The complexity of value

Considerations for WEEE, experience from lighting products, and implications for policy

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The complexity of value: considerations for WEEE, experience from lighting products, and implications for policy

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Abstract

This paper presents a general overview of WEEE and value considerations (both real and potential) as well as the specific results of a research project analysing the performance of EPR systems for lighting products, with particular focus on closing material loops. The research is based on a literature review, case studies, and interviews with key stakeholders. The case of recovery of rare earths elements (REE) from fluorescent lamps is an illustrative example of how EPR systems can create opportunities to recover valuable materials from WEEE. The rapid development of light emitting diode (LED) technology also raises questions of how to anticipate and manage value under uncertainties. The paper reflects on these findings within the general context of valuable waste and the specific implications for EPR policy in a transition to a circular economy.

1 Introduction

An extended producer responsibility (EPR) programme entails the establishment of collection schemes designated for targeted products like waste electrical and electronic products (WEEE). Some WEEE contains critical and valuable materials that represent an opportunity for many different actors to recycle, close material and product loops, and further promote a circular economy strategy [1]. This has also raised certain challenges for EPR programmes under the WEEE Directive 2012/19/EU that have been designed generally assuming waste with little or no value because this is no longer the case for many WEEE waste streams [2]–[5]. The aim of this paper is to contribute to a discussion of value in terms of WEEE and EPR; identifying key factors, actors, and contexts that can inform an agenda for research in the future.

This paper presents a review of the topic of valuable WEEE and EPR, with an interdisciplinary perspective drawing upon academic literature from diverse disciplines. It also presents a new case of lighting products in which EPR and other policies can be a significant enabler of value recovery. The case research is based on literature, EPR performance data in Eurostat and semi-structured interviews with key actors including producer responsibility organisations (PROs), recyclers, retailers, and municipal waste management organisations. A review of WEEE and EPR academic and grey literature reveals many of the observed conditions in which value has arisen in WEEE. The case of lighting products reveals additional conditions in which value can arise and the complex and dynamic nature of value that is influenced by individual and company level value considerations, policies on different levels, global market conditions and technological developments.

2 Valuable WEEE and EPR

There is little debate about the environmental benefits of recycling rather than landfilling of WEEE [6]. Sometimes recycling can recover material of value that exceeds the cost of the collection and recycling processes and this is what is most often meant by valuable WEEE; for example, this is true for many types of mobile phones and laptops.

Potential value can also be considered for different WEEE streams. For example, in 2014 a report for the EU Commission reviewed the suitability of imposing individual targets for WEEE categories [7]. The study primarily focussed on a status quo (overall WEEE targets rising to 85% of waste generated in 2019) versus an individual target (85% waste generated) scenario for each waste stream. Costs of additional collection and recycling (2008 estimates) were weighed against the potential material value of the embodied raw materials (e.g. based on metal prices). For three waste streams (small electronic equipment, small ICT, and PV panels), the report showed material value of the products exceeding costs of collection and recycling and found these categories to therefore be the most suitable for increased collection efforts[1].

[1] The study concluded that for these product groups the relevance of individual targets is high, though in the end it advised individual targets in general to be too administratively cumbersome to implement and that this should be left to the individual member states. France has individual targets for all WEEE categories with a margin of tolerance except for lamps [8].

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However, the study had several significant assumptions in its approach that illustrate consideration of the potential value of WEEE is much more complex. First, treatment costs in the report included the costs of collection, transport, recycling, recovery and revenue from recycled fractions. However, the study acknowledged that treatment cost figures were old and that recyclers indicated costs had decreased as much as 50% for some waste categories. Factoring in this decrease would result in all WEEE categories having a higher value of materials than net treatment costs by the study methods. It also demonstrated potential of maturing recycling technology to influence the potential value of WEEE.

Further, in considering the value of materials the report uses a more theoretical approach, with estimates of the material composition of different product categories (in grams), the recoverability of these materials (in %) and the prices for these materials (e.g. based on metalprices.com). The study assumes some metals like aluminium to be 100% recoverable while others like rare earth elements (REE) to only be 30% recoverable. In reality the recovery can vary significantly depending on the type of product, product design, and recovery process. The value of materials is meant to represent the potential value lost to society, but the fact remains that many of the metals are not recovered (either at all or at the assumed rate) by the recycling processes currently used [9], necessitating development or use of different recycling processes. It is often assumed that the concentration of critical or precious materials being high in waste products, for example the concentration of gold in a mobile phone is significantly richer than that in an ore, makes e-waste an economical source for these elements [2], prompting researchers and policymakers alike to call for higher collection and recycling of WEEE to address supply of critical metals [9]–[12]. But most do not fully acknowledge barriers and the policies, technologies, and actions needed to drive this change. Though the concentrations of precious and critical materials in WEEE is indeed often much higher than an ore, it has a unique "minerology" that must be considered along with special techniques for these new urban mining activities [13], [14]. The cost effectiveness of different recovery techniques can also be context specific, e.g. dependent on labour costs for manual disassembly.

On the other hand, materials of value that can be easily recovered can make some WEEE attractive for informal and scrap recyclers outside of the established EPR system. WEEE that has value as reuse often ends up outside of official channels and often outside the EU – contributing to acknowledged problem of illegally transported e-waste [15]. This means that the treatment is not conducted by EPR system standards and the value recovery is not realised by EPR system actors. This has also led stakeholders to perceive that EPR systems are not effective for WEEE with value [5] (though it is hard to find clear differences in available Eurostat collection data indicating this). These challenges to meet higher collection rates of WEEE should not be underestimated [7], [16].

2.1 Smaller loops = greater value?

Moving up the waste hierarchy from recycling to reusing or refurbishment (i.e. following smaller product or material return loops as illustrated in Figure 1) is also often assumed to be an environmental gain because of the resource depletion and energy use avoided compared to manufacturing new (i.e. from a thermodynamic perspective) [3], [17], [18]. In a circular economy model, we would expect to see the value of closing loops increase the higher up the waste hierarchy (i.e. the smaller the loop to return products/material), but this is most often not the case [18].

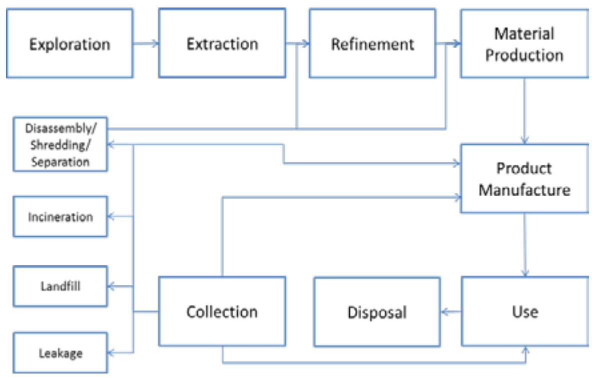

Figure 1 Generic Product Value Chain

The reality is more complicated and there are some cases where technological obsolescence results in only component reuse or recycling being preferable to whole product reuse; for example, if newer models of the product are significantly more resource and energy efficient to a standard beyond what remanufactured used products can achieve [19]. This is why the EU Waste Directive 2008/98/EC prescribes a lifecycle approach to considering the optimal management for waste (e.g. see Art. 4). There are other cases where repurposing (using the product for a different purpose) or remanufacturing (bringing the product back to at least its original performance with equivalent warranties) are preferable to direct reuse or reconditioning either for increased environmental gain or to meet consumer demands [18], [20]. Fashion obsolescence also represents a significant barrier for creating demand from consumers for used products [18], [19]. Reuse value can also be context specific, for example products are used for varying amounts of time and arrive at a reuse stage at different times in different EU member states [21].

2.2 Value for whom?

Also warranting consideration is how value is perceived by different actors. The importance of so-called "shared value" was argued by Porter and Kramer [22] and built upon in a subsequent "value mapping tool" [23] that considers value between and amongst different stakeholders, including: network actors (e.g. firms, suppliers, etc.), customers, society and the environment. The value of WEEE can also be dependent on stakeholders. For example, Esenduran, Atasu and Van Wassenhove [2] consider the value of waste products from the point of view of producers and unofficial collectors/recyclers. The value to producers is perceived mainly to be for meeting recycling targets under legislation, but also from sold recycled fractions. The authors also (less explicitly) consider the viewpoint of retailers and consumers who are enticed by better pricing of scrappers or other entities not within the official EPR compliance system. Despite their obligations to return end-of-use products to this system and the environmental benefits offered by the standards of the official system, it is clear that these actors are only considering the most immediate or highest monetary return value for the material [19].

It is not just unofficial entities that can impede producers from collecting, but also consumers. For example, many consumers who still perceive value to their old mobile phones will store them and this presents a major barrier to increased collection by either formal or informal channels [24], [25]. While these phones have value to their owners (or perhaps value in not being used by others if there is fear of access to personal data [19], [26]), these phones are rapidly decreasing in value for other potential users in the second-hand market [24]. Better understanding of how consumers value different WEEE is also key to understanding how to increase their use of EPR systems.

There is also a reuse value and value of the materials for society in general, particularly for strategic materials deemed critical for the economy and technological development [7], [9], [11], [19], [27]. Value to society may encompass more than the traditional valuable WEEE; and fully exploring this wider value means examining waste streams typically not seen as valuable waste. Lastly, the environment could be considered in many ways to be the primary stakeholder in EPR legislation through avoiding adverse effects from disposal of WEEE in nature, an externality with contested value (i.e. multiple valuation methods can be used) in traditional economic analysis.

3 The case of lighting products

Lighting products comprise their own category within the WEEE Directive, which covers all modern energy efficient lamps including fluorescent lamps and light emitting diodes (LEDs). Fluorescent, or gas discharge, lamps are also currently addressed as a sub-category and given special mention (e.g. Art. 5) due to the mercury they contain. For example, there are specific stipulations in the WEEE Directive to remove this mercury (Annex VII), which also warrants specialized processes to do so and adds another cost factor to ensure environmentally sound treatment.

As shown in Table 1, the recycling process yields mostly glass fractions, the value of which are highly dependent on contextual and geographic factors such as distance to lamp or glass manufacturers and competition from other recycled glass sources [28]. The requirement to treat at least 80% of fluorescent lamps and to remove mercury from lamps, means the recycling processes for lamps is tuned to remove a high level of the mercury-containing phosphor powder. It is this same powder that also contains the critical REE.

Fractions	***Approx. % (cfl – tube)***	***End use / disposal [28]***
Al/other metals	18-30%	Reused or recycled
Plastic /metal mix	20%	Recycling; energy recovery; landfill
Glass	45%-80%	Reused tubes; new lamps; construction material; landfill cover
Phosphors-REE, Hg, glass particles	2-3%	Separated into REO for new phosphors; separated to mixed REE in other applications (e.g. automotive); REE + Hg hazardous landfill

Table 1 Fractions from recycled fluorescent lamps

Despite the small amounts of REE in the lamp, the EPR system for collection and the advanced recycling processes has made these waste products a promising source for the first attempts at large-scale recycling of REE. Along with magnets and batteries, it is one of the few REE recycling processes considered to be mature and operational on a commercial scale [10], [29], [30]. The high 2011 REE prices as well as identification of their criticality for EU industries led to increased interest and funding for more research into recycling of REE from lamps, further developing techniques and efficiency (see e.g. [10], [31], [32]). However, technically promising recycling initiatives now face challenges to be economically viable since the high REE prices have since fallen.

Further scaling up recycling of REE, as well as other materials, from waste lighting products is also con-

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strained by collection rates and volumes [7], [10], [13]. Even with the WEEE Directive, the average collection rates in the EU are currently below 30% [7], [28]. It should be noted that this low collection rate is far from uniform throughout the EU as shown in Figure 2, with some countries such as Sweden collecting waste lighting products at very high rates.

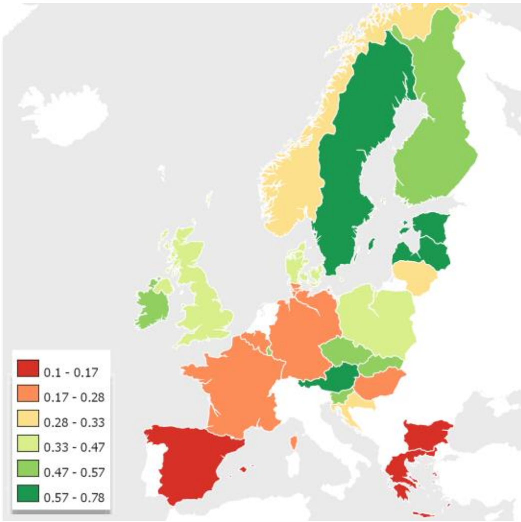

Figure 2 Collection rate 2013 / 2010-2012 average put on market (source: Eurostat and www.lwf.no)

While data reliability for collection rates is still an issue [28], the variance in collection rates indicates variation to the EPR systems in place in different member states. There is evidence that a well-designed EPR system can enhance collection rates. In a study of the Nordic countries' EPR systems for lamps, Richter and Koppejan identify several key success factors to EPR system design. These specific system factors for increased collection from households of small electronics to other factors identified by prior research, including history, motivation, opportunity, and capacity [28], [33], to outline important variables for operational performance of EPR systems (Figure 3).

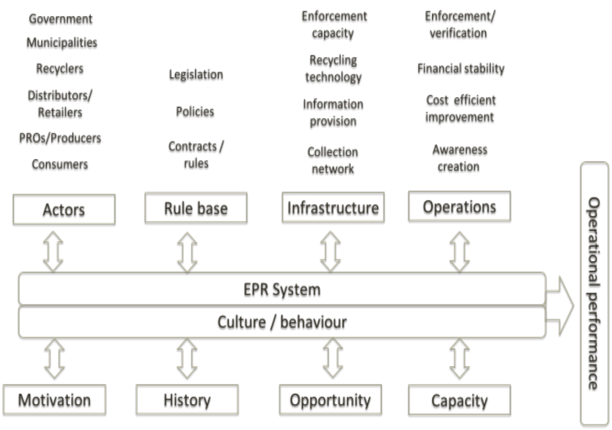

Figure 3 Factors for best practice in EPR for lamps (adapted from [26])

Lamps represent a classic product group for EPR policy as it was originally designed, i.e. they represent a net cost for treatment and recycling the waste products clearly avoids environmental harm. While some research estimates that implementing individual collection targets for lamps will incur increased costs [7], this is not true for all member states as some are already achieving high collection rates in this waste category. The lack of transparent data on WEEE collection and treatment costs makes it difficult to compare cost effectiveness more thoroughly [34]. However, it can be argued that the increased cost needed for higher collection in lower performing countries is the actual cost of running an effective EPR system and that these are the true costs that should be internalised as per the principle of EPR. For some EPR systems this might mean an increase in costs, but evaluation of current systems reveal that some systems are already effective at their current operational costs.

Gradual improvement of overall WEEE collection rates is an aim of the new targets (rising to 65% of put on market or 85% of waste generated in 2019), but there is already doubt about the ability of many member states to meet new targets [7], and even less certainty that these targets will increase individual categories like lamps. Meanwhile opportunities to collect (and retain the REE material) in waste lamps is a short term opportunity reliant on rapid, rather than gradual, improvement of collection rates. In the coming 10 years the waste from fluorescent lamps in the EU is expected to double [7]. However, after this, the amount of waste fluorescent lamps and the amount of REE available for recycling from this stream will decrease significantly. This is due to the rapid market penetration of LEDs to replace fluorescent lighting. This technology shift also means that there is less demand forecasted for REE in phosphors and that recycling could potentially meet a significant amount of demand if a closed loop system developed [30], [35].

The rapid shift to LED and solid state lighting technologies also means a shift in the value considerations for lighting products in their end-of-use stage. Compared to CFLs, LEDs have a higher initial price to the consumer, but also lower lifecycle costs, much longer projected lifespan (50000 hours), increased functionality, and lower overall environmental impact, particularly in the use and end-of-life stages [36]. LEDs, while containing critical metals including Indium, Gallium, and REE, also have much smaller amounts of REE compared to fluorescent lighting, which means recycling these materials from lamps in the future does not have a positive outlook [28].

The change in lamp product characteristics necessitates rethinking the end-of-use strategy for these products. While high recovery of REE could be less

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viable than with fluorescent lamps, the longer life and higher functional value of LEDs enable additional opportunities. These include reuse of LEDs and development of a second-hand market. The rapid development of the technology may also cause LEDs to reach fashion obsolescence before their end-of-life. An opportunity could develop for LED components to be repurposed or used in remanufacturing. The latter is more likely if lighting products move from a product ownership model to a functional ownership model, as some lighting producers like Philips already suggest as the preferred business model for value creation in a circular economy [37].

However, the development of product service models, modular design, and second-hand markets is not a given as there are barriers to reuse already mentioned in Section 2. There is also evidence of increasing integrated LED product design (i.e. integrated luminaires) rather than modularity, which can complicate reuse of components or recycling [28]. The value of used and end-of-life LEDs is likely highly influenced by design considerations taking place now. Smart design features, long life, standard fitting, and durability could result in valuable used or waste products. This raises questions about how policy should address issues such as competition for valuable used products and waste, the dynamic nature of value, and how it can best anticipate and manage value.

4 Implications of value for policy

4.1 Dynamic value and competition for waste

Waste streams with the highest potential value to cost of treatment ratios could well be the product categories best suited to individual targets in order to retain and recover valuable materials [7]. However, this value can also be problematic in achieving higher collection targets due to competition for waste from outside the official EPR schemes. Indeed, recognition of this issue has resulted in producers like Hewlett Packard suggesting that EPR policy should deal with value by only requiring "producers pay for waste where there is a cost" [4]. Esenduran, et al. [2], model the case of valuable waste and strong competition between producers and unofficial recyclers for waste, finding that higher targets for waste with value could potentially result in decreased landfill diversion overall as unofficial recyclers are pushed out of the market. The authors suggest one of two options: 1) tracking, registering and enforcement of standards for unofficial recyclers or 2) reducing collection and recycling targets imposed on producers. The authors argue several advantages to the latter approach, arguing that ambitious but not sufficiently high targets (as those in the current WEEE Directive) result in producers paying a higher recovery price to compete to recyclers, which in turn forces out recyclers and reduces the total welfare. In addition, it is argued that option 1 is made more difficult by leakage of valuable waste out of the EU [4].

There are several assumptions in these suggestions that need to be addressed. There is first the assumption that the environmental benefit simplified to only consider landfill diversion makes no differentiation between the environmental quality of treatment by official and unofficial recyclers [2]. In reality there is evidence that unofficial recyclers are more likely to only recover the materials with highest economic value while discarding the rest [19], [21], [38], [39]. Thus the environmental benefit of landfill diversion with unofficial recyclers is likely overestimated in the model. Standards for recycling like WEEELABEX are a welcome development and further assurance of environmentally sound treatment of WEEE is needed to confidently ensure the environmental objectives of EPR policy are being met. Lastly, the issue of leakage is a challenge that is widely acknowledged as needing to be addressed through better tracking and reporting [7], [15], [40].

The argument for scaled-back EPR for valuable waste is also contingent upon the fact that collection targets alone are not sufficiently high enough to result in the greatest overall welfare. This could be addressed more directly through more ambitious targets. While this may not be currently feasible at the EU level given the recent recast (with an aim to do just that), there is still room at the member state level for policies to go beyond the WEEE Directive in their requirements, for example as France has done with its individual product category targets. Best practices and success factors already identified can be further enhanced at the member state level to improve EPR systems [28].

There is also an assumption that the valuable WEEE will continue to hold its value. The fall of REE and other metal prices demonstrates that value can be dynamic, with boom-bust cycles. It is possible that the EPR policy can be designed flexibly enough to accommodate this with a mechanism for triggering responsibility, but this would raise issues of regulatory uncertainty. This in itself can be a cost for producers who would have to react to changing regulation. There is also a value to regulatory certainty that should not be underestimated.

4.2 Incentivising reuse and secondary supply of materials

There could be a role for policy in creating more certainty about value, particularly with regard to used products and recycled materials. Ideally EPR legislation would also include reuse targets. It is argued that this currently infeasible, with lack of data being the largest barrier [21]. Arguably this is an extension of existing challenges with information and tracking of WEEE. Better implementation and enforcement of data provision (for example, from reuse centres) and reporting requirements for both recycling and reuse (separately) should be a necessary starting point. Making a requirement that EPR schemes allow reuse organisations access to EEE and WEEE is also a way to increase reuse [19], [21] as well as documenting flows and ensuring quality of reused products [18].

Addressing demand for recycled materials is remains a challenge. As demonstrated by the case of fluorescent lighting, even with mature recycling technology and increased collection rates, recovery of critical materials is still dependent on market prices for the recycled materials. At the peak prices, spurred by Chinese control of the market, it was attractive to find alternatives to REE from China either by substitution to decrease the demand, opening (or reopening) mines like Lynas' Mount Weld in Australia and Molycorp's Mountain Pass in California to increase primary supply, or by recycling to provide a secondary supply [35]. The drop in REE prices saw interest in these initiatives wane too, resulting in closing mines like Molycorp's in California and the announcement by Solvay that it will discontinue its recycling from lamps [41]. While Lynas and Molycorp still struggle with low prices, there were some companies (e.g Siemens and companies in Japan) willing to sign longer term contracts with these companies (at presumably higher prices than those from Chinese suppliers) in order to have more certainty and control of their supply chains [30].

Managing supply chains to be more resilient, e.g. though alternative primary supply, has been advocated as a responsible way of addressing material criticality [42]. However, this will only be a mainstream practice if it is more widely acknowledged that this certainty of supply is of real value, i.e. an additional cost that companies are willing to pay. By the same argument, secondary supply from recycling can also help with certainty of supply for critical materials. However, there some concerns about volume, timing and quality, mainly because secondary supply chains remain less developed compared to more established primary supply chains [43]. Secondary supply of REE from waste products has another benefit in that it avoids the negative environmental and social impacts of extraction, which can be substantial given the considerable amount and nature of illegal mining practices in China [44], [45]. Further developing recycling and secondary supply of REE also contributes towards waste reduction and resource efficiency goals - all part of the circular economy agenda [35].

While retrieval of valuable secondary materials is part of the stated purpose of the WEEE Directive, this could be strengthened. For example, inclusion of recycling of targeted materials and products in the WEEE Directive (i.e. requiring recycling of critical materials where technology is mature, e.g. in fluorescent lamps) has been suggested [43] and would this would certainly help in incentivising the recycling of critical materials. An added emphasis on this aspect of the rationale for EPR could also be effective in realising higher collection rates (i.e. consumers return products not just to avoid environmental harm of landfilling but to actively conserve material resources [46]). However, this still does not necessarily assure that the recycling efforts match the market demand for the recycled materials. There also needs to be consideration in the critical materials strategy of how to best use or store critical materials if supply risks are anticipated but not immediate and the value for society of doing so.

To a certain extent, the characteristics of products initiate their value for reuse and/or recycling. As demonstrated by the case of lighting, design decisions made now will influence the feasibility of closing loops decades in the future. It is necessary to look at how policy can then further incentivise design changes that will make reuse, repair and recycling more likely to occur. While this is an aim of the WEEE legislation, this has also been a challenge due to the way EPR schemes are run (collectively) in practice [47]. Better understanding is needed of how to incentive producers to be more involved in the entire lifecycle of their products, e.g. through different business models. There is a role for the Ecodesign Directive and the WEEE Directive to both be enhanced in their design to further incentivise a transition to a circular economy, with producers not only thinking about the recyclability of their products, but also how recycled fractions or components of old products could be preferred for use in new products. Fundamental shifts in both producer and consumer perceptions of value are necessary if all waste is to become a resource.

The exploration of waste with value has demonstrated that the value of WEEE is dynamic and complex. Considerations of value depend on actor perspectives and objectives, networks, policies and market dynamics. Value also depends on consideration of the externalities, for example the negative environmental and social impacts of primary production and the wider benefits of recycling. It should not be understated that this is, and will continue to be, challenging for policy to address. However, transitioning to a more sustainable and circular economy will require more creative, ambitious and holistic policies encompassing the complexity of value in WEEE.

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