Remanufacturing strategies: A solution for WEEE problem

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Abstract

The electrical and electronic equipment (EEE) industry has increased its mass production; however, the EEE life span has similarly diminished. Owing to the rapid expansion of manufacturing, innovation and consumer demand, there has been a vast improvement in various electronic equipment, so the amount of waste electrical and electronic equipment (WEEE, or e-waste) generated has also increased proportionally to production. The main objective of this article is to evaluate the remanufacturing concept which can be adopt by the electronic manufacturing industry. The article reveals differential steps debated by industry as well as academia in assets to reduce the amount of e-waste. The concept of e-waste remanufacturing is quite dissimilar from case studies among developing and developed countries and regions. The findings can assist the academic research and leads to industry regardless remanufacturing of used EEE or WEEE by exemplifying different methods and ideologies of remanufacturing implementation plus the main issues in this field.

Keywords

EEE; Solution; e-products End of Life; Informal recycling; case studies; Electronics.

1. Introduction

Electronic manufacturing, innovations, and the variety of electronic products have expanded increasingly in the last three decades, which have a significant impact on WEEE generation (Baldé, C.P., Wang, F., Kuehr, R., Huisman, 2015). In the European Union (EU), the WEEE amount has been annually growing with the rate of 3-5%; Just in 2012 the total sum of treated e-waste was 3.6 million tons (Mt), of which 2.6 Mt were recovered (Eurostat, 2016). The international commerce, resource depletion, and miniaturization of components/products had enforced the e-waste legislation/policies to be changed in different countries, which depended on the local economic development and region. However, WEEE become a global issue because of the quick maturation of electronics, low recycling rate in some cases, utilization of raw materials, and pollution effects around the globe (Li et al., 2015a; Salhofer et al., 2015; Singh et al., 2016a and 2016b).

The formal recycling of e-waste on the global level, was just abound 13% (Gold et al., 2010; Reck et al., 2012). While informal recycling, artisanal mining of e-waste, eco-design, manufacturing, international markets, and the economic potential of buyers are playing a crucial role for material recovery and environmental issues (Awasthi et al., 2016a; 2016b; Umair et al., 2015). Among these, the informal recycling, electronic cannibalism and in some cases the possibility of re-updating leads to increasing e-waste (Narendra Singh, 2015; Singh N, 2014; Zeng et al., 2015). The result of this evidence has contributed to developing new strategies to implement e-waste eradication in an efficient way through the adoption of an eco-design (Li et al., 2014), as well as the capacity for updating electronics from its stage of manufacturing modeling (Ijomah et al., 2012). Remanufacturing is giving another option to the products, by transforming them to ''like-new''.

Recycling and remanufacturing increase the utilization of recovered materials or used and reconditioned components to reduce the raw material consumption and increasing the waste value. A worldwide distribution of WEEE and EEE remanufacturing situation is described in Fig. 1 according with the literature. This represents the current status of EEE remanufacturing related with the technological potential, regulations and governmental or private affiliations with remanufacture. The 60% non-hazardous waste that had been produced by manufacturers demands the implementation of legislation to reduce the environmental impacts of these products (Alejandra Sepúlveda, Mathias Schluep, Fabrice G. Renaud, Martin Streicher c, Ruediger Kuehr Christian Hagelüken, 2010; LaGrega, Phillip L. Buckingham, 2010;

Ongondo et al., 2011; Perkins, BS,DevinN.,Marie-Noel Brune Drisse, MS, Tapiwa Nxele, MS, and Peter D. Sly, 2014). In these cases remanufacturing strategies play a crucial role for original equipment manufacturers (OEMs) and remanufacturer (Nasr et al., 1996; Singh et al., 2016c).

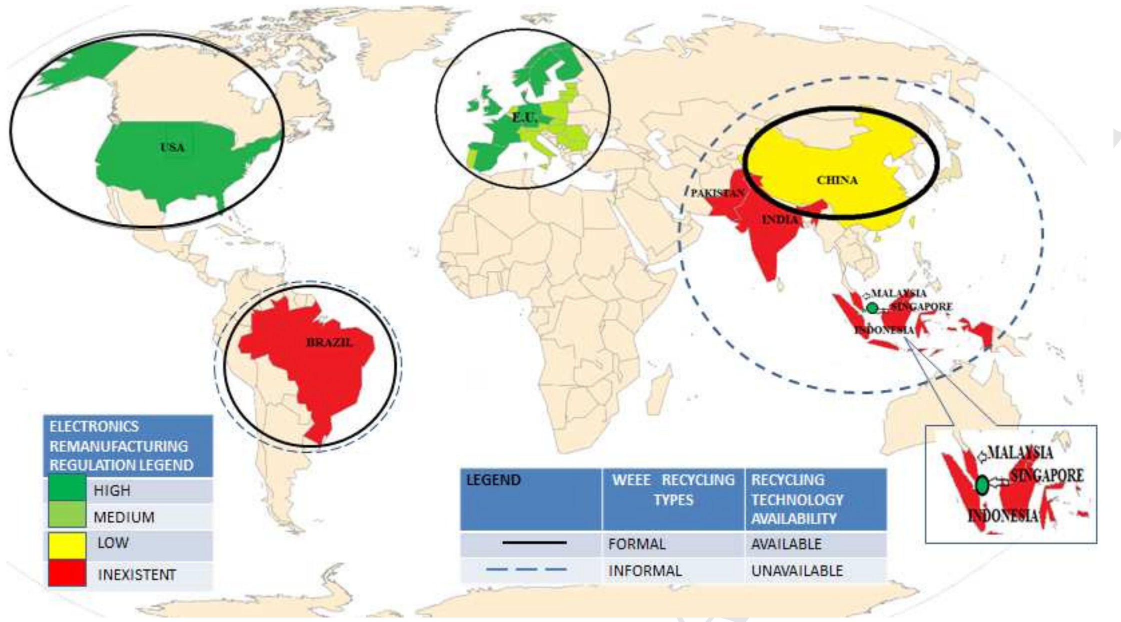

Fig. 1. Worldwide distribution of the remanufacturing status. Note: Data source of the assembled map are from the supplementary content Table A1.

OEMs produce different components with their own specification for the final products to differentiate their products from those produced by competitors, which can affect the price of products by reducing their final sale price. In regards to select their technology for determining the potential of remanufacturing, the strategy is developed in order to give the possibility of replacing some components by the owner or to be redirected to recyclers or remanufacturers at the end of its lifecycle (Bernard et al., 2011,Huang and Wang, 2016). In this case, the remanufactured products represent just 60-70% of the original price compared to a new product. The rehabilitation expenses for the remanufactured products are estimated to represent 35-60% of the original cost of production (Giuntini et al., 2003). Among all these factors, sustainability for the remanufacturing industry represents an important global interest (Guide 2000; Nabil 2006).

However, the eco-design is helping to improve the efficiency and effectiveness of development for updating products longevity (Ijomah et al., 2007a). Remanufacturing is a process of recovering/bringing used or worn-out products to a ’’like-new’’ functional condition, offering an equal functional warranty like a new product and reducing the environmental impacts, waste generation, landfill and the levels of raw materials used in production (Guide1999; Hormozi et al., 1996; Lund et al., 1984; McCaskey et al., 1994; Robot et al., 1996; Tan et al., 2014). This paper will articulate the remanufacturing typologies from different aspects, as implementation strategies, and provided a strategic solution for used EEE and WEEE sustainability (Li et al., 2015).

2. Remanufacturing emplacement

Through all economic, sustainable design, and technical remanufacturing processes, the concept of remanufacturing will develop and improve. According to Karvonen et al., (2015), the particular description of the concept of remanufacturing expresses the understanding of the assessment model, in order to create a sustainable application in industry and product reusability to reduce the waste that will/can be generated.

Also, these determinations demonstrate how to handle the waste. Explained by Steeneck et al., (2014), the reserve supply chains (RSC) and end-of-life (EOL) are parameters required to understand the original equipment manufacturers' (OEM) strategies. As a producer and remanufacturer of electronics and medical devices [ex: (XEROX-copy machine), (IBM-servers), and (SIEMENS-medical devices)] demonstrate the importance of (RSC, OEL and OEM) in their remanufacturing activity . Their objective is to recover their products and make profits before and after the product reaches the stage of the EOL and protect the environment (IBM, 2016a, 2016b).

According to the prevailing legislation, an example is given by the European's End-of-Life Vehicle and WEEE directives (Eurostat, 2016; Otieno et al., 2015). It is required for OEM's to handle their products' EOL by finding suitable solutions for reducing waste and environmental issues caused by their products (implementation of the take back recovery system) (Brett et al., 2009).

The above effects, reflect the implementation of remanufacturing which helps more industries and businesses to create new jobs, and develop their economy. For example, from 2009 and 2011 the United States increased the number of jobs and financial growth by 15% to at least 43 billion USD (Steeneck et al., 2014). According to the International Trade Commission, in 2012, the number of jobs was approximately 180,000) (Otieno et al., 2015). However, the factors that drive the remanufacturing industry include legislative regulation, as well as material and energy conservation. All, together, this describes an entire chain from material flow to recycling and can be called a value recovery strategy after the end-of-life (Table 1). The supply chain of the EOL products introduces remanufacturing as one of the main joints in the chain which can be state in Fig 2.

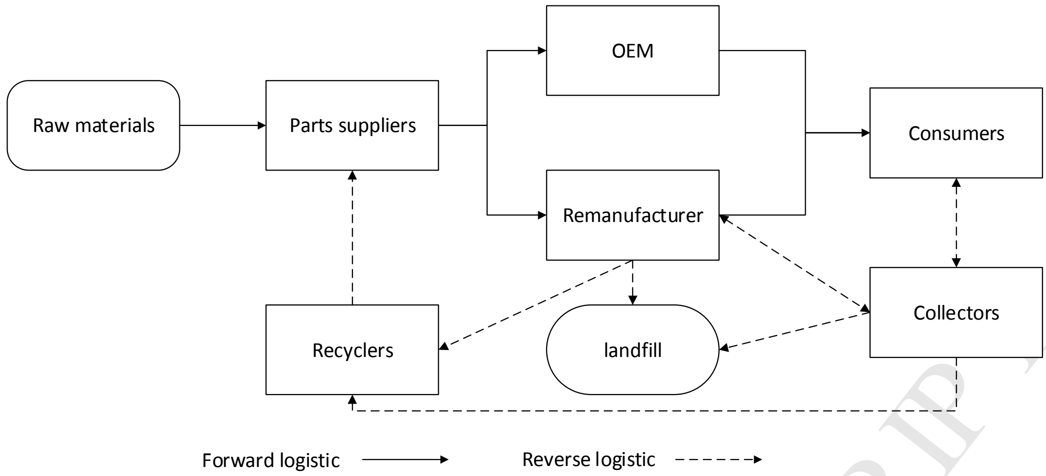

Fig 2. Materials and equipment chain with its forward and reverse destination. Note: SC represents supply chain; Modified from Steeneck et al, (2014).

This paper reflects the implementation of different strategies used in remanufacturing concepts, which show multiple perspectives used to understand the feasibility for the remanufacturing industry in the case of WEEE. The examples collected from the literature include reserve supply chain, policy, as well as design for remanufacturing, process optimization, business model, and marketing decision. In addition, this research illustrate, the intention to determine what are the most common methods being used in this field, to understand how the concept is adopted in different parts of the world, from the academic and industrial point of view.

Table1 Types of destination places for End-of-life (EOL) (Environment Protection Authority (EPA) USA, 2009; Ijomah et al., 2012).

EOL Option	Description
Landfill	Dispose of a product, or its parts, in a landfill.
Recycle	Recover material from the product or its parts.
	Any value depends on the form of the product, or its parts, and if it destroyed or not.
Resell	Sell product, or its parts, on used market as it is.
Repair/Refurbishment	Fix the product, or its parts, to some specified standard and sell them on the used market.
Remanufacturing	Re-make the product, or its parts, by using a mixture of recovered and replacement parts so that it meets the "like-new" specification (i.e. identical warranty to that for a new product).

Furthermore, these have been an influence on the remanufacturing process and business competition for the market requirements resulting that the WEEE forecasting, reuse, and remanufacturing potential is having an impact on reverse management (Gehin et al., 2008; Ijomah et al., 2007b).

3. Methodology

3.1. Data collection from conferences

The data for this paper has been collected and debated during the international trade show for remanufacturing REMATEC, (2015), in the IcoR Remanufacturing conference in Amsterdam in June 2015, and the Remanufacturing Summit Beijing 2016. During the events, most of the exhibitions, have consisted of the automotive remanufacturing and electronic remanufacturing issues. The most qualitative event was attendees of the workshop of IBM, from ICoR Amsterdam. The remanufacturing problems of used EEE and WEEE had been discussed and in such a way to understand the changing from the managerial point of view to a technical point. Cannibalism and material recovery plays an important role in the WEEE reduction, which has been discussed in trades and technical literature within this field(Linton 2008).

3.2. Data collection from literature

The literature reveals that the availability of documentation related with used electronics, and WEEE remanufacturing worldwide has shrunk to recycling, as seen in Fig 3(Govindan and Soleimani, 2016). Using Scopus to search for studies conducted between 1990 and 2016, associated with environmental issues and processing technology, with the key words of WEEE reuse, WEEE recycling, and WEEE remanufacturing, resulted in 987 closely related papers. Among these, 840 papers were related to the WEEE recycling situation, 112 papers related to WEEE reuse, and just 35 papers related to WEEE remanufacturing. All data suggests that the lack in the WEEE remanufacturing aspect is poorly represented and should receive more research focus.

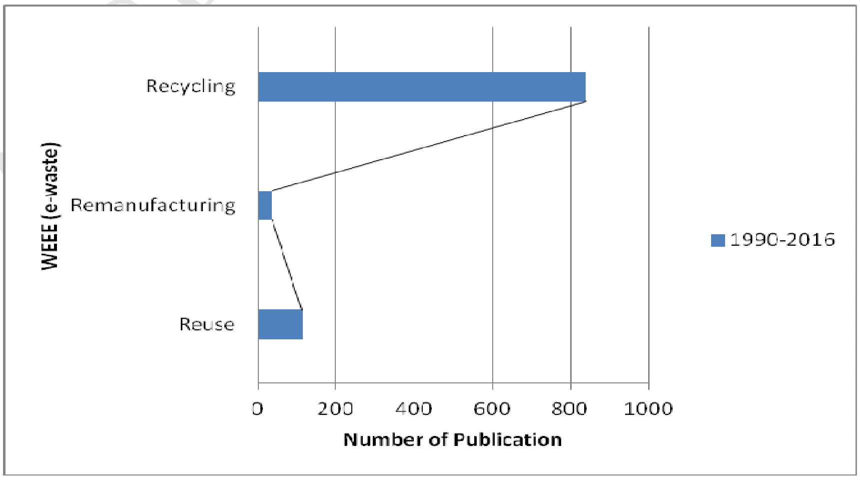

Fig. 3. Situation of WEEE remanufacturing literature based on SCOPUS.

During the ICoR IBM workshop, all participants contributed to the general understanding of the current situation in the field from different viewpoints, and expressed their needs regarding remanufacturing problems across the globe. The research includes the main points of the researchers from workshop that were debated and analyzed.

3.3. Case study

This research took several examples from literature and the cases of remanufacturing companies of copy machine as Concept Group by XEROX UK, servers by IBM and SIEMENS healthcare (medical devices) are mentioned. This paper will articulate the remanufacturing typologies from different aspects, as implementation strategies, and a strategic solution for sustainable global WEEE management, which can contribute to the remanufacturing concept. Because the remanufacturing is not sustainable with all the products, the profitability decreased in some cases as X. Li et al., (2015) concluded, the paper exemplify a case of copy machine remanufacturing from Concept Group by XEROX UK .

4. Results and discussion

4.1. Remanufacturing implementation from different points of view

The literature review provides examples to differentiate the perceptions used by different companies to achieve various goals. The diversification of the perceptual objectives were made for diverse objectives to facilitate the remanufacturing companies.

4.1.1. Overview of circular economy for remanufacturing

The analysis that had been done in the circular economy (CE) are focusing on the energy consumption, material flow (3R rule implementation), closed loop systems, and eco-design(Govindan and Soleimani, 2016; Preston, 2012). This reveals that at the micro-level of waste reduction everything changes. In the case of China's leapfrog development, the environmental policy had been implemented, and the CE started to increasingly work in a sustainable economic growth from 2002 riveting on energy consumption, resource and waste problems, environmental degradation, and conservation among other things (Su et al., 2013). Geng et al., (2010) estimated that the CO_2 emissions are growing at a rate of 7.5% annually in China, and were approximated to be 7693 million tons (Mt) in 2010.

In the developing countries, such as China, the impact of the manufacturing industry is playing an important role to germinate other industries such as recycling, while adopting the 3R rule (Su et al., 2013). The necessity of customization is increasing and at the same time, the materials are used, recycled, and then resold on different markets with less value for the customer demand. Product revolution, technology development, and policy implementation affect remanufacturing concepts of green-products life-cycle for entering in the supply chain of production/updating (Chung and Wee, 2008; Feng and Viswanathan, 2011).

In theory, the mathematical and software analysis Life Cycle Assessment (LCA), Cost Benefit Analysis (CBA), Life Cycle Cost (LCC) are incorporated to actualize and improve the remanufacturing scheme to minimize the environmental impact and to step-up the sustainability of the remanufacturing system (Feng et al., 2011; Richter et al., 2000; Tsai et al., 2012). The fuzzy, multi-aim of remanufacturing does not only help companies to develop but even to generate new perspectives for the consumers, clarify the connection among new and recycled materials, production/selling cost, machine yield, energy consumption, and CO_2 emissions (Su et al., 2014). The examples from the literature review have been implemented in Asia, Europe, and the USA.

4.1.2. The status of original equipment supplier and manufacturer

Independent remanufacturers and contractors in remanufacturing industry have different opinions regarding the use of concepts like, Original Equipment Manufacturing (OEM's), and Original Equipment Suppliers (OES) in the field. For example, in Europe, remanufacturing is considered as being connected with the production line depending on the remanufactured product (Junior and Filho., 2016; Martin et al., 2010). However, the U.S. considers that strategies should be deployed to increase the employment rate and after which, the outsourced/ contracted companies need to increase and help the remanufacturing process. Beside, both ideas in the OEMS were used and were adopted by automotive and electronic companies in U.S. (Otieno et al., 2015). Usually, the remanufacturing concept depends on the generic activities (Figure 4), product routing and process, and product types/company.

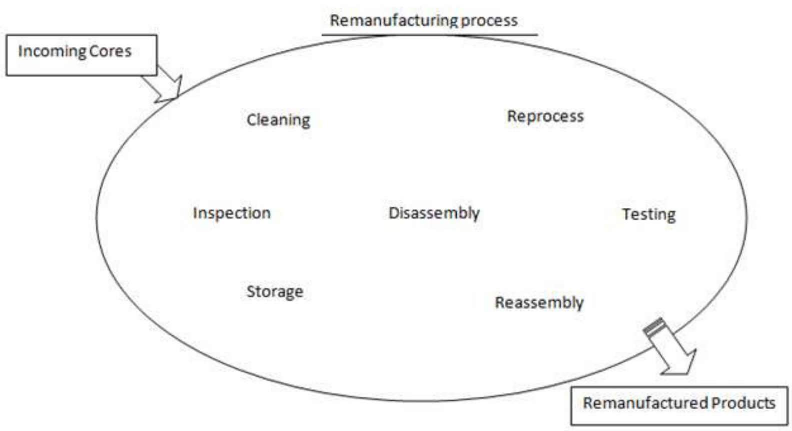

Fig. 4. Illustration of Generic Remanufacturing Processes (GRP).

All of the activities shown in the Fig. 4 are different from product to product depending on testing modalities, software update and missing/replacing parts of the product. This activity depends on the product quality, supply/demand, and technology migration. Among these, remanufacturing cost can be between 45%-65% depending on the product and marketplace which can be comparable with a new product (Otieno et al., 2015).

Developing the remanufacture concept the remanufacturing industry takes into consideration profitability, environmental sustainability, legislative regulations, marketing and perception, process design optimization, materials and energy conservation, business model and job creation according to IBM and academia description (IBM, 2016b). The sustainability of the factors mentioned before involves, in a manner, the understanding of a particular barrier and the motives that affect the remanufacturing industry, not only in the process of adaptability to legislation and production, but also recycling of different products.

4.1.3. Methods of remanufacturing implementation and examples

A suitable case is the Chinese remanufacturing industry lacks where the EEE interest is spreading to manufacturing and recycling rather than used EEE or WEEE remanufacturing(Hatcher et al., 2013; L. Wang et al., 2014).

In the cases of the technical design, market factor and legislation for electronic remanufacturing on the Chinese market the (MIIT – Ministry of Industry and Information Technology), in 2012, establish a catalog to guide the research institutes and companies. The Chinese situation reveals that even if the manufacturing industry is well developed and the variety of products and accessibility of EEE components are handier, remanufacturing companies are insignificant being only five in the whole country (Wei et al., 2015). One of the most relevant examples of sustainability is the IBM server remanufacturing facility plant in Shenzhen that has been open since February 2012 and being the IBM 22nd facility in the world. The main objective of IBM is IT remanufacturing with a rate of remanufacturing of 10.000 units/year and viability of 90% (IBM, 2016a). In the Chinese markets, the remanufactured products, which include IBM as well, have percentage ranges from 40 to 80% of the new product introduced for sale. The basic issues that had been discussed in the studies by scholars and governmental organizations reveal that the main barriers in China are environmental, ethical responsibilities, costumer orientation/recognition, and strategic implementation (Tan et al., 2014; Wei et al., 2015).

On the other hand, the main objective is to restore non-functioning products to a new condition while reducing WEEE and the consumption of raw materials with standards of a quality level that are equivalent to the new product and can offer a warranty level as well. Hatcher et al., (2013) explains the difficulties of having a proper direction of e-waste after they expire and the differences between DfRem (design for remanufacturing) and e-waste remanufacturing capacity which varies. In the case of China being the largest producer of electronics and importer of e-waste in the world, there is poor development in the electronic remanufacturing sector which is considerably unknown and an untried solution, which is becoming quite a challenge to undertake(Hatcher et al., 2013; Lau and Wang, 2009; Wei et al., 2015).

Basically, remanufacturers have to choose their process methodology and perspectives. (Ismail N, Guillaume, 2015) suggested in their research, different types/tools of the methodology used by remanufacturers and academia, sustainable development extension have different descriptions and dissimilar perspectives on remanufacturing.

Methods, types/tools:

- Remanufacturing and Product Profile (REPRO2);
- Close Loop Environmental Evaluation (CLOEE);
- Environmental Impact Simulator (EIS);
- Remanufacturing Decision-Making Framework (RDMF);
- Remanufacturing Network Design Modeling (RNDM);
- Research for efficient Configuration of Remanufacturing Enterprises (reCORE);
- Fuzzy multi-objective linear programming (FMOLP);
- Remanufacturing cleaning method.

Comparing their research and other case studies, this research extracted the most common ones that are used in industry and academia for management implementation in the remanufacturing industry. The profit maximization for reverse logistics and product design problems in case of remanufacturing, are plausible in practice(Agrawal et al., 2015; Geyer et al., 2007). By making future adjustments in the network and allowing gradual changes to a better flexibility, remanufacturing is incorporating different perspectives. Multi-period models demonstrate to have a better flexibility than the static one(Ferguson, 2010; Ferguson et al., 2009). For example, the logistic network design of remanufactured washing machines, in Germany, can save the cost of transportation between facilities which is explained by Alev et al. (2012).

Different perspectives on remanufacturing are implemented in the closed loop supply chain to understand the remanufacturing concept as followed in Table 2.

Table 2

IBM remanufacturing perspectives.

Remanufacturing and sustainable development	*Remanufacturing like a system*
Technical feasibility: • Materials, methods, man, machine, energy, and information, are included	Design for remanufacturing
Economic aspects: • LCA, cost, product recovery, disassembling, cleaning and washing, reconditioning, recovery, etc...;	Reserve supply chain(RSC), acquisition/relationship, reserve logistics
Social aspect: • attitude, orientation, behavior, warranty;	Information flow in the remanufacturing: • Composition of the product; • Magnitude and uncertainty of the return flow; • Market of remanufactured product; • Information about how product returns.
Environmental aspects	Employees knowledge and skills; • The remanufacturing operation; • Commercialization of the remanufactured products.

Depending on the product being remanufactured, each company chooses a different strategy in their approach to remanufacturing. For example, NEOPOST in France reviled by Guillaume, (2015) adopted the same strategy as the Concept Group by XEROX from Glasgow UK regarding the recovery of printers after the EOL. On average, they recovered 90% after a usage period of 4-5 years. In this period, they also offered technical support to their remanufactured products.

The main pillar of the returning products is very well developed by Concept Group by having a database that can provide all the information about the product type, client, technical situation of the product, and location according with CG. By using these systems, even Neopost expresses that the raw material consumption from remanufactured products can reduce the environmental impact by 37%, depending on the types of undertaken products(Guillaume, 2015). All the products were considered as being converted in an economical and sustainable fashion using complex algorithms which demonstrate the big gap between return, recycling (rate, cost) and CO_2 emission. Several researchers have demonstrated the differences between these factors presented in Table 3.

An important factor of these aspects is how the returned items are represented like a variable with a specific quality. Different parameters like demand, return and stochastic lead have a qualitative and quantitative influence on the cost and quality. All these influence the recyclability, economical cost for recycling, and environmental protection (Zanoni et al., 2012).

Table 3
WEEE sustainability potential (Garashi et al., 2013; Tang 2006; Zanoni et al., 2012)

Items	*Recycling rate*	*Recycling cost*	*Disassembly time ('')*
1Fan controller	0	21.77	0.93
2 Cable	4.00	35.31	26.4
3 PCI board	0	3.24	3.0
4 HDD	27.27	-114.51	4.2
5 FDD	9.09	-15.83	18.0
6 CDD	18.18	-55.83	18.0
7 Switch	0	21.09	15.6
8 Big fan	18.18	-42.29	28.2
9 Big fan cover	1.82	35.71	27.6
10 Small fan	9.09	-2.29	28.2
11Inside switch	0.91	20.69	15.6
12 Speaker	5.45	35.31	28.2
13 Memory	0	6.51	4.8
14 Motherboard	0	75.09	56.4
Total	93.99	40.61	302.4

4.2. Strategic solutions for sustainable global WEEE management

Future reusability, another branch of the remanufacturing implementation, had demonstrated an important goal in minimizing scrap recycling(Rubio and Jiménez-Parra, 2014). In the previous examples, can observe that end-of-life management before remanufacturing and management strategies to develop a proper sustainability for remanufacturing, involve not just a proper generation of product updating but also environmental friendly manufacturing (Parra, Rubio., 2012; Vishal V. Agrawal, Atalay Atasu, 2010; Zanghelini et al., 2013).

In this section of the paper, is discussed what is needs to be done for managing waste from the point of view of electrical and electronic businesses and what are their needs/issues for managing strategies required for a sustainable WEEE on a global basis. The remanufacturing in the WEEE sector, specifically the automotive and aerospace sectors, is more developed and more profitable(Williamson et al., 2012). However, the automotive and aerospace sectors are challenged by the updated/remanufactured products of the electronics, such as board computer, controllers, safety systems, and other specific electronics(Abdulrahman et al., 2015; Y. Wang et al., 2014). Buşu et al., (2015) highlighted the exiting challenges that are commonly found in the WEEE remanufactured equipment, and remanufacturing processes, such as: inspection, cleaning, disassembly, reprocessing, reassembly, testing, facilitating the remediation of WEEE storage, pollution and energy consumption.

WEEE from the remanufacturing side has two main camps (i) ***Operational level***, a conglomeration of activities that smoothly flows from EOL of the product to the remanufactured processes. (ii) ***Management strategies,*** which engage the circular economy, asset reuse, plans, policies, and tactics for ensuring the profitability of the remanufacturing.

In the following part, these decisions are included as if the electronic manufacturer would remanufacture the used EEE and WEEE from an OEM perspective or other private companies. All these had been debated with the IBM Global Asset Recovery Services and academia from different countries as in the annual ICoR workshop. Here the key discussions had been concentrated on reverse management, design for remanufacturing and reuse selection, while trying to optimize the real situation at the moment.

4.2.1. Reverse Management

The concerns for reverse management lay within the general idea that legislation appears to be blanketed by particular models. The transportation of waste is one of the general problems. This is, not just from the logistical point of view, but it even concerns the diversity of the waste involved. In these cases, the industry can be supported by the government and consumers. Among these, there is a potentially manufactured product that can be considered waste at a particular stage in its life cycle. The data, provided by the producer for the consumer and remanufacturer at the same time, would be about the product characteristics or the possibility of recovery after the EOL cycle.

It is important to articulate that the life cycle, which will be provided by the producer, can influence the policy makers to change the legislation regarding e-waste recovery from the electronic users. The general idea of waste designation and the lack of specific legislation for remanufactured products will change, thus giving a better opportunity for reversing the chain for reusability if the legislation for remanufactured products will be for their benefit. Group members put forward the case that joining value streams (between companies) would be difficult to achieve because of the business competition that prohibits co-operation between different companies. This is having an impact on the economic level for them.

Reverse management is currently dictated by particular models, depending on the product complexity. Thus, creating new models to encourage collection for remanufactured products will be a challenge. The increasing complexity of parts has had an adverse effect on the management process.

4.2.2. Design for remanufacturing

Different mechanical or electrical parts from different areas of the product can be remodeled/readapted to increase the life cycle and decrease waste. The key factor here, are the outsourcers, which provide solutions to the producer for updating the products in an economical way, equal to cost, complexity, and capabilities of a new product.

Remanufacturing strategies, in advice with the sustainability for remanufacturing have to increase the relations between the remanufactured and original equipment manufacturer (OEM) to reduce the price of producing via economy/sale.

Among these, the high production and updating of the products/design have an important role in changing the public reaction/behavior to the new products, even if the price is different, depending on the product category (new/re-manufactured). In regards with cost, quality, and capacity, the aspiration for manufacturing products having a statistical concept of efficiency versus flexibility is represented. Both of them are influenced by the supply and demand chain, giving a balance to the remanufacturing demand to be a higher-care for a low price.

An example is the copiers that are sold by Concept Group by Xerox UK to their original consumers or go to the sales market to begin their new life cycle, while offering a warranty and service at the same time. The logistic system of Concept Group is a partially closed loop, and some copiers go through more than one life cycle, as shown in Fig 5. All their products are separately monitories before ending as a use product by the producer and in this way can be categorized more efficient as profitable or non-profitable for remanufacturing. The figure reveals two channels designated for the products as revers logistic and remanufacturing.

The connection between them is given by the possibility of upgrading the electrical equipment, which has a shorter lifespan and a decrease of performance during the life cycle. From the IBM point of view being in the situation of the producer and remanufacturer, this type of situation is improved by offering a guarantee for the remanufactured products.

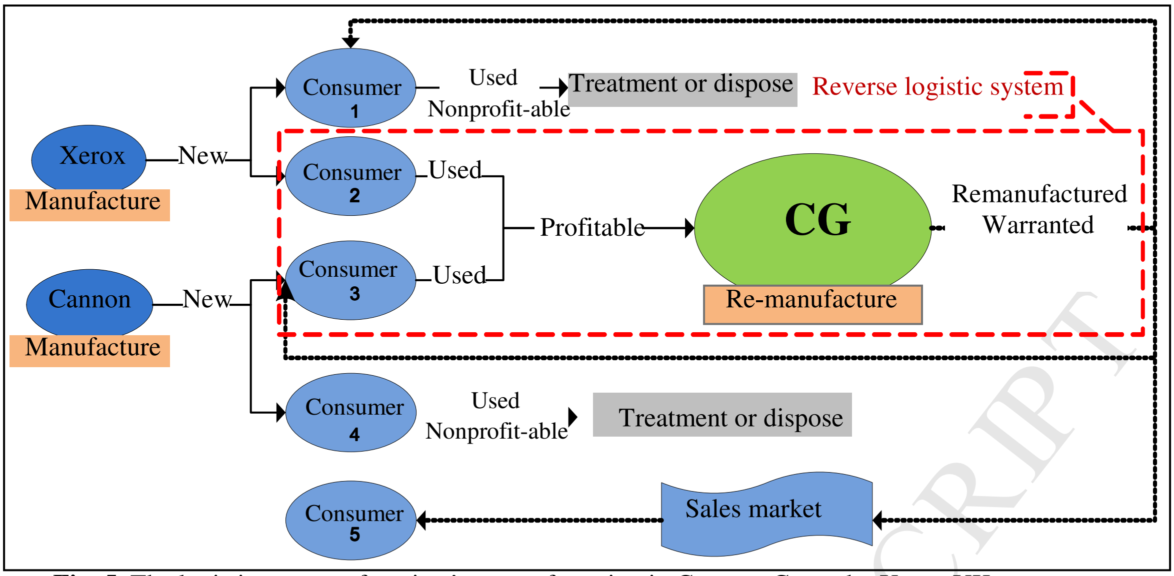

Fig. 5. The logistic system of copiers' remanufacturing in Concept Group by Xerox UK

IBM, SIEMENS, and Concept Group by XEROX, offers in their new remanufactured products the last upgrading, which means new interface and software, hardware, guarantee, and efficiency.

The big issue for these companies is the design of upgrade, which has a short lifecycle, not just for the entire product, but even for the small components. The high complexity of the components requires more investments in the graphic and technological design and production, which can affect directly or indirectly the product price but also even the business. In the case of IBM being in the position of the producer and remanufacturer at the same time, the adjustment to upgrade an old product is less expensive and simpler according to the IBM.

In the case of laptops' and medical equipment's high construction complexity and lower possibility of remanufacturing, not to mention, the emergence of new products or technological and political problem, the possibility of reselling is lower, in some developed countries.

4.2.3. Reuse selection

One of the most important factors in the regression of used electronics begins with *verification/validation* upon arrival and discusses the difficulties and the practicalities involved in the process of verification and validation (Govindan et al., 2016a).

For instance, the concept of verifying a standardized product against the process of verifying a customized product was discussed. Also, the fact that the level of validation required is such that the product must be shown to exceed the threshold of classification, where it would be defined as a solid waste or introduced into the category of recoverable products (Williams et al., 2008).

Forecasting successfully engages in WEEE management; good forecasting models are required for a better sustainability (Govindan et al., 2014). The point raised about this subject was the buyback option from IBM on equipment installed on sites, which would be required to be made a model basis (specific decision) and not a carpet buyback approach. The access to information is included to increase waste management of WEEE, and more information is required to be shared between the relevant bodies. The relevant bodies are the producers, third party waste management organizations such as remanufactures, and the policy makers to resolve the issues between different stages of remanufacturing and EOL (Govindan et al., 2016b; IBM, 2016a).

From business to business and business to customer, the case was put in discussion that potential reuse operators may need to be differentiated, depending on the application/person or organization that is forecast to receive the re-used products (re-used products in this instance is a generic term used to describe the resulting product that has been subject to an EOL process)(Sabbaghi et al., 2016, 2015).

Understanding that the value for the manufacturer/provider represents the full cost model (which goes from cradle to grave) would generally need to be required as a first step in understanding the value provided by the manufacturer. For a potential manufacturer to:

a) Conduct EOL strategies such as repair, recondition, remanufacture, etc...

b) Provide necessary information to allow others to carry out these practices smoothly and efficiently

c) Design products intending to carry out an EOL process such as remanufacture (thus products avoid costly disposal) while providing the cost model analysis as a requirement

d) Product life management is not necessarily aligned with re-use of a product.

The points raised here, touches essentially the current modeling of products that include product re-uses (or successive products re-use options). It may be the case that new or existing life management operations/plans need to be created or altered to cater large product reuse operations to small reuse operations(European Remanufacturing Network, n.d.; Shrawder et al., 2009).

4.3. Practical execution of remanufactured copiers' machine

This paper also illustrate an example of a copier remanufactured, made by Concept Group (CG), which is a subsidiary company of Xerox. They give the technical supports to CG, to make sure that the remanufacture processes are completed effectively and the quality of remanufactured copiers could be guaranteed. Meanwhile, they remanufacture some models of Cannon's copiers like IRC 30380 and IRC 20880 for more profit. CG takes back used Xerox or Cannon copier from the consumers and remanufactures them, then sells them to the original or new consumers. As a result, there is a partially closed reverse logistic loop between the manufacturers and the consumers, and CG is the link between. The process to realize their remanufacturing: disassemble, clean/ refinish/ rebuild/ mend, reassemble, which lasts about 10 hours and are represented in fig 6. Here is reveal the entire chain of the remanufactured process to understand the general decomposition of a Xerox machine and the steps that each component is having.

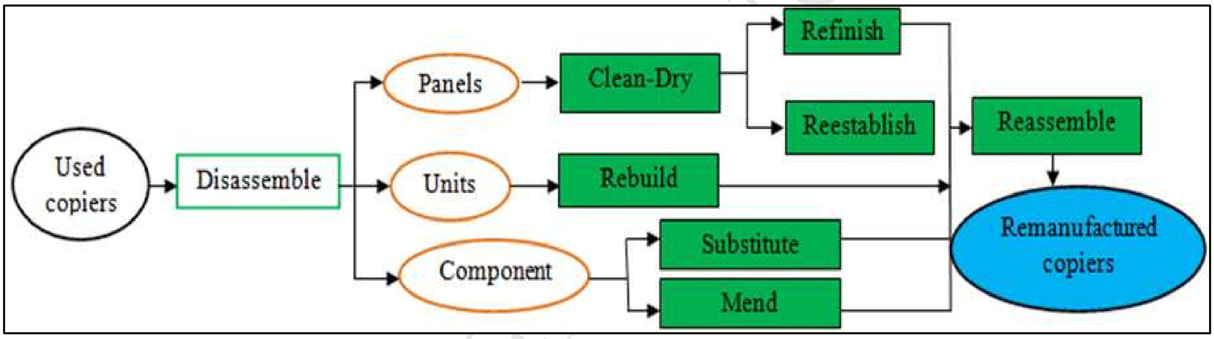

Fig. 6. The copiers' remanufacturing process in CG

All copiers are disassembled to a very high degree (Fig. 7a). First, the straight external panels, the paper pickup section, control panel, process units, fuel sections, transport sections are taken off from the machine and are cleaned. Finally, all the subassemblies and components are disassembled individually and manually. Usually, each machine will be disassembled into more than 20 parts, which could be cleaned, refinished, rebuilt or replaced easily, to satisfy the needs of remanufacture process.

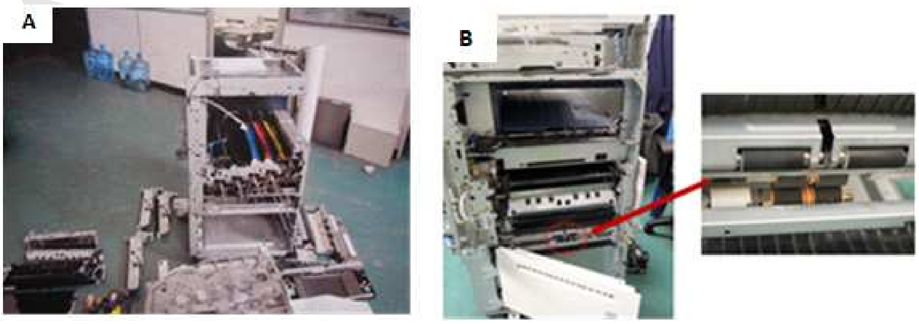

Fig. 7. a) The disassembled individual parts of copier. b) One of the sensitive components in copiers.

Some of the easily broken components like the fusing rollers and pick-up rollers would be substituted by new ones which are brought from OEMs. Buying a drum unit from the manufacturers (for example, Canon) would cost about 250 USD. Meanwhile, CG spends only 60$ if it takes out the drum blade (the easily broken components) to replace it with a new one from the OEMs. The components in the copiers are complex, and the total number of components in each copier is about 50 to 100, and they are composed of plastic, leather, metal and some other materials. In all the operations, there are no used special tools to deal with the sensitive parts (fig 7.b.) during the disassembly process.

Experienced technicians are trained by Xerox with one at each branch, for six months to get used to the different models and techniques to disassemble, rebuild, and adjust the copiers. This upholds the quality of the remanufactured products in CG. After the used copiers are remanufactured, they undergo a run test, copies test, and the final electrical safety test. Meanwhile, all the copiers essentially work the same way, and use roughly the same components, so the remanufacturing is similar, and there are no technical problems to remanufacture different models or brands of copiers.

Also, the broken components in CG, which cannot be remanufactured (i.e. brought back to at least 'as new' condition), are substituted by the new ones from the OEMs, rather than different manufacturers. From the perspective of environmental protection, more energy and resources are saved compared to the simple recovery of the material from copiers, as would be in the case with recycling.

The development of design, for joining other components during design and manufacture, makes the copiers much easier to remanufacture compared with the ones from many years ago. In addition, the stability of the copier technical development and the similar construction of different models and brands, make the remanufacturing of copiers much easier, and the economical-efficiency greater than other electrical and electronic products (Alev et al., 2012).

5. Conclusions and outlook

This article presents the existing operations of diverse approaches applied in remanufacturing models, which illustrate various viewpoints suggested to know the clear picture of remanufacturing feasibility for used electronic and WEEE industry. The key findings of this review are the elaboration and description of the different typologies of concepts and strategies that are used by the remanufacturer and their issues in the industry. This can be understood that not only just the concept of how to do remanufacturing will have an important role but also in which direction the operations should be applied to have a better sustainability from different sides. Currently, the policy makers are trying to develop new strategies for helping the companies to increase the remanufacturing process, reduce the environmental pollution, and raw materials reduction. The case of Chinese market debated in the case of the statically situation give a description of the possibility to implement remanufacturing by linking directly with the manufacturing. Future more recommendations can exemplify the CE concept if the OEM and remanufacturing industry connect each other as business to business and business to consumer. The exemplification reviled by the certain companies, US and Europe can strongly support other developing countries and companies to implement remanufacturing in a sustainable way creating jobs and reducing WEEE. Avoiding the main barriers as environmental issues and consumer recognition by implementing a good management, eco-design and reuse selection to increase the potential of the buy-back concept.

As a general overview, on all discussed examples and descriptions about the remanufacturing in this article, it can be concluded that remanufacturing industry could be suitable, if it will be implemented in the developed and developing country as well. Both can gain much more benefits from several aspects starting with the manufacturing and finishing with revers management and WEEE reuse or recycling. As is revealed many countries have a very week legislation and technological possibility to remanufacture especially in Asia. In some countries as China, the remanufacturing concept is developing just for some sectors excluded electronics even if technologically is possible to be implemented. From the legislative aspect the benefits of remanufacturing can be strongly reinforced if the governments accept the challenges and suggestions of other countries, companies and lean from their experiences. A good revers management, product design and reuse possibility of a e-product can bust the remanufacturing industry supporting the cost reduction, environmental impact and a healthy circular economy.

These are given as example by Xerox Group UK and IBM (China) remanufacturing by introducing the monetarize system at their products and increasing the possibility to regress old products and waste generation.

This article will help researcher to know the exiting situation worldwide of remanufacturing from the technological and legislative emplacement aspect. Different situation, cases, assumptions and modalities are reviled for a stronger sustainability of the remanufacturing in different countries. In other hand, the future development of the electronic industry will need to be more concern about their waste and they should consider all the aspects for a better functionality and life cycle of their e-products. Therefore, the detail work should be conducted to establish the perception of developing countries regardless remanufacturing potential, and proper implementation in different growing industries such as electronic manufacturing.

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References

Abdulrahman, M.D.A., Subramanian, N., Liu, C., Shu, C., 2015. Viability of remanufacturing practice: A strategic decision making framework for Chinese auto-parts companies. J. Clean. Prod. 105, 311–323. doi:10.1016/j.jclepro.2014.02.065

Agrawal, V. V., Atasu, A., van Ittersum, K., 2015. Remanufacturing, Third-Party Competition, and Consumers' Perceived Value of New Products. Manage. Sci. 61, 60–72. doi:10.1287/mnsc.2014.2099

Alejandra Sepúlveda, Mathias Schluep, Fabrice G. Renaud, Martin Streicher c, Ruediger Kuehr Christian Hagelüken, A.C.G., 2010. A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling : Examples from China and India. Environ. Impact Assess. Rev. 30, 28–41. doi:10.1016/j.eiar.2009.04.001

Alev, S.A., Saldanha-da-gama, F., Nickel, S., 2012. Multi-period reverse logistics network design. Eur. J. Oper. Res. Oper. Res. 220, 67–78. doi:10.1016/j.ejor.2011.12.045

Awasthi, 2016. Environmental pollution of electronic waste recycling in India: A critical review. Environ. Pollut. 211, 259–270. doi:10.1016/j.envpol.2015.11.027

Awasthi, A.K., Zeng, X., Li, J., 2016. Relationship between e-waste recycling and human health risk in India: a critical review. Environ. Sci. Pollut. Res. 23, 11509–11532. doi:10.1007/s11356-016-6085-7

Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The Global E-waste Monitor 2014. Bonn, Germany.

Bernard, S., 2011. Remanufacturing. J. Environ. Econ. Manage. 62, 337–351. doi:10.1016/j.jeem.2011.05.005

Brett, 2009. Science of the Total Environment E-waste : An assessment of global production and environmental impacts. Sci. Total Environ. 408, 183–191. doi:10.1016/j.scitotenv.2009.09.044

Buşu, A.A., Muntean, I., Stan, S.-D., 2015. An Analysis of the Current Challenges of WEEE Remanufacturing. Procedia Technol. 19, 444–450. doi:http://dx.doi.org/10.1016/j.protcy.2015.02.063

Chung, C.-J., Wee, H.-M., 2008. Green-component life-cycle value on design and reverse manufacturing in semi-closed supply chain. Int. J. Prod. Econ. 113, 528–545.

Environment Protection Authority (EPA) USA, 2009. Waste Guidelines [WWW Document]. URL https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjb-Zzem5rMAhXh26YKHWLXDRYQFggcMAA&url=http%3A%2F%2Fwww.epa.sa.gov.au%2Ffiles%2F4771336_guide_waste_definitions.pdf&usg=AFQjCNF5hKMiKNqe6JjwuXYJsjkQmI8GMQ&bvm=bv.1197 (accessed 4.1.16).

European Remanufacturing Network, 2015. Remanufacturing market study.

Eurostat, 2016. European Union. Waste Electrical and Electronic Equipment. [WWW Document]. URL http://ec.europa.eu/environment/waste/rohs_eee/legis_en.htm (accessed 4.26.16).

Feng, Y., Viswanathan, S., 2011. A new lot-sizing heuristic for manufacturing systems with product recovery. Int. J. Prod. Econ. 133, 432–438. doi:http://dx.doi.org/10.1016/j.ijpe.2010.04.018

Ferguson, M., 2010. Strategic issues in closed-loop supply chains with remanufacturing. Closed-Loop Supply Chain. New Dev. to Improv. Sustain. Bus. Pract. 1–12. doi:10.1201/9781420095265-c2

Ferguson, M., Guide, V.D., Koca, E., Van Souza, G.C., 2009. The value of quality grading in remanufacturing. Prod. Oper. Manag. 18, 300–314. doi:10.1111/j.1937-5956.2009.01033.x

Garashi, K.I., Amada, T.Y., Noue, M.I., 2013. Disassembly System Design with Environmental and Economic Parts Selection using the Recyclability Evaluation Method 64, 293–302.

Gehin, A., Zwolinski, P., Brissaud, D., 2008. A tool to implement sustainable end-of-life strategies in the product development phase. J. Clean. Prod. 16, 566–576. doi:10.1016/j.jclepro.2007.02.012

Geng, Y., Xinbei, W., Qinghua, Z., Hengxin, Z., 2010. Regional initiatives on promoting cleaner production in China: A case of Liaoning. J. Clean. Prod. 18, 1500–1506. doi:10.1016/j.jclepro.2010.06.028

Geyer, R., Van Wassenhove, L.N., Atasu, a., 2007. The Economics of Remanufacturing Under Limited Component Durability and Finite Product Life Cycles. Manage. Sci. 53, 88–100. doi:10.1287/mnsc.1060.0600

Giuntini, R., Gaudette, K., 2003. Remanufacturing: The next great opportunity for boosting US productivity. Bus. Horiz. 46, 41–48. doi:10.1016/S0007-6813(03)00087-9

Gold, O., 2010. Extreme prospects [WWW Document]. URL http://www.nature.com/nature/journal/v495/n7440_supp/full/495S4a.html (accessed 4.10.16).

Govindan, K., Garg, K., Gupta, S., Jha, P.C., 2016a. Effect of product recovery and sustainability enhancing indicators on the location selection of manufacturing facility. Ecol. Indic. 67, 517–532. doi:10.1016/j.ecolind.2016.01.035

Govindan, K., Madan Shankar, K., Kannan, D., 2016b. Application of fuzzy analytic network process for barrier evaluation in automotive parts remanufacturing towards cleaner production - A study in an Indian scenario. J. Clean. Prod. 114, 199–213. doi:10.1016/j.jclepro.2015.06.092

Govindan, K., Soleimani, H., 2016. A review of reverse logistics and closed-loop supply chains: A Journal of Cleaner Production focus. J. Clean. Prod. 142, 371–384. doi:10.1016/j.jclepro.2016.03.126

Govindan, K., Soleimani, H., Kannan, D., 2014. Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future. Eur. J. Oper. Res. 240, 603–626. doi:10.1016/j.ejor.2014.07.012

Guide, V., 1999. Remanufacturing production planning and control: US industry best practice and research issues. Proc. Second Int. Work. Pap. Re-use, Eindhoven 115–28.

Guide, V.D.R., 2000. Production planning and control for remanufacturing: Industry practice and research needs. J. Oper. Manag. 18, 467–483. doi:10.1016/S0272-6963(00)00034-6

Guillaume Moënne-Loccoz, N.S., 2015. Remanufacturing implementation within Neopost: key success factors and insight into the measurements of its environmental, economical and social benefits, in: International Conference on Remanufacturing (ICoR2015),. Amsterdam, Netherlands.

Hatcher, G.D., Ijomah, W.L., Windmill, J.F.C., 2013. Design for remanufacturing in China: a case study of electrical and electronic equipment. J. Remanufacturing 3, 3. doi:10.1186/2210-4690-3-3

Hormozi, A., 1996. Remanufacturing and its consumer, economic and environmental benefits, in: APEX Remanufacturing Symposium. pp. 20–22.

Huang, Y., Wang, Z., 2016. Closed-loop supply chain models with product take-back and hybrid remanufacturing under technology licensing. J. Clean. Prod. 142, 1–11. doi:10.1016/j.jclepro.2016.10.065

IBM, 2016a. IBM Company [WWW Document]. IT Infrastruct. URL http://www.ibm.com/it-infrastructure/uk-en/?lnk=buit-uken (accessed 4.26.16).

IBM, 2016b. IBM [WWW Document]. URL http://www.ibm.com/it-infrastructure/us-en/?lnk=buit&lnk2=learn (accessed 2.14.16).

Ijomah, W.L., Danis, M., 2012. 8. Refurbishment and reuse of WEEE, in: Stevels, V.G. and A. (Ed.), Waste Electrical and Electronic Equipment (WEEE) Handbook. WP WOODHEAD PUBLISHING, Chambridge, UK, pp. 145–162. doi:10.1533/9780857096333.5.591

Ijomah, W.L., McMahon, C.A., Hammond, G.P., Newman, S.T., 2007a. Development of design for remanufacturing guidelines to support sustainable manufacturing. Robot. Comput. Integr. Manuf. 23, 712–719. doi:10.1016/j.rcim.2007.02.017

Ijomah, W.L., McMahon, C.A., Hammond, G.P., Newman, S.T., 2007b. Development of design for remanufacturing guidelines to support sustainable manufacturing. Robot. Comput. Integr. Manuf. 23, 712–719. doi:10.1016/j.rcim.2007.02.017

Ismail N, Guillaume Mandil, P.Z., 2015. Analysis of the existing design for remanufacturing tools: A first step toward an integrated design platform for remanufacturing.

Jiménez-Parra, Rubio-Lacoba, S., V.-M., 2012. An approximation to the Remanufactured Electrical and Electronic Equipment Consumer, in: 6th International Conference on Industrial Engineering and Industrial Management. XVI. pp. 433–440.

Junior, M.L., Filho, M.G., 2016. The Management of Operations Production planning and control for remanufacturing : literature review and analysis 7287. doi:10.1080/09537287.2011.561815

Karvonen, I., Jansson, K., Tonteri, H., Vatanen, S., Uoti, M., 2015. Enhancing remanufacturing – studying networks and sustainability to support Finnish industry. J. Remanufacturing 5, 5. doi:10.1186/s13243-015-0015-6

LaGrega, Phillip L. Buckingham, J.C.E.D., 2010. Book review Hazardous Waste Management, Journal of Hazardous Materials.

Lau, K.H., Wang, Y., 2009. Reverse logistics in the electronic industry of China: a case study. Supply Chain Manag. An Int. J. 14, 447–465. doi:10.1108/13598540910995228

Li, J., Zeng, X., Chen, M., Ogunseitan, O.A., Stevels, A., 2015. "control-Alt-Delete": Rebooting Solutions for the E-Waste Problem. Environ. Sci. Technol. 49, 7095–7108. doi:10.1021/acs.est.5b00449

Li, J., Zeng, X., Stevels, A., 2014. Ecodesign in Consumer Electronics: Past, Present, and Future. Crit. Rev. Environ. Sci. Technol. 45, 840–860. doi:10.1080/10643389.2014.900245

Li, X., Li, Y., Cai, X., 2015. Remanufacturing and pricing decisions with random yield and random demand. Comput. Oper. Res. 54, 195–203. doi:10.1016/j.cor.2014.01.005

Linton, J.D., 2008. Assessing the economic rationality of remanufacturing products. J. Prod. Innov. Manag. 25, 287–302. doi:10.1111/j.1540-5885.2008.00301.x

Lund, R.T. and B.M., 1984. Remanufacturing: The experience of the United States and implications for developing countries.

Martin, P., Guide, V.D.R., Craighead, C.W., 2010. Supply chain sourcing in remanufacturing operations: An empirical investigation of remake versus buy. Decis. Sci. 41, 301–324. doi:10.1111/j.1540-5915.2010.00264.x

McCaskey, D., 1994. Anatomy of adaptable manufacturing in the remanufacturing environment, in: APICS Remanufacturing Seminar Proceedings, USA. pp. 42–45.

Nabil, 2006. Remanufacturing : A Key Enabler to Sustainable Product Systems. Proc. LCE 15–18.

Narendra Singh, Jiecong Wang, J.L., 2016. Waste cathode rays tube: an assessment of global demand for processing. Procedia Environ. Sci. 31, 465 – 474.

Narendra Singh, Jinhui Li, X.Z., 2016. Global responses for recycling waste CRTs in e-waste. Waste Manag. 57, 187–197. doi:doi.org/10.1016/j.wasman.2016.03.013

Narendra Singh, L.J., 2015. Bio-extraction of Metals as secondary resources From E-waste. Appl. Mech. Mater. 768, 602–611. doi:doi:10.4028/www.scientific.net/AMM.768.602

Nasr, 1996. Lifecycle analysis and costing in an environmentally conscious manufacturing environment, in: APICS remanufacturing symposium proceedings (Ed.), Lifecycle Analysis and Costing in an Environmentally Conscious Manufacturing Environment. pp. 20–22.

Ongondo et al., 2011. How are WEEE doing ? A global review of the management of electrical and electronic wastes. Waste Manag. 31, 714–730. doi:10.1016/j.wasman.2010.10.023

Otieno, W., 2015. Labor capacity assignment model for remanufacturing environments, in: International Conference on Remanufacturing (ICoR2015. Amsterdam, Netherlands, pp. 235–246.

Perkins, BS,DevinN.,Marie-Noel Brune Drisse, MS, Tapiwa Nxele, MS, and Peter D. Sly, M., 2014. E-Waste : A Global Hazard. Ann. Glob. Heal. 80, 286–295.

doi:10.1016/j.aogh.2014.10.001

Preston, F., 2012. A Global Redesign? Shaping the Circular Economy. Energy, Environ. Resour. Gov. 1–20. doi:10.1080/0034676042000253936

Reck, B.K., Graedel, T.E., 2012. Challenges in Metal Recycling. Science (80-.). 337, 690–695. doi:10.1126/science.1217501

REMATEC, 2016. Indonesia allows the import of goods for Reman purposes [WWW Document]. ReMaTec. URL http://www.rematec.com/news/news-articles/indonesia-allows-the-import-of-goods-for-reman-purposes/ (accessed 5.12.16).

Richter, K., Sombrutzki, M., 2000. Remanufacturing planning for the reverse Wagner/Whitin models. Eur. J. Oper. Res. 121, 304–315. doi:http://dx.doi.org/10.1016/S0377-2217(99)00219-2

Robot, T., 1996. LUND. The Remanufacturing industry-hidden giant.

Rubio, S., Jiménez-Parra, B., 2014. Reverse logistics: Overview and challenges for supply chain management. Int. J. Eng. Bus. Manag. 6, 1–7. doi:10.5772/58827

Sabbaghi, M., Esmaeilian, B., Cade, W., Wiens, K., Behdad, S., 2016. Business outcomes of product repairability: A survey-based study of consumer repair experiences. Resour. Conserv. Recycl. 109, 114–122. doi:10.1016/j.resconrec.2016.02.014

Sabbaghi, M., Esmaeilian, B., Raihanian Mashhadi, A., Behdad, S., Cade, W., 2015. An investigation of used electronics return flows: A data-driven approach to capture and predict consumers storage and utilization behavior. Waste Manag. 36, 305–315. doi:10.1016/j.wasman.2014.11.024

Salhofer, S., Steuer, B., Ramusch, R., Beigl, P., 2015. WEEE management in Europe and China - A comparison. Waste Manag. doi:10.1016/j.wasman.2015.11.014

Shrawder, J., 2009. Remanufacturing. Singapore. doi:2009/SOM1/MAG/WKSP/003

Singh N, Jinhui Li, X.Z.S., 2016. Solutions and challenges in recycling waste cathode - ray tube. J. Clean. Prod. Prod. 1–13. doi:doi.org/10.1016/j.wasman.2016.03.013

Singh N, J.L., 2014. Evaluation of Waste Cathode Rays Tubes (CRTs) Glass Recycling from Economic and Environmental Point of ..., in: Waste Management & Resource Utilisation. Waste Management & Resource Utilisation.

Steeneck, D.W., Camelio, J.A., Koelling, C.P., Sturges, R.H., 2014. Strategic Planning for the Reverse Supply Chain : Optimal End-of-Life Option , Product Design , and Pricing.

Su, B., Heshmati, A., Geng, Y., Yu, X., 2013. A review of the circular economy in China: Moving from rhetoric to implementation. J. Clean. Prod. 42, 215–227. doi:10.1016/j.jclepro.2012.11.020

Su, T.S., 2014. Fuzzy multi-objective recoverable remanufacturing planning decisions involving multiple components and multiple machines. Comput. Ind. Eng. 72, 72–83. doi:10.1016/j.cie.2014.03.007

Tan, Q., Zeng, X., Ijomah, W.L., Zheng, L., Li, J., 2014. Status of end-of-life electronic product remanufacturing in China. J. Ind. Ecol. 18, 577–587. doi:10.1111/jiec.12124

Tang, O., Teunter, R., 2006. Economic lot scheduling problem with returns. Prod. Oper. Manag. 15, 488–497.

Tsai, W.-H., Lin, W.-R., Fan, Y.-W., Lee, P.-L., Lin, S.-J., Hsu, J.-L., 2012. Applying a mathematical programming approach for a green product mix decision. Int. J. Prod. Res. 50, 1171–1184.

Umair, S., Björklund, A., Petersen, E.E., 2015. Social impact assessment of informal recycling of electronic ICT waste in Pakistan using UNEP SETAC guidelines. Resour. Conserv. Recycl. 95, 46–57. doi:10.1016/j.resconrec.2014.11.008

Vishal V. Agrawal, Atalay Atasu, K. van I., 2010. The Eect of Remanufacturing on the Perceived Value of New Products Consumers â€™ Perceived Value of New Products. Manage. Sci.

Wang, L., Wang, X.V., Gao, L., Váncza, J., 2014. A cloud-based approach for WEEE remanufacturing. CIRP Ann. - Manuf. Technol. 63, 409–412. doi:10.1016/j.cirp.2014.03.114

Wang, Y., Chang, X., Chen, Z., Zhong, Y., Fan, T., 2014. Impact of subsidy policies on recycling and remanufacturing using system dynamics methodology: A case of auto parts in China. J. Clean. Prod. 74, 161–171. doi:10.1016/j.jclepro.2014.03.023

Wei, S., Cheng, D., Sundin, E., Tang, O., 2015. Motives and barriers of the remanufacturing industry in China. J. Clean. Prod. 94, 340–351. doi:10.1016/j.jclepro.2015.02.014

Williams, E., Kahhat, R., Allenby, B., Kavazanjian, E., Kim, J., Xu, M., 2008. Environmental, social, and economic implications of global reuse and recycling of personal computers. Environ. Sci. Technol. 42, 6446–6454. doi:doi:10.1021/es702255z

Williamson, I. a, Pearson, D.R., Aranoff, S.L., Pinkert, D. a, 2012. Remanufactured Goods : An Overview of the U . S . and Global Industries , Markets , and Trade 284. doi:10.1006/mare.1996.0019

Zanghelini, G.M., Cherubini, E., Soares, S.R., Life, C., 2013. INFLUENCE OF REMANUFACTURING ON LIFE CYCLE STEPS : AIR COMPRESSOR STUDY CASE IN BRAZIL.

Zanoni, S., Segerstedt, A., Tang, O., Mazzoldi, L., 2012. Multi-product economic lot scheduling problem with manufacturing and remanufacturing using a basic period policy. Comput. Ind. Eng. 62, 1025–1033. doi:10.1016/j.cie.2011.12.030

Zeng, X., Gong, R., Chen, W.-Q., Li, J., 2015. Uncovering the Recycling Potential of “New” WEEE in China. Environ. Sci. Technol. doi:10.1021/acs.est.5b05446

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Countries	Regulations		Associations involve in WEEE reduction, recycling, and remanufacturing	Recycling types		Rem. Technology availability	Common equipment rem.	References
	WEEE	Rem.		Formal	Informal			
E.U.	✓	✓	European Rem Network (ERN)	✓	-	✓	Cartridge; AC; Printers; ICT; PC; Mobile phones; Servers; Medical equipment	(Long et al., 2016; Sthiannopkao and Wong., 2013)
U.K.	✓	✓	Scottish Institute for remanufacture	✓	-	✓		(Center for Remanufacturing & Reuse. 2009)
U.S.	✓	✓	U.S. International Trade Commission, Remanufacturing Industry Council (RIC)	✓	-	✓		(Williamson et al. 2012; Sthiannopkao and Wong 2013)
China	✓	✓	National Key Laboratory for Remanufacturing	✓	✓	✓		(Sthiannopkao and Wong 2013; Bijuan 2012)
India	✓	-	Environmental Ministry, Automotive Tyre	✓	✓	-		(Sharma et al., 2016; Awasthi et al., 2016; Rathore et al., 2011)
Brazil	✓	✓	Brazilian Cartridges' Remanufacturers Association (ABRECI)	✓	✓	-		(J. Neto., 2013; Zanghelini et al., 2013; Saavedra et al., 2013)
Indonesia	✓	-	Minister of Industry	✓	✓	-		(Fatimah and Biswas 2016; REMATEC. 2016)
Malaysia	✓	-	APEC, Basel Conv.; Ministry of Environment	✓	✓	-		(Centre of Remanufacturing and Reuse. 2015)
Singapore	✓	✓	National Environment Agency	✓	-	✓		(National Environment Agency. 2016)
Pakistan	✓	-	Ministry of Industries and Production, Ministry of Environment	✓	✓	-		(Hameed et al., 2013; Puckett et al., 2002)

Table. A1
Worldwide distribution of the remanufacturing status

EOL Option	Description
Landfill	Dispose of a product, or its parts, in a landfill.
Recycle	Recover material from the product or its parts. Any value depends on the form of the product, or its parts, and if it destroyed or not.
Resell	Sell product, or its parts, on used market as it is.
Repair/Refurbishment	Fix the product, or its parts, to some specified standard and sell them on the used market.
Remanufacturing	Re-make the product, or its parts, by using a mixture of recovered and replacement parts so that it meets the “like-new” specification (i.e. identical warranty to that for a new product).

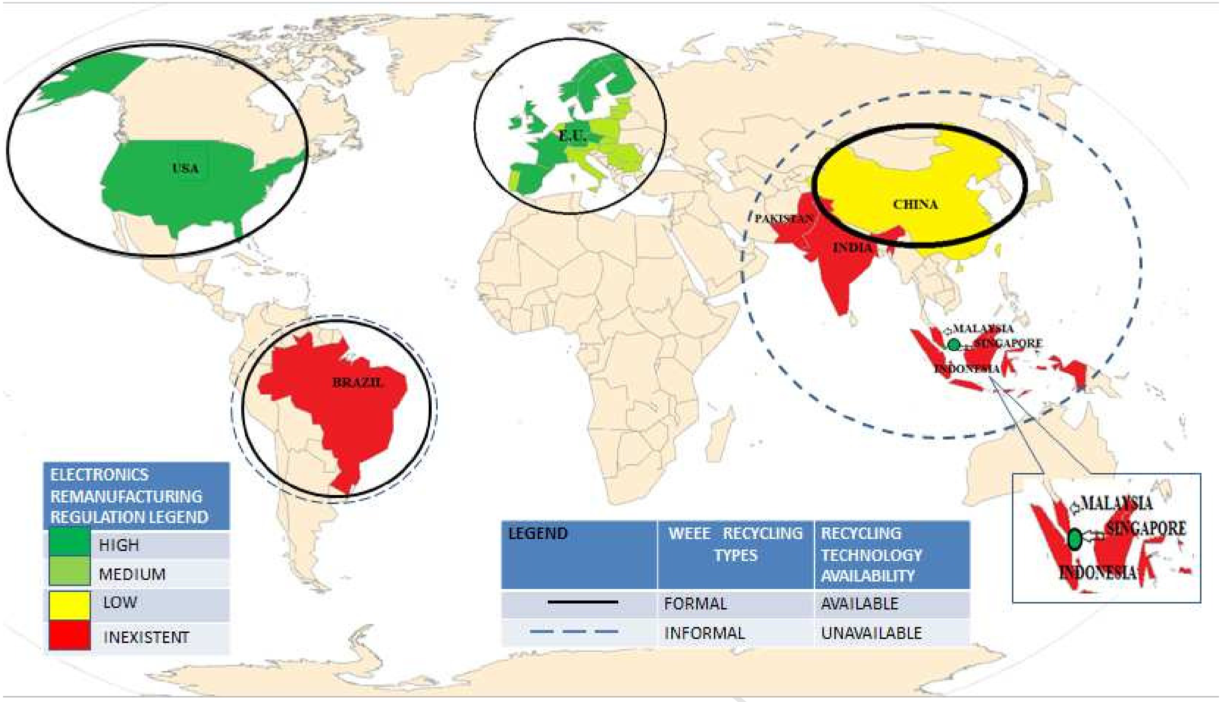
Table. 1 Types of destination places for End-of-life (EOL)

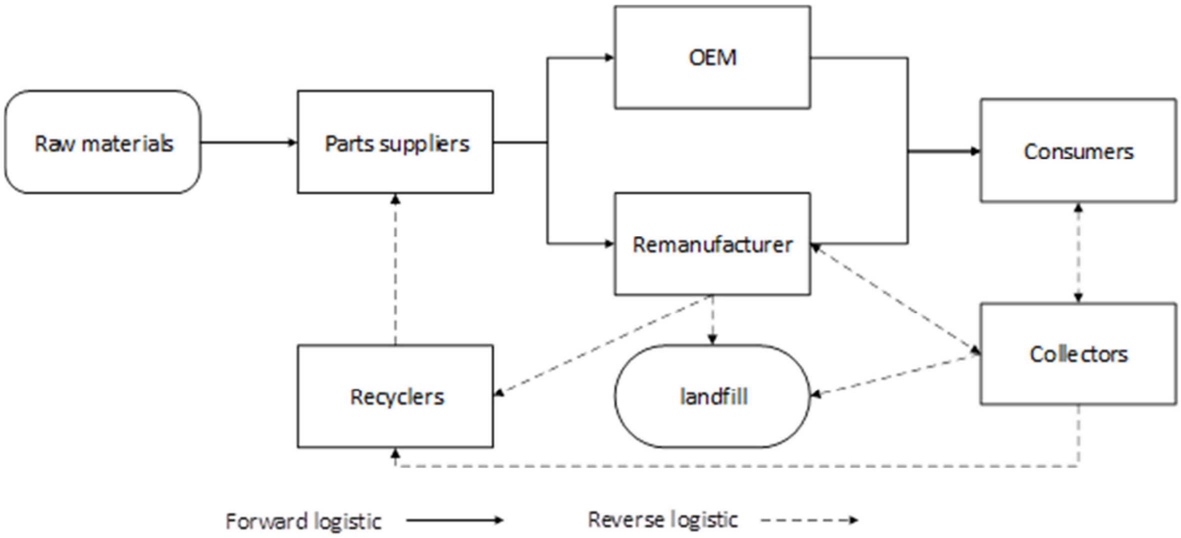
Remanufacturing and sustainable development	**Remanufacturing like a system**
Technical feasibility: • Materials, methods, man, machine, energy, and information, are included	Design for remanufacturing
Economic aspects: • LCA, cost, product recovery, disassembling, cleaning and washing, reconditioning, recovery, etc...;	Reserve supply chain(RSC), acquisition/relationship, reserve logistics
Social aspect: • attitude, orientation, behavior, warranty;	Information flow in the remanufacturing: • Composition of the product; • Magnitude and uncertainty of the return flow; • Market of remanufactured product; • Information about how product returns.
Environmental aspects	Employees knowledge and skills; • The remanufacturing operation; • Commercialization of the remanufactured products.

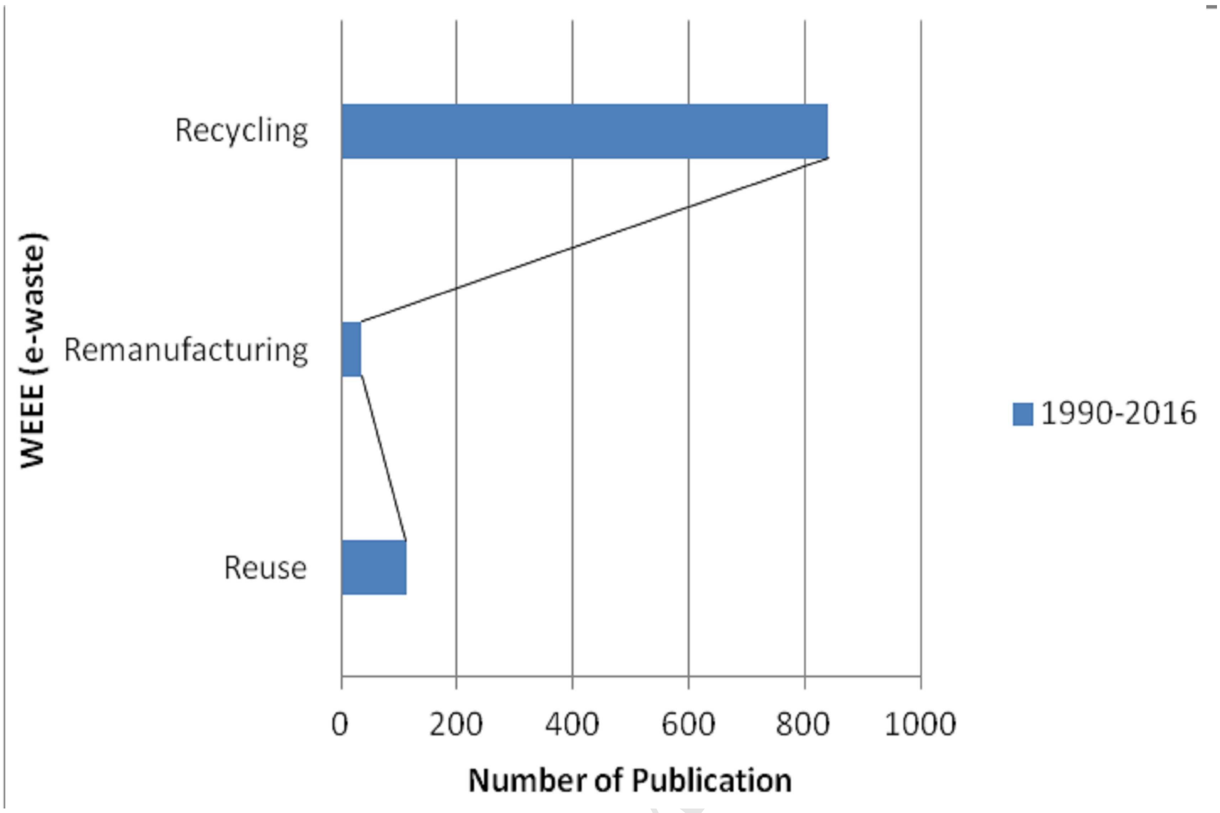
Table. 2
IBM remanufacturing perspectives.

Items. Nr:	**Recycling rate**	**Recycling cost**	**Return**	**CO2 saving rate**
1	64.02	21.77	0.93	0.62
2	29.10	20.06	0.94	0.15
3	64.02	17.49	0.95	2.22
4	79.25	17.49	0.96	1.82
5	19.08	17.49	0.97	1.52
6	29.10	13.37	0.98	2.18
7	39.27	13.37	0.99	o.60
8	48.43	17.49	0.100	2.28
9	57.71	36.51	0.101	8.31
10	67.44	17.49	0.102	7.92
11	79.69	17.49	0.103	3.08
12	83.19	18.41	0.104	19.28
13	95.48	17.31	0.105	2.16
14	95.48	17.49	0.106	15.21
15	95.48	17.49	0.107	1.27

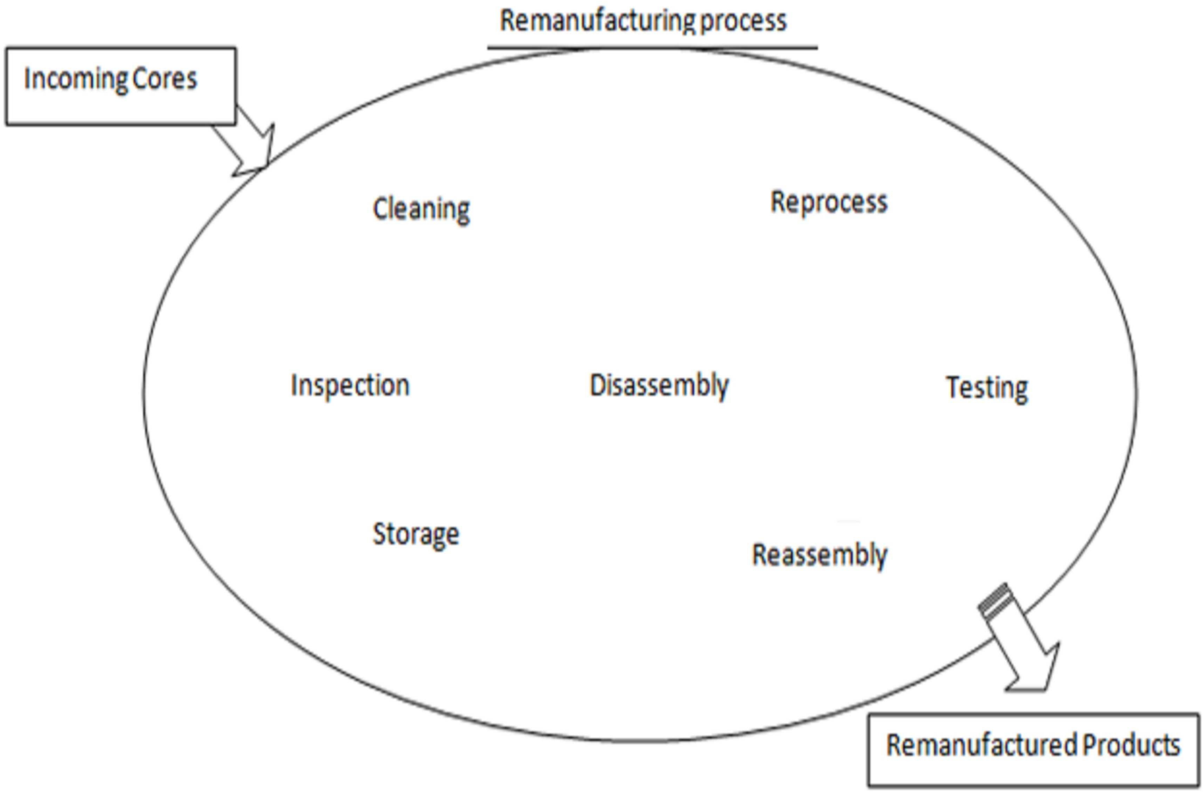
Table. 3
WEEE sustainability potential

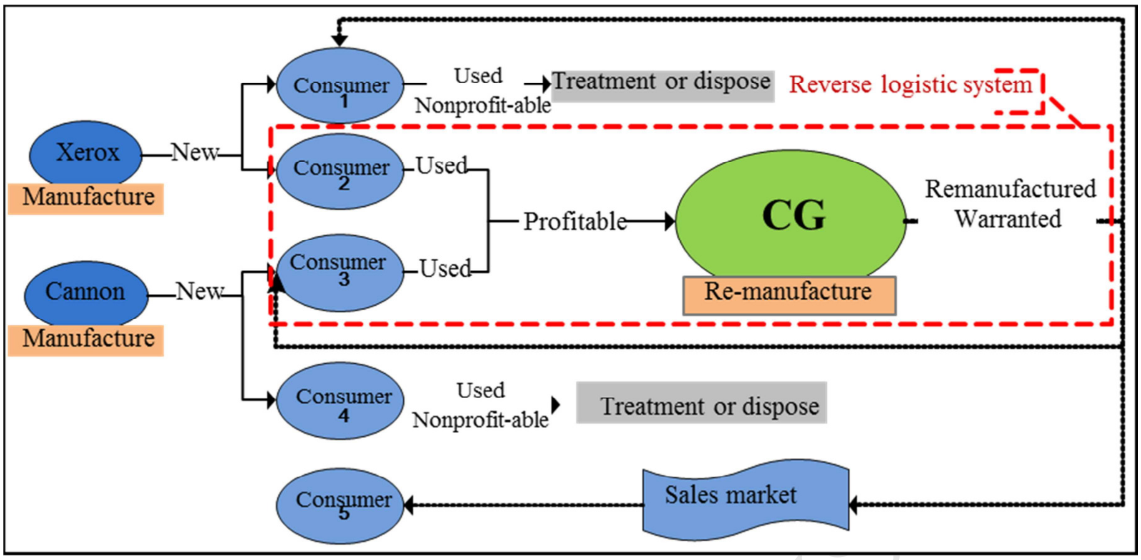

USA
E.U.
CHINA
PAKISTAN
INDIA
BRAZIL
MALAYSIA
SINGAPORE
INDONESIA
ELECTRONICS REMANUFACTURING REGULATION LEGEND
HIGH
MEDIUM
LOW
INEXISTENT
LEGEND
WEEE RECYCLING TYPES
RECYCLING TECHNOLOGY AVAILABILITY
FORMAL
AVAILABLE
INFORMAL
UNAVAILABLE

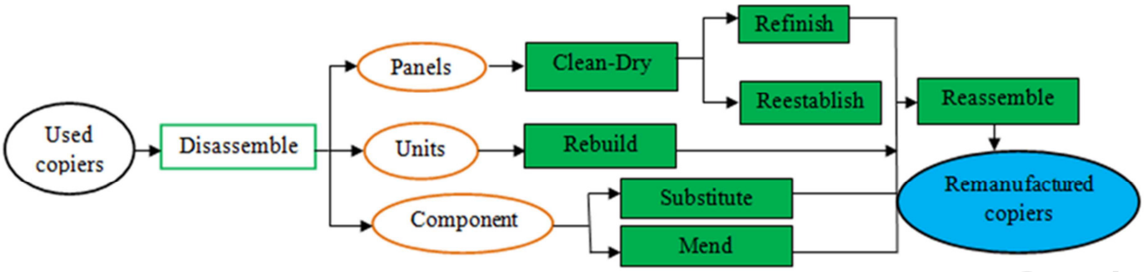

Raw materials
Parts suppliers
OEM
Remanufacturer
Consumers
Collectors
Recyclers
landfill
Forward logistic
Reverse logistic

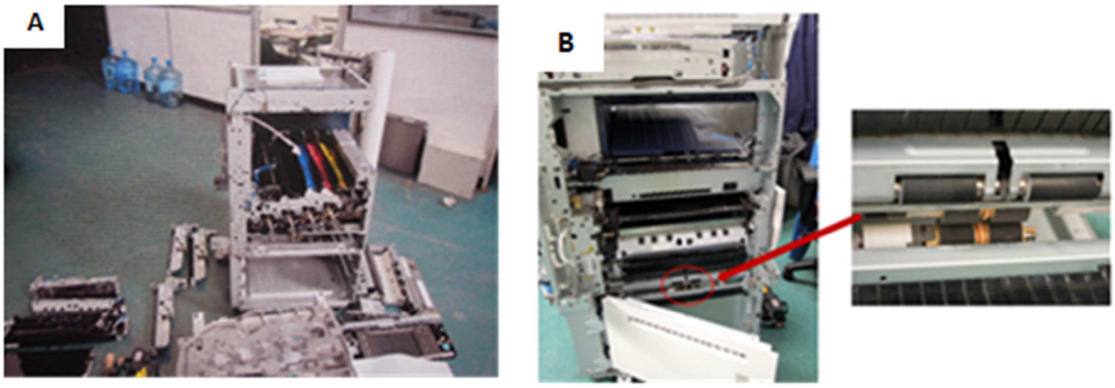


Recycling
Remanufacturing
Reuse
WEEE (e-waste)
0
200
400
600
800
1000
Number of Publication
1990-2016


Remanufacturing process
Incoming Cores
Cleaning
Reprocess
Inspection
Disassembly
Testing
Storage
Reassembly
Remanufactured Products


Xerox
Manufacture
New
Cannon
Manufacture
New
Consumer 1
Used
Nonprofit-able
Treatment or dispose
Reverse logistic system
Consumer 2
Used
Consumer 3
Used
Profitable
CG
Re-manufacture
Remanufactured
Warranted
Consumer 4
Used
Nonprofit-able
Treatment or dispose
Consumer 5
Sales market


Used copiers
Disassemble
Panels
Units
Component
Clean-Dry
Rebuild
Substitute
Mend
Refinish
Reestablish
Reassemble
Remanufactured copiers


A
B

Research highlights

1. Perception overview of remanufacturing implementation.
2. Implemented methods for a revers end of life e-products.
3. Evaluated situation of remanufacturing between China and remanufacturing companies from Europe (Glasgow-UK).
4. Remanufacturing barriers.