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An assessment of achievements of the WEEE Directive in promoting movement up the waste hierarchy: experiences in the UK

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ABSTRACT

Rapidly developing technology and an increasing number of products containing electrical or electronic functions, has led to discarded electrical and electronic equipment (EEE) being one of the fastest growing waste streams. The European Union (EU) has enacted several iterations of the Waste Electrical and Electronic Equipment (WEEE) Directive to address this complex waste stream. However, recycling dominates treatments for e-waste, despite the established 'waste hierarchy' showing waste prevention and reuse are generally preferable to recycling.

This paper reports on 30 semi-structured interviews, undertaken across the EEE value chain, examining the impact of the WEEE Directive in the UK. The interviews confirmed that reuse takes place for a limited number of product types, mostly on a small scale. Additionally, whilst legislation has prompted innovation in recycling and higher capture rates, resource recovery is in practice limited to easily salvageable materials, whilst recovery of critical raw materials is often neglected. Furthermore, there is confusion around available collection networks, particularly for small WEEE, which consistently appears in residual waste streams.

The waste hierarchy remains the key component of EU waste strategy and moving to the higher levels of the waste hierarchy is an essential part of achieving sustainable waste management and moving towards a circular economy. The paper proposes a series of measures to this end: promoting recovery routes and practices that facilitate reuse of suitable products, adapting recycling technology to increase recovery of critical raw materials and targeted policies to encourage the application of the waste hierarchy within a resource efficiency-oriented framework.

1. Introduction

In recent years the rate at which electrical and electronic products are manufactured, purchased and discarded has led to the generation of substantial quantities of e-waste (Balde et al., 2014). Global e-waste, which totalled around 41.8 million tonnes in 2014 (Balde et al., 2015), consists of a highly diverse assortment of electronic products (WRAP, 2011a) containing high levels of embodied carbon due to resource extraction, production and transportation processes (Allwood et al, 2012; Norman et al., 2016). Their environmental impact is exacerbated by items being discarded before the end of their useful lives (Cooper, 2010). The recovery and treatment (i.e. depollution, disassembly, shredding, recovery or disposal) of e-waste poses a challenge to waste management systems, due to its quantity, variety, the presence of toxic materials e.g. lead, mercury, cadmium) (Kolias et al., 2014; Balde et al., 2015; CHEM Trust, 2017) and difficulties associated with the release of hazardous materials during processing activities (Savvilotidou et al., 2014). The unsustainable way in which resources are currently used has resulted in climate change, ecosystem degradation and concerns about resource supplies (UNEP, 2013). Attempts to adapt for, and mitigate against, the challenges posed by climate change have led to the introduction of carbon reduction targets in the UK (Climate Change Act, 2008) and internationally (United Nations, 2015). To meet these targets a multi-faceted response is required, addressing material flows and moving towards a circular economy (CE), with waste reduction, repair, reuse and enhanced recycling becoming more evident (Scott and Barrett, 2015; European Commission, 2015). However, complex systems dynamics exist with synergies and trade-offs across

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domains and an awareness is necessary that changes to carbon emissions in one part of the system may have an adverse impact elsewhere (Iacovidou et al., 2017a; Millward-Hopkins et al., 2018).

Moving towards a true implementation of a CE requires expanding beyond conventional methods of assessing and estimating "value". One should adequately address this creation and dissipation of a "systemic and multidimensional value" spanning social, environmental, economic and technical domains and this cannot be "collapsed" on to a single parameter. In order to do this, existing LCA, LCSA, CBA models cannot be relied on; it would require frameworks and toolkits that have the potential to address systemic challenges in a transparent, dynamic and multi-domain aspect (Iacovidou et al., 2017a; Millward-Hopkins et al., 2018).

However, the recovery and treatment of e-waste offers a secondary source of valuable metals such as aluminium, gold and copper and other critical raw materials (CRMs) (WRAP, 2011a, 2011b; EIP, 2016), which could mitigate the environmental impacts of global demand for electrical and electronic equipment (EEE) by reducing the necessity for primary resource extraction (i.e. mining) (European Commission, 2009).

The European Union introduced legislation in 2002 in the form of the WEEE Directive in 2002 (2002/96/EC) and refreshed, or recast, this a decade later (2012/19/EU). The WEEE legislation offered the potential to improve waste collection and recycling infrastructure and drive environmental benefits in terms of resource efficiency and reduced carbon emissions. However, the extent to which expected outcomes have materialised since the introduction of the Directive is contested (Mayers et al., 2011).

The aim of the research reported in this paper was to critically evaluate current practices, challenges and implications for e-waste in order to assess the effectiveness of the WEEE Directive in the UK. The paper investigates expert opinion on current end-of-life recovery and treatment of WEEE, drawing upon empirical data from 30 semi-structured interviews with stakeholders across the electrical and electronic equipment value chain (Gereffi et al., 2005) (defined here as the network relating to any part of the life cycle of EEE, from conception to final disposal).

The paper broadens discussion on WEEE legislation beyond a narrow focus on recycling by framing it within the context of a CE approach where materials and products are recovered and reused, to keep resources in use for as long as possible (Stahel, 2016). Empirical evidence from the expert interviews clarifies previous discussion, substantiates arguments and enables firm recommendations aimed at reducing the environmental impact of e-waste by enhancing product recovery and targeting higher levels of the waste hierarchy. Insights gained from evaluating the impact of the WEEE Directive may thus provide an indication of the future efficacy of similar legislation worldwide, with ramifications for design and production of EEE globally through future strategy recommendations.

2. An overview of European Union legislation

Resource use is increasingly referenced in regard to the CE, described as one "that is restorative by design, and which aims to keep products, components and materials at their highest utility and value" (Webster, 2017). The CE model is promoted by many governments, notably China and Japan (Haas et al., 2015), as well as international organizations (e.g. European Commission, 2015).

The EU Circular Economy Package employs a systemic approach to waste reduction, and proposes to address the reparability, upgradability, durability and recyclability of products (European Commission, 2015). These approaches represent strategies to address sustainable resource use by acting at the top of the waste hierarchy (Fig. 1), a five-point approach to waste management which has become widely accepted, though is not without critics (e.g. Gharfalkar et al., 2015; Van Ewijk and Stegemann, 2016). The waste hierarchy is particularly relevant for e-waste due to the vast quantities involved, levels of embodied carbon (WRAP, 2011b) and valuable and scarce materials they contain (Binnemans et al., 2013; EIP, 2016).

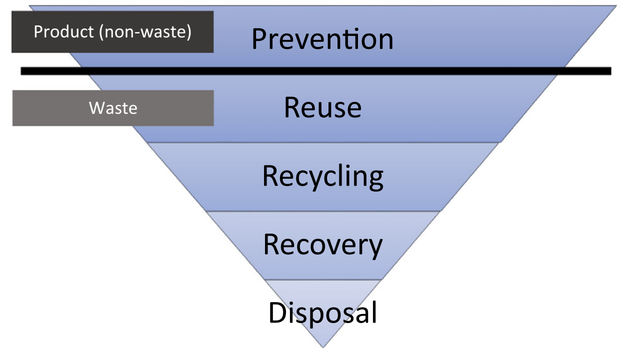

Fig. 1. The waste hierarchy (European Union, 2008).

2.1. Legislative management of WEEE

Most contemporary UK legislation addressing control and management of WEEE originated in the European Union (EU), and has evolved significantly since the 1970s, when the Waste Framework Directive (75/442/EEC) first introduced the definition of waste, the waste hierarchy, and strategies aimed at preventing the detrimental impacts of waste on human health and the environment.

A variety of approaches to tackle e-waste have been adopted due to the highly toxic materials it contains (Oguchi et al., 2013). For example, the Basel Convention (UNEP, 1989), a global treaty, implemented by EU member states in 1992 to control and reduce transboundary movements of hazardous waste and restrict hazardous practices when treating WEEE (Kummer, 1992). This has been a particular problem in developing countries where regulation, enforcement and environmental awareness may be limited (Ongondo et al., 2011).

The end-of-life impact of EEE is influenced by initial design, materials content, user behaviour and disposal routes (Calcott and Walls, 2005). Recognising this, the original WEEE Directive (2002/95/EC), provided a regulatory framework for separate collection and treatment of electrical and electronic equipment (Turner and Callaghan, 2007). The Directive covers a diverse range of operations, such as collection, storage, transportation, disassembly and recovery of materials or components, to mitigate against possible environmental and health risks caused by incorrect treatment and minimise environmental impact of e-waste (Ongondo et al., 2011; Salhofer et al., 2016).

The recast WEEE Directive (2012/19/EU) provides a legislative tool with the potential to further increase reuse and recycling of WEEE, recover secondary raw materials, enhance resource efficiency and contribute to the CE. The recast Directive also widened the scope of the previous version, enabling products new to market to be covered (Salhofer et al., 2016). However, some products with electronic functions are still not addressed, for instance the rapidly developing e-textile sector (Köhler et al., 2011; McLaren et al., 2017).

2.2. Levels of the waste hierarchy

E-waste is a complex, heterogeneous waste stream, comprising products manufactured from many different components and materials, with special end-of-life requirements (WRAP, 2011a, 2011b). Furthermore, many common-place items contain toxic materials requiring specialist recovery processes (Kolias et al., 2014). Handling and treating e-waste is further complicated by the way e-waste is dispersed amongst consumers and business users and the diverse range of collection methods (WRAP, 2011b, 2011c, 2012). For individual consumers there are various options; municipal collection, in-store take-back and direct producer take-back (Zero Waste Scotland, 2012; Sthiannopkao and Wong, 2013; WRAP, 2017), but the success of each of these vary depending on consumer behaviour, awareness and local conditions (Cole et al., 2014). Although, current legislation aims for the management of such waste to move to the higher levels of the waste hierarchy, described earlier, in order to reduce environmental impacts (Hauschild et al., 2004; Williams, 2015) only a relatively small proportion of the products in the e-waste stream are reused (Ongondo et al., 2011; Cole et al., 2017).

2.2.1. Reduce

The first principle of the waste hierarchy is to reduce. This has variously been taken to reduce the quantities of waste generated, or to reduce the addition of toxic and harmful substances through ecological design. However, it also encompasses consumer behaviour, with waste avoidance practices such as reusing items, repairing broken items and resisting purchases (Williams, 2015).

2.2.2. Reuse

Reuse offers significant benefits by reducing environmental impacts of WEEE through the extension of product lifetimes (Cooper, 2010; Cole et al., 2017), thus slowing the growth of e-waste (WRAP, 2011d). However, although second-hand markets exist for many types of EEE (WRAP, 2011e; Gregson et al., 2013), reuse does not form a major part of the legislative framework (Cole et al., 2014). Additionally, whilst items may still hold some value in a political, socio-cultural or institutional context (Iacovidou et al., 2017b) there may be 'critical reuse ages', beyond which environmental benefits are debatable due to decreased efficiency of worn-out products (Millward-Hopkins et al., 2018), and technological progress embodied in new items (Devoldere et al., 2009).

Many barriers to reuse exist (Williams et al., 2012; WRAP, 2012), including consumer reticence towards purchasing second-hand items (Bulkeley and Gregson, 2009). Reconditioned and remanufactured products face similar barriers (King et al., 2006). Consequently, reuse is limited when discarded products need repair, or minor remedial work, particularly in the case of lower value items (Alexander and Smaje, 2008; WRAP, 2012). Crucially, the potential for extending a product's lifetime through reuse is lost once items are classed as 'waste' and receive less careful handling (Zero Waste Scotland, 2015; Cole et al., 2016). In the absence of targets for reuse of whole appliances and a lack of clear emphasis on reuse in national implementation of European legislation, opportunities to promote reuse are being lost (Furniture Reuse Network, 2006; WRAP, 2011e; Rreuse, 2015).

This is particularly unfortunate given that benefits of reuse go beyond environmental protection and waste reduction (Castellani et al., 2015). Promoting reuse provides low income households with access to more affordable items and creates social benefits through the provision of employment and training opportunities in third sector organisations (Alexander and Smaje, 2008; Williams et al., 2012; WRAP, 2011d; Cools and Oosterlynck, 2016).

2.2.3. Recycling

The introduction of legislation requiring separate treatment of e-waste led to improvements in recycling infrastructure (Dalrymple et al., 2007). Recycling targets in the WEEE Directive drove innovation to develop separation technologies and establish markets for materials salvaged through separation processes (Ongondo et al., 2011). Recycling is now accepted by the EEE sector as the standard method for processing e-waste products (Robinson, 2009; Ongondo et al., 2011). Recycling is a low-cost solution enabling compliance with environmental regulations (Watson and Crowhurst, 2007; Li et al., 2013) and it is not without its critics. Most recycling processors utilise destructive shredding technologies that recover a limited number of metals (e.g. steel and aluminium) and plastics (Dalrymple et al., 2007) at a fraction of their potential value (Lambert and Gupta, 2004; Zuidwijk and Krikke, 2008, Green Alliance, 2015) and benefits of recycling when accounting for the GHG emissions involved in reprocessing have been questioned (Iacovidou et al., 2017b). The process could be improved by the formation of product-specific recycling systems to ensure higher quality recovered materials (Cucchiella et al., 2015).

3. Methodology

This paper seeks to present empirical evidence to clarify previous discussion on the sustainability of end-of-life electrical and electronic equipment, utilising a critical interpretive synthesis method (Dixon-Woods et al., 2006) and a series of thirty semi-structured interviews (Fig. 2). This section provides an overview of the methodological approach used.

3.1. Critical interpretive synthesis

Critical interpretive synthesis (Dixon-Woods et al., 2006), an approach to the synthesis of multidisciplinary and multi-method evidence, was utilised to analyse the literature, guide sampling strategy and frame interview questions. This approach allows research questions to be refined iteratively and to search and select literature to enable scientific enquiry across disciplinary boundaries (Seale et al., 2004).

The literature exploring challenges faced with end-of-life management of EEE, including collection, reuse and recycling was studied and analysed, including academic papers, industry and non-government organisations' reports, and EU and UK legislation.

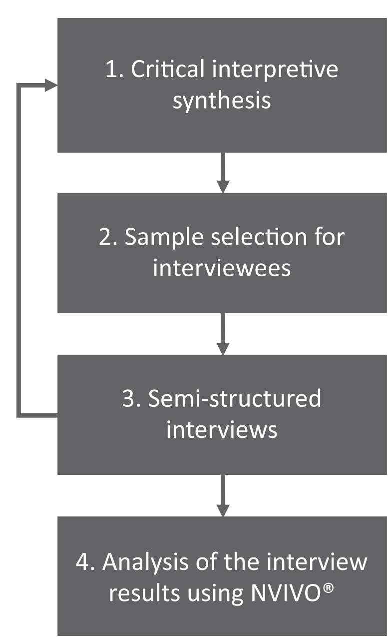

Fig. 2. Overview of the methodology.

Responsibilities, interests, key themes and challenges were identified in order to obtain the evidence and opinions necessary to enable a thorough investigation across the sector.

3.2. Sample selection

A purposive sampling strategy was used to recruit interview participants (Shenton, 2004; Palinkas et al., 2015). Known professionals in the sector were approached. In addition, a convenience sample composed of key informants identified by participants of the purposive sample, was used (Kelley et al., 2003).

Efforts were made to obtain a diverse sample of stakeholders across the EEE value chain, defined here as groups or individuals affected by, or who can affect, the recovery and treatment of WEEE (Table 1), with each interviewee holding a high-level position within their organisation. Interviewees were selected to offer different perspectives, operational experiences, campaigning strategies, motivations and principal challenges.

Initial contact, either by email or telephone, allowed the researcher to explain the study and extend an invitation to take part in the interviews.

3.3. Data collection

Thirty semi-structured, face-to-face interviews were undertaken. The interviews were designed to enable interviewees to shape their contribution and lead the debate towards topics central to their particular area within the life cycle of products (Fig. 3). This ensured different observations from each interviewee (Galletta, 2001; Bryman, 2012), with discussion allowed to become more fluid than a structured interview (Bryman, 2012), providing greater insights into the interviewee's perspectives. Interviewees are not personally identified, this enabled interviewees to speak openly and truthfully without fear of identification. At no time did any interviewee refuse to answer individual questions. Each interview lasted approximately an hour.

Table 1
Type of organisation represented in the interviews.

Interview reference	Type of organisation represented
001	Lobby group, Brussels
002	Government spokesperson
003	Compliance scheme
004	Reuse Network
005	Asset recovery business
006	National charity
007	Compliance scheme
008	Lobby group, Brussels
009	Reuse and recycling company
010	Local government
011	Waste management company
012	Reuse company
013	Compliance scheme
014	Retailer
015	Government delivery body
016	Think tank, UK
017	Asset recovery business
018	Academic
019	Charity retail association
020	Academic
021	WEEE processor
022	Reuse retailer
023	Manufacturer
024	Government delivery body
025	Local government
026	Government spokesperson
027	Logistics company
028	Compliance scheme
029	Repair charity, UK
030	Repair campaigner, International

A formal set of initial questions prepared in advance was used for consistency and comparable responses, and to ensure the goals and objectives of the study were met. They were open-ended, providing the necessary flexibility to expose insights that had not been anticipated (DiCicco-Bloom and Crabtree, 2006), and followed up with further questions where appropriate. The interviews were conducted by the same researcher, minimising any effects of different personal interviewing styles (Irvine et al., 2013).

3.4. Analysis of interviews

Interviews were audio-recorded and transcribed. Data analysis ran concurrently with data collection, enabling earlier interviews to inform the recruitment of later interviewees (Galletta, 2001). Transcripts were coded using NVivo© qualitative analysis software package, a computer-assisted qualitative data analysis (CAQDAS) tool. NVivo© is suitable for coding, analysing and interrogating large volumes of text-based data (Silver and Lewins, 2014).

The data analysis process utilised Yin's (2009) general analytical framework. It involved open-coding, generating codes at different levels of theoretical complexity (from simple descriptions to conceptual categories) and constant comparison between and within codes to ensure good 'fit' with the data. It also required a process of (re)grouping codes within broader and more theoretically relevant meta-codes, identifying common themes, and establishing complementary and contradictory areas (Silver and Lewins, 2014; Silverman, 2015). This process continued until theoretical saturation was reached and no further new codes, themes or insights were generated.

4. Results and discussion

This section reports on empirical data collected during the semi-structured interviews. The interviews explored issues around collection and treatment of e-waste and the current legislative framework, including the WEEE Directive and its effectiveness. The discussion went beyond a narrow focus on collection and recycling to a CE, system-wide approach that builds on the waste hierarchy, addressing global material flows, through waste reduction, improving product durability and extending product lifetimes through increasing instances of reuse. These topics are discussed below; each is supplemented with quotes from interviewees relating to the issue being discussed.

4.1. Successes of the WEEE Directive

The research revealed that in some respects the WEEE Directive has been a success. This includes implementing separate collection for e-waste and providing recycling facilities.

4.1.1. Infrastructure, collection and treatment

Whilst the overarching European legislation, the revised Waste Framework Directive (2008/98/EC), proposes that waste is managed in accordance with the waste hierarchy, the WEEE Directive does little to encourage waste prevention and reuse. Current UK infrastructure for WEEE processing concentrating on recovery and recycling (WRAP, 2011c). The majority of interviewees felt current municipal collection systems for e-waste were to blame, with staff damaging many products and doing little to protect any reuse potential those items may have had.

> "Our systems are set up for waste. We're very good at collecting waste ... not necessarily good at collecting products and keeping them as products" [011, waste management company].

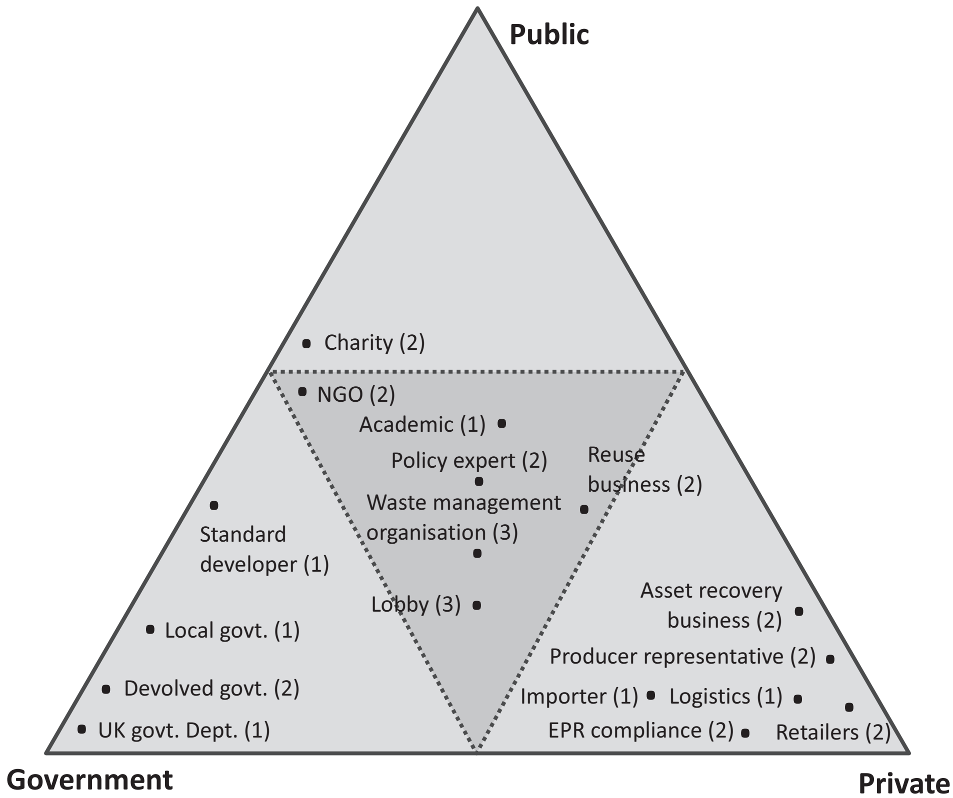

Fig. 3. Distribution of interviewees across the EEE value chain.

Conversely, some interviewees saw successes in the current system and questioned what the alternatives would be. A compliance scheme operator thought the WEEE Directive was working well, setting in place separate collection and treatment structures and removing WEEE from residual waste streams. He alluded to problems that might occur without the Directive:

> "If the WEEE legislation wasn't there, what would happen? ... the WEEE system is a great success" [007, compliance scheme].

This acknowledges the role the Directive plays in ensuring large quantities of WEEE are collected and processed safely. One interviewee explained the rationale for using local government sites as WEEE collection points, stating: "This was an easy quick fix ... these sites already existed and all that had to be done was for a space to be provided (to enable storage of WEEE)" [011, waste management company]. However, whilst convenient for consumers and economical to set up, once items are delivered to such sites as waste they quickly lose any reuse potential, with options for maintaining items in useable condition compromised. Additionally, the onward transport for treatment organised by local authorities and funded through compliance schemes financed by producers (to meet their legislative obligations) had its critics. One interviewee spoke about how producers influence environmental issues through financing collections through compliance schemes in this way:

> "(We have) producer-driven compliance schemes which are heavy lobbyists (with) the backing of big international businesses" [013, compliance scheme].

This interviewee suggested that producers think environmental requirements reduce profit margins and a strong reuse market would impact on sales of new items. He argued: "they (compliance schemes) are run by producers of electricals; they want to sell more electrical goods". He suggested that, in order to protect future sales, some producers discourage compliance schemes from promoting reuse. He continued: "a number of the large producer-led compliance schemes demand 100% recycling, no reuse" [013, compliance scheme]. This suggests that new sales are the primary interest for many producers, with minimum compliance with legislation taking preference over environmental interests.

The influence that compliance schemes exert over treatment options for e-waste was also alluded to by an interviewee from a local authority (LA) advisory body, who suggested that local authorities no longer have a strong influence over the treatment of WEEE because compliance schemes (and therefore producers) have such power over the collection and management. She even suggested that WEEE collection and processing was no longer considered to be their problem:

> "The way WEEE legislation has been implemented in the UK, and producer responsibility - in effect local authorities do not see it (WEEE collection) as their problem anymore" [011, waste management company].

Compliance schemes perform a recovery function for producers to meet collection targets for WEEE set by the UK Government through Defra. Exploring recovery targets and collection structures in the interviews led to suggestions of alternative ways in which collection systems could have been established. For example, the recovery rate for small items of EEE is relatively low, such items often appear in residual waste because "if it fits in a bin, it will go in a bin." [017, asset recovery business]. One interviewee suggested an alternative route for smaller items:

> "Everyone who sells small WEEE should do take-back ... because a lot of small WEEE is bought on a like-for-like basis" [020, academic].

Such a system, exchanging old items for new purchases, has potential to recover more of the small electrical items that are currently disposed of through residual waste collections. Facilitating appropriate collection, perhaps by routing discarded goods through retail outlets to the reuse sector, is one way to drive e-waste up the waste hierarchy. Legislation, innovation and economic measures should encourage a focus on recovery systems enabling the reuse of more products and the recovery of more materials through improved recycling processes.

Legislation, innovation and economic drivers should be further used to encourage improved collections and infrastructure in order to enable the recovery and reuse of more products and the recycling of more material: "it (environmental practices with end-of-life WEEE) hasn't developed, it needs a further step now" [022, reuse retailer]. Appropriate disposal options and segregated collection schemes are lacking in some regions in the UK. That said, consumer interest in the environmental impacts of EEE is limited:

> "Customers are only interested in functionality ... they are not interested in its eco-credentials or making decisions about the treatment of end-of-life of products" [005, asset recovery business].

There is evidently still a need to educate consumers on the environmental impacts of e-waste and to raise awareness about reuse and different recovery options. Low levels of participation can undermine the success of collection systems.

4.1.2. The dominance of recycling

E-waste is mostly processed through recycling in the UK (WRAP, 2011c), with resource recovery currently concentrating on salvaging easily recovered materials through shredding technologies (WRAP, 2011b). Many stakeholders interviewed expressed the opinion that recycling was currently happening regardless of other options in the waste hierarchy, blaming this on the legislative framework. For example, one stated:

> "everyone agrees that recycling is encouraged at the expense of reuse; it (the WEEE Directive) encourages recycling at the cost of pretty much everything else ... other than disposal" [020, academic].

Supporting this, others spoke of the WEEE Directive being "just about recycling" [020, academic] and argued that it "seems to pretty much incentivise recycling and doesn't incentivise reuse enough, so the whole system works against reuse" [002, government spokesperson]. Overall interviewees confirmed the current system focusses on recycling, disregarding other levels of the waste hierarchy, particularly opportunities to extend product lifetimes through repair and reuse.

When probed as to why recycling is so dominant, interviewees referred to collection systems using LA waste collection networks. Collection for recycling or other waste treatment (i.e. incineration or landfill) requires less effort than collecting for reuse. One interviewee said

> "for recycling you can process them [items] on a larger scale, so it is clearly favouring recycling" [004, reuse network].

A further interviewee explained there are higher collection costs associated with handling goods carefully to ensure they retain reuse potential, but sought to justify mass collection for recycling, citing environmental benefits: "we can maximise payloads in collection vehicles, giving a lower carbon footprint per tonne of material moved (for recycling)" [003, compliance scheme].

Recycling may have a lower environmental impact than reuse when items are transported long distances, or in small quantities. Whether the WEEE Directive addressed environmental impacts appropriately was questioned by one interviewee, who asserted that it is "about finance and collection schemes" [004, reuse network]. Another suggested that, by joining compliance schemes, producers escape their environmental obligations, stating that "the conundrum with the WEEE system is that the producer's prime interest is in keeping costs low" [003, compliance scheme]. Reusable items enter waste collection systems for recycling, regardless of their condition, because this is cheaper. It was suggested some producers view compliance scheme membership fees as an alternative to taking action to reduce the environmental impact of EEE: "producers pay lip service to reuse and waste prevention; they pay in; they look on it (compliance fees) as similar to carbon credits" [015, government delivery body].

In justifying recycling's central role in e-waste treatment, several interviewees argued that recycling is better than other alternatives, notably landfill or illegal export. One said: "It was originally designed in such a way to do that (encourage recycling) rather than disposal" [015, government delivery body], whilst an interviewee from an e-waste processor, whose company developed a plant to treat e-waste safely and capture easily recoverable materials stated:

> "The WEEE Directive is there for the right reasons .... We structured the Company around the Directive ... We try and recycle as much as possible, and that's (because of) the WEEE Directive" [023, manufacturer].

The existing infrastructure and current e-waste collection processes lock companies into solutions that favour recycling. A WEEE recycling processor explained:

> "We shred almost everything. We treat hazardous products separately (TVs and fridges) but the rest are shredded, after we remove some components (circuit boards and motors) for resale" [021, WEEE processor].

Innovation has concentrated on recovery and shredding technologies. Therefore, current processes typically treat large quantities of e-waste quickly, taking no account of the presence of CRMs contained in small amounts in most WEEE (WRAP, 2011b, 2011c), which are reduced to fine dust during shredding processes and are therefore mostly not recovered. Whilst the recovery of CRMs will become more urgent as they become scarcer, current processes face the dilemma of balancing environmental benefits against the financial costs associated with difficult recovery processes (Savvilotidou et al., 2015). The urgency with which material recovery from WEEE needs to be addressed has been recognised at national and international levels (Singh et al., 2014), with access to raw materials and their circular use a growing concern in the EU (Blengini et al., 2017). Recycling could address security of supply of many CRMs, with the recovery of materials from recycling WEEE assumed to be a more secure source than other primary supply sources (e.g. mining).

In summary, the interviews confirmed that more could be done to encourage the reuse of goods and to recover more materials from recycled WEEE by utilising processes other than shredding. WEEE legislation only covers products once they have been discarded and are classed as 'waste'. Extension of this legislation into the period before products are discarded could contribute to longer lasting products by encouraging reuse

4.2. Challenges faced by the WEEE Directive in operationalising the waste hierarchy

Despite being higher in the waste hierarchy and delivering social, economic and environmental benefits (CIWM, 2016), the extent of reuse of EEE is far more limited than recycling (Truttmann and Rechberger, 2006).

4.2.1. Barriers to reuse

Two major barriers to reuse are the additional costs associated with collection and reconditioning for reuse (possibly involving repair, testing and cleaning) and the lack of easy access to reusable discarded products. The perception that reuse is too often neglected was a strong theme in the interviews, although concerns from two competing compliance scheme operators such as "I don't think the WEEE Directive does anything on reuse" [013compliance scheme] and "I think we are doing less well on reuse" [007, compliance scheme] contrasted with a view among other interviewees that the reuse sector has changed since the introduction of the WEEE Directive.

There was agreement that once goods are labelled as 'waste' they tend to be regarded as suited only to landfill or incineration, offering little opportunity for reuse. Despite this, some organisations operate successful recovery, repair and reuse businesses (Cole et al., 2017), sourcing goods for sale from the waste stream and one interviewee considered that "allowing (the) reuse sector access to waste streams for reuse was a big change and a move in the right direction" [008, lobby group, Brussels]. However, there are still concerns about additional costs, with one compliance scheme operators stating:

> "Handling products carefully for reuse would be a far greater cost and producers would have a much higher bill" [003, compliance scheme].

In contrast, a competitor's view to facilitating reuse differed, albeit limited to items that are economically viable to recover and reuse:

> "I've helped to recover white goods for reuse because they are the easiest to recover and probably the easiest to reuse" [015, government delivery body].

Reuse varies across product ranges: white goods have an active second-hand market, but other items are less economically attractive, particularly if there are additional costs associated with ensuring items are in safe working condition before reuse. Items for reuse need to be handled individually and transported carefully to retain their reuse potential. Any repairs may require specific skill sets, often beyond basic cleaning and Portable Appliance Testing (PAT) for safety. One interviewee suggested that this additional processing was the reason why, for some operators, recycling is more attractive than reuse:

> "The WEEE Directive favours recycling over preparation for reuse because it is much more complicated to do preparation for reuse" [001, lobby group, Brussels].

Collecting and transporting for recycling was often considered easier and more cost-effective. The additional costs associated with careful handling and transportation [004, reuse network; 006, national charity]. As well as any cleaning and repairing, reduces the range of products that are economically viable for reuse. Processes to prepare items for reuse were thought by a LA advisory body [011, waste management company] to be a limiting factor.

Some organisations positively embrace reuse; despite the perceived additional costs involved. Interviewees from across the supply chain (importer, retailer, local government, charity network, furniture reuse network, reuse organisations, compliance scheme operators, logistics company and waste management company) all offered experiences of goods being processed for reuse through their organisations. This varied between direct reuse within their own organisations, passing items to other organisations, and allowing third party organisations access to their waste streams to recover reusable items. One compliance scheme operator commented: "I'm motivated to facilitate flexible organisations to access material (for reuse)" [015, government delivery body].

Numerous difficulties were highlighted including costs, handling, and monitoring progress, particularly how to calculate and record reuse:

> "It (reuse) is the sensible and good thing to do, but how do you measure it?" [001, lobby group, Brussels] and also: "Reuse happens informally between family, friends and colleagues and formally through online sales, car boot sales and charity shops. How do we count all that?" [008, lobby group, Brussels].

Such items are being reused before they enter the waste stream, therefore, the WEEE Directive does not apply. Providing a solution to the issue of monitoring progress, whilst challenging, would reveal the full extent of reuse.

Suggestions for increasing reuse included moving from waste management systems to resource recovery systems. Interviewees from a national reuse charity, furniture reuse organisation and reuse business, each suggested this could be achieved by utilising retailers' reverse logistics systems, which may be better suited to handling goods carefully:

> "There's a whole supply chain that could've done reverse logistics differently"[011, waste management company].

The level of care taken when new goods are delivered needs to be replicated by people handling reusable goods in order to prevent damage.

Many issues regarding the waste hierarchy emerged throughout the interviews. These included a lack of clear focus on operationalising higher parts of the waste hierarchy, individual stakeholders' limited influence across the complete value chain, challenges to policy makers to ensure enforcement of Directives throughout the value chain, and disconnection between product design and end-of-life processes.

All interviewees claimed their organisations worked to align practices with the waste hierarchy. However, a LA waste officer, suggested the environmental aspect of waste reduction was not always the primary motivation:

> "Companies focus on things that actually aren't important ... like zero waste to landfill ... but it's going to the incinerator! We're not dealing with the problem; we're just saying get rid of it somewhere else" [028, compliance scheme].

This interviewee explained that his authority supported the waste hierarchy, diverting waste from landfill to a cheaper disposal method. However, it still "looks good on CSR (corporate social responsibility) statements" [028, compliance scheme]. Here, the authority's primary motive is financial rather than environmental.

Another interviewee suggested that actions were being taken at all levels of the waste hierarchy, although this was not always recognised:

> "We (this compliance scheme) are doing recycling, recovery and appropriate treatment and that should be highlighted to producers and retailers" [015, government delivery body].

This shows conflicting opinions about the extent to which end-of-life treatment meets environmental targets and works with the waste hierarchy. The higher levels of the waste hierarchy are neglected: recycling is the primary end-of-life process for electrical and electronic equipment despite waste prevention and reuse being higher in the hierarchy. One interviewee explained: "It [the WEEE Directive] is a waste directive; it's about the environment, and therefore it's about recycling" [004, reuse network]. He further argued: “Reuse should be encouraged because environmentally it’s better” and “the waste hierarchy isn’t really implemented . . . they still recycle” [004, reuse network].

Through the interviews it became apparent that stakeholders believed their actions were aligned to the waste hierarchy, thus lessening the environmental impact of e-waste, even though they were not working at its higher levels. Some stakeholders felt they could only influence the treatment of e-waste at a certain level of the waste hierarchy. Interviewees from waste management companies, compliance schemes, reuse organisations, reuse charities and logistics companies felt they had more control over products at the lower levels (e.g. recycling and disposal) and that designers, guided by manufacturers and retailers, were better placed to influence higher level strategies (e.g. reducing waste, reusing resources, designing for sustainability, repair, reuse and recycling) (Fig. 4). This was supported by interviewees from the policy think tank, academia, the delivery body and government departments.

Ensuring that all stakeholders address the higher levels of the waste hierarchy is challenging for policy makers: “the difficulty is how you legislate for it [the higher levels of waste hierarchy]” [015, government delivery body] and “we could do more for reuse . . . Maybe reuse wasn’t thought of when the WEEE Directive came out” [007, compliance scheme]. This suggests an attitudinal change is necessary before collection and treatment processes supporting reuse are put in place.

Other issues emerging from the interviews included the perception of a disconnect between product design and end-of-life processes, leading to higher levels of the waste hierarchy being ignored. This emerged in many interviews from across the value chain (lobby group, standards developer, academics, LA advisory body, government delivery body, asset management company and logistics company), pointing to a “lack of understanding of how product design is related to waste” [027, logistics company] or an “asymmetry between approaches” [027, logistics company]. It was suggested that “designers work on a product by product approach, with reasonable timescales, but waste management deals with thousands of tonnes of mixed materials and components on a daily basis” [002, government spokesperson]. Understanding materials, including their intrinsic properties, connected the two parties, and yet they remain largely unconnected, and so do their work practices. Many designers and marketers focus on the marketability of the materials they use in products, rather than end-of-life processes, waste managers concentrate on treatment methods and markets for recovered secondary materials. Aside from their knowledge of materials, the two parties often act as if they have little in common (Fig. 5). If their perspectives and interests could be assimilated opportunities to reduce environmental impacts of e-waste might emerge. The difficulties associated with this challenge are not overlooked, particularly when the design of relatively simple products such as plastic bottles highlights some of the end-of-life challenges. To ensure a tight seal and prevent leaks, the lids of plastic bottle are made from different polymers to the bottles. Designers have solved a problem during the manufacture and use phases but caused a problem for recyclers where the mixed polymers attract a lower price. This challenge is even harder with the more complex products found in e-waste. Improvements are necessary to the current system to encourage diverse actors to work together towards activity at higher levels of the waste hierarchy.

The interviews raised many other challenges to complying with the waste hierarchy, including product durability, repairability, reusability, disassembly (to enable recovery of resources) and the CE. These problems and their potential solutions will be discussed later.

4.2.2. Moving up the waste hierarchy

There was broad agreement on the need for improvements to collection methods and treatment, but approaches varied depending on the stakeholder’s responsibilities. Proposals included circular business practices (including a reverse route for goods up the supply chain), comprehensive resource recovery and designing out waste. Producers attracted blame for the environmental impact of products caused by the frequency of sales-driven replacement cycles. Interviewees proposed amending producer responsibility arrangements and waste infrastructure, away from their focus on recycling:

> “Encourage greater producer responsibility, really start focussing on the top of the waste hierarchy, rather than recycling” [020, academic].

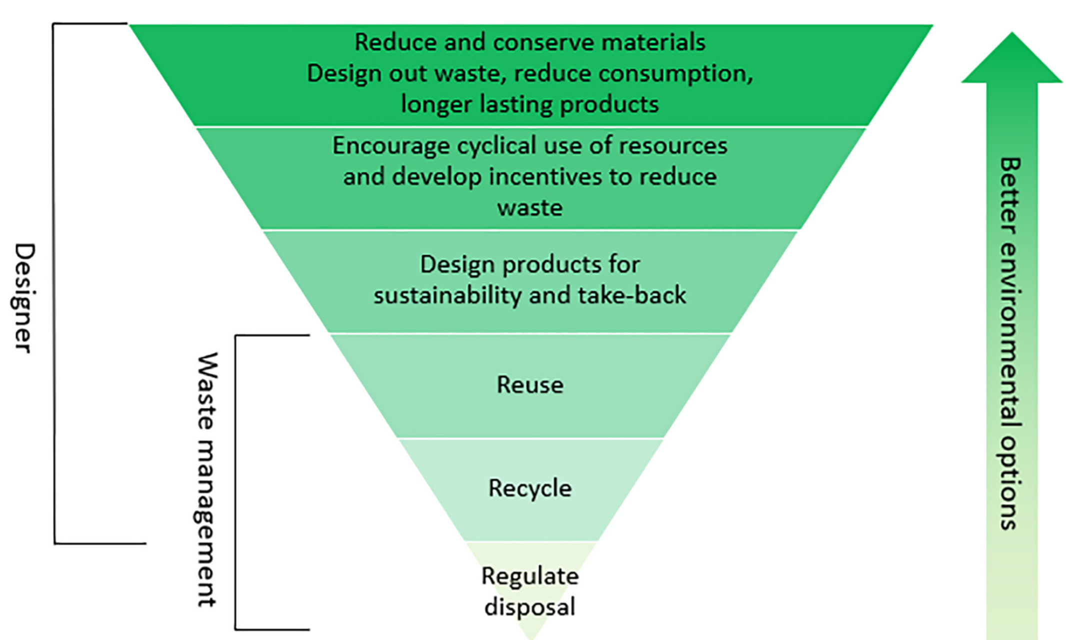

Fig. 4. Points of influence by designers and waste managers in the waste hierarchy.

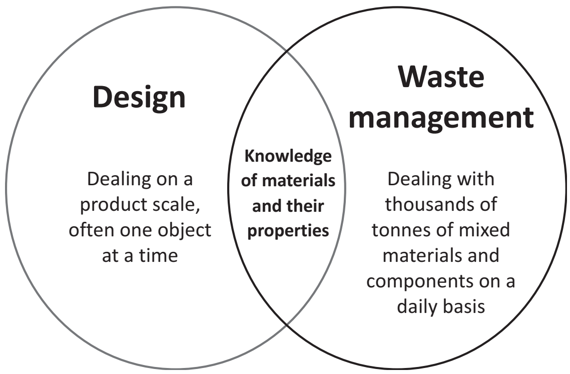

Fig. 5. Knowledge of materials and their properties linking design and waste management.

The complex nature of the e-waste problem was recognised, with potential implications for producer responsibility, product design, finance and infrastructure. One suggestion was taking a service-based approach, with ownership of goods retained by manufacturers, and consumers charged for services provided by those goods. Service providers would want reliable equipment, encouraging the development of more durable, easily repairable goods, thereby slowing replacement cycles. An interviewee explained this:

> "The WEEE Directive just encourages a certain percentage of electronic goods to come back. It doesn't really encourage a shift from sales to service … if we really want to see things changing and getting better, we have to move to a service-based economy" [022, reuse retailer].

Additionally, some producers recognise the importance of recovering resources from their products, aware that the components and materials they contain retain value and can be reused:

> "A lot of producers now seem to want their own stuff back. They want to control it and that's better from a circular point of view" [016, think tank, UK].

Prompted by concerns around resource security and potential material shortages, some manufacturers are starting to develop recovery strategies for their products because they know what they contain; these include part-exchange systems and financial incentives for owners to return unwanted items to them.

The development of more durable and repairable products capable of being used, perhaps more intensively, in product-service systems would represent a move from the current 'take, make, dispose' linear economy towards a more sustainable, circular one. Many consumers are attracted to more sustainable products and, when aware of their existence, willing to use recovery schemes.

5. Discussion

This paper reports on various successes and challenges associated with the WEEE Directive including the implementation of separate collection and processing infrastructure for the treatment of WEEE. Previous studies show discarded EEE is generally destined for recycling due to unfavourable handling during collection (Ongondo et al., 2011; WRAP, 2011c; Cole et al., 2017) and the favourable cost of recycling in comparison to landfill and incineration (WRAP, 2018). Additionally, many items of small WEEE remain in the residual waste stream (WRAP, 2016; ZWS, 2017) due to consumers being unaware of alternatives.

The research suggested alternative collection, possibly using reverse logistics associated with retail networks. This could enable reuse of functioning items, maintaining products at higher value (Green Alliance, 2015; IRP, 2018) and working at higher levels of the waste hierarchy (Williams, 2005).

Whilst reuse can bring about social, as well as environmental and economic benefits (CIWM, 2016; IRP, 2018) working 'in silos' delivers short term solutions (Iacovidou et al., 2017a). Therefore, a holistic approach is suggested accounting for a whole life cycle from conception to end-of-life and beyond. Waste has been described as a failure in design (McDonough and Braungart, 2010) but the challenges of designing products to carry out their intended purpose without further negative impacts on the environment are acknowledged, as is the requirement of a logistical system to divert a well-designed product into the infrastructure that can process it correctly. For instance, Baker-Brown (2017) cites the example of a keyboard designed to be dismantled for easy repair and reuse will still be shredded for recycling without a sufficient repair network in place.

6. Conclusions

This study investigated expert opinion on the end-of-life treatment of electrical and electronic equipment and the impact of the WEEE Directive through a series of semi-structured interviews. The paper extends discussion in this area of research beyond a narrow focus on recycling by considering the waste hierarchy within the context of a CE approach designed to reduce the amount of WEEE generated, improve resource recovery and treatment, and increase reuse and repair.

Recycling has, to date, been the primary treatment method for e-waste. This is problematic because it has neglected, to some extent, the potential to increase product longevity, repair and reuse. Ambition and innovation appear limited by current legislation, which may be used as a minimum standard, limiting activities at higher levels of the waste hierarchy. Solutions suggested in the interviews included moving to circular business models, improving existing collection, transportation and WEEE treatment infrastructure, and adopting sustainable design practices.

Waste management companies have been innovative in developing facilities to meet legislative requirements but largely depend on shredding technologies to capture easily recoverable materials in large quantities. They neglect the recovery of CRMs due to the unfavourable economic case caused by difficulties in their retrieval and the very small amounts in which they appear in products. However, recovery of CRMS would mitigate against future potential risks to security of supply, particularly with materials originating from areas of conflict.

The WEEE Directive aims to reduce the environmental impact of e-waste by ensuring separate collection and treatment. Our research provides evidence from a wide range of experts that it does not achieve the potential environmental benefits to be gained from movement up the waste hierarchy in the form of lower waste volumes, energy and materials consumption, and carbon emissions.

The Directive has led to an increase in recycling, which is preferable to incineration and landfill, but has done little to encourage repair, refurbishment and reuse. There is a need to strengthen it, or related legislation (such as the EcoDesign Directive), to encourage design for disassembly to enable goods to be separated into major materials for recycling more easily (i.e. without shredding) and improves the capture of CRMs.

Revising the Directive to address the period before a product is discarded more directly could contribute to waste prevention through increased product durability and product life extension. There is potential to introduce preparation for reuse targets, such as those recently introduced in Spain. It could encourage the use of recycled content in new EEE: currently, commodity trading market prices of virgin and recycled materials influence their content within new products.

The quantity of e-waste is increasing globally as new applications for electrical and electronic components are introduced in a growing number of goods such as e-textiles and smart products associated with the 'internet of things'. The diminishing supply of finite resources necessitates improved strategies to increase reuse, maximise the return of EEE, and improve component and material recovery. This requires interventions, including new infrastructure, to facilitate a systemic change such that products remain in use for optimum lifetimes and recovery and recycling are adequately supported at the end of their lives.

There will always be a concern with legislation that it will lock companies into a minimum standard and that this will prevent innovation. Legislation is necessary, but will not suffice. Society also needs to be more ambitious and set out on a pathway that recognises the importance of the environment and aims well above the minimum, increasing product lifetimes, prioritising reuse ahead of recycling and enhancing recycling systems to maximise resource recovery.

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