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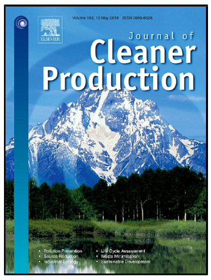

Reverse logistics activities in three companies of the process industry

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	Opportunities for Reverse Logistics in the Process Industry		
Process	Beverage manufacture	Paper manufacture	Cement manufacture
Supply: raw materials in bulk and packaging	none	none	none
Manufacturing: scraps and process waste	none	Internal reuse (solid and liquid waste) and reuse from other industries (papers)	Internal reuse (pulverulent solids and hot gases) and reuse from other industries (fly ashes, minerals, and vegetables)
Maintenaince: technical materials	Remanufacture of parts, subsystems, and equipment	Remanufacture of parts, subsystems, and equipment	Remanufacture of parts, subsystems, and equipment
Distribution: final product	Reuse (pallets and cases)	Reuse (pallets)	Reuse (pallets)
Post-consumption: waste and packaging	Collection by municipalities and sponsorship to collectors´ cooperatives	Collection by municipalities	Collection by municipalities

Reverse logistics activities in three companies of the process industry

1. Introduction

Reverse logistics (RL) aims at recovering part of the original value of used goods, producing economic, environmental, and social gains, mainly in industrialized regions (Carter and Easton, 2011). In regions with an expressive generation of waste, RL helps to reduce the pressure on public sanitation systems (Berthier, 2003), giving a proper destination to obsolete materials generated by obsolete technology-based products or by industrial processes (Chung and Wee, 2011). Furthermore, stringent legislation and consumer pressures (González-Torre et al., 2004) force companies to establish and pursue environmental objectives (Bernon and Cullen, 2007). Among other possibilities such as eco-design and cleaner production techniques, RL can help achieving such environmental objectives (Lee and Dong, 2009).

RL differs from direct logistics (DL). While DL moves goods towards the customer, RL moves goods from the customer (Sellitto et al., 2015). RL and DL involve the same elements: transportation, warehousing, inventory management, and information systems (Lambert et al., 2011), sharing networks and activities (Hu et al., 2002; Schultmann et al., 2003) such as after-sales services and after-consumption collection (Rogers et al., 2012). Operations include waste identification, collection, sorting, compaction, intermediate storage, recollection, transportation, delivery, and value recovery (Ravi et al., 2005). Management stages include the definition of routes and vehicles and the integration with direct channels for resource optimization (Rogers et al., 2002), which maximizes value recovery and eco-efficiency of the entire operation (Heese et al., 2005).

Process industries use raw material and generate waste in large amounts (Pati et al., 2008; Papageorgiou, 2009). In closed-loop supply chains (CLSC), waste applies as low-cost raw materials or fuel (Janse et al., 2009). Process industries add value to materials by mixing, separating, and processing raw materials by granulometric transformations or chemical reactions. Raw materials originate from extractive processes, such as mining, agriculture, or forestry and may be liquids, fibers, powders, and gases. Process industries require environmental control and investment in capital goods. The manufacturing processes are continuous, batchwise, or mixed. In continuous processes, the production run is long, interruptions are irrelevant, and the lot size is infinite. In batchwise processes, the production runs are short, the production is intermittent, and the lot size is finite. In mixed processes, the manufacturer produces a continuous product and delivers it in discrete units, like liquids in bottles or grains in bags (Fransoo and Rutten, 1994).

The purpose of this article is to identify how to recover value from waste generated by process industries. The research question is: What are the reverse operations with the greatest potential for recovering value in process industries? The research method is the multiple case studies, involving three cases in the beverage, paper and pulp, and cement industries. The specific objectives are to describe the reverse processes of the companies; and to organize and compare the findings, according to their intensity and importance. The major contribution of the article is a guideline to managerial efforts and further research in RL in the process industry.

The remainder of the article is organized as follows. Section 2 presents a literature review on reverse logistics and reverse channels. Section 3 presents the research methodology. Section 4 presents the results of the study. Section 5 discusses and summarizes the findings. Finally, section 6 concludes the article and suggests directions for future research.

2. Literature Review

RL and CLSP are not a novelty in the extant literature. Comprehensive surveys and reviews can be found in Agrawal et al. (2015), Gowindan and Soleimani (2017), Gowindan et al. (2015), and in Pokharel and Mutha (2009). According to the Reverse Logistics Executive Council (RLEC), RL is the process of planning, implementing, and controlling the flow of raw materials, inventories, finished products, and information, from the point of consumption or disposal of the good to the point of origin, to recover remaining value or provide appropriate disposal (RLEC, 2017). In short, RL activities aim to recover a part of the remaining value or at least give correct disposal to used materials. However, due to the uncertainties involved and the capillarity of the generation points, only a small part of the waste returns to a new use (Beullens, 2004). In general, the reverse channels are not operated by the focal company of a network, which subcontracts specialized logistics service providers (LSP) (Rossi et al., 2013; Govindan et al., 2012). The studies of Pedram et al. (2017) and Choudhary et al. (2015) present and discuss examples of operations integrating DL and RL in supply chains. Figure 1 shows typical DL and RL material flows.

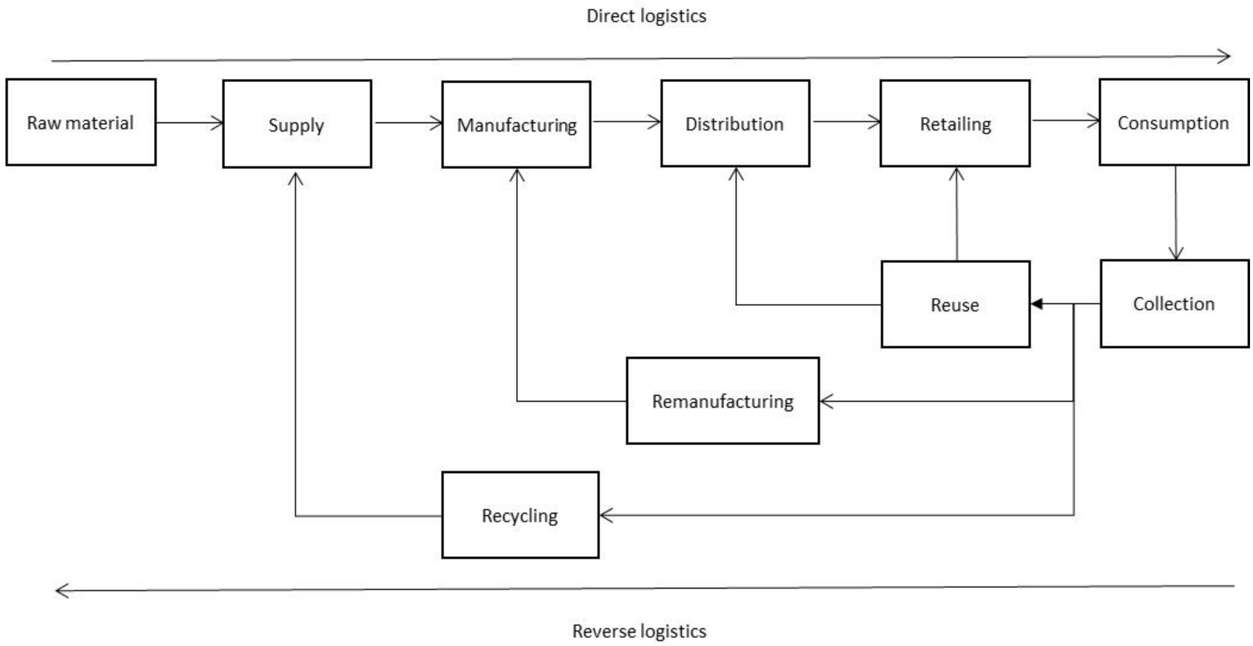

Figure 1: Graphic representation of direct and reverse logistics typical flows

RL can recover economic, environmental, and social value. The economic value includes cost reduction for industrial companies and municipalities. Industrial companies receive returns at low prices and use as raw materials or fuel (Daugherty et al., 2002). RL also helps to create and maintain a positive corporate image and to comply with legislation (Srivastava and Srivastava, 2006). RL helps municipalities to reduce the cost of urban waste disposal (Berthier, 2003). The environmental value includes reducing the use of virgin materials (Pokharel and Mutha, 2009) and the use of landfills (Berthier, 2003). The social value includes generating jobs and income for vulnerable populations of poor communities (Sarkis et al., 2010).

Stindt and Sahamie (2014) classify the materials returns according to the phases of the product lifecycle: manufacturing, distribution, and post-consumption returns. This study adds maintenance returns. Typical RL operations include the return of materials not sold by the retailer, due to forecast errors, default, obsolescence, or lack of validity. It also includes the return of packaging, the recycling of industrial waste, safe disposal of hazardous materials, and dismantling, recovering or final disposal of obsolete equipment and parts (Korchi and Millet, 2011). Reverse flows originate at various points in the CLSC, consolidating at storage and redistribution points (Sellitto et al., 2013), such as recycling cooperatives (Ravi and Shankar, 2005; Ravi et al., 2005) and industrial warehouses for cargo consolidation (Sellitto et al., 2012).

2.1 Reverse channels: recycling, reuse, remanufacturing, disposal

RL uses four channels: recycling, reuse, remanufacturing, and disposal. Regarding recycling, cooperative or intermediate companies separate and process discarded materials (paper, glass, metals, and plastics, among others) that return as low-cost raw materials for industries (Rahimifard et al., 2009). To exemplify the cost reduction, Morris (1998) established relationships between prices of virgin and recycled raw material for the aluminum, paper, and plastic industry. By the time of the research, the prices of recycled aluminum, paper, and plastic ranged, respectively, around 65%, 25%, and 40% of the price of the respective virgin raw material. More recently, Ghisolfi et al. (2017) established the social and economic importance of recycling computer waste.

Regarding reuse, companies collect their waste and reuse it as low-cost raw material or route it to other companies, after small interventions like washing and cleaning. Used packaging, pallets, trimmings, discarded parts, refused parts, scraps, chips, filings, or leftovers of virgin sheets, among many others, are examples of returned waste (Nardi et al., 2017). Reuse is also considered in the design of a new product, the so-called eco-design (Sellitto et al., 2017). Used appliances, vehicles, or capital goods return to resale after minimal repairs, such as washing, painting, or replacement of damaged parts (Barker and Zabinsky, 2011). Such kind of reuse contributed to establishing an attractive industry, with a regular and permanent market. Oliveira Neto et al. (2017) established some directions to evaluate the efficiency in reusing electronic waste.

Regarding remanufacturing, parts or subsystems are dismantled, inspected, recovered, and reassembled, not always in the same function. For example, bearings, gears, or motors recovered from repaired machines can return to another type of machine, usually after major repairs (Guide Jr., 2000; Ongondo et al., 2011). For example, goods rejected in the quality control or in the retail can return for reconstruction in the manufacture (Linton et al., 2005; Linton et al., 2005; Guide and Wassenhove, 2001). Eventually, despite the quality control, early failures occur, which forces the return for repair. The literature calls it refurbishing (Piplani and Saraswat, 2012; Chan et al., 2012; Rogers et al., 2012).

Disposal is the last option, eligible in the absence of any relevant remaining value. In this case, the material routes to landfills, incineration, or renewable energy systems (Chanintrakul et al., 2009; Lau and Wang, 2009). Table 1 summarizes and characterizes the return channels retrieved from the literature and the respective studies.

Table 1: Reverse channels

Channel	Features	Literature
Recycling	The material routes to cooperatives for sorting, separation, and processing. The waste becomes new feedstock at the same or another industry, at a lower cost.	Cruz et al. (2014); Rahimifard et al. (2009); Morris (1998); Moh and Manaf (2014); Tam and Tam (2006a); Tam and Tam (2006b); Wei and Huang (2001); Tsai and Chou (2004); Oliveira Neto et al. (2017); Ghisolfi et al. (2017).
Reuse	The materials are used several times before needing minor repairs. Adjustments or segregations do not modify the primary structure of the material.	Janse et al. (2009); Lau e Wang (2009); Ravi et al., (2005); Barker e Zabinsky (2011); Ongondo et al. (2011); Sellitto et al. (2017). Wei and Huang (2001); Oliveira Neto et al. (2017).
Remanufacturing	The materials undergo major repairs or pass through a dismantling process. The useful parts return to the manufacture of new products, not necessarily the same.	Schultmann et al. (2003); Kerr and Ryan (2001); Guide Jr. (2000); Janse et al. (2009); Lau e Wang (2009); Linton et al., 2005; Ravi et al., (2005); Ongondo et al. (2011); Borchardt et al. (2009).
Final Disposal	Value recovery is unfeasible and the material routes to landfill, incineration, or energy generation, which is a type of recycling.	Schultmann et al. (2003); Hu et al. (2002); Ongondo et al. (2011); Chanintrakul et al., 2009; Tseng (2011); Economopoulos, 2010; Zlamparet et al. (2017).

3. Methodology

The research method is the multiple case study. The study involves three cases in three process industries, beverage, paper and cellulose, and cement and mortars industries. The raw materials originate from extractive activities (water, minerals), agriculture (malts, hops, barley), forestry (eucalyptus forests), and chemical industry (syrups and additives). The research is qualitative. The findings originate mainly from opinions and judgment of experts, emphasizing their personal perspectives on the processes. The scope does not include analytical models, suggested for further research.

The research techniques are bibliographical and documentary research on specific material of the industries; meeting and guided visits with practitioners; and non-participant observation during the visits. The research methodology followed the framework of Eisenhardt (1989): definition of a research question, selection of the cases, definition of the data collection method, visits to the operations, within- and cross-case analysis, hypotheses for further studies and generalization, comparison with pertinent literature, and closure by theoretical saturation. The main limitation of the study is the number of cases, which preclude theoretical saturation (Eisenhardt and Graebner, 2007). The hosts are executive managers of the companies. Table 2 presents information on the cases.

Table 2: Information on the cases

Company	Industry	Host	Strategy for gathering information and analysis (all cases)
A	Beverage	Engineer and MSc in Industrial Engineering, ten years in the company, and twenty years in industrial management	Consult of specific literature on the industry, websites of the companies, internal documentation, meetings with experts of the industries, guided visits, and non-participant observation. Tabulation of data, within-cases analysis, cross-case analysis, graphical comparison of flowcharts and tables, and analysis of regularities as directions for further research. Evaluation of the potential for value recovery according to the experts´ judgment, based on the relevance of the returning flux in the context of the respective case.
B	Paper and cardboard packaging	BSc in Industrial Chemistry and MBA in Management Science, four years in the company, and ten years in industrial management	
C	Cement and mortar	Engineer and MSc in Industrial Engineering, seven years in the company, and forty years in industrial management	

Case studies require validity and reliability concerns. The validity is the extent to which the research correctly approaches the research object, without external interferences. The reliability is the extent to which different applications of the procedure reaches the same results (Voss et al., 2002).

Case studies should address internal, external, and construct validity (Gibbert et al., 2008). Internal validity assures that the observations depend only on independent variables, not on spurious variations on uncontrolled variables or assessment errors (Cozby and Bates, 2012). Triangulation (respondents, documents, and observations), respondents' feedback, models retrieved from the literature, and peer review (relevant studies founded the definition of the variables) assured internal validity (Johnson, 1997). External validity assures some degree of generalization when the objects have similarities, even if the generalization is not a major objective of case studies (Stake, 1990). To assure external validity, the research included three cases of the process industry. Construct validity refers to the extent the research really studies what it claims to study (Gibbert et al., 2008). The data collection methodology assures construct validity of case studies. The theoretical structure combining reverse channels and processes used to allocate the findings assures construct validity. Regarding reliability, the study used the same objective structure of processes in the three applications.

4. Results

4.1 First case: beverage industry

Company A produces, bottles, and distributes soft drinks and beers using glass and plastic bottles, and aluminum cans. Operational activities include supply, manufacturing, maintenance, and distribution. Logistic operations use returnable items, like plastic crates, wooden pallets, plastic shrinks, and packs. Pallets, crates, and glass bottles return indefinitely, whereas the others damage after a certain number of shipments. The company sponsors waste collector cooperatives that recycle post-consumer waste collected by municipalities and local entities.

In the supply stage, bulk raw materials arrive in tank trucks that discharge directly into silos, without any possibility of recycling. Raw materials of smaller volume arrive on returnable pallets discharged by forklifts, protected with plastic. The plastic is separated, compacted and segregated and periodically routes to waste collectors' cooperatives to be recycled for use in the plastic industry as low-cost raw material. According to the host, this operation has low-value recovery potential.

In the manufacturing, a treatment station neutralizes the liquid waste that returns to the hydrographic basin of the region. The remaining sludge has no remaining value and goes to landfills. The amount is less than 5% of the volume of effluents. The continuous monitoring of parameters guarantees the neutrality of the effluents. Damaged cans and bottles route to waste collectors' cooperatives. This returning flow has low-value recovery potential, given the low volume and the high cost of transportation.

In maintenance, the return generation is erratic, coinciding with equipment retrofits, preventive replacement of parts, or severe failures. Due to frequent modernization and renews, maintenance obsoletes machines, subsystems, and components with remaining lifetime, which return to reuse through intermediaries or to remanufacturing. In one year, the company routed more than ten tonnes of equipment to a new use. Refused materials (lubricants, machining chips, and metallic sheets) route to recycling. Metallic items routes to waste collectors' cooperatives, which segregate, compact, and sell them to scrap dealers that supply the steel industry. Oils and greases go to intermediaries that reprocess and sell them as a low-cost raw material for the chemical industry, mainly for the manufacturing of cleaning products. Reuse and remanufacturing flows have high-value recovery potential, due to the price of industrial machines and components. Recycling flow has low-value recovery potential.

In the distribution, the company delivers to distributors in plastic crates (glass bottles) and bales protected by plastics, on wooden pallets. In manual operation, the pallets do not leave the vehicle. In mechanized operation, the plastic protection involves the pallet and the distributor delivers in advance the same number of pallets that receives. In warehousing, the distributors store, recombine, and dispatch the loads to the retailers. Most of the delivery is manual, and the pallet does not leave the vehicle. Retailers with mechanized unloading return the same number of pallets to the distributor. The crates pass from the distributor to the retailer. Both return the same number of crates they receive. The distributors accumulate the protection plastics and route them to waste collectors' cooperatives. Given the capillarity and extension of the network, there is no control of company A on the waste return. However, some large distributors have agreements with cooperatives, not necessarily those sponsored by A. The others use public selective collections. The return flow of distribution has a high potential for value recovery.

Post-consumption waste requires social initiatives supported by A. The main item is PET bottles. Due to the volume and geographical dispersion of consumers, it is impossible to manage the post-consumer reverse flow. Therefore, the company chose some locations to support waste collectors' cooperatives. The company calls them popular recycling sheds.

The purpose of the initiative is the productive inclusion and generation of income for populations at risk, supporting projects of popular entrepreneurship. The focus is social, although the company recognizes the environmental result obtained with the recycled volume. The projects include technical and financial cooperation with the sponsored cooperatives. In the last three years, the average income of more than 1,500 workers in 121 sheds in 41 cities increased circa 40%. The volume of recycled materials increased circa 23% overcoming 35,000 tonnes per year. The municipalities collect the waste. Due to the low density, which increases the transportation cost, sheds must be close to collection points.

In the sheds, the workforce separates the material into plastics, glass, metals, and cardboard. The materials are pressed, baled, and delivered to intermediaries, which buy small volumes of various sources and scale up the recycling operation. Plastics go through washing, drying, and milling, becoming raw material for the manufacturing of non-structural artifacts such as brooms, household containers, and some furniture items. Glasses are milled and sold to the crystal industry. Metals turn into raw material for the steel industry. Cardboard is cut into chips, moistened, and processed into paste, supplying the toilet paper and packaging industry. One severe difficulty is the lack of knowledge of the industry about the use of recycled raw material at a lower price, which slows down the growth of the operation. The post-consumption return flow has high-value recovery potential, mainly due to its capillarity.

In short, the main gains of company A are: (i) cost reduction of 1% to 2% of the logistics cost by pallet reuse and the sale of more than ten tonnes of equipment in one year; (ii) less dumping of solid waste in landfills by the post-consumption destination; and (iii) corporate image created by the social support given to more than 120 cooperatives.

4.2 Second case: paper industry

Company B operates in the paper and pulp industry in Brazil and South America, producing corrugated packaging and industrial bags. Typical products are cardboard boxes, cement bags, and food bags. The company receives the paper in sheets and processes, formats, and prints it in colors according to the specific customer's design. Company B operates four business units: (i) forestry, which produces and sells logs; (ii) paper, which produces and sells virgin or recycled kraft paper for their owned manufacturing; (iii) packaging, which produces and sells packaging materials to other industries, such as food, beverages, household appliances, hygiene, cleaning and beauty, pharmaceutical, fruit, and floriculture; and (iv) industrial bags, which produces and sells bagging and packaging items to other industries, such as cement, fertilizers, and food. The company has ISO 9001 and ISO 14001 certification for its industrial operations and FSC (Forest Stewardship Council) certification for its forestry operations. The company is a global reference in sustainability.

Regarding the supply stage, the company receives raw materials and fuel by trucks, without the possibility to establish any reverse flow. The company also receives small items, such as paints and maintenance materials. The company stores the used packages in the warehouse until reaching a volume that justifies transportation to a cooperative. This returning flow has low-value recovery potential.

In the manufacturing, the company reuses paper scraps. A pneumatic conveyor automatically collects leftovers, scraps, and conveys them to an accumulator that presses the waste to form bales. Periodically, a forklift collects the bales and replenishes the raw materials feed hopper of the paper machines, mixing it with the virgin raw material from forestry. This returning flow may arrive up to 5% of the total feed of the machines. The liquid effluent passes for chemical treatment and returns to the water recirculation circuit. A small portion of the recirculating water evaporates and is replaced by new water from the hydrographic basin of the region. Scrap paper received from the recycling industry completes up to 10% the raw material supply of paper machines. Therefore, besides re-using the own waste, the company reuses waste generated in other industries. This returning flow of scrap has high-value recovery potential.

In the maintenance, the returning flow is similar to that of company A. The maintenance also generates leftovers of lubricating oils and greases, but in more regular quantities due to scheduled maintenance practices. Similar to company A, waste collectors' cooperatives receive metal items, and specialized intermediaries receive oil and grease to sell as a low-cost raw material for the chemical industry. Specialized intermediary companies receive machine subsystems and parts to dismantle and resell on the secondary market for remanufacturing. The remanufacturing flow has high-value recovery potential. In one year, the company routed circa 2 tonnes of equipment.

In distribution, the main opportunity is the return of pallets, as required by the ISO 14000 certification. The delivery package consists of a returnable pallet, adhesive strips, protective plastics, and handling metallic strips, all reusable or recyclable. The company dispatches the product to the distributors that collect the components of the packaging systems, sending them to waste collectors' cooperative or to municipal recycling facilities.

The company integrates DL and RL to reduce cost. With computational support, the distributor optimizes the route, including customers and intermediate storage facilities, according to two rationales. In the first, each time the vehicle delivers a new load, it takes back the same number of pallets. In the second, the company collects only after accumulating a given amount of pallets. In the first rationale, the average recovery value is small, due to the low return freight. It is not uncommon a vehicle deliver, for example, two tons of products and return with less than 500 kg of pallets. In the second rationale, the customer must have a warehousing infrastructure to accumulate pallets. It is not uncommon for the customer to receive new products two times in a week and retain the pallets for more than two months until reaching a volume suitable for the return.

Pallets can return in perfect conditions, in repairable conditions, or in nonrepairable conditions. In the first case, the pallets return to the manufacturing immediately. In the second case, the pallets go to an outsourced company for remanufacturing. In the third case, the pallets route to waste collectors' cooperative for recycling. There is no individual tracking of pallets, but the company estimates by the number of replacements that pallets support four to eight times before remanufacturing and more than ten times before recycling. According to the host, the attractiveness of reuse is high for nearby destinations, but the biggest benefit lies in the corporate image shared with customers and service providers, associated with environmental preservation and ISO 14000 certification. The company does not support cooperatives directly. The returning flow of pallets flow has high-value recovery potential.

Post-consumption is similar to what happens in company A. The returning flow depends on the public municipality, mainly due to capillarity of the routes and geographic dispersion in the generation of waste. The post-consumption returning flow has high-value recovery potential.

In short, the main gains of company B are: (i) cost reduction of 2% to 5% of the logistics cost by pallet reuse and reduction of up to 10% of the supply of virgin material; (ii) less use of forestry virgin material and less dumping of solid waste in landfills by the reuse of scraps; and (iii) corporate image created and maintained by environmental concerns and by the ISO 14000 certification.

4.3 Third case: cement industry

Company C manufactures granular chemicals products for civil construction, typically cement and mortars. The company operates two types of processes, mining, and manufacturing. The mining process extracts raw material from quarries, crushes it in preliminary operations, and generates raw material for the cement manufacturing. The company dispatches the final product in trucks and trains, in bags or in bulk format. The main customers are resellers of building materials, constructors, and concrete pieces and artifacts manufacturers. Customers operate the distribution logistics.

In the supply stage, the company receives most of the raw material in bulk format, by train or truck, without packaging and reverse flow. A small returnable part of the supplies (sacks and bags, ink for dating devices, and maintenance materials) accumulates in the warehouse until reaching an economic quantity that justifies sending to a local waste collectors' cooperative. This returning flow has low-value recovery potential.

In the manufacturing, the reverse flow includes emissions of pulverulent process gases, captured by sleeve filters and electrostatic precipitators and returned in a closed circuit. The filters separate the solid part of the gas that returns to the process, whereas the clean air returns to the atmosphere. The operation created a positive corporate image with the nearby community. The reuse of raw material can reach up to 1% of the total feed of the processes. It also includes temperature recovery from hot process gases, which return to preheat the feedstock. Mineral waste received from other industries (coal fly ashes, rice husks, electric arc furnace dust, steel mill scale, and petroleum silica) complete the supply, at a cost that is much lower than that of virgin material. Similarly, biomass and waste from other chemical industries complete the low-cost supply of fuel. Therefore, besides recycling the own waste, the company recycles waste generated in other industries. The case of coal fly ash is emblematic: in some products, the addition of ashes is greater than 40% of the weight of the product. Per year, the company consumes more than 20,000 tonnes of coal ash that otherwise would be dumped in controlled landfills. The returning flow of the manufacturing has high-value recovery potential.

In the maintenance, the crew recycles lubricating oils and metallic waste and remanufactures removed equipment, components, and their main subsystems, as in companies A and B. In one year, the company routed more than 20 tonnes of equipment. The returning flow of the maintenance for remanufacturing has high-value recovery potential.

In distribution, the company delivers in bulk, directly in the customer's vehicle, which does not generate reverse flow. The company also delivers in 25- and 50-kg bags in palletized loads directly from the silos to the customer's truck by robotic machines or from the warehouse by forklift, employing returnable pallets. The trucker delivers the same number of pallets that he or she receives. The company maintains a small inventory of pallets, less than half a day's supply, to compensate variations between deliveries and receipts. The buyer is responsible for the pallets, managing their useful life. The company does not manage the return. The returning flow of pallets has high-value recovery potential and provided a substantial reduction of logistic cost.

The post-consumption flow involves used dirty industrial bags. The company does not manage this flow. Despite the efforts involving resellers that could receive and give a proper destination to returned bags, due to the capillarity of the consumption and the low individual volume, the company failed in implementing a reverse flow of bags. Therefore, buyers send industrial bags to waste collectors´ cooperatives or separate they for public selective collection. The company has no control over this initiative.

In short, the main gains of company C are: (i) cost reduction of up to 30% of the fuel by reuse of waste from other industries, sale of up to 20 tonnes of obsolete equipment, and reduction of up to 5% of the logistic cost; (ii) less use of virgin material and less dumping of solid waste in landfills by the reuse of waste of other industries; and (iii) corporate image created by environmental concerns.

5. Discussion

The three companies deliver discrete products (bales, packages, bags), use fungible raw materials (liquids, fibers, ores), and operate continuous processes. The cross-case analysis considers the similarities between the cases, suggesting directions to further research. Figure 2 shows a synoptic representation of the cases, emphasizing the similarities.

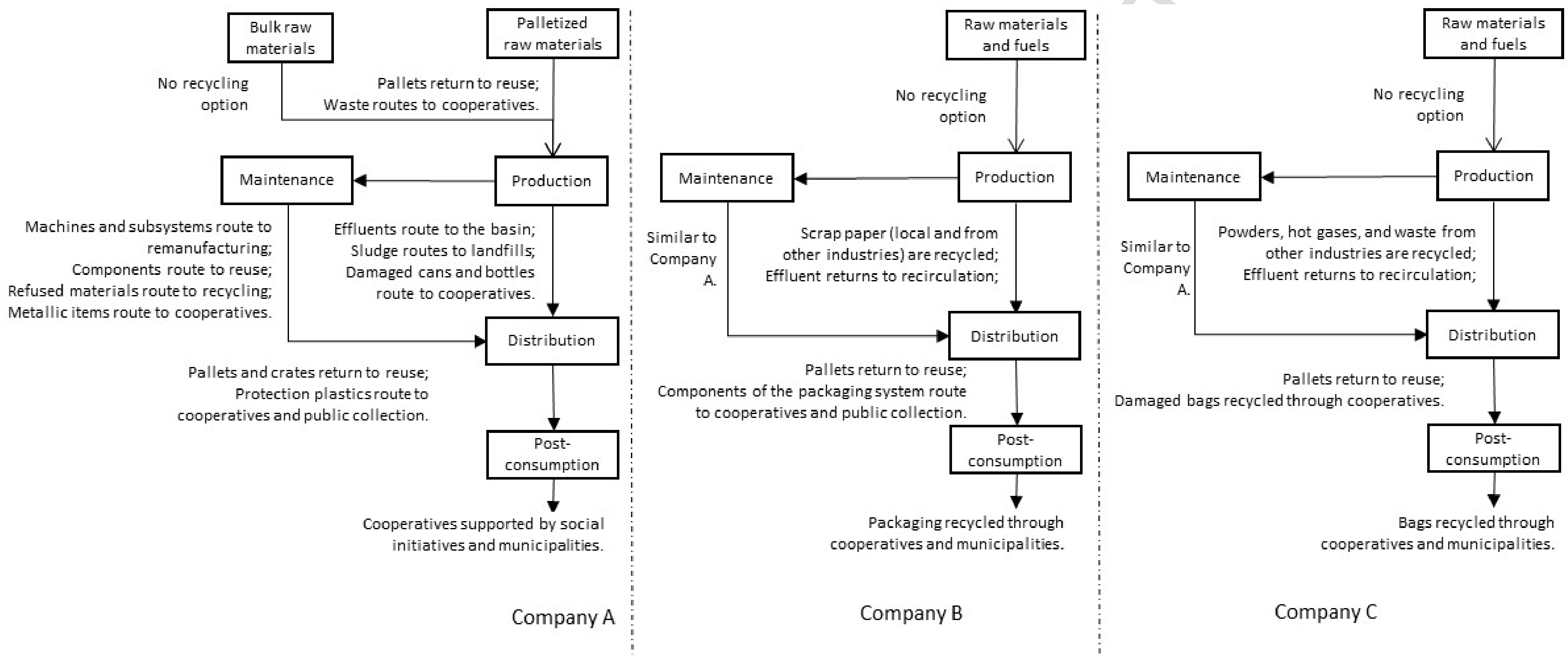

Figure 2: Synoptic representation of the cases

Raw materials arrive in bulk format. Vehicles transfer the product directly to silos, without packaging or other materials. Reverse activities have no importance, limited to some packaging materials of low volume. To the best of the available knowledge, no relevant literature was found supporting reverse activity regarding bulk raw materials.

In the manufacture, the same process that generates scrap and waste reuses them. The reuse included liquids (company B), hot gases and powders (company C), and waste, internal and from other industries (companies B and C). The volumes range between 0.5% and 1% of the production. Even small in quantity, the reuse can produce substantial financial gains. The cases have some similarities with the studies of Bing et al. (2015) and Safaei et al. (2017) that handle with the reuse of waste in CLSC.

Maintenance activities generate items for remanufacturing and recycling according to erratic patterns, because reforms and retrofitting occur at different moments, generating different volumes of parts. Only the remanufacturing of machines and parts has a high potential for value recovery. The cases have some similarities with the studies of Yi et al. (2016), Wei et al. (2015), Fang et al. (2017), and Li et al. (2015).

In distribution, A, B, and C return pallets. A also returns crates. All companies route secondary packaging materials for recycling. B and C have a high potential for value recovery with pallets. The findings are similar to those of the studies of Adlmeier and Sellitto (2007) and Nardi et al. (2017).

In post-consumption, the companies sale in geographically dispersed areas, which makes unfeasible a unified collection. Therefore, collection and recycling depend on municipalities´ support. Only A sponsors recycling cooperatives supplied with the public collection. There is a high potential for recovery value, mainly through the use of cooperatives. The cases have similarities with the study of Chen et al. (2017), among many others.

Table 3 summarizes the contribution of the cases, emphasizing the similarities.

Table 3: Contribution of the cases

Returning flow	Features	Present in company		
		A	B	C
Reuse in the manufacture	Reuse of internal waste or waste from other industries, which decreases cost due to the substitution of raw material and fuel;		X	X
Remanufacturing in the maintenance	Use of parts, subsystems, or equipment in a new product or position after substantial reconstruction, with financial gains;	X	X	X
Reuse in the distribution	Use of returnable pallets and packaging, with environmental gain and positive corporate image, limited to short distances;	X	X	X
Recycling in the post-consumption	Cooperatives routes materials to a new use, preferably sponsored by the company and supported by the municipality, with significant environmental and social gains.	X	X	X

Table 4 shows the high-value returning flows of the cases, representing possibilities for further studies on RL in the process industry. The evaluation considered the peculiarities of each case and relied on the experts´ judgement expressed during the meetings and the guided visits.

Table 4: Reverse activities with high potential for recovering value in the process industry

Process	Company		
	A	B	C
Supply: bulk raw materials and packaging	none	none	none
Manufacturing: scraps and process waste	none	Internal reuse (solid and liquid waste) and from other industries (papers)	Internal reuse (pulverulent solids and hot gases) and from other industries (fly ashes, minerals, and vegetables)
Maintenaince: technical materials	Remanufacture of parts, subsystems, and equipment	Remanufacture of parts, subsystems, and equipment	Remanufacture of parts, subsystems, and equipment
Distribution: final product	Reuse (pallets and crates)	Reuse (pallets)	Reuse (pallets)
Post-consumption: waste and packaging	Collection by municipalities, sponsored cooperatives	Collection by municipalities	Collection by municipalities

The cases allow conclusions, with internal validity. In similar process industries, such conclusions can be starting points for the analysis of RL activities:

- In the supply of raw material, deliveries in bulk format eliminate reverse activity. The companies also receive packaging and protective materials whose recycling is possible, but the small amount reduces the economic feasibility;

- In maintenance, despite the erratic consumption pattern, materials, parts, and equipment can generate relevant reverse remanufacturing activity. As for recycling, cooperatives and intermediaries can scale up the activity and reduce uncertainty by operating with multiple sources;
- In the manufacturing, although representing only a small fraction of the supplied raw material, continuous processes can use the waste that it generates as well as waste from other industries;
- In the manufacturing, the reuse of waste can integrate several supply chains (the waste from one supplies other, forming CLSC);
- In the distribution, companies can reuse crates and pallets, and recycle secondary packaging materials, supporting waste collectors´ cooperatives;
- In post-consumption, due to the dispersion of the geographical basis of consumption, the companies need to rely on the waste collected by the municipalities and on cooperatives to recycle the post-consumption waste. The companies should think about support cooperatives and sponsor their activities in popular recycling sheds.

Table 5 summarizes and synthesizes the reverse activities with higher potential for value recovery, according to the practitioners´ judgment. Future research in process industries should focus on these opportunities. This framework for future research is based on the findings of the cases.

Table 5: Opportunities for further research in RL in the process industry

	Reverse channel			
process	recycling	reuse	remanufacturing	disposal
supply				
manufacture		X		
maintenance			X	
distribution		X		
post-consumption	X			

In the manufacturing, there is a higher potential for value recovery by reusing the internally generated waste and the waste generated in other industries. In maintenance, there is a higher potential for value recovery by remanufacturing parts, subsystems and machines. In the distribution, there is a higher potential for value recovery by reusing pallets and packaging. Finally, in the post-consumption, there is a higher potential for value recovery by recycling through collectors´ cooperatives and municipalities facilities. These directions are the major contribution of the research.

6. Conclusion

The theme of the article was the use of reverse logistics and reverse channels in the process industry, aiming at recovering part of the original value of used goods. The objective of the article was to identify how to recover value from waste generated by process industries. The research methodology was the multiple case studies in three companies of the process industry. The research techniques were the bibliographical research, meetings with experts of the industry, and guided visits to the operations. The research question was: What are the reverse operations with the greatest potential for recovering value in process industries?

Answering the research question, the study concluded that the reverse operations with greater potential for recovering value in the process industry are: (i) reuse of internal and external waste in the manufacturing; (ii) remanufacturing of parts, subsystems, and machines originated from maintenance activities; (iii) reuse of returnable pallets, containers, crates, and packaging in the distribution of products; and (iv) recycling of post-consumer solid waste. In the cases, the supply operation does not offer significant opportunities. The companies also do not need the final disposal channel (landfills) to give a correct destination to their waste. Only one operation was observed, involving very small non-toxic volumes dumping to landfills. The major implications of the study are directions for further research and to guide practitioners that want to recover value in the process industry. Other important outcomes are: (i) practitioners can achieve important reduction in logistic, maintenance, and manufacture costs if they emphasize the reuse, the remanufacturing, and the recycling of the waste they generate in their industrial plants; (ii) companies can create and maintain a positive corporate image if they support social initiatives such as waste collectors´ cooperatives; and (iii) municipalities can enlarge the useful life of landfills, if they stimulate companies to support cooperatives.

The limitations of the study derive from the methodology: the reduced number of cases and the qualitative approach. Future research can bridge these limitations with more in-depth case studies, with quantitative approaches to the reuse of waste, remanufacturing of parts, reuse of returnable packaging, and recycling of post-consumption waste. More cases can help to derive constructs and indicators for a future survey in an entire process industry. Quantitative approaches can provide analytical models based in temporal series and supported by multicriteria analysis, as already made in the previous studies of Luz et al. (2006) and in Sellitto et al. (2011) that provide methodologies for a complete and comprehensive appraisal of the environmental performance of an industrial activity.

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Highlights:

1. Reverse logistics activities include the return of used goods and the partial recover of its originally existent value
2. Four channels are relevant: recycling, reuse, remanufacturing, and final disposal
3. There is a high potential for value recovery by reusing the internally generated waste
4. There is a high potential for value recovery by remanufacturing parts, subsystems and machines.
5. Value can also be recovered by collectors´ cooperatives and municipalities facilities.