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Enhancing reuse and resource recovery of electrical and electronic equipment with reverse logistics to meet carbon reduction targets

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Abstract

Technological advances, with increasing numbers of products containing complex electronic circuitry, have resulted in e-waste becoming the fastest-growing global waste stream. High levels of embodied carbon in these products ensure that, to meet emissions reduction targets proposed by the United Nations Paris Agreement, tackling e-waste requires strategies to address climate change United Nations Sustainable Development Goal 13 (UNSDG13). This paper identifies the contribution improved reverse logistics can make to extending product lifetimes through facilitating reuse. Semi-structured interviews were conducted with academics, industry-leaders and policymakers in the United Kingdom and Europe. This research identified that improvements in availability and efficiency of reverse logistics processes would increase reuse potential and efficient resource recovery. Availability and efficiency challenges can be addressed through careful promotion, incentivisation, and engagement of existing compliance schemes. If these challenges are approached from a life cycle perspective, it will be possible to protect against value loss in global supply chains (UNSDG12) and address the climate action agenda.

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Keywords: Reuse, Electrical and electronic equipment, Reverse logistics, Product lifetimes

1. Introduction

The speed of manufacture, growth in sales and replacement of electrical and electronic equipment has led to expotential growth in the generation of e-waste. In 2014, global e-waste was estimated to be approximately 41.8 million tonnes [1]. E-waste contains high levels of embodied carbon due to extraction, production and transport processes [2]. Additionally, many valuable metals such as aluminium, gold and copper and other critical raw materials (CRMs) are present in these products [3]. Improving material efficiency [4] and ensuring a product reaches its optimal lifespan would minimise emissions throughout its life cycle from design and manufacturing, to disposal [5, 6]. In order to meet carbon reduction targets a multi-faceted response is required that takes products through repeating use cycles. This would keep products, components and materials at their highest utility and value, will slow material flows and avoid waste [7]. Moving towards a circular economy, with repair, reuse and enhanced recycling as part of a whole life cycle approach to embodied carbon [8] are essential strategies that are becoming more crucial [9].

The European Union (EU) Waste Electrical and Electronic Equipment (WEEE) Directive put in place a framework for separate collection and treatment processes for e-waste. This recognises the need to process e-waste differently to general waste because of the presence of highly toxic materials which require specialist treatment [10]. However, the existing WEEE

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management system, which focuses only on material recovery, does not exploit other end-of-life options [11]. A circular economy [9] includes end-of-life options for EEE, which increase product longevity, either by extending a product's first life or addressing issues of repair, reuse and remanufacturing [12, 13]. These options are also more resource efficient and offer more environmental savings than recycling [14, 15], although this is often overlooked [16], and could be facilitated by improvements in the reverse supply chain [17]. This is increasingly relevant to electrical items, given the loss of materials they contain, particularly critical raw materials, which have higher environmental and economic importance and face issues around the security of supply [18] in addition to the loss of potential products for reuse.

The problems of dealing with e-waste are not restricted to the area in which unwanted items are discarded. Exporting consumer goods to developing countries for reuse, whilst providing utility to consumers in developing countries, can have negative social consequences where there are inadequate disposal practices or policy for any resulting waste [19]. Less developed countries rarely possess the technology or enforcement regimes necessary to mitigate the external effects of disposal of e-waste and the hazardous materials it contains [20]. It is these global social costs that the Basel Convention aimed to prevent by restricting the shipment of e-waste, whilst allowing shipment of reusable products. This paper presents initial findings from a series of interviews with stakeholders across the EEE value chain. The interviews covered various aspects relating to end-of-life treatment of e-waste, exploring issues related to extending product lifetimes, repair and reuse. The interviews identified the reverse flow of goods through established waste collection systems, and other means, as an important part of closing loops and improving material flows in a circular economy. Ensuring a life cycle approach is taken will ensure products reach their optimum lifetimes and the capture of resources is improved. Other points of discussion included how financial payments made by manufacturers to compliance scheme operators in order to comply with producer responsibility could finance a better reverse flow of goods, improving resource efficiency.

1.1. United Nations Sustainable Development Goals

The 17 United Nations (UN) Sustainable Development Goals (SDGs) and their associated 169 targets provide a global agenda for sustainable development and set an ambitious action plan requiring commitment from all stakeholders globally [21]. Several of the UNSDGs can be addressed by extending product lifetimes and slowing material flows by facilitating reuse of products through the adaptation of reverse logistics models. This can take either an organisational or sector-based approach to e-waste [22].

1.2. Reverse logistics to enhance reuse and resource recovery.

Reverse logistics is the process of moving products from the point of use to the point of origin for the purpose of recapturing value or proper disposal [23]. This involves collecting item from end users for the purpose of repair, reuse, remanufacture, recycling, or disposal [24, 25] and thus has an essential role to play in both extending product lifetimes and improving resource efficiency [17]. Considerable attention has been paid by academics in recent decades to reverse logistics due to the potential it offers for value recovery from used products [26, 27, 28]. However, many difficulties have been identified [22]. These include the location and availability of processing facilities [17] and consumer attitudes, both at the point of product discard [29] and purchasing reused items [30].

There are various examples of reverse logistics operating in the EEE sector [31]. The literature addresses many of these, generally concluding that the benefits are dependent on the type of businesses and products involved [17, 23]. Many successful examples of reuse involve the producer in the process, as they are knowledgeable about their own products [25, 23]. Opportunities exist for manufacturers to coordinate their supply chain and reverse logistics to facilitate reuse, refurbishing and remanufacturing of their products and to maintain control of market share of both new and returned products [31]. Producer responsibility was introduced to provide manufacturers with a financial incentive to produce less harmful products, and as such, provides the motivation to facilitate reverse logistics together with members of the supply chain [31, 32, 33]. Additionally, manufacturers maintain control of constituent materials within recovered products [34] which will become increasingly important as resources become progressively scarcer. Barriers and drivers to increased use of reverse logistics to facilitate reuse of products are shown in Table 1.

Table 1. Barriers and drivers to increased reuse via reverse logistic recovery (Adapted from Agrawal *et al., 2015).*

Barriers	Drivers
Company policy	Competitiveness
Cost of implementation	Customer preferences
Customer preferences	Economic (reducing waste disposal costs)
Financial constraints	
Lack of collection, storage and processing infrastructure	Environmental interests
	Legislation
Lack of consumer awareness	Producer responsibility
Lack of recognition in regulation (at EU &UK level)	Resource scarcity
	Reclaiming value from returns

2. Methodology

This study combines a critical interpretive synthesis review of the literature [35] and a series of 30 semi-structured interviews to investigate expert visions on existing end-of-life treatment of electrical and electronic equipment in the UK. Utilising empirical data from interviews with stakeholders (defined here as groups or individuals affected by, or who can affect the issue being researched) [36] from across the electrical and electronic equipment value chain, which is defined here as the network relating to any part of the life cycle of EEE, from conception to end use and beyond. The research has excluded the opinions of consumers, whilst recognising that all the interviewees are also consumers in a personal capacity and this may effect some of their responses during the interviews.

A preliminary literature review of current practices, challenges and implications for e-waste was conducted, guiding the sampling strategy and framing the interview questions.

2.1 Sample selection of interviewees

A purposive sampling strategy was used to recruit interview participants [37, 38]. Efforts were made to obtain a diverse sample of stakeholders across the EEE value chain (Figure 1).

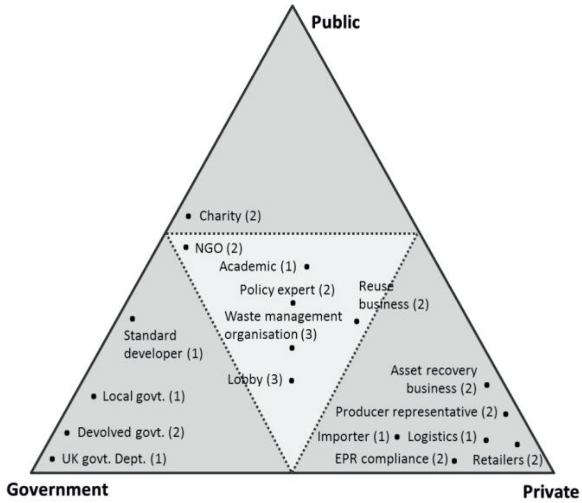

Figure 1. Distribution of stakeholders interviewed for this research across the EEE value chain.

The choice of interviewees was focussed on ensuring a range of differing perspectives were explored across the value chain, as previously defined. These included operational experiences, campaigning strategies, motivations and principal challenges faced in the area under investigation (Table 2).

Table 2. Interviewees' primary and secondary areas of expertise.

Sector /area of knowledge	No. of experts Primary expertise	Secondary expertise
Academia and research	2	
Campaigning and lobbying	4	2
Compliance	4	1
Government department	3	
Logistics	1	4
Manufacturing	1	
Non-government organisation	4	3
Retail	1	
Reuse	5	8
Social impact	3	1
Waste management	4	2

2.2 Semi-structured interviews

A series of semi-structured face-to-face interviews were undertaken. A formalised set of questions were initially used, to ensure the goals and objectives of the study were met, and a further series of open ended questions allowed flexibility to expose answers that had not been anticipated through building a rapport with interviewees [39]. This offered differing observations from each of the interviewees. The purpose was to:-

- Assess potential arrangements available to improve the prospects for reuse and repair of WEEE, together with advantages and disadvantages.
- Critically evaluate barriers identified to extending repair and reuse of WEEE in the UK, and identify strategies to overcome them.

Interviews, each lasting approximately an hour, were conducted. Interviewees spoke on topics that were central to their particular place in the life cycle of products. This paper reports some findings from these interviews. The interviews were audio-recorded, transcribed and analysed to identify both areas of agreement and disagreement; these are discussed to identify strategies and policy areas that could be improved.

2.3 Data analysis

Data analysis ran concurrently with data collection using the constant comparative method of a grounded theory approach [40]. This enabled earlier interviews to shape the selection of later interviewees and to allow themes to be explored comprehensively, whilst also supporting comparison with pre-existing literature and practice.

Transcripts were coded using NVivo© qualitative analysis software package, a tool for computer-assisted qualitative data analysis (CAQDAS), suitable for coding, analysing and interrogating large volumes of text-based data [41]. The data analysis process utilised [42] general analytical framework and involved: open-coding, generating codes at different levels of theoretical complexity (from simple descriptions to conceptual categories); constant comparison between and within codes to ensure good 'fit' with the data and a process of (re)grouping codes within broader and more theoretically relevant meta-codes, identifying common themes, establishing complementary and contradictory areas [41, 43]. This process continued until theoretical saturation was reached, with no further new codes, themes or insights being generated. Appendix A presents the first order and 2nd order codes resulting from the inductive data analysis.

3. Results

This section reports on empirical data collected during a series of 30 semi-structured interviews with stakeholders across the electrical and electronic equipment value chain. The results reported on and discussed in this paper relate to the issue of reverse logistics at the point an item is discarded. Taking a life cycle approach to e-waste can help address global material flows through waste reduction, extending product lifetimes, and increasing instances of reuse.

It is widely acknowledged that, to date, recycling has been the primary treatment method for e-waste and this is problematic because it neglects to some extent repair, refurbishment and reuse; activities that can be better undertaken when a suitable reverse logistics system is in place to facilitate them. These topics are discussed below, supplemented with a selection of quotes from interviewees.

3.1. Waste collection as a barrier to reuse.

The way goods are collected after they are discarded at the end-of-life is perceived to be one of the main barriers to reuse. Many items enter the waste system, before being recovered for reuse. Goods processed in this way become damaged and have little, or no, reuse value. This loss of 'reuse potential' was the reason a national charity with a network of reuse shops explicitly state that:

"*We don't really want an electrical item going into a waste collection facility before it comes to us.*" (Charity)

When items are being treated as 'waste' there is little care taken in how they are handled by collection crews. This results in damage to goods and effectively removes any chance of that item being accepted for reuse by the consumer. The problem of items retrieved from the waste system losing value was also supported by another interviewee. This interviewee is employed by a company that is part of the reverse logistics chain for a major retailer. The company also works with local government waste departments to salvage items for reuse, when comparing the two sources of goods for reuse they commented:

"When we collect goods from local government-run waste collection establishments, the reuse potential is negligible." (Private Company)

The loss of 'reuse potential' was a greater problem with goods received from the local government waste department, than those received as part of the retailer's reverse supply chain. The reverse logistics model was seen as a better option for sourcing reusable goods. The difference in how goods are handled as part of the waste management system was discussed in an interview with a compliance scheme operator, who explained:

"*If you handle a product badly, damage the outer skin of a washing machine or fridge, then that's it…although it is only cosmetic, acts as a barrier to being able to refurbish and sell it potentially more so than a drum bearing or something which is technically usually cost-effectively replaceable*." (Compliance scheme operator)

The damage caused following collection, during transportation, of items was an issue that many of the interviewees felt acted as one of the greatest barriers to reuse. Recording reuse potential at different stages of an items journey, through testing, repair and onwards to new owners is possible with a reverse logistics model. This type of work is undertaken by one of the organisations involved:

"*equipment would be verified as having been visually inspected, tested for safety, data wiped and functionally tested and then labelled as having been through this process to reassure potential next users…that the equipment is safe and fit for use.*" (Asset management company)

Carrying out these activities enables this organisation to maintain records on the condition of items they process for reuse. They are also able to ensure equipment is of high enough quality to offer reassurances about its condition to new owners. Thus, passing information along the reverse supply chain about the quality and condition of equipment can further facilitate reuse and can also ensure the economic viability of this work.

The acquisition practices of the national charity and other reuse organisations interviewed have, to some extent, changed to ensure they receive goods via reverse logistics, which had not become consigned to the waste system. This ensures they benefit from obtaining items that have a higher value on the second-hand market, with more reuse potential.

3.2 Reverse logistics to improve reuse

Indicating that the way collection and treatment of e-waste has been implemented in response to the WEEE Directive created the problem, and suggesting a change in e-waste collection methods as a possible solution, a local government representative said:

"*There's a possibility of it [collection services] having been done in a different way because there's a whole supply chain that could've done reverse logistics differently.*" (Local government representative)

The collection and treatment facilities currently in place in the UK addresses discarded EEE as waste. This takes no account of any reuse potential that any of those items may have. The prompt and safe removal and treatment of waste is essential to reduce the impact on both the environment and public health [29]. However, with little, or often no account taken of the condition of items, the possibility that those items could remain in service if minor cleaning or repair activities were carried out diminishes and the overall environmental impact increases with shorter than necessary product lifetimes [12].

The waste system is seen as a barrier to reuse, with the UK compliance system being seen as a way for producers to off-set their end-of-life responsibilities, "in a similar way to carbon trading" (compliance scheme operator). As an advocate of holistic reverse logistics this interviewee explained the reuse benefits.

"*When something gets delivered, they'll often say they can take away the old one. The logistics of that work a lot better, it's not waste logistics*." (Compliance scheme operator)

This would need the retailer, or delivery service to be involved in the collection of goods that are being discarded. Using delivery crews to facilitate the collection and reverse movement of items suitable for reuse was seen as a critical step to seeing goods being handled with care, retaining value, and increasing the likelihood of them being reused. The compliance scheme operator continued:

"*From collection on it can be managed in a different way…in a way that retains the functionality.*" (Compliance scheme operator)

Where discarded products do go through a reverse supply chain, enabled by collection at the same time of delivery, there is a higher probability of those items being reused by a second owner. The interviewee from the national charity explained:

"*movement from the customer to the hub, or store means that it is more likely to be reused or maintain its reuse potential because products are carried in vehicles that are designed for delivering new products by people who are* *trained to move new products…its being treated as returned product (rather than) being treated as waste*." (National charity)

Individual collection of goods improves the chances of reuse. However, the movement of goods through the supply chain is a linear flow from the manufacturer, through retailer to consumers. The reverse flow is much more complicated, with many dispersed starting points in numerous consumer locations. This problem could be addressed in the way suggested, by collecting discarded items when new ones are delivered "if you're going there anyway, it's more efficient" (Waste management company). This was supported by a reuse organisation that receives items from a national retailer who explained that "we get them back through this reverse supply chain in the best order". There may be some problems to address with this system, such as hygiene issues with old products being carried alongside new items and other difficulties associated with exchanging items during a delivery round. However, there are some benefits to businesses when taking this approach, some use it as a marketing tool to attract customers. This example was cited by an academic:

"*Some businesses advertise it as a benefit, deliver your fridge and we'll take away the old one for you*." (Academic)

In this instance it was suggested that the removal of the old item (fridge) was an additional service to the consumer, making the purchase of a new item easier as there was no problem with the disposal of the unwanted item. Other convenient ways consumers could discard items were suggested by an interviewee from a waste management company:

"*If you buy a new item, take your old one into the shop, your point of sale, the retailer as the deposit point for items rather than going to the civic amenity point or having it collected in your rubbish*." (Waste management company)

By diverting discarded items to the retailer, away from the waste management system the goods may remain reusable. It was also implied by this interviewee that if goods go back to the retailer, the forward supply chain takes responsibility for the end-of-life goods and that in doing so there are better environmental outcomes for both working goods and the materials they contain.

"*Waste collection infrastructure has a disengagement…the material coming in is totally divorced from an interaction with the producer*." (Compliance scheme operator)

The waste collection services are not the best route for e-waste if it has any reuse potential. The more effective and higher levels of reuse activity depend on producers being engaged in the stream of their products coming back. Some companies provide repair services, take-back items or offer trade-ins when making new purchases. The environmental lobby group explained:

"*Different companies, depending on their business model, have got different levels of ability to access back their old product*." (Environmental lobby organisation)

Many reasons exist for operating in this way, including compliance with legislation and high levels of customer service. Furthermore, manufacturers possess the highest level of knowledge of their own products. In organisations that offer services rather than selling equipment, reverse supply chains are further developed, enabling them to offer their consumers continuity of service, quickly and easily repairing or replacing items. There is a growing need to address material flows, particularly of critical raw materials and this may see more goods recovered and returned to manufacturer's control through the reverse supply chain.

4. Conclusions

Reuse represents an important activity that needs to be encouraged in a multi-faceted approach to reducing carbon emissions. The results reported on and presented in this paper offer evidence to support change in an area that has received far too little attention at a regulatory level in European member states. Addressing barriers discussed in the series of interviews, such as handling goods carefully to prevent loss of 'reuse potential' after they are discarded and using the reverse supply chain to address issues of aesthetic appearance, functional condition and safety could result in increased reuse.

A focus on extending products lifetimes through reuse directly addresses targets within UNSDG12, responsible consumption and production, but also impacts on several of the other SDGs particularly when related to products with high levels of embodied carbon.

There are opportunities for direct reuse of items that require minimal inspection, repair, cleaning or maintenance to move them back into supply chain, thus forming closed loops within a circular economy. Taking a life-cycle approach, increasing reverse logistics operations and changing design processes from 'design for marketing' to 'design for remanufacture and reuse' would extend product lifetimes and reduce the use of new resources.

Therefore, it is recommended that the key issues of removing e-waste from the waste system and the logistical challenges this poses are further explored. This could ensure a framework is established to enhance reuse alongside recycling, making it an easier option for e-waste.

Addressing reverse logistics processes to encourage return of items increases the opportunities for reuse and offers benefits to both the consumer, with convenient disposal points, and the manufacturer with access to resources recovered from their original products. Optimal recycling and reuse locations appear to be essential to enable the reverse flow of goods, making it more convenient for consumers to participate in the reverse supply chain. Due to cost and operational effectiveness, the reverse flow of goods may need to either be addressed on a product by product basis and will require infrastructure changes to take account of the quality and quantity of reverse flows of products.

As proactive management of environmental issues becomes more vital for addressing the challenges associated with climate change and resource efficiency, there are opportunities for reverse logistical solutions. These include increasing various forms of reuse of products throughout the supply chain. The environmental gains associated with handling goods carefully, facilitating reuse and prolonging product lifetimes are issues that will help reduce carbon emissions as we seek to meet climate change targets.

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Appendix A. First order and second order codes identified during data analysis. Please visit the following web-link: https://docs.google.com/document/d/1hjT1qpXM5GmX5D-J4_1NjAg1W4ysgF61K9ShZxE2m9w/edit?usp=sharing

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