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Reverse logistics and closed-loop supply chain of Waste Electrical and Electronic Equipment (WEEE)/E-waste: A comprehensive literature review

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A R T I C L E I N F O

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A B S T R A C T

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 157 papers published between 1999 and May 2017 were selected, categorized, analyzed using content analysis method. The method involves four steps: material collection, descriptive analysis, category selection and material evaluation. For the systematic literature review, the steps were followed and four main types of research in the field of RL and CLSC of E-waste, namely designing and planning of reverse distribution, decision making and performance evaluation, conceptual framework, and qualitative studies were identified and reviewed. Research gaps in literature were diagnosed to suggest future research opportunities. The review first of its kind that may provide a useful reference for academicians, researchers and industry practitioners for a better understanding of WEEE focused RL/CLSC activities and research.

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 to 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 the closed-loop supply chain (CLSC) evolved. It considers efficient product return management and conducts value recovery activities so that secondary materials can be used as input for ''new'' customer product. Rather considering legal, social responsibilities, or even operational and technical details of the FSC and RSC, the CLSC focuses explicitly on business perspectives of the supply chains. According to Guide 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

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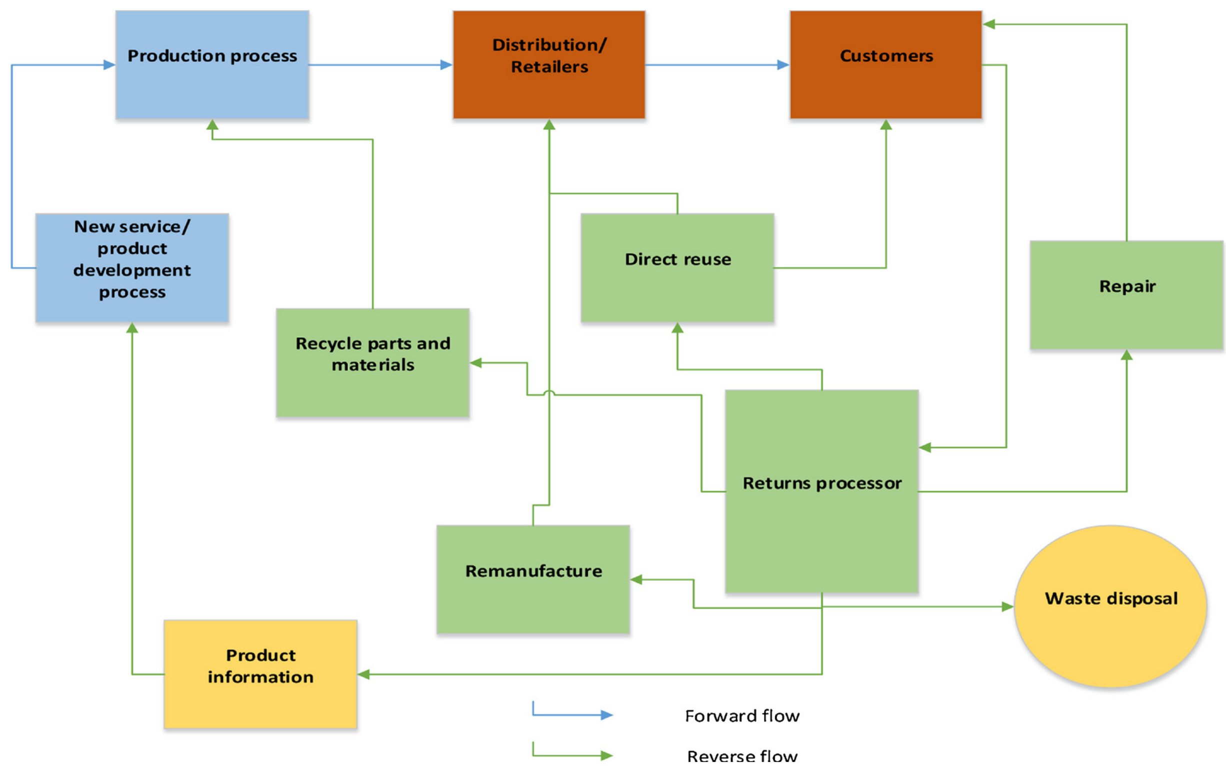

Fig. 1. Generic diagram of CLSC including forward and reverse flow, adapted from Chopra and Meindl (2007).

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.

Among the various EOL products identified in RL and CLSC research, E-waste is found as a significant one. The question is how different is the RL and CLSC systems from a generic form when WEEE is considered. A lot of previously published papers have not clearly specified the difference which is a drawback of some of the earlier studies.

E-waste possesses some special characteristics and features that make its RL and CLSC systems unique from general RL and CLSC systems. 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). According to "Global E-waste Monitor Report 2017" published by United Nations University (UNU), in the year 2016, 44.7 million tonnes (Mt) of e-waste was generated in the world and only 20% was recycled through proper channels (Baldé et al., 2017). This generation volume is significant compared to other EOL items. For example, every year, only 8 to 9 million tonnes of end-of-life vehicle (ELV) is generated (Eurostat, 2018) which is 5 times less than the WEEE generation. Globally, to tackle the emerging waste stream under comprehensive WEEE management policies, several countries implemented regulations towards minimizing the negative environmental impact and prioritizing valuable resource recovery. To bind all the stakeholders legally in managing E-waste, European Union (EU) is at the forefront. On 13th August, 2012, the EU WEEE DIRECTIVE 2012/19/EU came into force by which member countries in the EU are obliged to follow the recovery and recycling target implementing EPR policy. According to the Directive, E-waste is divided into ten different categories (until 15 August 2018) (Directive, 2012). Table 1 shows WEEE product categories with target recovery and recycling rate.

In principle, complex processes of RL and CLSC start with the disposal of EOL electrical and electronic equipment (EEE). However, in WEEE's return management, multiple factors along with a higher degree of uncertainties such as quality, quantity and time are involved (Chen and He, 2010). First, the huge amount of generation is coming from three distinct sources: households, government and institutions, and businesses (Li et al., 2006). Households dispose of a range of equipment starting from large household equipment like refrigerators, washing machines to small consumer electronics, mobile phone; whereas information and communication technology (ICT) equipment is largely discarded by organizations. On the other hand, for the same equipment, average lifespan varies significantly. Second, the method of E-waste collection from the sources varies substantially in terms of collection points (e.g. municipality collection points, retailers, product manufacturers, EEE repairs, third party recycling service provider companies etc.) involved in a EOL-WEEE recovery process (Iacovidou et al., 2017). For instance, households can discard their E-waste in a number of ways: 1) at the municipal collection points, 2) leave it to their kerbside, 3) drop it off at special events, 4) return back to retailers/ point of purchase, and 5) return back to manufacturers/recyclers appointed by manufacturer. For business and other organizations, leasing became increasingly popular and in this process, leasing companies are responsible for EOL dispositions which further involve RL service providers for transportation, local recyclers and small businesses that deal with reuse of EEE items. Disposing E-waste to permanent drop-off locations is also practiced by institutions. Third, collected quantities then transported to treatment facilities where WEEE goes through testing, inspection, and sorting and dissembled according to specific product categories before transferred for processing. An optimized network design plays a crucial role in efficient and successful RL processes. For example, in Switzerland, three take-back systems, SWICO, SENS, Swiss Lighting Recycling Foundation (SLRS) together established 6000 collection points by which 95% of the E-waste is collected and recycled (SWICO, 2017). Fourth, depending upon the material content and value proposition (i.e. quality of waste), five different disposition alternatives (e.g. reuse, repair, remanufacture and