Resources, Conservation & Recycling

Manuscript Draft

Manuscript Number: RECYCL-D-17-01400

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Article Type: Review Article

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Total word count: 10759 (excluding abstract and references)

Waste Electrical and Electronic Equipment (WEEE)/E-waste in reverse logistics (RL) and closed-loop supply chain (CLSC) research: A review

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Abstract

Reverse logistics (RL) and the closed-loop supply chain (CLSC) are integral parts of the holistic waste management process. One of the important end-of-life (EOL) products considered in the RL/CLSC is Waste Electrical and Electronic Equipment (WEEE)/E-waste. Numerous research papers were published in the RL and CLSC disciplines focusing WEEE separately. However, there is no single review article found on the product-specific issues. To bridge this gap, a total of 155 papers published between 1999 and May 2017 in four main types of research, namely designing and planning of reverse distribution, decision making and performance evaluation, conceptual framework, and qualitative studies were selected, categorized and analyzed using content analysis. Research gaps in literature were identified to suggest future research opportunities. With limited attempt, the review first of its kind that may provide a useful reference for academicians, researchers and industry practitioners for better understanding of WEEE focused RL/CLSC activities and research.

Keywords

Reverse logistics (RL), Closed-loop supply chain (CLSC), Waste Electrical and Electronic Equipment (WEEE), E-waste, Content analysis, Sustainability.

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List of Abbreviations

AHP	Analytic hierarchy process	MCDM	Multi-Criteria Decision Making
AMPL	A Mathematical Programing Language	MIP	Mixed integer programing
ANP	Analytic network process	MINLP	Mixed integer non-linear programming
BSC	Balanced Scorecard	MEU	Maximum expected utility programing
CLSC	Closed-loop supply chain	NSGA	Non-dominated Sorting Genetic Algorithm
CRM	Critical raw materials	NLPA	Non-linear programing algorithm
CLND	Closed-loop network design	OECD	Organisation for Economic Co-operation and Development
CCs	Collection centers	OLND	Open-loop network design
CLDSC	Closed-loop distribution supply chain	OEMs	Original equipment manufacturers
CDM	Clean Development Mechanism	PLC	Product lifecycle
DPRL	Designing and planning of reverse distribution	PSO	Particle swarm optimization
DEA	Data Envelopment Analysis	RL	Reverse logistics
DfE	Design-for-the-environment	RSC	Reverse supply chain
DSS	Decision support system	RP	Recycling plant
EOL	End-of-life	RCs	Recycling centers
EPR	Extended producer responsibility	RN	Recovery network
E-waste	Electronic waste	RLND	Reverse logistics network design
ECA	Election campaign algorithm	RNA	Recovery network arrangement
EPC	Electronic Product Code	RCPSP	Resource constrained project scheduling problem
FL	Forward logistics	RFID	Radio-frequency identification
FSC	Forward supply chain	SCs	Sorting centers
FAHP	Fuzzy analytic hierarchy process	SAA	Sample average approximation
GA	Genetic algorithm	SDP	Stochastic dynamic programming
GAMS	General Algebraic Modeling System	3PRLP	Third-party reverse logistics provider
GRASP	Greedy Randomized Adaptive Searching Procedure	TRA	Theory of Reasoned Action
GP	Goal-programing	TSs	Transfer stations
GRSC	Global reverse supply chain	TFs	Treatment facilities
ILP	Integer linear programing	TOPSIS	The Technique for Order of Preference by Similarity to Ideal Solution
IP	Integer programing	TFT-LCD	Thin-film-transistor liquid-crystal display
IT	Information technology	VR	Vehicle routing
ICT	Information and Communication Technologies	VRP	Vehicle routing problem
LP	Linear programing	VW	Virtual warehousing
LINMAP	Linear programing technique for multi-dimensional analysis of preference	WEEE	Waste electrical and electronic equipment
LCA	Lifecycle assessment	ZOGP	Zero-one goal programing
LCCs	Lifecycle costs		
LCEC	Lifecycle energy consumption		
MILP	Mixed-integer linear programing		

1. Introduction

Due to growing environmental regulations, potential recovery of valuable material resources for the secondary market, and sustainable business practices, over the last twenty years, the concept of reverse logistics (RL) has been accepted and widely practiced in manufacturing industries all over the world. The definition of RL according to Stock (1992) refers to *"... the term often used for the role of logistics in recycling, waste disposal and management of hazardous materials; a broader perspective includes all issues relating to logistics activities carried out in source reduction, recycling, substitution, reuse of materials and disposal"*. This definition links directly RL activities in a waste management scenario that provides a more holistic approach in resource conservation and recycling of end-of-life (EOL) products. As waste generation by various industries is increasing at a skyrocketing pace, many governments across the globe compel the producer/manufacturer to implement the extended producer responsibility (EPR) principle. According to the Organisation for Economic Co-operation and Development (OECD), *''EPR is a policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products* (OECD, 2017). With this instrument, manufacturers now have to develop a sustainable reverse supply chain (RSC) besides the conventional forward logistics (FL) system. According to Stevens (1989) a forward supply chain (FSC) is *''a system consisting of material suppliers, production facilities, distribution services, and customers who are all linked together via the downstream feed-forward flow of materials (deliveries) and the upstream feedback flow of information (orders)''*. On the other hand, when the FSC and RSC systems are considered in an integrated manner, the concept of closed-loop supply chain (CLSC) evolved. It considers efficient product return management and conduct value recovery activities, so that secondary materials can be used as input for ''new'' customer product. According to Guide Jr and Van Wassenhove (2009) *''CLSC management is the design, control, and operation of a system to maximize value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time''.* From the sustainability viewpoint in all three dimensions – social, economic and environmental - in conjunction with the circular economy, RL/CLSC is an emerging area of research that attracts both academic and industry practitioners. According to Geissdoerfer et al. (2017) *'' A circular economy is a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing the material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling'' and sustainability is defined as the balanced integration of economic performance, social inclusiveness, and environmental resilience, to the benefit of current and future generations.* Based on the above definition of RL/CLSC, the generic diagram can be illustrated as in Fig. 1.

[Fig. 1. Here]

Among the various EOL products identified in RL/CLSC research, waste electrical and electronic equipment (WEEE) is one of the fastest-growing streams at present due to a shorter product lifecycle (PLC) and rapidly changing customer attitudes towards disposing of them (Islam et al., 2016;Nnorom and Osibanjo, 2008). Compared to other EOL products, WEEE or electronic waste (E-waste) has a complex material structure containing both hazardous substances and critical raw materials (CRM). Thus, in its return management, multiple factors along with a higher degree of uncertainties such as quality, quantity and time are involved (Chen and He, 2010). For this reason, the RL/CLSC of WEEE has received significant attention among researchers and industry practitioners.

The number of international peer-reviewed articles published on RL/CLSC issues focusing on WEEE is increasing considerably. However, no single review has yet been conducted to summarize all the relevant articles with a product specific focus. To the best of the authors' knowledge, this is the first attempt at reviewing RL/CLSC articles focused on WEEE. As the body of literature is growing considerably, this review aims to provide a complete picture of the field, by categorizing the content of the literature and reviewing it into four distinct research types: designing and planning of reverse distribution, decision making and performance evaluation, conceptual framework and qualitative studies. After reviewing the articles, research gaps were identified and a number of future research directions have been identified so that future researchers can work in line with the research gaps in the field. The paper is organized as follows: Section 2 discusses the research methodology of the study. Section 3 provides a detailed analysis of the articles. Research gaps are analyzed and future research directions are addressed in Section 4, and finally, Section 5 reaches a conclusion.

2. Research methodology

A literature review plays a critical role in scholarship as well as it helps to explore and structure thoroughly a particular research area (Easterby-Smith et al., 2012;Vom Brocke et al., 2009). With a valid literature review, knowledge on the concerning area can be further advanced by identifying key conceptual contents that works as a path to new theory development and new scope of investigation (Machi and McEvoy, 2016;Meredith, 1993). For a systematic literature review, this study implemented four steps processes as prescribed by Mayring (2001) under the content analysis method: material collection, descriptive analysis, category selection and finally, material evaluation. Several of the previous review articles (non EOL product focused) in the RL/CLSC field (e.g. Seuring and Gold (2012), Gold et al. (2010), Govindan et al. (2015), Agrawal et al. (2015)) implemented this methodology.

2.1 Material collection

In this literature review material collection and unit of analysis is the first step. A single journal article/conference paper/book chapter was defined as unit of analysis. In this study, a two-phase process was initiated. In the first phase, keywords such as ''reverse logistics'' and ''closed-loop supply chain'' along with ''WEEE or E-waste'' were used in title, abstract and keywords to carry article search. This keywords were used in the Scopus (www.scopus.com), and Web of Science (WoS) databases with an option that search only the papers those written in English. After analyzing title and abstract, further search of literature were inductively connected with the categorization of RL/CLSC i.e. designing and planning of reverse distribution, decision making and performance evaluation, conceptual framework and qualitative studies (e.g. survey, interview etc.). In this case, some of the essential key words were utilized, for instance, ''open-loop network design'', closed-loop network design'', ''third party reverse logistics provider'', ''vehicle routing'', ''product recovery'', ''organization and business perspective'', product return'' and ''reverse logistics processes''; along with the mandatory search term ''reverse logistics'', ''closed-loop supply chain'' and ''WEEE/E-waste''. Besides, studies those considered waste battery and printer cartridges were also included in this study. Total 258 papers were retrieved and all collected papers were taken into consideration for a fast check of relevancy and final content for the literature review. Articles those found most relevant with the above mention categorization were considered for this study. Finally, total 155 papers were selected, reviewed and analyzed in detail. Besides, journal articles, in the final collection 26 conference papers and 3 book chapters are included. The selection of the papers for this state-of-the-art review seems sufficient because of concentration (e.g. RL/CLSC of WEEE) on particular issues.

2.2 Descriptive analysis

To understand the broad range of concepts, motivation, modeling approach of a specific problem, papers were arranged from more than sixty journals. Fig. 2. shows the articles published by numerous outlets. From Fig. 2, it is found that most of the papers were published in renowned journals such as *International Journal of Production Research, Resources, Conservation and Recycling, Waste Management, International Journal of Production Economics and Production and Operations Management.*

[Fig. 2. here]

Annual distribution of number of papers published from year 1999 to 2017 in both RL and CLSC is shown in Fig. 3. Most of the papers were selected from recent publications. 20 papers out of 155 papers were published before the year 2006, whereas rest of the articles (135) were selected from the year 2006 and afterwards. Highest number of papers were published in the year 2010.

From this trend, it is clear that number of published papers is growing considerably in the last few years due to the increase interest of WEEE centric RL/CLSC analysis.

[Fig. 3. here]

2.3 Category selection

The main categorization of the content of this study and research framework is presented in the Fig. 4. As mentioned in the material collection section, the literature is classified into 4 major research types/categories. These four categories are (1) Designing and planning of reverse distribution; (2) Decision making and performance evaluation (3) conceptual framework based studies; (4) Qualitative studies. Distribution of research articles for 4 different categories is shown in Fig. 5. Designing and planning of reverse distribution has the highest percentage (54%) of publications whereas other categories possess less percentage which depicts the necessity for future exploration of these areas under the broad RL/CLSC of WEEE research field.

[Fig. 4. here]

[Fig. 5. here]

Open-loop network design (OLND), closed-loop network design (CLND), third-party reverse logistics provider (3PRLP) selection and vehicle routing (VR) related papers fall broadly under the category of designing and planning of reverse distribution (DPRL). DPRL represents more than 50% of the published papers in the RL/CLSC of WEEE research field. Fig. 6 shows the trend of published papers in the DPRL research area. Furthermore, the papers in the main field of research were further sub-categorized into specific issues (that evolved during material collection and category selection stages) which are shown in Fig. 7.

[Fig. 6. here]

[Fig. 7. here]

2.4 Material evaluation

The last and final stage of the content analysis process is material evaluation. Rigor in validity is attained by validation test performed by two researchers using the deductive and inductive approaches simultaneously. Reliability of the content was measured by both intra-rater reliability and inter-rater reliability. After material collection, all necessary information extracted from the selected articles were input in spreadsheet software conducted by the researchers by which repetition error by the researchers were minimized. With the same keywords used to search the articles were utilized in the google scholar database, and two researchers found the similar results in identifying correct articles and coding their content in spreadsheet application. With this reliability was established. Furthermore, through searching and cross-checking the publications independently, sufficiency as well as validity of the correct content of the collected paper was accepted.

3. In-depth analyses of the literature

3.1 Analyzing papers on DPRL

3.1.1 Open-loop network design (OLND)

According to Salema et al. (2007) *''An RL network establishes a relationship between the market that releases used products and the market for "new" products. When these two markets coincide, we talk of a closed-loop network, otherwise of an open loop''*. OLND focuses on the activities and flows of the reverse channel. Collection, inspection, sorting, disassembly, reprocessing/recycling and disposal operations are the major RL activities, with the flow of returned products from one place/process to another (Akçalı et al., 2009). The selected papers under the heading of OLND in this study are divided into 4 major subcategories that are described in this subsection. The detailed summary of the OLND studies is illustrated in Table 1.

3.1.1.1 Location-allocation problem

Shokouhyar and Aalirezaei (2017) determined the most appropriate locations of collection centers (CCs) and recycling plants (RPs) in a WEEE RL network in Iran using multi-objective genetic algorithms (GA). Important decisions on the trade-off among social, environmental and economic impacts of the network design can be made from this study. Ayvaz et al. (2015) developed a two-stage stochastic programing model that determined optimal locations for collecting, sorting and recycling centers (RCs). Besides finding the locations, it also determined the amount of WEEE (in weight) to be transported between nodes in a generic RL network. Kilic et al. (2015) developed a stochastic mixed-integer linear programing (MILP) model that determined the optimum locations of storage sites and recycling facilities that fulfill the minimum recycling rate prescribed by EU WEEE Directive 2012/19/EU (Directive, 2012).

Shokohyar and Mansour (2013) developed a simulation-based optimization model to determine the optimal locations for CCs and RPs in a network. This research considered three dimensions of the sustainability criteria. Considering a social sustainability indicator, this research considered employment, damage to worker, local development. Total net profit was considered under an economic sustainability indicator, while environmental impact was quantified using an Eco-indicator related to WEEE transportation. Gomes et al. (2011) proposed a generic nationwide WEEE recovery network (RN) model to identify the best location of CCs and sorting centers (SCs) with short-term (e.g. tactical - less than a year) network planning. Besides economic cost, environmental costs attributed to CO_2 emissions may influence network decisions - locations and mode of transport. Tuzkaya et al. (2011) developed a novel methodology for RL network design (RLND) that utilized integrated multi-criteria decision making (MCDM) and GA methodology to investigate two strategic-level (long-term) objectives such as the best possible locations for CCs and cost minimization of the RL network.

Xianfeng et al. (2010) proposed a linear-programing (LP) model for the recycling network to identify collection and recovery locations, resource allocation, and material flows of the network. This simulation-based work identified that the uncertainties of the recycling network were time, quantity and quality and recycling levels. Hanqing (2009) analyzed a model that was concerned with a self-sustaining recovery pattern of a 3PRLP focusing on appropriate recovery locations. Wang et al. (2008) developed a fuzzy multi-objective LP model that optimizes the locations of transfer stations (TSs) and treatment facilities (TFs) considering five objective functions.

Chang et al. (2006) developed a mixed-integer programing (MIP) model that aimed to optimize the RL network structure and minimize the total cost including the collection cost, fixed costs, transportation cost, daily operation cost, waste disposal cost. Cost minimization was achieved by selecting optimum locations for disassembly/reprocessing plants in the network. Shih (2001) proposed an optimization model for infrastructure design and reverse network flow for home appliances and computers in Taiwan. In the model, the authors considered the total cost (e.g. transportation cost, operating cost, fixed cost for new facilities, final disposal cost and landfill cost) minimization in various aspects of the RL network such as collection and recovery locations, resource allocations and material flows within the network. Chong et al. (2014) examined an economically self-sustained RL network design considering collection centers, processing centers, transportation, secondary market, recycle centers and disposal sites that can cover the overall expenses of an RL system.

Ayvaz and Bolat (2014) presented a two-stage stochastic RLND model making strategic decisions on RP locations. Wang et al. (2011) developed a multi-echelon RL network for the purpose of collecting and processing WEEE. The authors tried to identify the best possible locations of CCs and disposal stations. Source-specific circulation of WEEE from collection centers to disposal facilities was also identified. Grunow and Gobbi (2009) developed an MILP model to evaluate the configuration of the existing CC's locations. The study found that collective schemes (in Danish Producer Responsibility System) are economically beneficial for logistic activities, better-off in developing a competitive market and cost-efficient in providing services.

3.1.1.2 Product recovery (PR)

Qiang and Zhou (2016) developed a robust RL network-optimization model considering uncertainty of recovery on the basis of a risk preference coefficient and a penalty coefficient. Assavapokee and Wongthatsanekorn (2012) created a deterministic strategic infrastructural RLND for the state of Texas in the USA, so that product recovery activities can be supported by the network for old TVs, CPUs and CRT monitors. Golinska and Kawa (2011) proposed a recovery network arrangement (RNA) model with a focus on recycling. The authors solved problems arising in the typical dynamic configuration of an RL network - goods flow visualization, coordination mechanism with FL, minimization of delivery time, stock and cost.

Kawa and Golinska (2010) proposed a model to restructure the configuration of a recycling RN for waste computers in a dynamic supply-chain scenario where recycling enterprises are dependent on each other. Their model provided potential ways in finding cost-efficient supply-chain paths of the whole enterprise network, according to their individual appropriate capacities. The leader company in the supply-chain network can provide supply of recycled materials to its customers quickly with competitive price. Cagno et al. (2008) proposed an analytical model for RN to evaluate the capacity and cost of the existing network of refrigerator recycling with an estimation of future values. Lee and Dong (2008) developed a network-flow-based deterministic programing model for the purpose of designing an end-of-lease computer products RN that consists of both forward and reverse logistics flow.

Srivastava, Samir K (2008) designed a multi-period value RN of returned white goods such as refrigerators, washing machines. He found that for flexible volume acquisition, remanufacturing is not a viable economic proposition for India. Fleischmann et al. (2001) developed a facility location model for PR and remanufacturing by integrating RN with the existing RL structure in the Netherlands. Fixed costs, transportation costs, rate of return, recovery processing technology, combining FL with reverse transportation, regional legislative requirements and EOL management were considered in the model. Sodhi and Reimer (2001) developed a non-linear mathematical programing model for optimizing recycling operations (i.e. disassembly and material-recovery decisions of recyclers and processors) in such a way that the net cost for material removal becomes a minimum, thus economic sustainability of WEEE recycling can be achieved. Krikke et al. (1999) established a stochastic dynamic-programing (SDP) model to determine an optimal degree of disassembly with optimal recovery and disposal options, so that the recycling cost of PC monitors can be reduced.

3.1.1.3 Cost

Shanshan and Kejing (2008) developed an integrated optimization model for location of the disassembly and bulk recycling facilities in a recycling network. In addition, optimized material flows among different actors in the network were determined, where cost minimization was considered as the objective function. Yu and Solvang (2016) proposed a stochastic optimization model to design and plan an RL system considering economic efficiency and environmental impacts on the system. The model provided policy implications for government authority in allocating subsidies for companies working with WEEE treatment.

Elbadrawy et al. (2015) proposed a mathematical model for an RL recycling network that aimed to minimize the total cost of the network, consisting of collection cost, installation cost of sorting, repairing. Besides, the costs, the model also considered the processing capacity of the recycling facilities and the optimal transported weights of WEEE from collection to recycling facilities. Yu and Solvang (2013) designed an RL network to treat multi-sourced WEEE considering environmental (in the form of greenhouse gas emission from transportation) and economic (cost minimization) dimensions. They found that, even though reuse, repair, remanufacturing and recycling of WEEE significantly increases the profit of the network, government still needs to provide subsidies and incentives to operators present in the RL network.

Dat et al. (2012) proposed an RL network-optimization model for recycling that aimed to minimize the total processing cost of the network. They found that, in order to reduce the total cost, the transportation cost should be minimized. Achillas et al. (2012) presented a single-period multi-criteria optimization model for multi-type carriers of WEEE to allocate the types of carrier to be used in an RL network. Total logistics costs, consumption of fossil fuel and production of emissions due to transportation were estimated by the model. Deng and Shao (2009) proposed an analytical recycling network configuration model to find the total minimum cost (transportation cost, operating cost and final disposal cost) in the presence of a recycling capacity constraint of the network, and sales revenue of reclaimed materials derived from the network. The authors found that WEEE compression at pre-processing sites is an important task for the entire recycling process and provided the essential implication of product design for recycling.

3.1.1.4 Others

Liu et al. (2014) developed an evolutionary RL network model that measured the enterprise's logistics capability standard as an effective output of the network. Xie et al. (2013) proposed a conceptual model on an RL reuse network based on the election-campaign algorithm (ECA). Piplani and Saraswat (2012) developed a min-max based robust optimization model using MILP to determine the suitability of facility utilization according to product flow and to address the uncertainties of the repair and refurbishing network - number of products returned, percent of faulty products and warranty fraction of modules. Cao and Zhang (2011) proposed an integrated method based on multi-objective optimization (NSGA II) and a multi-attribute decision-making model analyzing the optimal flow of WEEE in an RL network considering the total profit and accumulated energy consumption in the network.

Bereketli et al. (2011) developed a fuzzy linear-programing technique for multi-dimensional analysis of a preference (LINMAP) model to evaluate and select the best WEEE treatment strategy in an RL network. It was found that reuse and recycling were the best strategy in the current management practice in Turkey. Guo-jian Zhi et al. (2010) formulated a two-stage resource-constrained project-scheduling problem (RCPSP) based RL network with a remanufacturing focus. Choi and Fthenakis (2010) developed an operational mathematical model to assess the feasibility of developing a recycling infrastructure for thin-film solar photovoltaic (PV) waste.

Achillas et al. (2010) presented a decision support tool for policy makers to optimize the existing infrastructure of collection points and recycling facilities in an RL network in Greece. Guerra et al. (2009) developed a modular simulation model for the number of vehicles to be assigned in an RL network considering minimization of the intervention time at the collection centers. Rousis et al. (2008) developed a decision-making model based on the MCDM method using PROMETHEE to investigate possible alternative scenarios for WEEE management in Cyprus. According to the developed model, partial disassembling of WEEE and forwarding the recyclable material fractions to secondary markets and disposing of the residues to landfills was the best scenario in the existing setting.

Kara et al. (2007) developed a simulation-based RL network model for collecting EOL white goods from the Sydney Metropolitan Area in Australia. With the study, it was understood how the collection system interacted with the current WEEE management structure. Ahluwalia and Nema (2006) developed an integrated planning and design model using integer linear programing (ILP) to minimize the environmental risk as well as cost from a computer-waste management system. With the model, they presented a decision support tool that can be used to select an optimum configuration of waste management facilities - segregation, storage, treatment/processing, reuse/recycle and disposal, and allocation of waste in the facilities. Franke et al. (2006) developed a generic mobile-phone remanufacturing plant’s capacity planning and facility adoption planning by using a discrete-event capacity and program planning simulation model. In the model, they considered uncertainties in the remanufacturing process, such as the quantity and condition of mobile phones, reliability of capacities, processing times, and demand for remanufactured product.

Nagurney and Toyasaki (2005) presented a multi-tiered network equilibrium model that focused on a policy instrument for recycling. They found that policy instruments that involve original equipment manufacturers (OEMs) and integrate a classic supply-chain network with recycling perform best in terms of efficiency and effectiveness, as seen in Japan and in European member states. Nagel and Meyer (1999) proposed a new approach that systematically analyzed and modeled EOL networks, focusing on disassembly and recycling of refrigerators in Germany from ecological and economical points of view. To achieve better RSC management with flexibility in its design, Wang and Yang (2007) developed an MILP model that integrated facility location and configuration problems of WEEE recycling. Maximizing the overall utilization of the returned products and revenue generation from recycling were the two major objectives in their RL modeling.

[Table 1 here]

3.1.2 Closed-loop network design (CLND)

Network design with CLSC refers to transforming a supply chain into a closed-loop entity by forming a direct and coordinated relationship between FL activities (i.e. manufacturing, distribution and operation) and tasks associated with RSC (Akçalı et al., 2009). Compared to

OLND, only a few studies have been found that considered a CLSC network focusing on WEEE; they are discussed in this part of the paper. A summary of the CLND studies are presented in the Table 2.

Chen et al. (2015) developed a CLND in which the delivery routes and quantity of different materials derived from printer cartridges were considered, for achieving a maximum recycling rate and profit. Their model provided near-optimal and time-efficient solutions for optimization of the CLSC network. Amin and Zhang (2013) proposed a multi-objective three-stage CLSC model to evaluate and select three major factors in a network that determine the configuration of the network: suppliers of used products, remanufacturing subcontractors, and refurbishing sites. Qiang et al. (2013) investigated a CLSC network in the USA, considering competition, distribution-channel investment, and uncertainties in the network for printer cartridges. In their model, they considered three decentralized decision makers – raw-material suppliers, manufacturers (they collect recycled products directly from the demand market), and retail outlets.

Alumur et al. (2012) proposed a multi-period profit maximization CLSC model aiming to improve the network configuration and capacities of inspection centers and remanufacturing plants by optimizing locations. The model made an impact on reducing transportation costs between facilities. Amin and Zhang (2012) proposed an MILP model based on return–recovery pairs and PLC to configure a CLSC network that consisted of manufacturer, collection, repair, disassembly, recycling, and disposal sites for waste mobile phones in Canada. Krikke (2011) proposed a CLSC network-configuration model with combined disposition and location-transport decisions to assess the impact of photocopier machine recovery and remanufacturing on carbon footprinting. The author found that a regional CLSC network could perform efficiently and effectively when recycling is included.

Easwaran and Üster (2010) presented a multi-product CLND model that considered hybrid manufacturing/remanufacturing facilities and finite-capacity hybrid distribution/collection centers to serve a set of retail locations. Kannan et al. (2010) developed a mathematical model using MILP considering a multi-echelon, multi-period, multi-product CLSC network with a focus on cost reduction, for making decisions in the material procurement, distribution, recycling and disposal of waste batteries. Fernandes et al. (2010) constructed a CLSC network-optimization model of spent lead batteries considering production of the batteries, their distribution to customers, and EOL collection in Portugal. The costs included in their modeling were cost of opening warehouses, raw materials acquisition from supplier, EOL product acquisition from customers, and transportation resources.

Grant and Banomyong (2010) investigated product-recovery-management related activities that affected the strategic design and implementation of a CLSC for single- use cameras. They found that OEMs could benefit from the entire supply chain by standardizing high- quality raw materials, using a modular product structure, maintaining control over the entire process and avoiding third- party collectors and processors. Gupta and Evans (2009) developed a multi-product multi-objective goal-programing (GP) model that analyzed the operational level of a CLSC using three different techniques - why–what's stopping analysis, fundamental objective hierarchy, and means objective network. Chouinard et al. (2008) proposed a stochastic programing model to design a CLSC network considering location specific network-design decisions such as recovery and demand volumes with respect to capacity constraints and operating costs.

Chandiran and Surya Prakasa Rao (2008) investigated a centralized CLSC network-design model that had facility location and network configuration for distribution and collection of spent batteries. Decentralized network, manufacturer's dilemma in managerial control over the collection, disturbance to existing network, time pressure and integral design of both reverse and forward supply chain flow were addressed in the study. Hammond and Beullens (2007) presented a variational inequality approach to strategic modeling of oligopolistic CLSC considering legislation. The authors suggested that reverse-chain activities could be stimulated by legislation when some minimum recovery levels of all new products were included. On contrary, when there is interdependence of a number of factors: increase in collection targets, landfill costs and manufacturer-pay schemes, legislation became difficult to implement.

Schultmann et al. (2003) developed a hybrid CLSC planning and optimization model that deals with location-specific recycling options for spent batteries in the steelmaking industry. They found that the performance of recycling can be improved by modifying the recovery strategies of a network. Jayaraman et al. (1999) proposed a remanufacturing-focused CLSC model that focused on the location of remanufacturing/distribution facilities, the trans-shipment, production, and stocking of the optimal quantities of remanufactured products, and managerial decisions.

[Table 2 here]

According to Mata-Lima et al. (2013) the dimensions of the sustainability triangle comprise social, economic and environmental aspects linked with technology. Considering these dimensions, papers on both OLND and CLND were analyzed for which dimension they covered. Fig. 8 shows the coverage of sustainability dimensions in the network-design studies. It was found that the economic dimension was given the highest priority in designing the networks, whereas social and environmental issues are poorly addressed along with the technological aspect. Only three studies were found that considered economic, social and environmental dimensions all together.

[Fig. 8. here]

Another important aspect in network designing is the consideration of uncertainty. Fig. 9 shows the percentage of different uncertainty parameters considered in the network-design studies. The return amount (28%) was found to be one of the most used uncertainty parameters in designing networks whereas environmental influence, source and reliability of capacities were considered relatively less (only 3%).

[Fig. 9. here]

3.1.3 Analyzing third-party reverse-logistics provider (3PRLP) selection

The concept of 3PRLP was introduced after the successful experience from third-party logistics (3PL) in the forward supply chain. Krumwiede and Sheu (2002) was one of the first papers that studied flexibility of transportation activities. It showed that 3PRLP plays a significant role by taking back obsolete items from customers/end-users in implementing EPR principles (Mahmoudzadeh et al., 2013). In this study, out of the 155 papers (in the main research areas), only 11 papers focused on the 3PRLP problem; they are discussed in this subsection of the paper.

Sabtu et al. (2015) presented a study to find influential attributes for selecting and evaluating 3PRLP. They found that the organization role was the most significant attribute that intensified the total logistic provider's performance. Xuping et al. (2013) investigated the relationship between production enterprises and 3PRLP. They found that 3PRLP's environmental protection ability and effort level towards working with asymmetric information under the constraints determines the financial incentive for recycling. Atasu et al. (2013) developed a mathematical model to investigate the impact of the collection cost structure on the optimal reverse-channel choice of manufacturers who have the ability to shape the sales of retailers, and collection quantity (in the case that manufacturers remanufacture their own products).

Wei and Zhao (2013) investigated the decisions of reverse-channel choice in a fuzzy CLSC environment where a manufacturer, a retailer, and a third party collect used products for profit in three different collection modes. The authors considered the demand, manufacturing cost and collecting cost are fuzzy rather than stochastic or deterministic. Hong and Yeh (2012) developed a retailer-non retailer collection model for profit maximization. In the retailer-based collection model, a manufacturer cooperated with a third-party to collect the used product from customers, and in a non-retailer case, a third-party company is commissioned by the manufacturer for collection activities. The research found that when the return rate, manufacturer's profits, and channel members' total profit were considered, non-retailer based collection performs better than the other. However, if the third-party firm is a not-for-profit organization working for recycling and disposal, then retailer-based collection outperforms.

Sasikumar and Haq (2011) designed an optimized multi-echelon, multi-product closed-loop distribution supply chain (CLDSC) network integrating the issue of selecting the best 3PRLP in order to achieve efficiency in cost and an optimum delivery schedule. Results of the study showed that cost reduction from CLDSC could be achieved by optimizing the cost of the forward-distribution channel. Cheng and Lee (2010) developed a decision-making approach for practitioners of RL in industrial marketing on outsourcing of 3PRL for the thin-film-transistor liquid-crystal display (TFT-LCD) sector in Taiwan. The authors found that information technology (IT) management is an essential activity in outsourcing (in terms of accommodating return) and this task can be performed better by 3PRLP than the manufacturers of TFT-LCDs. Kannan (2009) proposed a structured model for evaluating and selecting the best 3PRLP under a fuzzy environment for the battery industry by formulating the problem as MCDM which was solved by the AHP and fuzzy analytic hierarchy process (FAHP).

Yuksel (2009) developed a WEEE collection-center location model for 3PRLP considering three factors - cost, accessibility and environment using the AHP method. The model evaluated the existing locations of the centers in Turkey then compared with the best alternatives. Xanthopoulos and Iakovou (2009) proposed a methodology that aimed to integrate optimal designing of disassembly processes and aggregate planning of the recovery processes for WEEE. In the study, a simulation was implemented for capturing uncertainties in RL operations. The overall objective of the methodology was to recover both ecological and economic value from the recovered WEEE items, and thus reduce the produced quantities of WEEE. This methodology provided effective decision support to mid-level management involved in resource recovery. Xu (2008) introduced a WEEE take-back information platform based on the Electronic Product Code (EPC) that allowed involvement of various agents in the RSC for information sharing and to measure the responsibility and efficiency of the 3PRLPs in the take-back system.

3.1.4 Vehicle routing problem (VRP)

Based on combinatorial optimization and IP, the vehicle routing problem (VRP) typically seeks the optimum set of routes in a network for vehicle fleets delivering goods or services to a given set of customers at minimum cost (Dantzig and Ramser, 1959). In the conventional FSC, vast number of papers were published, however, in the RL/CLSC literature, this topic should be considered as new. In this subsection the papers are summarized.

Mar-Ortiz et al. (2013) designed a Greedy Randomized Adaptive Searching Procedure (GRASP) algorithm to determine the collection capacity and processing time of a fixed and heterogeneous fleet of vehicles with special features that were generally used in the collection of WEEE from customers. Mar-Ortiz et al. (2012) developed an algorithm to optimize emerging waste-white-goods collection systems with three different manufacturing interfaces: network design, vehicle routing and cellular disassembly. Mar-Ortiz et al. (2011) proposed a facility-location oriented collection vehicle routing model to evaluate the overall performance of collection routes and to optimize a recovery network (RN) in Spain. The authors redesigned the recovery network and reduced the number of vehicles and the depot size required in the collection route.

Gamberini et al. (2010) presented a WEEE transportation-optimization network model that considered both technical (in terms of saturation of vehicle capacity, the utilization of vehicle working times) and environmental performance. Manzini (2011) proposed a model that integrated VR and the allocation of customer demand (according to suppliers) under various modes of transportation. Both cost and environmental effects minimization were considered in the model that supported decision making in transport planning. Gallo et al. (2010) proposed a methodology to analyze the processing time at collection centers to treatment centers combining VR. The research identified efficiency parameters in waste recovery from the customer at the collection center and reprocessing center, for recycling that quantifies the current trend of WEEE flows. Guerra et al. (2009) described a logical model of VRP that analyzed the WEEE distribution flow that consisted of the number of vehicles allocated within a region in Italy and the minimum intervention time required at the collection centers. The research explored different network configurations and scenarios without imposing high costs, which was achieved by information on the number of vehicles to be adopted in the network.

Kim et al. (2009) presented a VR model in order to minimize the transport distance from WEEE CCs (of local authorities) and distribution centers of major manufacturers to four regional recycling centers located in Korea. Fernández et al. (2006) presented a recycling-focused RSC model concerned with the optimum amount of waste mobile phones to be collected to guarantee the supply of waste for recycling companies. In this VR problem, they considered: 1) the locations of the central and transfer stations, 2) the limited capacity in the VR and 3) the presence of multiple depots in the network. They found that in long-term planning, if a centralized recycling facility is considered in a network it will not be profitable.

3.2 Analyzing the decision-making and performance-evaluation studies

A vast area of research in the RL/CLSC of WEEE focuses on decision making and performance evaluation of the RL/CLSC processes (see Fig. 1) and networks (including transportation), the economic and environmental performance of organizations and businesses and WEEE management. Product acquisition, collection, inspection and sorting, and disposition (i.e. recycling, reuse, repair, remanufacturing and disposal) are the major RL/CLSC processes (Agrawal et al., 2015). The papers are summarized in Table 3.

[Table 3 here]

3.3 Analyzing conceptual framework studies

Due to the complexity of EOL product characteristics and the involvement of many different actors in RL/CLSC, new research areas were interlinked by researchers from various disciplines. These studies generally try to consider new approaches, conceptual modeling and interconnected ideas that emphasize the importance of product-specific RL/CLSC activities. Some of the studies that used a conceptual framework are described in this section.

3.3.1 RL/CLSC system and/or process focused studies

Pimentel et al. (2013) proposed a conceptual model for developing an RL system in Brazil. Funding, system cost and development requirements for the WEEE recycler's certification were the major components of the model. From an Asian perspective, Chong et al. (2014) developed a conceptual mathematical model to assess the amount of profit from reselling refurbished computers and components to cover the overall expenses of an EOL computer RL system in Malaysia. Shi et al. (2012) developed a model based on a framework of industrial information integration engineering that focused on application of enterprise systems or e-business systems in the RL process of used batteries, investigating the information flows that can be implemented in designing an RL system.

3.3.1.1 Remanufacturing

El korchi and Millet (2011) introduced a framework that allowed generation of alternative structures that have less environmental impact and higher economic benefits in RL, with a remanufacturing focus. The authors found that the location of treatment facilities was the key performance indicator of a remanufacturing system when integrated-product forward logistics and reverse-logistics channel-design decisions need to be made. Van Wassenhove and Zikopoulos (2010) developed a conceptual mathematical model to estimate the grading errors occurring because of overestimation of the quality of a returned product that affects the optimal procurement decisions of a remanufacturer. Robotis et al. (2005) studied the characteristics of remanufacturing as a tool to develop a secondary market from a reseller's perspective by developing a conceptual mathematical model. For mobile phones, the authors found that, based on the technology and competition in a market, adding value by remanufacturing and making the used products more attractive to customers can increase resellers' profits significantly. This way resellers could manage their inventory to serve a secondary market and take important procurement decisions.

3.3.1.2 Repair

Landers et al. (2000) developed a conceptual framework of a virtual-warehousing (VW) model for real-time global visibility of logistics assets such as inventory and vehicles. With a case study of a mobile phone company's effort the authors found that VW had a significant contribution to repair service when considering transportation, labor costs and service times.

3.3.1.3 Reuse

Geyer and Doctori Blass (2010) developed a conceptual and descriptive model that summarized the exiting business model of mobile collection, reuse and recycling in the USA. They found that the incentives given to the manufacturers and refurbishers were not aligned with the environmental-performance-examining reuse case.

3.3.1.4 Recycling

Li et al. (2010) presented a descriptive multi-level management model to establish an RL coordination mechanism among Chinese recycling companies in order to internalize the externalities of recycling, such as air and land pollution, which were often not taken into consideration by the policy makers. With the management model, the role and responsibilities of the government departments and manufacturers were highlighted, achieving larger profit from material recovery by WEEE recycling. Walther et al. (2008) developed a conceptual mathematical model using LP. Furthermore, the concept of a negotiation approach was implemented into the programing via Lagrangian relaxation and sub-gradient optimization. In the model, a coordination mechanism was established between one primary recycling company and a group of other recyclers in a recycling network who must meet the obligations of environmental legislation.

3.3.1.5 Regulatory-instrument focused WEEE management

Camgöz-Akdag and Aksoy (2014) initiated a conceptual model for WEEE management considering green-supply-chain management. Limited information from the manufacturing firms, finding available data about the outcomes of the system, and the reluctance of firms to share information were found to be major difficulties in implementing a legislation-driven RL system.

3.3.1.6 Organizational perspective

Lei and Qu (2011) analyzed obstacles, necessity, risks and functional modules of an information-sharing platform in a virtual symbiotic network that allowed WEEE reverse-logistics stakeholders (i.e. member enterprises) to realize effective communication among the members. They found that, if information flow is utilized effectively, an enterprise's profit, environment benefits and social efficiency could be attained. Atasu and Souza (2013) presented a conceptual deterministic-monopoly demand-model in order to understand the trade-offs in product recovery that affect a company's choice (i.e. optimal quality and pricing choices when compared with the benchmark scenario without PR). The authors found that, depending on the form of PR, product quality choice can be better or decline, while product take-back legislation can induce an enhancement in quality choice by firms. In addition, it was found that EOL product can be collected either by a retailer collection channel or by the original OEMs. Savaskan and Van Wassenhove (2006) developed a model that focused on the interaction of the manufacturer's choice of collecting small consumer items such as waste single-use cameras and mobile phones, and strategic product pricing decisions when retailing is competitive.

At present, electronics manufacturers are attempting to create an image of corporate citizenship that reflects their effort to deliver environment-friendly products to customers. Guide and Wassenhove (2001) developed a conceptual analytical framework to analyze the profitability of reuse activities and PR management of the firms that influence the operational requirement of business decisions (i.e. acquisition price and the nominal quality of the returned product) in the product-acquisition process. The authors found that product acquisition was the control lever of an EOL PR system, and in reuse activities profitability was a real concern for the firm.

3.3.1.7 Formal and informal sector

Ghisolfi et al. (2017) developed a model on social inclusion of informal waste pickers into the environmental policy in the RSC in Brazil. The authors found that, for developing such a system, environmental policy should be restructured according to the country-specific WEEE management agenda, with a high collection rate of used products, robust infrastructure, technology, supply of skilled labor and increase demand for recycled products. Liu et al. (2016) proposed a quality-based price competition model for PR in a dual-channel environment (informal and formal sector recycling). During product acquisition, quality is the single most important factor in determining the acquisition price of returned product for both sectors. In addition, they found that the acquisition price is an important factor in a competitive recycling market. When the government subsidy is low, the informal sector is at the forefront in collecting WEEE, while the formal sector has limited penetration in the market for PR. They suggested that the controlling authority should re-adjust the subsidy level for the informal sector and that the sector should only be considered for refurbishing activities.

3.3.1.8 Product return

Srivastava, Samir K. (2008) proposed a model considering the strategic, operational and customer-service constraints of product returns in the Indian context. Zikopoulos and Tagaras (2007) developed a mathematical model considering RSC that consisted of two collection sites and one refurbishing site that confronted a stochastic demand for refurbished products in a single-period setting. With the model, the authors investigated the impact of uncertainty in an inventory management scenario, when the returned product's (e.g. computers, printers and mobile phones) quality affected the system profitability. With a conceptual framework based on the Maximum Expected Utility (MEU) principle, Parlikad and McFarlane (2007) showed that the availability of product-specific information has a positive impact on PR. The authors also found that Radio-frequency identification (RFID) was an efficient product identification technology that provided efficiency in PR decisions.

3.3.1.9 Others

Developing countries have already received an opportunity to get carbon credit from developed countries under the Clean Development Mechanism (CDM). Research conducted by Caiado et al. (2017) found that WEEE is one of the growing waste streams in developing countries, and with the novel concept of RL carbon credit, developing countries could develop WEEE recycling and disposal infrastructure. Xu et al. (2017) designed a conceptual global reverse-supply-chain (GRSC) model using MILP for WEEE recovery and recycling under various uncertainties (transportation costs and currency exchange rates) and carbon emission constraints, considering transboundary movement of WEEE from Greece to China.

3.4 Analyzing the qualitative studies

Due to a growing environmental concern evolved in customers, industry practitioners and government agencies in product disposal and subsequent operations (i.e. in the RL and CLSC processes), there is a necessity to identify how customers behave to specific actions taken at regional level across the globe. Customers play significant role in RL dispositions (Shumon et al., 2014). The topic regarding the level of awareness towards WEEE and the behavior to dispose of it appropriately by customers received attention among researchers in shaping RL/CLSC processes. Overall, in this study qualitative refers to the studies conducted via in-depth interviews and surveys, where the respondents were customers, companies, and other stakeholders/actors associated in the WEEE RL/CLSC activities. This specific study type can lead to new theory development via practical understanding and knowledge (Govindan et al., 2015).

Jafari et al. (2017) the investigated factors affecting a resident's behavior in returning WEEE and participating in RL activities in Iran. The authors conducted a questionnaire survey followed by a statistical analysis with logistic regression using Minitab and SPSSS. In the research, a consumer's incentive dependency towards WEEE recycling was characterized, and it was found that household income, household size, education and marital status were important factors in planning formal RL efforts taken by the government. Besides, government's support in incentives and awareness building programs was found to be crucial for the success of shaping attitudes towards WEEE recycling. Public perception is an important factor in developing an RL model. For example, Cao et al. (2016) estimated the generation of WEEE, as well as public perception and opinion on WEEE management, via material flow analysis (MFA). In regions where WEEE-related data are incomplete, conducting a survey was found to be essential to overcome the limitation. The researchers employed a public survey of 1215 respondents to model an RSC for Zhejiang Province in China. They found that in the province people are more inclined to recycle their WEEE items through informal WEEE recyclers.

Recycling was previously analyzed from manufacturers' and suppliers' point of view, however Gonul Kochan et al. (2016) reported that the customer perspective in recycling was analyzed for the first time in their research that implies a holistic approach to develop a RL model. To assess recycling behavior in line with the Theory of Reasoned Action (TRA), the authors surveyed 327 university students. Structural-equation modeling was utilized for analysis and they found that attitudes and moral norms act as driving forces in WEEE recycling. Perceived convenience was also considered as an important factor that creates more involvement in the process.

Dixit and Badgaiyan (2016) found that perceived behavioral control, subjective norms, moral norms and willingness to sacrifice unused items act as antecedents to the return behavior of customers returning their waste mobile phones. For analysis, the authors constructed a structural-equation model where the Theory of Planned Behavior (TPB) was implemented. The authors urged that government and non-government organizations (NGOs) have a great impact in changing the social views and attitudes of customers, which may have a positive impact on WEEE RL processes. Disposal behavior can positively influence the increased level of return, which can be capitalized on by RL managers in acquiring more WEEE from customers.

Demajorovic et al. (2016) conducted an exploratory qualitative research to identify major challenges and barriers to implementing an RL model for computers and mobile phones in Brazil. The technological gap in recycling industries, the country's contexts, taxation challenges and conflicts between waste picker organizations and the industry were found as the major challenges in developing a sustainable RL system. Dixit and Vaish (2013) examined the impact of demographic variables, namely age, gender, income and place of residence, on post-consumption disposal choices of urban Indian consumers for their mobile wastes in identifying the antecedents of consumer behavior that act to develop an effective RL system.

Hanafi et al. (2013) identified three performance indicators of a waste mobile-phone collection pilot project in Indonesia, namely participation rate, return rate, and cost. The authors found that, even though a formal recycling channel was created in the city of Jakarta, customers still felt reluctant to participate in the program because of the high presence of informal-sector WEEE recycling. The performance of the WEEE project in the developing country's context can be boosted through increasing publicity and building partnerships among electronic retailer, government and telecommunication companies. Agarwal et al. (2012) studied the customer return behavior of WEEE items at different financial incentive levels and attempted to incorporate the latest practices into their research. Initial data collection was done by a sample survey. By developing an optimization model using particle-swarm optimization (PSO) algorithms and the simulation package ARENA, they identified that product and component reliability were critical in developing a customer incentives policy.

Based on survey questionnaires for Taiwan's electronics industry Chiou et al. (2012), identified factors of RL implementation - environmental regulations and directives, consumer's environmental awareness, competition among stakeholders. The factors were ranked using the FAHP method with a focus on environmental management. Kissling et al. (2012) illustrated a definition of a typological operating model of reuse focusing on two WEEE items, namely Information and Communication Technologies (ICT) equipment and whitegoods, considering four dimensions of reuse structure: supply chain, offer, customers and finance. The authors developed the model to understand the complex structure and dynamics of the reuse sector in Latin America, Africa, North America and Europe, thus providing a concise description of reuse activities and outcomes in the continents.

Lee et al. (2007) investigated the perception gap of RL service quality for the mobile-phone industry in Taiwan using a PZB model, which generally identifies the gaps between the service-quality expectation of customers and an organization's performance on service quality. Accurate pricing, motivation towards high recycling, free-of-charge product upgrading within warranty period, convenient location for product return and exchange, free repairing, and finally post-repair notice were found to be crucial for a mobile-phone RL service model. Hung Lau and Wang (2009) investigated whether the Chinese electronics industry is performing RL activities according to the current RL theories and models, mainly with the focus of promotion of corporate image, fulfillment of obligation for environment protection, and improvement of customer service. The authors found that low public awareness on environmental protection, underdevelopment of recycling technologies and lack of enforceable regulations were the critical barriers for RL implementation.

Queiruga et al. (2008) evaluated the appropriateness of the WEEE recycling sites in Spain using a discrete MCDM method- PROMETHEE (Preference Ranking Organization METHod for Enrichment Evaluations). The factors that were considered for selecting plant site locations were economic objectives (e.g. land cost, personnel costs, energy price), Infrastructural objectives (e.g. facility access, agglomeration effects, proximity to inhabited areas, absence of other WEEE recycling plants and availability of labor) and legal objectives (e.g. availability of a local waste-processing program and environmental grant). Autry et al. (2001) investigated RL performance and satisfaction from a catalog retailing perspective which were influenced by sales volume, firm size, customers' satisfaction and disposition. The performance had an impact on the sales volume, while industry effects (e.g. market structure) significantly impacted satisfaction. On the other hand, the location of the responsibility for disposition had no significant impact on performance and satisfaction.

4. Analysis of research gap and future research directions

Several issues were identified as potential research avenues for the future. The above description and detailed analysis of the articles created a comprehensive knowledge base on the overall RL/CLSC of WEEE sector. After careful consideration, research gaps were identified and future research directions are given as below:

- Even though both RL and CLSC research focusing on WEEE is increasing over the years, there is a lack in progress of the CLSC network design. A more integrated approach, considering both the FL and RL of WEEE is required. Although a few studies were conducted in the CLSC area, most of them were based on a generic framework, and often the authors of the articles urged for more empirical research based on real-world scenarios.

- Among the main research fields in the studies, the designing and planning of reverse distribution is the most researched topic, as it contains some of the critical topics such as open-loop and closed-loop network design. Future researchers should consider conducting qualitative research in the field. Qualitative, especially survey-based, research provides an in-depth understanding of the practical problems that lead to theory development (Govindan et al., 2015). In addition, there is a serious lack of specifying the source of WEEE generation, which should be included in designing the RL network. Generally, WEEE generation is characterized by three types of sources – households, government organizations and institutions, and the business sector. Source specific WEEE RL network design could provide valuable policy implications for responsible authorities managing their RL network with better economic and environmental performance. This was also evident from Fig. 9 when considering source as one of the uncertainties in network designing.

- In the OLND, recycling is the most important disposition considered by the articles, however, there is a scope for future researchers to consider recycling in CLSC networks (using coordinated approach with other firms using secondary raw materials), where economic efficiency, environmental cost and environmental impacts need to be included in the objective functions of RL modeling. Furthermore, there is a need for investigation of other alternatives – reuse and repair in the network. No single research was found that considered recycling, remanufacturing, reuse and repair in an integrated manner. On the other hand, MILP was the most utilized modeling approach, with alternatively stochastic and fuzzy programing approaches. However in future, when MILP/MIP is being utilized, strategic management, environment legislation, customer service, and asset management can be included as modeling objectives for RL network design. In real-world scenarios, a number of complex and uncertain variables may arise in computation. When the number of variables and constraints increases in modeling, meta-heuristic algorithms like GA or heuristic integer programing, for instance a scatter search, can be implemented (Amin and Zhang, 2012). In collaborative planning, application of GP in CLSC network modeling could be an interesting research (Gupta and Evans, 2009). In addition, for better computational performance in algorithm-based research, heuristic, meta-heuristic, approximations and a sampling-based solution approach can be employed for a large number of scenario-based problems. EOL product management from the RL/CLSC perspective is scarce in the literature. In developing models, decomposition and heuristic approaches can be implemented for this particular field. To improve the reusability and recyclability of WEEE, the eco-design concept has the potential to integrate into RL/CLSC network design. Additionally, simulation-based collection processes in an RL network should be considered for research in the area of DPRD studies.

- There is a clear deficit of implementing a multi-level and/or multi-objective and/or multi-period modeling approach in RL networks. Tactical objectives such as return forecasting, product return handling and aggregate production planning; and operational level objectives, for instance vehicle planning and scheduling, optimal disassembly sequences of remanufacturing processes, should be included more in modeling open-loop RL networks. Moreover, multi-period nondeterministic modeling in WEEE product recovery networks needs further investigation. Likewise, inventory management of CLSC networks along with strategic safety stocks of RL considering remanufacturing in particular, is another research direction. Multi-objective programing considering risks and resource savings should be included in RL network modeling.

- In terms of uncertainty, the cost of remanufacturing/recycling, the price of remanufactured product, revenue, volume of return (quantity), time of returns, quality, capacity of facilities (e.g. treatment, recycling, remanufacturing), WEEE generation rate (location specific), the market need/demand for recycled products should be introduced in RL network models. In particular, the product return rate in multi-period CLSC networks with an interaction of demand could be an interesting topic of research in future. In addition, the price of remanufactured product based on market demand is another research area in WEEE CLSC network design. Considering demand as probabilistic function can be included in modeling. Sensitivity analysis can be included in studies that deal with relatively low-volume products in terms of return (e.g. products with longer lifecycle). For products with a shorter lifecycle, fuzzy-set theories can be implemented. Uncertainty in the WEEE recycling network such as quantity in conjunction with transportation cost is a potential area of research. In addition, during development of RL network infrastructure, strategic planning tools, such as balanced scorecard, and simulation tools can be implemented when such uncertainties arise. Environmental influence and supplier selection are two less considered uncertainty parameters (shown in Fig. 9.) in network modeling that could be an interesting topic for future research.

- From Fig. 8, it is clear that sustainability dimensions – social, economic and environmental - were considered by very few articles (only 3 papers), whereas economic issues (e.g. cost, price, revenue etc.) were the most prominent dimensions (considered by 76% of the papers). It will be interesting if another new dimension – technology under the sustainability context - is considered. This could provide a more holistic insight of the RL/CLSC system itself as well as achieving an overall goal of sustainable development. Specifically, the impact of RFID and ICT-based network support systems, for inventory management and product-recovery information management system development, could be a new area of research in this context. This might provide better information flow among all actors. As social sustainability saw less research, new parameters under this criteria, such as public health and safety, can be included in developing the RL network model using a game-theory method where the preferences and participation of customers and government as actors can be included in models. Another important perspective that needs further research is customer participation in determining recycling fees and quantity generation in an RL system, creating a competitive EEE market.

- Further research should be carried out in the area of 3PRLP selection and VRP. In the first area, large-scale empirical studies with multi-WEEE product scenarios should be initiated. On the other hand, in 3PRLP studies, reverse channel choice by small and large companies according to profits and cost were the highest priority in the past. However, there is a lack of study in developing a comprehensive framework under which several RL processes such as product acquisition, repair, reuse and remanufacturing need to be performed by 3PRLP. Furthermore, the impact of legislative initiatives on the performance of 3PRLP considering all sustainability dimensions needs further investigation. In addition, the negative impact of 3PRLP inclusion by OEMs and the interaction of small companies in a sustainable CLSC system should be investigated, rather than only RL operation. The collaboration between small and large companies in RL management, in other words outsourcing, should be a future research topic. As limited research was conducted in vehicle routing, one of the research directions could be to observe the impact of disassembly systems in vehicle routing. The environmental performance of vehicle routing, for instance reduction of CO_2 emission with distances during transportation and collection, was a less-researched topic. Classical vehicle routing problems can use Tabu search and scatter search with sensitivity analysis for holistic analysis of a specific problem. Routing design is often concerned with the length and number of tours, and can be solved by implementing GRASP and MIP or even a global information system (GIS) system.

- In the category of decision making and performance evaluation, the product lifecycle perspective received less attention among the researchers. RL processes such as disassembly and inspection demand environmentally and economically optimum product design, by which both time and cost in the overall RL system could be saved and/or minimized. As seen earlier, most of the articles were concerned with the economic aspects of the RL and CLSC of WEEE. However, when considering environmental aspects, there is a need to consider the use of two specific modeling techniques: LCA and MFA. A limited number of papers considered these approaches, and future researchers should consider them. From the circular-economy and efficient-resource-utilization perspectives, which top management of recycling and remanufacturing firms struggle to consider, using these tools (LCA and MFA) could tremendously assist in minimizing the total cost and maximizing the environmental performance of the RL and CLSC process. These tools are also able to provide valuable information on the available critical raw materials that can be recovered, and potential mitigation of greenhouse gas/CO_2 emission (as a measure of environmental performance) for efficient and effective RL operations. Moreover, the impact of uncertainty parameters, such as the capacity level in facilities, cost and collection rate, on the lifecycle performance in a CLSC environment could be the most promising research direction for the future.

- In the conceptual-framework based studies, relatively less attention was given to RL processes - reuse and repair. The impact of these two alternatives on overall RL management organized by manufacturers could be interesting future research direction. For the case of recycling, there is a need for open-sourced online-based market information system that can determine the recycling fees of a product in an RL system where WEEE would be collected by OEMs or by recycling firms. In addition, research could be considering the impact of regulatory instruments such as EPR, with the interaction of the formal and informal sectors on WEEE collection and recycling.

- Disposal rate (frequency), type of WEEE items disposed, average lifetime of disposed product, storage time, customer awareness, willingness to pay (WTP), top-management attitude (from company's perspective) are some of the critical issues that need to be addressed at a regional level to develop sustainable RL/CLSC systems. In such a context, qualitative studies could be a successful research methodology which needs further implementation.

- There is a lack of product/case-specific WEEE RL network modeling initiatives among the studies. Future research should consider more product-oriented studies such as for waste batteries, IT equipment (e.g. laptop computers, printers, cell phones, telephones, personal digital assistant products (PDAs), ipads, and tablets), small consumer electronics (e.g. portable music-players, toys) and whitegoods. Computer waste recycling, reuse and remanufacturing (in an integrated manner) based RL/CLSC networks should have particular attention.

- Finally, future researchers should envision utilizing the concept of circular economy in developing infrastructure and formulating sustainable RL/CLSC activities at national level. Current body of literature often fails to collaborate these issues. As the WEEE generation is growing exponentially to almost every country in the world, the integrated understanding of sustainability, circular economy and CLSC from supply-chain management perspective is an important research avenue to explore.

5. Conclusion

This review paper focused on identifying and analyzing the main areas/research types in the field of RL/CLSC with a particular EOL product - WEEE or E-waste - which is one of the fastest-growing streams due to a shorter product life and a rapid disposal pattern. Although papers were published considering WEEE as an EOL product in the RL/CLSC area, often discussion on the product is scattered. No single review on this broad topic was performed. To bridge this gap, a detailed clarification and categorization of the selected body of literature is provided through this study. With the aid of content analysis, the study provides a state-of-the-art overview and broad picture of the numerous dimensions involved in WEEE RL/CLSC research in the past eighteen years. With extensive search criteria, 155 papers were selected and reviewed that were published in the international peer-reviewed journals, conference proceedings, and book chapters during the period 1999-2017 in four major research types namely, designing and planning of reverse distribution, decision making and performance evaluation, conceptual framework, and qualitative studies. After reviewing, several research gaps were identified with important implications for future research. The authors think that this review provides a holistic overview of the whole system perspective on the research field, and identifying key future research directions would be useful for researchers. The categorizations and citied references may be utilized as a broad frame of references to advance concepts and models for the future research. There are also potential ways of improving this review article itself. Taking a higher number of research articles from grey sources, such as company reports, annual reports, white papers and online sources could enrich the content. Another improvement could be categorization of contents by geographical locations, qualitative vs. quantitative approaches and different modeling approaches and solution methodologies.

Acknowledgement

The authors would like to thank Dr Keith Imrie for proof-reading this paper.

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Figure(s)

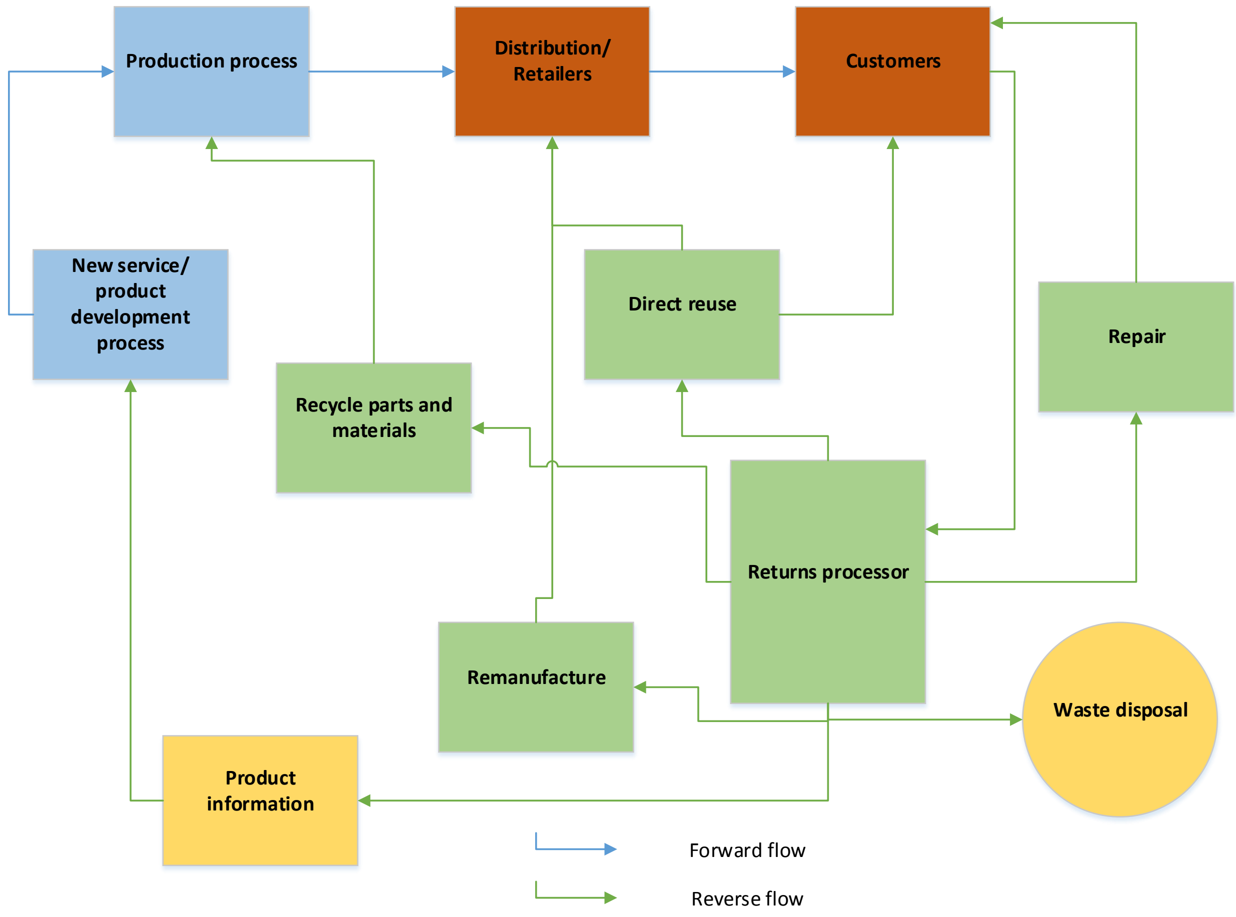

Fig. 1. Generic diagram of CLSC including forward and reverse flow, adapted from Chopra and Meindl (2007)

Fig. 2. Number of papers published in journals, conferences and book chapters

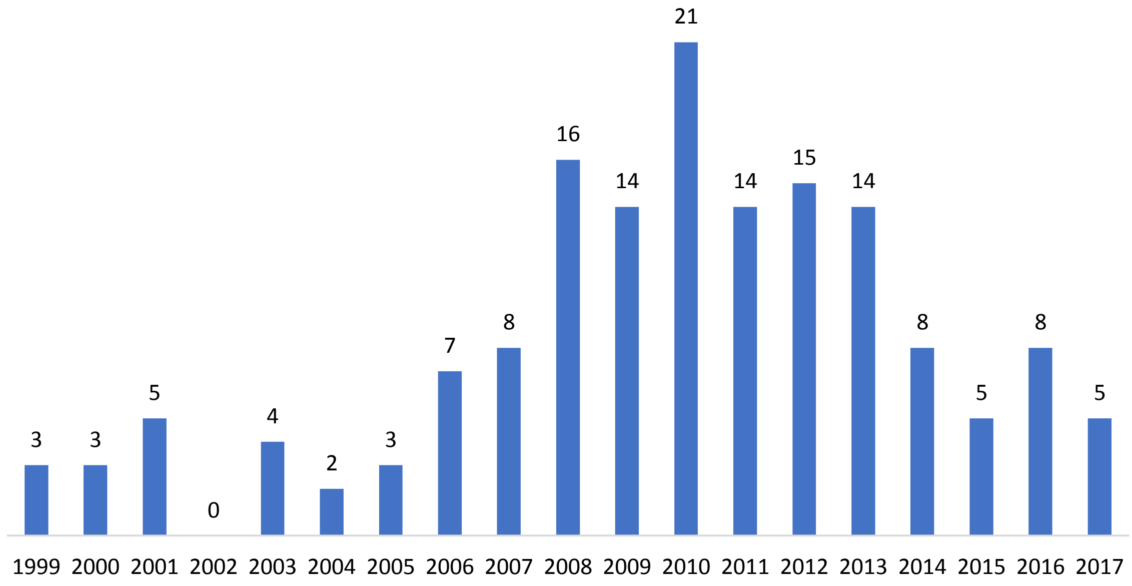

Fig. 3. Annual distribution of the published papers (155 papers: 1999-2017)

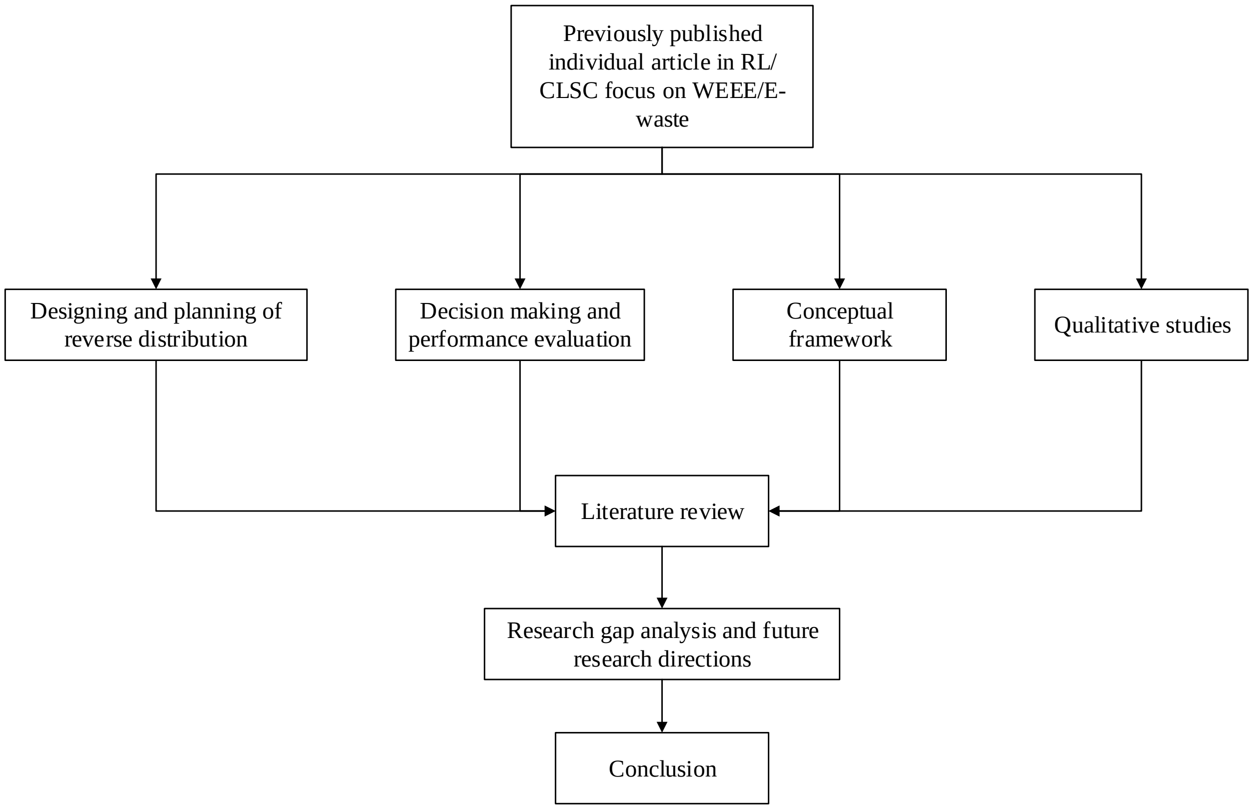

Fig. 4. Categorization and research framework of the studies

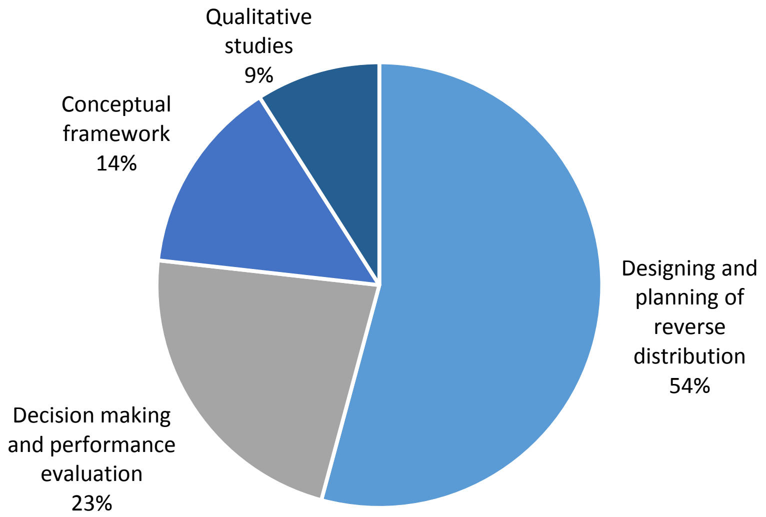

Fig. 5. Distribution of research articles for different categories

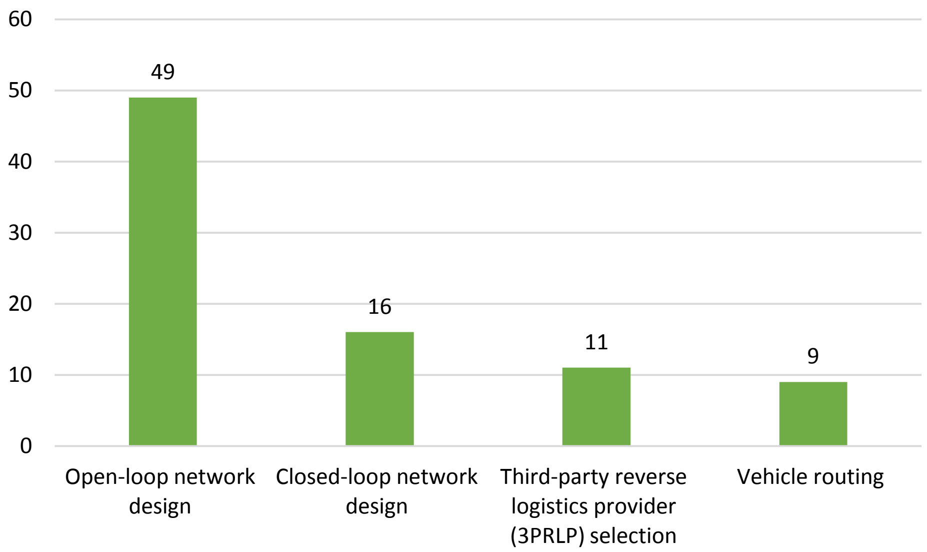

Fig. 6. Number of articles published on DPRL

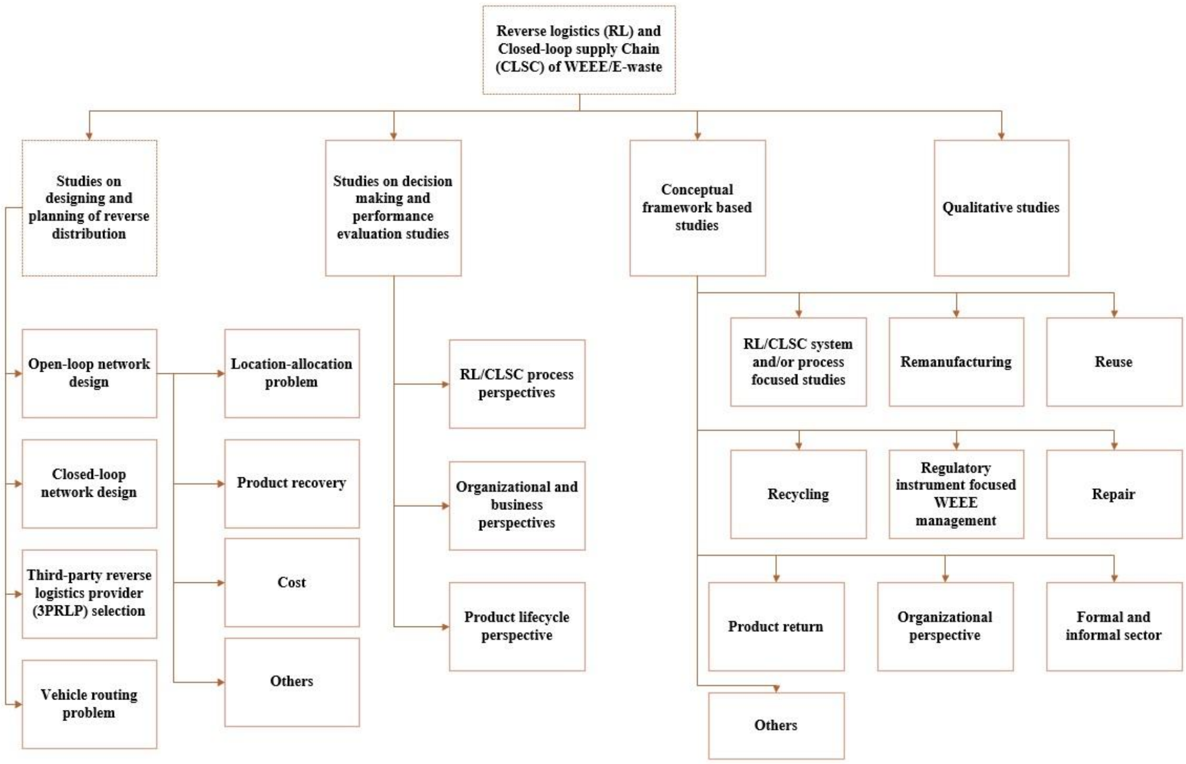

Fig. 7. Issues of the main research fields of RL/CLSC of WEEE

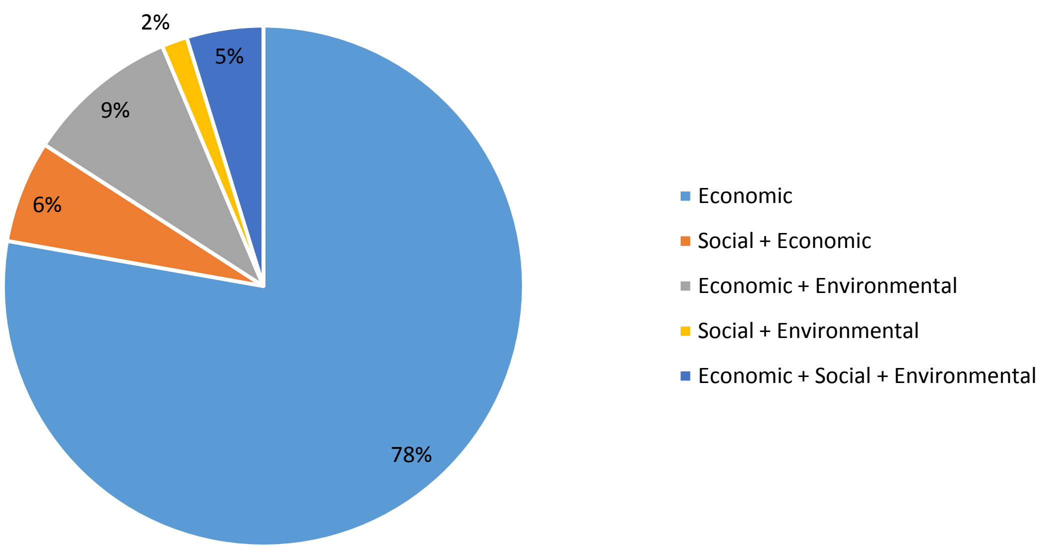

Fig. 8. Sustainability dimensions considered in open-loop and closed-loop network-design studies

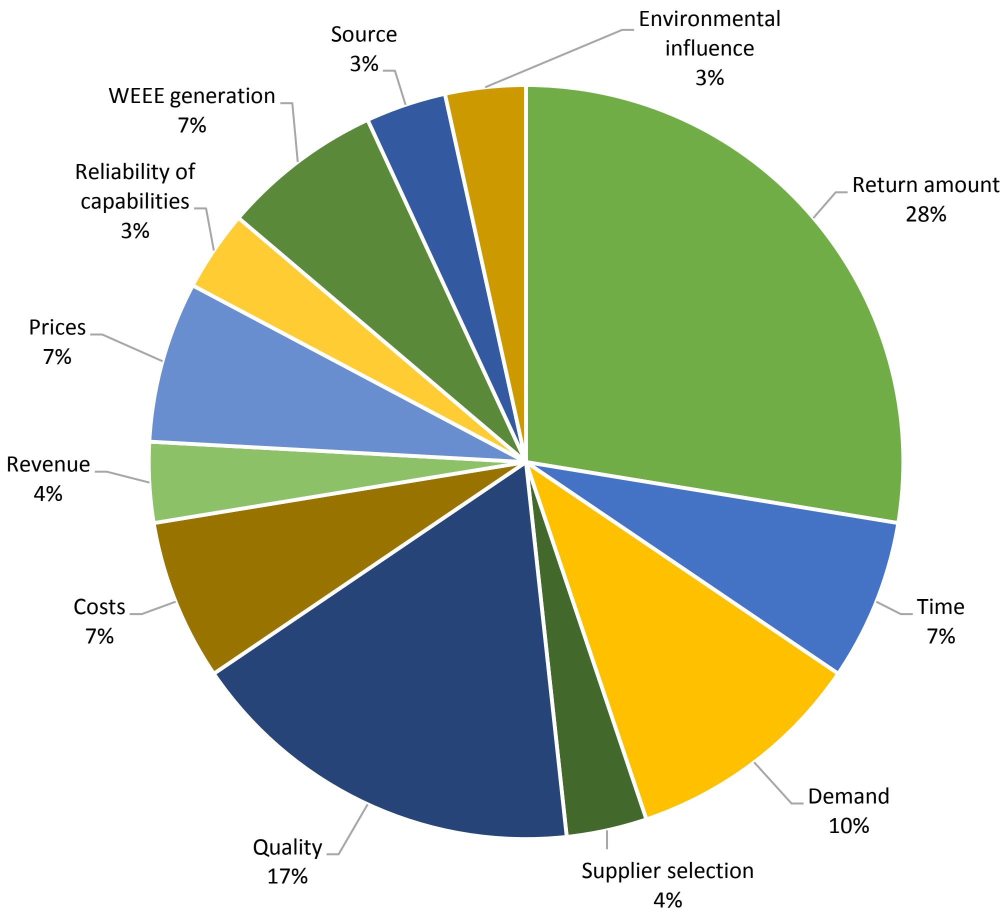

Fig. 9. Uncertainty parameters in RL/CLSC WEEE network designs

Table(s)

Table 1: Summary of the WEEE/E-waste OLND studies

Reference	**Model focus**	**Objective functions**	**Uncertainties/ constraints considered in the model**	**Utilized modeling approach**	**Solved by**	**Sustainability dimension considered**	**Country**
Shokouhyar and Aalirezaei (2017)	Facility location	-	-	Mathematical modeling	GA	Social, Economic and Environmental	Iran
Qiang and Zhou (2016)	Network design and optimization	Minimum cost of network operation	Quantity of recycled, reused and disposed WEEE	MILP	Simulation - LINGO	Economic	China
Yu and Solvang (2016)	Designing and planning of a generic multi-source, multi-echelon RL system	Cost and carbon emission	Generation of WEEE, price of recycled products, price of recycled materials, different sources of WEEE and the environmental influence	Stochastic – mixed-integer programming (MIP)	Sample average approximation method	Economic and environmental	Norway
Ayvaz et al. (2015)	Optimum locations for collecting, sorting and recycling centers	Profit maximization	Return quantity, sorting ratio (quality), and transportation	Stochastic programming	Sample average approximation method	Economic	Turkey

			cost				
Elbadrawy et al. (2015)	Facility location and material flow	Total Cost minimization	-	Mathematical modeling	GA	Economic	Egypt
Kilic et al. (2015)	Facility location and material flow	Profit maximization with minimum pollution	Returned product quantity	Stochastic-MILP	-	Economic and environmental	Turkey
Chong et al. (2014)	Facility location design	Profit from reselling of refurbished computers	-	Mathematical modeling	-	Economic	Malaysia
Ayvaz and Bolat (2014)	Whole network design	Cost minimization	Returned product quantity and quality	Stochastic programming	CPLEX	Economic	Turkey
Liu et al. (2014)	Evaluation of enterprise logistics capability standard	-	Quality of recycling products, recovery time	Multi-objective program using theory of constraints	LINDO, WITNESS	Economic	China
Shokohyar and Mansour (2013)	Designing and optimization of collection center locations and recycling plants	Maximum of profit and social benefits with minimum environmental impact	WEEE generation rate	MIP and simulation	Analytic hierarchy process (AHP) and Arena software	Social, economic and environmental	Iran
Yu and Solvang (2013)	Whole RL network design	Minimization of cost and greenhouse gas	-	Bi-objective MIP		Economic and social	Norway

		emission					
Xie et al. (2013)	Optimization of reuse RL network	-	-	-	ECA	Economic	China
Achillas et al. (2012)	Network design and optimization with transportation media focus	Cost and emission minimization	-	Multi-objectives LP	-	Economic and environmental	Greece
Dat et al. (2012)	Optimal facility locations and material flows	Minimizing total processing cost	-	A Mathematical Programming Language (AMPL)	CPLEX	Economic	Taiwan
Assavapokee and Wongthatsanekorn (2012)	Development of RL infrastructure	-	-	MIP and simulation	Statistical analyses	Economic	USA
Piplani and Saraswat (2012)	Design and optimization of service network	Minimization of the total cost	Number of returned products, percent of faulty products and warranty fraction	MILP	CPLEX	Economic	Singapore
Cao and Zhang (2011)	Optimal flow distribution of WEEE in an RL network	Maximization of total profit	-	Evolutionary algorithm – (non-dominated sorting genetic algorithm – NSGA)	The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)	Economic and Environmental	China

Wang et al. (2011)	Facility location	Optimum number of locations, capacities of collection spots and disposal stations at minimum disutility of consumer.	-	Multi-objective integer programing (IP)		Social and Economic	China
Bereketli et al. (2011)	WEEE treatment strategy	-	-	Multi-attribute group decision making model	Fuzzy linear programming technique for multidimensional analysis of preference (LINMAP)	Social and Economic	Turkey
Gomes et al. (2011)	WEEE recovery network	Minimize total network cost	-	MIP and General Algebraic Modeling System (GAMS)	CPLEX	Economic	Portugal
Tuzkaya et al. (2011)	Methodological development of RL network design	Alternative locations of centralized return center and cost minimization	Variation in expected return volume of WEEE	Integrated Analytic network process (ANP) and fuzzy-TOPSIS	GA	Economic	Turkey

Xianfeng et al. (2010)	Decision support for RL network design	-	-	LP	LINGO, Flexsim	Economic	China
Guo-jian Zhi et al. (2010)	Remanufacturing-based RL network design	Optimal location of collection centers, disassembly centers, returning centers and identification of optimum shipment path.	-	Mathematical modeling	GA	Economic	China
Choi and Fthenakis (2010)	Operational modeling of Photovoltaic (PV) recycling network	-	-	Mathematical modeling	-	Economic	USA
Gamberini et al. (2010)	Resource allocation and environmental impacts of WEEE transportation network	Necessary working days and minimum number of required vehicle for operation	-	Lifecycle assessment (LCA) modeling and simulation	SimaPro 6.0 and Simul8	Economic, environmental and Technical	Italy
Achillas et al. (2010)	Optimization of collection points and recycling facilities	Minimization of cost	-	MILP	CPLEX	Economic	Greece

Kawa and Golinska (2010)	Recovery network arrangement (RNA)	-	Recovery time and return quantity	Graph theory and agent technology	-	Economic	Poland
Hanqing (2009)	Recovery station locations for Third-party RL service provider	-	-	Mathematical modeling		Economic	China
Deng and Shao (2009)	Multi-product flow-based recycling network	Minimization of total cost	-	Analytical modeling	MATLAB	Economic	Taiwan
Guerra et al. (2009)	Vehicle analysis – number of vehicles to be allocated	Minimization of intervention time	-	Simulation	ARENA	Economic	Italy
Grunow and Gobbi (2009)	Optimization of locations of collection stations in an RL network	-	-	MILP	CPLEX	Economic	Denmark
Wang et al. (2008)	Optimization of the treatment and transfer station locations	Total cost, distances and WEEE amount to be transferred	-	Fuzzy multi-objective IP	LINGO	Economic	China
Shanshan and Kejing (2008)	Optimization of WEEE recycling network	Cost minimization	-	MILP	LINGO	Economic	China
Cagno et al. (2008)	Evaluation of the capacity and cost of the existing RL network	-	-	Analytical model	-	Economic	Italy
Lee and Dong	Location-	-	-	Two-stage	CPLEX	Economic	Singapore

(2008)	allocation of product recovery network			heuristic-deterministic programming			
Queiruga et al. (2008)	Performance evaluation of the recycling plant locations	-	-	MCDM-PROMETHEE	-	Economic	Spain
Rousis et al. (2008)	Determination of best WEEE management scenario (i.e recovery locations, network design)	-	-	MCDM-PROMETHEE	DECISION LAB software	Economic, social and environmental	Cyprus
Srivastava, Samir K. (2008)	Cost-efficient location–allocation of value recovery network (i.e. collection centers and rework facilities)	-	-	-	-	Economic	India
Wang and Yang (2007)	Designing Location and configuration of recycling network	Maximum utilization of resources and maximization of revenue	-	MILP	CPLEX	Economic	Taiwan
Kara et al. (2007)	Cost of RL network	-	-	Simulation	Arena software	Economic	Australia
Chang et al. (2006)	Location selection in RL network	Minimization of the total	-	MIP	LINGO	Economic	China

		cost					
Ahluwalia and Nema (2006)	Multi-objective optimization of RL network	Minimizing environmental risk and cost	-	ILP	-	Economic and environmental	India
Franke et al. (2006)	Remanufacturing capacities and production programs optimization	-	Quality, quantity, reliability of capacities, processing times, demand for remanufactured products	ILP	LINGO	Economic	Germany
Nagurney and Toyasaki (2005)	Development of recycling policy instruments for multi-tiered recycling network	-	-	-	FORTRAN based algorithm	-	USA
Shih (2001)	Optimization of infrastructure design and reverse network flow (Collection and recovery locations, resource allocations, material flows)	Minimization of total cost	Fixed cost and operation cost, and revenue from selling reclaimed material	MIP	-	Economic	Taiwan
Fleischmann et al. (2001)	Impact of product recovery on RL network and	-	-	MILP	CPLEX	Economic	The Netherlands

	facility location						
Sodhi and Reimer (2001)	Recycling network modeling	-	-	Non-linear mathematical programming	CPLEX and General algebraic modeling system (GAMS)	Economic	USA
Krikke et al. (1999)	Product recovery and remanufacturing	Minimization of total operational cost	-	MILP	-	Economic	The Netherlands
Nagel and Meyer (1999)	Aspects of RL, disassembly and recycling in EOL networks	-	-	LCA	Computer programs (Fortran, C, C++, Java)	Economic and environmental	Germany

Table 2: Summary of WEEE/E-waste closed-loop network-design studies

Reference	**Model focus**	**Objective functions**	**Uncertainties/constraints considered in the model**	**Utilized modeling approach**	**Solved by**	**Sustainability dimension considered**	**Country**
Chen et al. (2015)	Location allocation and product recycling	Maximization of recycling rate and profits	-	IP	GA	Economic	China
Amin and	Network	Minimization	Supplier selection process	Multi-	GAMS,	Economic	Canada

Zhang (2013)	configuration	of costs and defect rates, and maximization of weights, and on-time delivery	and demand	objective MILP	sensitivity analysis, fuzzy sets theory		
Qiang et al. (2013)	Network design	-	Demand and prices	Mathematical modeling	Continuous and convex algorithm	Economic	USA
Alumur et al. (2012)	Network design	Profit maximization	-	MILP	-	Economic	Germany
Amin and Zhang (2012)	Network optimization	Profit maximization	-	MILP	GAMS, sensitivity analysis	Economic	Canada
Krikke (2011)	Network optimization	-	-	-	Streamline LCA	Social and environmental	The Netherlands
Easwaran and Üster (2010)	Network design	Minimization of cost and optimum facility location	-	MILP	CPLEX and Benders' decomposition technique	Economic	USA
Kannan et al. (2010)	Network design with recycling focus	Minimizing total cost	-	MILP	GA and GAMS	Economic	India
Fernandes et al. (2010)	Network design and optimization	-	-	MILP	-	Economic	Portugal

Grant and Banomyong (2010)	Product recovery management	-	-	-	-	Economic	UK
Gupta and Evans (2009)	Operational design of CLSC network	Minimization of cost and maximization of profits	-	Non-preemptive GP	LINGO	Economic	USA
Chandiran and Surya Prakasa Rao (2008)	Network design	-	-	MILP	-	Economic	India
Chouinard et al. (2008)	Recovery network design	Minimizing cost	-	Stochastic programming	Monte Carlo sampling methods, Sample average approximation (SAA), CPLEX	Economic	Canada
Hammond and Beullens (2007)	Strategic planning of network	-	-	Extra-gradient non-LP	MATLAB	Economic and social	UK
Schultmann et al. (2003)	Network optimization	-	-	Simulation	-	Economic	Germany
Jayaraman et al. (1999)	Remanufacturing-focused network	Minimizes the total cost	-	MIP	GAMS, sensitivity	Economic	USA

	design				analysis		

Table 3: Summary of decision-making and performance-evaluation studies on RL/CLSC – WEEE/E-waste

Focus	**Authors**	**Method/modeling approach**	**Factors/Remarks**	**WEEE product**	**Country**
RL/CLSC process perspectives	Tari and Alumur (2014)	Multi-period multi-objective MIP	Facility Location, Equity and distribution, cost minimization, steady flow of WEEE, collection center capacity	Not specified	Turkey
	Temur et al. (2014)	TOPSIS, Type-2 fuzzy sets	Social acceptability, environmental risks, biodiversity conservation, operation and investment costs, energy and transportation infrastructure, legal/political environment,	Not specified	Turkey

			and growth potentials		
	Moussiopoulos et al. (2012)	MCDM (ELECTRE III)	Transportation costs, facility locations, future alternatives for WEEE collection, national and local waste management conditions, profitability from recovered quantity	Not specified	Greece
	Ponce-Cueto et al. (2011)	AHP	Maximum collection quantity, collection center location	Waste batteries	Spain
	Machado et al. (2010)	Assignment model	Minimum transportation cost, Distance between sorting center and treatment/recovery centers, Maximum WEEE flow within the centers, vehicle capacity	Multi product - Large electro-domestic equipment, Refrigeration and freezing equipment containing CFC, Small equipment, Television devices and cathode ray tube monitors	Portugal
	Tonanont et al. (2008)	DEA, BSC, AHP	Customer satisfaction, sorting and storing, asset recovery and transportation	IT equipment	USA
	Wadhwa et al. (2009)	MCDM and fuzzy-set theory	Effective and efficient flexible return policy, cost, time, legislative factors, environmental impact, quality and secondary market	White goods, House hold appliances, TVs, Computers and accessories, brown goods.	India

	Zhang et al. (2004)	Pseudo-disassembly tree and the least-squares fit (LSF) method	IT application in decision making, reverse manufacturing, product environmental impact assessment, Evaluation of recycling and remanufacturing operations	desktop, laptop, and network server equipment	USA
	Jayaraman (2006)	Mathematical programming	Production planning and control for CLSC, on product recovery, reuse and remanufacturing	Mobile phones	USA
	Ferrer and Ketzenberg (2004)	Markov chain decision process (stochastic dynamic programming)	Value of information (remanufacturing cost, process capabilities, facility performance) on remanufacturing	Copier machines and medical equipment	USA
	Krikke et al. (2003)	MILP	Optimal locations of centralized and decentralized CLSC repair network, product design optimization for minimum environmental impact and total cost	Refrigerators	The Netherlands
	Ravi et al. (2005)	ANP and BSC	Determinants, dimensions, and enablers of the RL, productivity improvement, four dimensions from RL perspective were derived: customer, internal business, innovation and learning, and finance	Computers	USA
Organizational and business perspectives	Liu et al. (2010)	Multi-step fuzzy analytical method	Impact of flexibility, openness and extensibility on RL capability at organization level	Not specified	China
	Shih et al. (2012)	ANP and sensitivity analysis	Forecasting model to determine recycling and treatment fees as incentives given by government.	Waste battery	Taiwan
	Subramanian et al. (2013)	Mathematical modeling	Manufacturer’s component commonality decision of remanufacturing in a CLSC environment.	Ipad	USA
	Nenes and	Multi-period MILP	Economic viability of reuse activities,	Mobile phones	Greece

	Nikolaidis (2012)		incorporating multiple suppliers and several quality levels of returned items managed by a remanufacturing company.		
	Li et al. (2009)	Two-step stochastic dynamic programming	Accessing the optimal collection price of used-products considering risk attitude of remanufacturer and estimate optimal selling price for quantity of remanufactured products as profit.	Printer cartridge	China
	Galbreth and Blackburn (2010)	MINLP	Multi-commodity network flow with economies of scale and product obsolescence when off-shore remanufacturing occurs.	Mobile phones	USA
	Keh et al. (2012)	-	Performance evaluation of IBM Montpellier based on: 1) economic opportunities via reselling and reusing of parts and components, 2) dealing the issues of waste management and legislation compliance and 3) meeting social challenge by preserving local jobs.	ICT equipment	France
	Maslennikova and Foley (2000)	-	Performance on product recovery and productivity improvement by reduction of resource and energy from Xerox's manufacturing plants.	Photocopier	UK
	Linton and Johnston (2000)	Algebraic equation and simulation	Decision support system (DSS) for Nortel Networks in order to improve its remanufacturing operations for circuit assemblies and integration of RL operation with information technology to better plan outbound and inbound product flows.	PCBs	USA
	Sharma et al. (2007)	MILP	Better leasing, logistics and asset management decisions including EOL	Not specified	USA

			disposal options, maximize the discounted net profit		
	Potter et al. (2011)	-	CLSC performance by investigating parameters such as, level of product stocks, effect of inaccurate forecasting at organization level and acquisition of high quantities of products before launching from integrated distribution management; links between both faulty and non-faulty PRs in design, sourcing, manufacturing and forecasting related to forward supply chain as well as the performance in the integrated condition.	Mobile phones	UK
	Dhib et al. (2016)	-	Compromising strategy for sustainable performance and decision-making of WEEE management.	Not specified	Tunisia
	Guide Jr and Pentico (2003)	Closed-loop hierarchical planning model	Financial incentives to control PR from managerial perspective. Decision support in product acquisition, operational planning and control of reuse, as well as demand management and product pricing for remanufacturing.	Mobile phones	USA
	Wee Kwan Tan et al. (2003)	-	IT based system to oversee off-shore PR and its impact on repair, refurbishment, recovery and return management	Computer	Singapore
	Guide et al. (2008)	Analytical modeling	Disposition decision driven PR considering time value of returned product, the condition of the product and the impact of congestion at remanufacturing facility.	Printer	USA
	Janse et al. (2010)	-	A diagnostic tool that was theoretically and	Consumer	The

			empirically grounded to assess the practice and potential improvement of RL activities. Performance improvement can be made by strategic partnerships, performance visibility, top management awareness, strategic focus on PRs, reclaiming value from returns, and prompt supply of remanufactured products to market.	electronics (not specified)	Netherlands
	Mukhopadhyay and Ma (2009)	Two-stage stochastic programming	Determining and evaluating optimal quantity of used products to acquire, and production decisions (i.e. buying new parts from external suppliers) for a remanufacturing firm.	Single use camera	Republic of South Korea
	Tan and Kumar (2008)	LP	To access the viability of RL operation under profit maximization condition. RL is profitable when return volume of waste computer is high and returns are reused, repaired instead of disposal.	Computer	Singapore
	Wee Kwan Tan and Kumar (2006)	System dynamic, simulation	To access manufacturer's profit maximization in RL operations. Part replacements from hardware suppliers are more profitable than refurbished parts. Regardless of return volumes (during processing), viability of the operations can significantly be affected by transportation delay and supplier delay.	Computer	Singapore
	Ravi et al. (2008)	ANP and zero one goal programing (ZOGP)	Selecting feasible RL projects according to available resources of a company.	Computer	India
Product lifecycle perspective	Mazhar et al. (2007)	Life cycle data analysis, Weibull and artificial neural networks	To estimate useful remaining life of electrical and electronic components for their reuse.	Washing machine	Australia
	Chung et al. (2014)	Architecture and supply	Analyzed lifecycle costs (LCCs) and lifecycle	Coffee maker	Taiwan

		chain evaluation method (ASCEM), Modular Design Approach	energy consumption (LCEC) to provide the most beneficial modular structure product design decisions from lifecycle perspective within CLSC environment.		

Highlights

- Literature review on reverse logistics (RL) and closed-loop supply chain (CLSC) of waste electrical and electronics equipment (WEEE)/E-waste.
- Reviewed 155 articles published in the RL/CLSC of WEEE research fields.
- Research gaps are identified and future research directions are suggested.