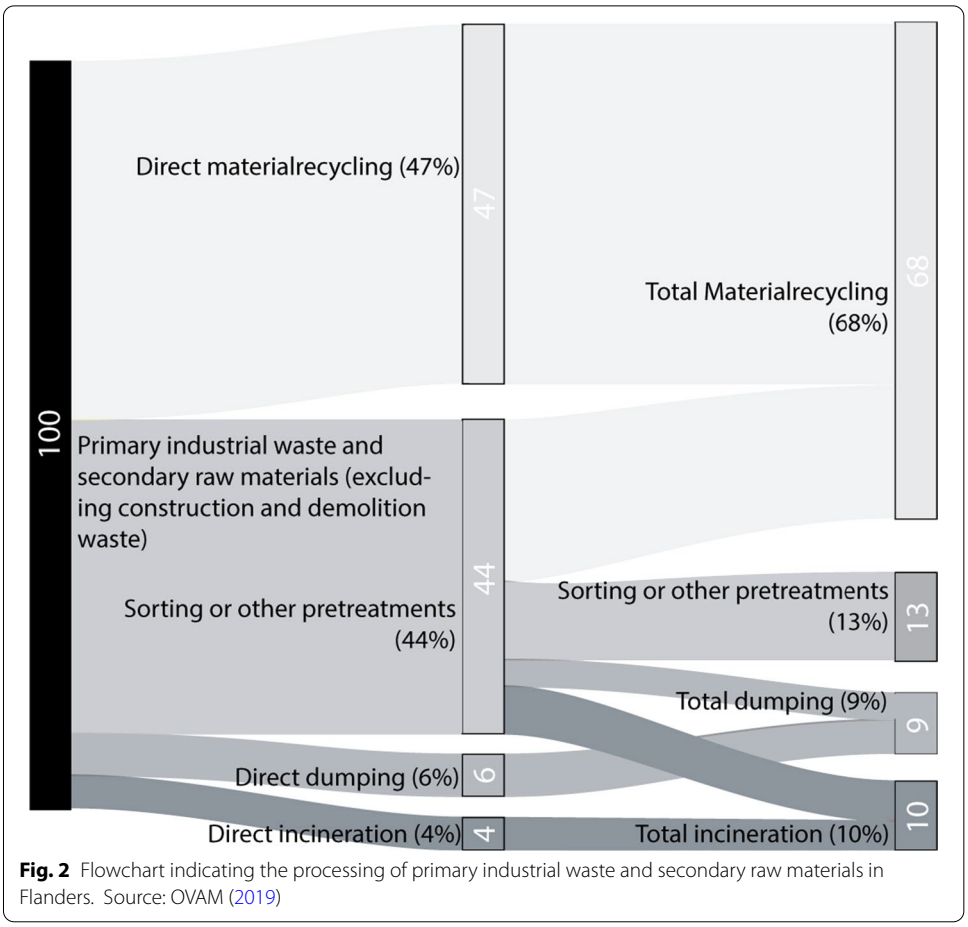


Fig. 2 Flowchart indicating the processing of primary industrial waste and secondary raw materials in Flanders. Source: OVAM (2019)

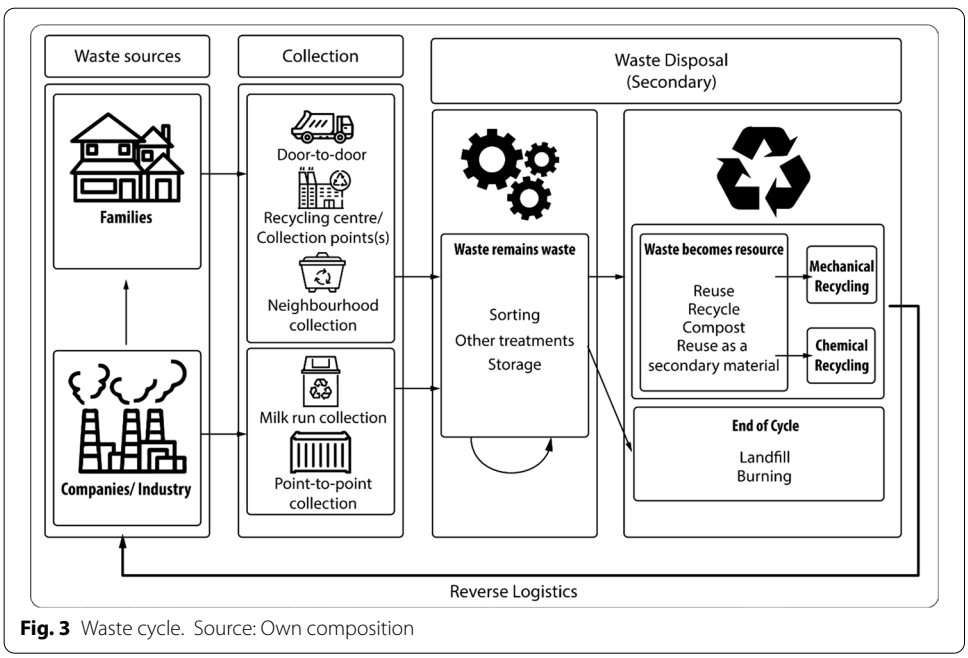


Fig. 3 Waste cycle. Source: Own composition

sorted and 68 percent recycled in different ways. Mapping out the processing capabilities and proportions in this way makes it possible to reflect to the potential of recycling in Flanders.

The purpose of this paper is to *develop a qualitative model to assess new and alternative logistics supply chain solutions/applications for waste logistics with the emphasis on a sustainable environment*. The goal is to optimize waste streams and induce less logistics flows and external cost while enabling efficient waste processing. Considering different waste streams like consumer household waste and industrial waste sources, a Parameter Impact (PI) model is drawn up based on expert interviews to qualitatively assess the different scenarios' relevance. The PI model is a decision-support framework to evaluate various waste logistics innovations without the need for extensive, quantitative information. Due to the frequent unavailability of data, using the PI model will allow to perform a quick scan of the specified scenario. If the result of this qualitative assessment is positive, the decision can be made to invest into collecting and analyzing application-specific data.

In this paper, the PI model will be applied to three scenarios: telemetry to forecast logistics planning, the usage of waste compactors to decrease the need for additional trips, and a modal shift toward inland waterways. To support these applications, different databases were consulted to understand better the current waste problem within Belgium and the current collection methods. The further structure of the paper is as follows: 2. Literature review 3. Methods 4. Applications of the framework 5. Conclusion 6. Discussion.

Literature review

The phase after the production and consumption process is sometimes called the extended logistics chain. Attention is paid not only to the so-called reverse logistics but also to its effects on the environment, people, and animals. The implementation of reverse logistics will affect the production and planning process, converting waste goods into products to meet consumer demand. (Suzanne et al. 2020). Companies are increasingly aware of the benefits that certain green measures bring and do not only participate from a marketing point of view (i.e. sometimes greenwashing[1]). Production companies, therefore, have the opportunity to source extra raw materials from ever more efficient recycling programs. In many cases, this additional supply of raw (secondary) materials results in increased availability. Residual materials can be defined according to Van Dyck (2008) as; (1) solids: by-products, waste; (2) liquids: emissions to water, liquid by-products; (3) gasses: emissions to air, gaseous by-products; and 4. residual heat. Cooperation has become a keyword in order to be able to reduce the costs of collecting the goods. In the case of textiles—that reach the end of their life cycle rather sporadically—home collection can be costly and ineffective. Alternatives are installing large collection containers that can be emptied weekly (Hole and Hole 2020). The role of logistics is to take on a proactive role within the *green* world and to think about various processes that can

[1] Greenwashing is the process of conveying a false impression or providing misleading information about how a company's products are more environmentally sound. Greenwashing is considered an unsubstantiated claim to deceive consumers into believing that a company's products are environmentally friendly. – Source: (Kenton & James, 2021).

contribute to making the industry sustainable, maximizing the recovery of various secondary materials—i.e. raw materials from waste.

Still, logistics and production companies use *green* as an attention-grabber and do not represent full commitment to their own sustainable goals. Various reasons can be: (1) the additional costs it entails compared to the linear way of working; (2) the additional investments to be made to collect, recycle and reuse the goods in the production process; (3) the uncertainty as to the quality of the goods that can be used; (4). the uncertainty regarding the delivery of goods (i.e. quantity over time). Gemoets (2021) cited this during an interview and questioned the continuity of the production and logistical process when completely switching to secondary goods. Therefore, Gemoets urged for a (short-term) future where the secondary material stream is complementary. According to industry experts, the preceding are all critical reasons, ensuring that a large number of companies active in the industry have not (yet) switched to secondary material flows to produce products. (Gelder 2021; Michail 2021; Quidousse 2021).

In the case of the waste sector, there are still opportunities for improvement. It is important to note that the vast majority of transport is done by road. The density of road transport opens up opportunities for more sustainable transport modes such as inland waterways and rail. However, there are barriers being inland waterway infrastructure and international rail regulations that make it inconvenient to transport goods—and in particular waste—internationally. In addition, the organization of recycling activities and production on a local scale can help reduce the number of empty kilometers to a minimum together with its associated emissions. Borbon-Galvez et al., (2021) define industrial symbiosis as the exchange of materials and energy between companies located *near* each other that have a different purpose for each other's materials. This can be partly determined by the *life cycle assessment (LCA)* and the material flow analysis (Borbon-Galvez et al. 2021).

The waste cycle (Fig. 3) shows an overview of the different waste processes and also distinguishes among waste sources, collection methods, and waste treatment options. A distinction is made between two sources of waste—households, and businesses. Typical waste collection options are (1) home collection in connection with district collection (glass bulbs, collection boxes, Etc.) and (2) recycling centers. The collection of waste at businesses is often done via a milk round or a point-by-point collection. After collection, the waste disposal phase follows. A split is made between two different types of waste processing: 1. waste that remains waste: this can be sorted or; stored (i.e. landfill in most cases); 2. waste that becomes raw material: waste can be recycled into secondary materials fit for use in different production processes through mechanical and/or chemical recycling.

Recycling waste can be done in two different ways. On the one hand, *mechanical recycling* is where waste goods are sent through a mechanical *program/processing* that divides the product into smaller parts, including basic raw materials. The raw materials can then be recovered by means of a process of rinsing, sorting, and extracting. This process must not affect the structure of polymers/raw materials. Circular goods that are eligible for mechanical recycling include plastics, metal, textiles, paper, tires, construction waste wood, and various other types of goods. On the other hand, chemical recycling can be implemented whereby waste undergoes a process in which the molecular

chain is broken, forming a way of recycling. Clearly, it is stated that this is an additional procedure. For all plastics impossible to recycle mechanically, chemical recycling can be a solution to prevent landfill. (Bluevision sd; Zero waste Europe 2018; Emis sd; Plastics Europe sd).

Collecting textile waste for recycling is often still difficult, even though it is the second-largest polluting industry in the world. Still, only 13% of all textiles are recycled (compared to 73% of technological waste and 90% of glass waste) (Hole and Hole 2020). Several reasons are indicated by Hole & Hole (2020) as the cause: (1) a lack of incentives that motivates the end user to recycle; (2) too few informational and educational programs; (3) collection opportunities are often expensive (i.e. door-to-door collection); (4) absence of a policy—most countries have no or few standards when it comes to recycling itself; (5) the variety of materials—it is apparent that many garments are made from different types of yarn, making it difficult and therefore also costly to split up the goods and eventually recycle them. Nevertheless, Matt Coz (VP recycle America) said, "if we don't make recycling convenient for the consumer, it's unlikely that we'll be successful". Therefore, certain prerequisites need to be considered to stimulate recycling from a governing point of view. First of all, research is required to determine the preferences regarding the frequency of collection from the system users. Hereby, the collection options should be adjusted accordingly. Second, in some cases, the waste collection is organized by a public company that historically grew into operating under the maximum efficiency potential—resulting in idle capacity and reducing economies of scale within that region. Thirdly, an assessment needs to be made on what to do with sparsely-populated areas (Gevaers et al. 2012).

A further gain can be made by using waste collection for eliminating empty trips. Empty return trips have a negative impact on the environment but also on the cost structure of a company. If empty return trips can be matched with waste collection, both internal and external costs are saved. For this to work, certain conditions need to be made up for different types of cargo (i.e. no contamination possibilities, etc.)—taking into account regulations for the transport of waste leading to a fragmented logistics market. So-called waste matching platforms can play an essential role in setting up return logistics networks. Platforms like Cyrkl, NISP, and Reloop can ensure that the supply and demand of secondary material flows complement each other to exchange goods. *Cyrkl* is a waste2resource marketplace that companies can join to sell secondary waste flows as a by-product from various production processes. Examples of secondary waste flows are; plastic granules, cardboard boxes, building material, and others (Cyrkl 2021). *NISP* was one of the first industrial symbiosis programs in the world and was introduced in 2007. The program found entry in more than 20 countries worldwide, providing training and consultancy services to improve sustainability (International synergies, sd). *Reloop* is a broad platform with a shared vision for a circular economy. The platform tries to bring together different stakeholders i.e. industry, government, NGO's to form a network. Enabling to create better conditions for circular raw materials flowing across the global economy, forming a catalyst to generate economic and environmental opportunities within the supply chain (Reloop 2020). OVAM, the Flemish Public Waste Agency, has launched a platform called *symbioseplatform,* where up until now, 200 + residual waste streams are offered to exchange since its launch in 2019 (OVAM 2020). Therefore,

manufacturers, their strategic partners, and network of suppliers cooperate and conduct business over the internet as part of an online marketplace. As a result, company costs decrease and revenue potentially increases together with participant productivity (Sathish and Jayaprakash 2017). From a logistics point of view, the logistics stakeholders have to be involved for transport to take place as efficiently as possible. Relating to the Corona pandemic, OVAM (2020) reported a significant rise by 65% in volume of high-risk medical waste. Organizing the disposal safely, alternative collection methods were used.

In many developing countries, waste management is held back by technically inefficient waste management systems, a lack of financial resources, and generally restricted public collaboration. As a result, waste management decision-making has become very complex, and picking intervention choices is often characterized by contradicting criteria. This necessitates the application of specialized decision-making tools. Even during planning, there is a need for accurate data on the features and flows of a specific area. This data is frequently incomplete, forming the primary barrier to corrective action planning. To overcome this, a qualitative decision support system can be implemented to assess the viability of different scenarios before investing into the collection of actionable data—i.e. a PI model. (Makarichi et al. 2018).

Methods

The methods used in this paper are rather inductive based on practical examples. The goal was to find out which type of transport is the most beneficial, considering the goods' nature and destination.

Desk research was used to give an overview of reverse logistics' limitations and opportunities as a precedent for the following analysis. Stakeholder workshops[2] were set up to form the basis of the parameter impact model. During the first stakeholder workshop, the topic was jointly delineated and definitions aligned. The second workshop focused on waste flows from which specific lessons could be taken. Workshop 3 was used to judge the parameters to be used in the PI model, as collected from the desk research, as well as to start identifying use cases to which the PI model could be applied in our analysis. Workshop 4 was a final validation moment for the parameters, and was also used to determine the final set of use cases to which the PI model framework would be applied. The fifth and final workshop featured a discussion and validation of the use case PI application results. Both the desk research and the stakeholder workshops gave insights into the importance of different parameters within waste logistics and its correlating processes. In turn, these parameters form the fundaments to assess the implementation of the various applications within the (reverse) supply chain. Further elaboration on the specific applications can be found in Sect. 4.

The framework: parameter impact (PI) model

The aim of the Parameter Impact (PI) model is to qualitatively assess the impact that certain waste collection scenarios have in terms of (1) the logistics cost of the processes,

[2] See participants in Annex.

(2) the waste processing outcome and (3) sustainability effects. The PI model can also be seen as a quick scan of a scenario before an extended business plan is worked out and serves as a framework to identify the most essential cost elements. It is clear that this is not a comprehensive model in which complex arithmetic calculations form the basis. Instead, it is a model that focuses on the relationships between the various observed parameters that play a role within the circular model. It allows getting rather fast qualitative insights into the waste logistics application. The next part explains the PI model's theoretical underpinnings and working methods. In the application section, the PI model is applied to three different cases. Four different steps can be distinguished in the process of building an individual PI model.

Step 0: building the model: determination of the parameters that are important in waste logistics and the associated processes

Based on a literature analysis, conversations with stakeholders, and user groups, a list of important parameters within waste logistics can be drawn up. These parameters can in turn be divided into three different categories, namely: 1. the characteristics of the logistics activities, 2. the characteristics of the waste, 3. parameters that reflect environmental considerations and social awareness. These parameters can be qualitative and have an (in)direct effect on the logistics costs. Figure 4 shows all of these parameters, based on the previously mentioned sub-division:

Step 1: description of the scenario to be investigated (e.g., pilot case)

The first step defines the scenario to be investigated (i.e., the pilot case). A distinction is made between a reference scenario (H0) and the alternative scenario (H1). H0 describes the current situation (without the pilot case) and H1 represents the alternative (innovative) scenario (with pilot case). Meaning that the PI model can only be used when changing existing activities. When defining a scenario, it is best to depart from a contract to collect x ton (on an annual basis) from one or more waste producers. Each assignment consists of different journeys divided into duration and distance. Afterwards, the total duration and distance to be traveled can be calculated.

Step 2: determination of the effects of the scenario on the parameters (1 per 1)

When the most relevant parameters are known (step 0) and the scenario to be investigated is described as good as possible (step 1), step 2 assesses the scenario's effects on the different parameters. Each parameter is therefore assessed individually in a self-developed Excel tool. Depending on the parameter, the evolution can be explained by: "higher/lower", "more/less", "wider/less wide". Each parameter is filled in by the assessor, based on own experience or on information collected at relevant stakeholders. In some cases, it is impossible to estimate this evolution, which is indicated by "No effect/Non-Relevant (NR)". Clearly, the PI model is not drawn up from one party's vision in the logistics chain. The intention is always to estimate the effects for all possible parties, ranging from logistics service providers to shippers. A hypothetical example is shown in Fig. 5.

Parameters that are important in the assessment of waste logistics and its associated processes		
Characteristics of logistics (pick up and collection)	Characteristics of the collection area	Supply of waste
		Window times during which waste can be collected in cities and municipalities Possibility to collect waste at night Size of pick-up area Collection distance per trip Possibility to bundle waste during a ride Collection is mainly a point to point collection Fine-meshed collection is necessary Number of waste providers Geographical concentration of supply and demand Volumes to be retrieved are located in one place Waste is collected in an urban or rural environment Tonnage to be retrieved during assignment
		Demand for waste
		Number of collection channels Density of waste hubs and processing facilities (including incinerators) Number of collectors of waste
	Storage, transshipment sorting space attributes	Need for additional transshipment movements of waste Availability of transshipment storage and sorting space Cost of transshipment, storage and sorting space (euro/year)
	Characteristics modal choice of transport	Need for pre- and/or post-transport when using inland waterways or train Frequency of service when using inland waterways or train Transport time per trip Reliability of service when using inland waterways or train Flexibility of service when using inland waterways or train Safety when using inland waterways or train Economies of scale when using inland waterways or trains
	Fleet and technology used	Vehicle characteristics
		ICT systems used for routing Depreciation value of the vehicle (EUR/ year) Residual value of the vehicle (EUR/ vehicle) Driver's staff costs (EUR/hour) Taxes (traffic taxes, road charges, etc.) (EUR/year) Insurance (EUR/ year) Overhead (EUR/year) Interest burden (EUR/ year) Fuel cost (EUR/ liter or EUR/km)

Fig. 4 Different characteristics of the parameters explained. Source: Own composition

Step 3: determining the joint effect of the changed parameters on the total logistics costs, waste treatment, and sustainability aspects

After the individual effects of each parameter have been filled in, a qualitative assessment of the changed parameters on the total logistics costs, waste treatment and

		Average consumption (Quantity/ 100km) Maintenance costs (EUR/year) Distance travelled (per assignment) Time travelled (per assignment) Expected operating time per year Expected distance travelled per year Employability of the vehicle for other assignments Number of journeys per assignment Number of escorts required for transport
	Characteristics of the location where the collected waste is treated and or processed	Infrastructure and resources needed to process waste Total volumes of waste to be processed Compatibility with current operation (in case new type of waste is collected) Necessary technological developments at the place of processing
	Characteristics of customers where waste is collected	Pick-up time at customer (window times) Requested frequency of collection Required customer presence at collection
	Type of load carriers used	Volume of cargo carrier used (e.g. container size) Combinability of waste fractions in the transport carrier Need for another type of load carrier
	Regulations	Waste transport Introduced incentives to collect waste Environmental surcharges Necessary permits to transport waste Training required to transport waste Collection obligations of waste fractions Application of the Major Act in the transport of waste Presence of cross-border restrictions Administrative burden due to transport of waste
Characteristics of waste	Recyclability	
	Combinability with other goods	Bundling different waste streams Need to clean out load carrier Extent to which waste can be compacted
	Volume density	
	Continuous availability of waste streams and planning	
	Dry versus wet waste	
	Possibility of storage of waste	Difference between value of waste and created raw material (added value) Consideration of alternative valorizations (costs/ revenues) Difference with classic price raw material

Fig. 4 continued

sustainability aspects must be made. To categorize these effects, Fig. 3 is used. It shows an overview of a number of typical, logistics waste processes in which the focus is on the generation of waste in Flanders. In Table 1, a distinction is made between three blocks (logistics, processing and sustainability). In the "logistics" block, an

	Purity	
	Pre-sorting rate	
	Waste treatment cost	
	Ton/ m^3	
Environment and social awareness	Household awareness (e.g. to recycle) Awareness of product design Awareness of packaging design Awareness within companies Pressure from society to change approach	

Fig. 4 continued

Characteristics of customers where waste is collected	Pick-up time at customer (window times) Requested frequency of collection Required customer presence at collection	Wider Less No

Fig. 5 Hypothetical example. Source: Own composition

estimate is made of the effects on the logistics cost of the processes (from the point of view of different stakeholders), based on the exercise in Step 2. For each type of collection and stakeholder, an indication is made on how this changes the logistics cost. In the "processing" block, an analysis is given of the processing outcome on waste treatment, divided by type. Finally, sustainability effects can be assessed by indicating how raw material recovery and external costs occur. External costs are costs that the transport user causes for third parties without paying for it themselves.

Applications to the framework

The paper's PI model aims to take a deep dive into new initiatives within the waste logistics sector affecting the implementation of the circular economy. The emphasis is on introducing a logistics interpretation to ensure higher efficiency and/or effectiveness in the recovery, collection, and transport of various (secondary) material flows. Three projects were selected to go deeper, based on 1. economic feasibility, 2. practical feasibility within the project planning (e.g.: are people willing to participate in this?), 3. compliance with the project scope, 4. relevance to the company in question, 5. the degree of innovation and the potential for improvement, and 6. the leverage effect (or scale-up potential) for the Flemish logistics sector.

Sensor technology on outlets and roll containers (telemetry)

Telemetry is the remote measurement of parameters, with many applications in the context of waste logistics—i.e. filling rate of textile containers, glass spheres, semi-underground containers, Etc. Making predictions with the aid of telemetry, an assessment of whether a container needs to be emptied and/or collected can be made remotely. As a

Table 1 Step 3 of the PI model

Logistics															**Processing**			**Sustainability**	
Effects on the logistical cost of the processes															Waste processing outcome			Effects on the environment	
First collection														Next collection	Waste remains waste	Waste becomes raw material	End of cycle	Raw material recuperation	External costs
Collection at Households										Collection at businesses				Point to point					
DD		RC		NC		TS + CP				Milk-round		Point to point							
Households	Collection	Households	Collection	Households	Collection	Households	Collection	KC + IP		Businesses	Collection	Businesses	Collection	Businesses	Collection				
0	↓	NR	NR	NR	NR	NR	NR	NR		NR	NR	NR	NR	0	0	Nothing	Nothing	Nothing	Nothing	Less

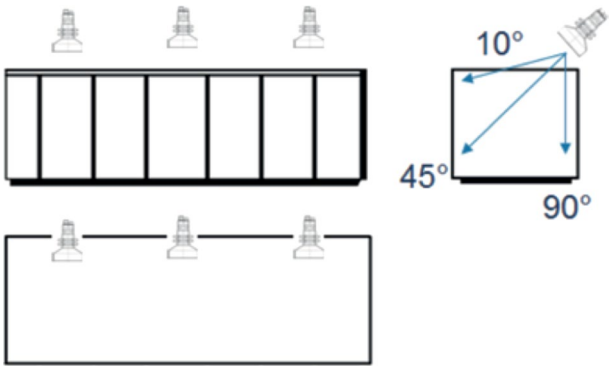


Fig. 6 Placement of ultrasonic sensors. Source: VIL

result, pick-up schedules are easily drawn up, and the customer no longer has to contact the waste company to collect full containers. The optimization takes place as the collector is able to create the most optimal routes based on the filling rate of the different containers. This is in contrast to today, where the containers are emptied by means of a fixed route independent of the filling rate—leading to unnecessary emptying and additional costs that are irrelevant and avoidable.

The filling degree can be measured using smart ultrasonic and/or infrared sensors (Fig. 6). Many of these sensors are already on the market offered by a multitude of providers, including Enevo, Smartbin, Sigrenea, and others. The great advantage of the ultrasonic sensor is that it can be used in an outdoor environment and that the measurement results are reliable for different types of waste. The open container with a volume of $30m^3$ is the most common and used in this case. The measurements in the project were made using an ultrasonic and infrared multi-beam LED scanner—both from Pepperl + fuchs. The intention was to get an idea of the placement of the sensors and the amount of sensors needed to get good insights of the filling degree. When using ultrasonic sensors, three are required to get a good picture placed under an angle of 45° (De Vylder et al. 2016).

The sensors can provide added value by predicting when a container is full. Remote containers, therefore, should not be emptied uselessly, bringing significant efficiency gains and no additional cleaning costs. When applying the scenario to the PI model, the following reference and alternative scenario can be formulated:

- H0: Containers (household waste) are collected according to a fixed schedule
- H1: The planning of the collection of the containers (household waste) is done according to the filling degree.

The following tables reflect the influence on the different variables and the correlating logistics costs.

Reflecting from Tables 2 and 3, it is clear that the telemetry usage only influences the logistics and sustainability part of the (reverse) waste chain, aiding to the efficiency of collection, leading to fuller trucks and fewer kilometers to be driven. This allows lowering the external cost caused by pollution of combustion engines used by trucks.

Table 2 Results step 2 case 1 telemetry

Logistics															**Processing**			**Sustainability**	
Effects on the logistical cost of the processes															Waste processing outcome			Effects on the environment	
First collection														Next collection	Waste remains waste	Waste becomes raw material	End of cycle	Raw material recuperation	External costs
Collection at families										Collection at businesses				Point to point					
DD		RC		NC		TS + CP				Milk-round		Point to point							
Households	Collection	Households	Collection	Households	Collection	Households	Collection	KC + IP		Businesses	Collection	Businesses	Collection	Businesses	Collection				
NR	NR	0	↓	0	↓	NR	NR	NR		NR	NR	NR	NR	0	0	Nothing	Nothing	Nothing	Nothing	Less

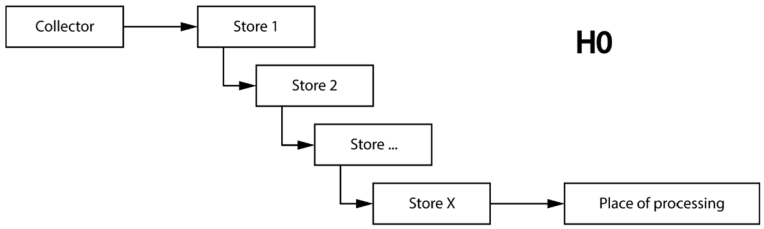
Table 3 Results step 3 case 1 telemetry

Parameters that are important in the assessment of waste logistics and the associated processes (step 0)			Effects of the scenario (step 2)
Characteristics of logistics	Characteristics of the pick-up area	Supply of waste	
		Collection distance per ride	Smaller
		Possibilities for bundling	More
		Fine-meshed collection is necessary	Less
	Characteristics of storage transshipment and sorting space	Demand of waste	
	Characteristics mode of transport		
	Fleet and technology used	Vehicle characteristics	
		ICT systems used for routing	More
		Average consumption (/100 km)	Higher
		Distance travelled (per assignment)	Lower
		Time travelled (per assignment)	Lower
		Vehicle's usability for other contracts	Higher
	Characteristics of the location where the collected waste is treated/ processed		
	Features customers where the waste is collected	Demanded frequency of collection	Less
	Type of cargo carriers used		
	Regulation		

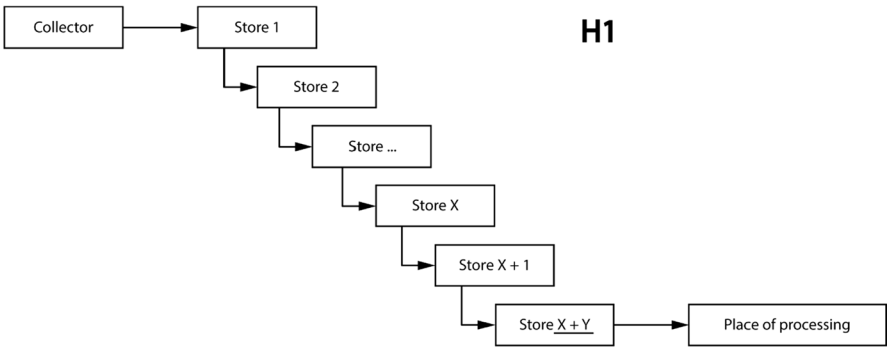
Table 3 shows that the collection distance per trip is smaller, because of more efficient routing (avoiding redundant trips). On the other hand, extra stops can be included that were not possible if telemetry is not used (more bundling possibilities). Less fine-meshed collection is the consequence. The average consumption is assessed to be higher, because of a higher filling rate of the vehicle.

Small waste compactors

Waste compactors are hydraulic or electric presses that use mechanical force to reduce the generated waste's volume to weight ratio. Usually, the results are the biggest with waste that has a low material density, such as cardboard, paper, plastics, metal etc. (Mil-tek, sd). The most significant advantage is that waste compactors can be small enough to be installed at the point of collection—i.e. stores or other businesses. Enabling to optimize the restricted load capacity—of a garbage truck—and thus also optimizing routing and stops. Two different waste compactors can be distinguished by type: 1. vertical balers and 2. horizontal balers. Vertical balers use horizontal force to press waste and are usually bigger in size (used at recycling centers). Horizontal balers use vertical force to press waste together and are more often used at pick-up points. By using a compactor on the business side, the customer's waste no longer has a negative value, and the latter can receive a fee since the collector has to carry out fewer trips. The focus is on the compacting of waste at the place of



a: Diagram case 2: small waste compactors - Source: Own composition



b: Diagram case 2: small waste compactors - Source: Own composition

Fig. 7 a: Diagram case 2: small waste compactors. Source: Own composition. b: Diagram case 2: small waste compactors—Source: Own composition

production. By compacting waste, it becomes possible to transport more tonnage per volume as compared to not using a waste compactor. The reference scenario and the alternative scenario for the PI-model can be formulated as follows:

- H0: Waste is not compiled in the first place of collection (company waste)
- H1: Waste is compiled in the first place of collection (company waste)

Derived from Fig. 7, it is clear that using a waste compactor makes it possible to collect waste from a bigger collective of pick-up points.

Table 4 clarifies that there are only changes in the logistics part of the business waste chain. Only businesses have enough cardboard and paper waste to use a waste compactor. As with the usage of telemetry, the need for extra trips is reduced due to an increase in the tonnage-to-volume ratio. For indoor waste compactors, this volume reduction can range from a 10 to one ratio up to a 15 to one ratio depending on the type of compacted waste. Resulting in a potential 10/1 lowering of trips needed. Always taking into account the weight limitations of the trucks used. (Kennedy, sd). This in turn leads to a reduction of emissions caused by combustion engines and is reflected by a decrease in external costs. Note that implementing a waste compactor leads to a decrease in logistics costs for the collection company and a potential cost increase for the collection points at the business side (investment in waste compactor).

Table 4 Results step two case 2 (Small waste compactors)

Logistics																**Processing**			**Sustainability**	
Effects on the logistical cost of the processes																**Waste processing outcome**			**Effects on the environment**	
First collection														Next collection		Waste remains waste	Waste becomes raw material	End of cycle	Raw material recuperation	External costs
Collection at Households										Collection at businesses				Point to point						
DD		RC		NC		TS + CP				Milk-round		Point to point								
Households	Collection	Households	Collection	Households	Collection	Households	Collection	KC + IP		Businesses	Collection	Businesses	Collection	Businesses	Collection					
NR	NR	NR	NR	NR	NR	NR	NR	NR		↑	↓	↑	↓	NR	NR	Nothing	Nothing	Nothing	Nothing	Less

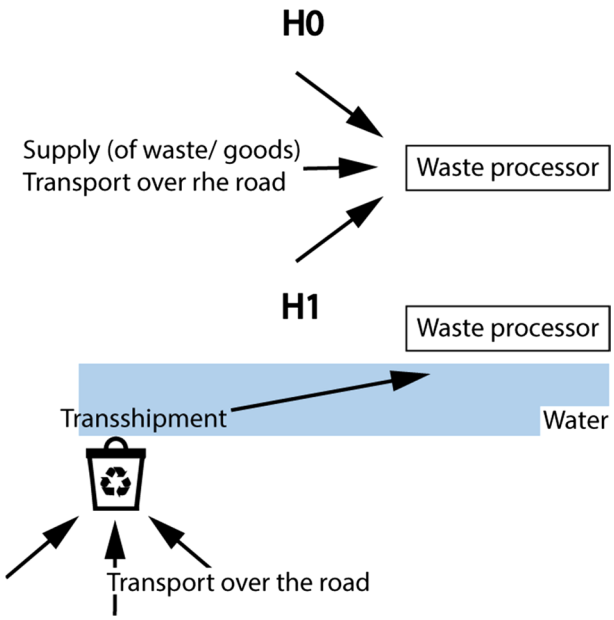


Fig. 8 Representation of transport over water. Source: Own composition

Table 5 Results step 3 case 2 (Waste compactor)

Parameters that are important in the assessment of waste logistics and the associated processes (step 0)			**Effects of the scenario (step 2)**
Characteristics of logistics	Characteristics of the pick-up area	Supply of waste	More
		Collection distance per ride—possibilities for bundling	
		Demand of waste	
	Characteristics of storage transshipment and sorting space	Availability of transshipment/ storage / sorting space	More
	Characteristics choice of mode of transport		
	Fleet and technology used	Vehicle features	
		Distance travelled (per assignment)	Lower
		Time travelled (per assignment)	Lower
		Vehicle deployment possibilities for other routes	Higher
		Number of routes per assignment	Less
	Characteristics of the location where the collected waste is treated/ processed		
	Features of the customers where the waste is collected	Requested frequency of collection	Less
	Type of cargo carriers used		
	Regulation		
Characteristics of waste	Ton/ m^3		Higher
Environmental and social awareness			
Other effects			

Table 5 represents the different parameters that are impacted due to the implementation of a waste compactor. Clearly stating a boost in efficiency of the logistics side and an increase in waste density.

Modal shift—waste over water

With an increasingly pressing problem of waste, congestion, and the environment, the logical consequence is to look for alternative modes of transport. Inland waterway and rail transport meet the conditions and can be used perfectly for the transport of waste—and in particular residual waste. An overview of this process can be found in Fig. 8. The flows are large enough to enjoy the economies of scale. Therefore, this application aims to verify whether it is interesting to work out a business case to transport residual waste by water if the shipper and the recipient are located alongside the water. It is crucial as additional steps in the supply chain come at a high cost. Specifically, the last mile is very cost-intensive.

The reference scenario and the alternative scenario are formulated as follows:

- H0: The waste treatment plant is not next to the water. Only road transport is used for the supply of waste.
- H1: The waste treatment plant is located next to the water. The supply of waste is done as much as possible with inland shipping.

In the PI-analysis carried out, the focus is on transport via road. In HO, waste is collected at several collection points and transported directly to the waste processor. Whereas in H1, waste is collected at several collection points and transported to a transshipment location. Based on the PI analysis, one might conclude that road transport becomes cheaper, and the success of H1 will depend on the extra cost of inland navigation. Therefore, the lessons learned from the IOK case can be used.

The effects on road transport are straightforward (Table 6). Truck distances will be reduced because the transshipment location is closer than the actual distance to the waste processor. In case inland navigation is used, bundling is the direct effect. An extra transshipment point is included (density of waste hubs and processing facilities), incurring additional CAPEX (Capital Expenses) and OPEX (Operational Expenses). It is evident that the costs related to trucks will be lower than in the case of direct transport (HO). Whether or not this case will be interesting will depend on the extra cost of using inland navigation (transshipment infrastructure and costs).

Using inland waterways can lower costs for the collection side since economies of scale are favorable and attainable under the right conditions—i.e., location, terminal, equipment, consolidation point, type of waste, etc. (De Vylder et al. 2016). Nevertheless, the solution does not influence the processing or sustainability aspect of the waste chain. Though it is clear that the usage of inland waterways results in a reduction of external cost—i.e., lower emission per ton—and is reflected in Table 7.

The intercommunal development company for the Kempen (IOK) collects all residual waste from the region that undergoes mechanical recycling, drying, and filtering. What remains is Refuse-Derived Fuel (RDF), a commodity that sits on the boundary between waste and fuel. Due to the negative value, the IOK has to pay for the

Table 6 Results step 2 case 3 (modal shift over water), effect on road transport

Logistics															**Processing**			**Sustainability**	
Effects on the logistical cost of the processes															**Waste processing outcome**			**Effects on the environment**	
First collection														Next collection	Waste remains waste	Waste becomes raw material	End of cycle	Raw material recuperation	External costs
Collection at Households										Collection at businesses				Point to point					
DD		RC		NC		TS + CP				Milk-round		Point to point							
Households	Collection	Households	Collection	Households	Collection	Households	Collection	KC + IP		Businesses	Collection	Businesses	Collection	Businesses	Collection				
0	↓	0	↓	0	↓	0	↓	0		0	↓	0	↓	NR	NR	Nothing	Nothing	Nothing	Nothing	Less

Table 7 Results step 3 case 3 (modal shift over water)

Parameters that are important in the assessment of waste logistics and the associated processes (step 0)			Effects of the scenario (step 2)
Characteristics of logistics	Characteristics of the pick-up area	Supply of waste	
		Collection distance per ride—possibilities for bundling	Lower
		Demand of waste	
		Density of waste hubs and processing facilities (including incinerators)	More
	Characteristics of storage transshipment and sorting space	Need for additional transshipment movements of waste	More
		Availability of transshipment, storage and sorting space	More
		Cost of transshipment, storage and sorting space	Higher
	Characteristics choice of mode of transport		
	Fleet and technology used	Vehicle features	
		Distance travelled (per assignment)	Lower
		Time travelled (per assignment)	Lower
		Vehicle deployment possibilities for other routes	Higher
	Characteristics of the location where the collected waste is treated/processed		
	Features of the customers where the waste is collected		
	Type of cargo carriers used		
	Regulation		
Characteristics of waste			
Environmental and social awareness			
Other effects			

processing of this RDF by other companies. One such company is the Stora Enso paper mill located in Ghent. Although both are located alongside the water, only road transport is used due to historical evolution, favorable rates, and the paper mill does not prefer to have too much stock of RDF because of its highly flammable character. Table 8 reflects the cost index of different scenarios of transport of RDF from the intercommunal development company to Stora Enso.

It is clear that even when both companies are located on the water, road transport is still favorable in terms of costs. The costs depend on the type of goods transported and the preconditions for the transport to be fulfilled.

Table 8 Cost index of road transport versus inland shipping solutions. Source: (De Vylder et al., 2016)

Transport price per ton (relative representation)	
Road transport 2016 incl. kilometer charge	100 (= basis)
Inland shipping containers—1 departure per week (700 ton) with purchased reach stacker	102
Inland shipping bulk—1 departure per week (700 tons)	115
Inland shipping containers—1 departure per week (700 tons) with rented reach stacker	116
Inland shipping bulk—2 departures per week (350 tons per departure)	123
Inland navigation bales—1 departure per 10 days (1.000 tons)	124
Inland navigation bales—1 departure per week (700 tons)	140

Conclusion

More and more importance is being attached to sustainability and corporate social responsibility. Reflecting in new production processes and expanding logistics activities—i.e., waste logistics. The latter in particular is essential and is often overlooked. In many cases, it is technically possible to work via the principles of "cradle to cradle", but often the logistics side and its correlating costs of the supply chain are forgotten. As long as it is impossible to organize the supply chain logistics sustainably and efficiently, the "cradle to cradle" model is not feasible. Often the problem is the fact that the waste market is very fragmented. Requiring a lot of sunk costs to create large volumes—and thus economies of scale—to reduce the unit cost. It is important to remember that when volumes are large enough, rail and water transport can be perfect substitutes, considering that both parties need to be located at the waterfront and/or rail since additional transshipments are expensive, as is last-mile delivery. The applicability of rail and inland waterway transport is partly facilitated by the non-time-critical character of waste and no need for short lead times. Sensors can form a viable application for those containers that are hard to reach and thus costly to empty. Reflecting in a net positive business case resulting in lower emissions and lower collection costs. Utilizing waste compactors at businesses positively impacts reverse logistics, enlarging the weight to volume ratio of residual products/waste with a low material density. Affecting the load capabilities of collection vehicles, reducing the need for extra trips, leading to a positive effect from a sustainability point of view.

Even though this paper only discusses three different applications, a lot more can be implemented, establishing a base for further research. Shortcomings of the model can be that the qualitative assessment does not reflect all the potential restrictions of waste logistics innovations since the parameters enumerated in Fig. 4 are not inclusive. Resulting in the inability to use the model within specific scenarios. Nevertheless, the model can be updated and adjusted to the ever-changing variety of innovations. Thus, reflecting a learning curve over time, adding new/additional parameters to become a multipurpose model. Additionally, it should be emphasized that the PI model is a qualitative model to assess different waste scenarios rather direct without the need for additional information. Giving the first insight into the feasibility of the waste logistics scenario.

Annex: external participants stakeholder workshops.

Coeck	Thomas Coeck
Contraload	Jesse Sels
nv De Scheepvaart	Gert Peeters
Derbigum/Imperbel	Koen Sneiders
Desso	Kirsten Rutten
Gyproc	Tom Rommens
Infrabel	Geert Mels
	Geert Robbroeckx
Komosie	Fred Goossens
	Ivan Roelands
POM Oost-Vlaanderen	Danny Vanrijkel
	Maarten Manhaeve
Siemens	Denny Decorte
Shipit	Jan D'Haeyer
SITA	Filip De Breucker
	Peter Bevers
The Brussels Airport Company	Christel Vandenhouten
Unilever	Jannie van Andel
	Karen De Sitter
Van Heede Environmental logistics	Koen Smits
Van Moer Group	Dennie Lockefeer

Abbreviations
CAPEX: Capital expenses; CSR: Corporate social responsibility; CP: Collection point; DD: Door-to-door; EPR: Extended producer responsibility; LCA: Life cycle assessment; NC: Neighborhood collection; NGO: Non-governmental organization; NR: Non-relevant; OPEX: Operational expenses; PI: Parameter impact; RC: Recycling center; RDF: Refuse-derived-fuel.

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Authors' contributions
TP conducted the main analyses in the study, with support by EV, and under supervision by TV. SS took care of company inputs and validation of results. JW conducted the writing of the report. All the authors read and approved the final manuscript.

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Availability of data and materials
The dataset analyzed during the current study is available in the EUROSTAT repository, Statistics|Eurostat (europa.eu). Data sharing is not applicable to this article as no datasets were generated during the current study.

Declarations

Competing interests
Not applicable.

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