Pan-European Infrastructure Development (B4)

Critical Raw Material Closed Loop Recovery Project

With the contribution of the LIFE financial instrument of the European Community

Contents

Acronyms

AATF	Approved Authorized Treatment Facility
CRM	Critical Raw Materials
DCF	Designated Collection Facility
DTS	Distributor Take-back Scheme
EEE	Electrical and Electronic Equipment
EoL	End of Life
EPR	Extended Producer Responsibility
EU	European Union
HREEs	Heavy Rare Earth Elements
HWRC	Household Waste Recycling Centre
ITE	IT & Telecommunications Equipment
Kt	Thousand tonnes
LDAs	Large Domestic Appliances
LREEs	Light Rare Earth Elements
Mt	Million tonnes
PCB	Printed Circuit Board
PCS	Producer Compliance Scheme
PGMs	Platinum Group Metals
POM	Placed on Market
PPM	Parts per Million
REEs	Rare Earth Elements
UEEE	Used Electrical Electronic Equipment
WEEE	Waste Electrical and Electronic Equipment
WG	Waste Generated

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Executive summary

The total WEEE (waste electrical and electronic equipment) generated within the EU-28 is expected to rise from around 10Mt in 2018 to 11.1Mt by 2030. In contrast small IT WEEE generation, i.e. rich in CRMs (critical raw materials) is projected to decline slightly to around 700Kt in 2030. The expected fall in CRM rich WEEE is due to a decline in waste generation from heavier items such as desktop computers and telecommunications equipment. Although the number of units from mobile phones, smartphones etc. are likely to increase WEEE generation in terms of units arising, they represent a relatively small increase in terms of weight generated.

Even though the majority of countries within the EU-28 are also expected to see a decline in the generation of small IT WEEE, there are some notable exceptions. In particular, the Netherlands and Poland are large economies that are expected to see increasing small IT WEEE generation over the period to 2030.

Countries across Europe are performing significantly different in terms of WEEE collection and recycling performance. Based on Eurostat data we are able to identify the relative performance of the EU at recovery (recycling and re-use) from WEEE by country and by WEEE category. The EU collected 3.5Mt of WEEE from household and other sources in 2014, 38% of WEEE placed on the market in that year. In terms of IT and Telecommunications Equipment (ITE) the EU collected around 49% of the total amount placed on the market in 2014.

The majority of EU-28 particularly large economies collect between 45% and 65% of the IT placed on the market (this includes the UK, Germany and Italy out of the trial countries). At the other end of the performance scale there are other large economies that only collect around 25% to 40% (including the final trial partner country, the Czech Republic). If all of the countries in this poor performing group could raise their collection performance in line with the current EU average (49%) would result in an additional 51Kt of CRM rich WEEE being collected each year.

According to Eurostat figures around 3Mt of WEEE are recycled or re-used in the EU each year (including 500Kt of ITE). Germany, France and the UK account for 50% of total accredited WEEE recycling in the EU. However, taking account of recycling not carried out by accredited facilities and re-use of parts not accounted for in the official statistics this may increase to around 4Mt.

This variation in performance may reflect the size and economic development of their economies but is also likely to be because of the benefits of existing waste management infrastructure and policy environment.

Despite there being encouraging performance levels in reprocessing CRM-rich WEEE, this does not necessarily mean that the CRMs embedded in them are recovered for further use from either a technical or an economic perspective. Depending on how the products are presented and reprocessed many or all of the CRMs may be dissipated, making recovery very difficult.

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There are only four known plants in Europe (located in Belgium, Sweden and Germany) that recover CRMs on a commercial scale. Despite this, the ability to process CRMs is thought to be limited to post-production scrap and end-of-life equipment derived from industrial sources. Although there is limited capacity (at least in terms of number of operators) to recycle the CRMs within Europe (and even these primarily source from industrial sources) there are operators who aggregate different CRMs for export for reprocessing. Depending on how contracts are set up, it can be the case that the recovered CRMs are returned to Europe for re-use.

The recycling of CRMs is not always economically feasible. High investment and operating costs for sorting and recycling technologies deter the private sector from investing in recovery infrastructure. Additionally, regional disincentives may exist in relation to the complexity of processes for the acquisition of requisite licenses and permits. Rapid product and material developments and innovations result in changes to the composition of WEEE and recovery processes, which creates uncertainty and increases risk to companies seeking to invest in technology that may quickly become unsuitable for future waste streams. A lack of demand for secondary material, due to high costs, low or inconsistent quality, and volatile market prices, provide further disincentives for investment in recovery of CRMS.

The lifetime of CRMs in EEE largely depends on their application and the product’s end-use. For example, lifetimes of rare earth elements can vary from a few years (or even months) for lamps, and up to decades in high efficiency motors. Nor is it possible to generalise on the ease of disassembly (and hence of repair, remanufacture or re-use) of certain parts containing CRMs, as this depends on the type of product and even its brand. The trend of miniaturisation of electronics is generally making disassembly and recovery of components increasingly challenging.

At the same time, the recovery of CRMs from WEEE largely depends on the type of application and on the value of the raw materials contained within products. For example, precious metals in electronics (e.g. platinum group metals in printed circuit boards) are generally separated and recycled because this is economically viable. On the contrary, the recovery of materials such as gallium, germanium, indium, silicon metal, and rare earths is more challenging because of their dispersed use in products.

The overall aim of the Critical Raw Material Closed Loop Recovery (CRM) project trials was to investigate whether there was a demonstrable link between the collection and recovery of WEEE for the economically viable recovery of CRMs and what lessons could be learned and applied for a wider rollout across Europe. Quantities of CRMs within individual products are small and therefore challenging to recover. In order to make recovery financially attractive a minimum quantity is required to be recovered. There are a number of challenges to ensure there are sufficient concentrations of CRMs in the product to be treated.

Through better collection many of these can be overcome. This report outlines the requirements necessary to increase collections of CRM rich WEEE. For example, by concentrating products with similar CRM content the project will show how recovery efficiencies can be improved. Indeed the project trials were successful in demonstrating that the quality of the collection, in terms of both the methods used and the products collected, is a vital factor in the economic recovery of CRMs.

The recovery systems trialed during the project demonstrated that collection systems should be designed and marketed with the end recovery process in mind – whether that is re-use, component recovery, or reprocessing for the extraction of CRMs. If re-use is the final from of CRM recovery then the trials suggest that collections need to target newer, high specification items with a relatively high resale value. However, depending on the CRM recovery process it may be optimal to target older WEEE that have a high concentration of components used, e.g. PCBs.

Although we note that the cost and revenues from the individual collection and recovery trials are not directly comparable, they do suggest that collecting high value products (that can be resold with little or no repair), as economically as possible (via a retailer), could offer the most effective means of increasing CRM recovery. Further work should investigate the potential additional costs that could be included (e.g., revenue lost to a retailer from the loss of floor space) and whether economies of scale in both collection and recovery could increase the effectiveness of this method of collection. This report has identified where there are gaps in infrastructure necessary to increase the collection and recovery of CRMs. However, we note that further research is required to accurately estimate 'real-world' collection and recovery costs beyond the trial stage.

A key insight from the trials is that retailers and charity shops have a great opportunity to increase collections of WEEE. Retailers that are part of consumers' everyday habits (e.g. small convenience stores) offer an economical way to collect small WEEE from consumers. Trusted retailers may also give consumers confidence to hand-over appliances where data security issues are greatest (e.g. smartphones). This also increases the potential economic returns on collections since items returned are likely to be of relatively high value.

In this report we estimate that if the 'WEEE bring banks in stores' trial that took place in Italy was scaled up to the EU level (based on the number of outlets as the scaling factor) then this could result in the collection of an additional 600Kt of small WEEE each year. If citizens are given the right guidance, then much of this material may be available to be resold, with WEEE that cannot be resold being more likely to see its CRMs recovered.

This report makes three key recommendations to policymakers and industry to take forward and develop infrastructure locally.

-Increased awareness through improved information and data provision.
-Harmonised collections that are smarter at targeting CRM rich WEEE
-financial incentives to collect and re-use CRM rich products or otherwise recover CRMs.

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1. Objective

The objective of this report is to provide recommendations for the development of infrastructure that will result in better collection, increased re-use and improved dismantling of WEEE and increased recovery of CRMs across Europe.

Infrastructure development will have multiple benefits for the EU including: the creation of a stable market for products and recovered materials, a reduced requirement for virgin raw materials, and increased valorisation of WEEE through product re-use, disassembly and preparation for re-use of component parts, and recovery of CRMs at end of life.

2. Methodology

This report analyses data available on WEEE collection and recovery at an EU and a country level. Due to a lack of comprehensive data, this report also references other reports that have analysed unaccounted for flows in WEEE across the EU. This is an important point to note in considering the evidence presented in this report.

Using findings from a desk-based research exercise together with feedback from stakeholders, we have compiled the known infrastructure to recycle WEEE and recover CRMs in Europe; detailed research in this area is not publicly available. We then discuss some of the commercial considerations that influence the incentives of recycling and recovery businesses.

The report then analyses the results of the collection and recovery trials undertaken as part of the CRM project. Firstly, to understand the costs and benefits of the different trials methods, and secondly to understand the link between collection and recovery and to identify lessons that should be taken forward if the trials are to be rolled out across Europe. As the trials are effectively small, one-off exercises, there are likely to be significant opportunities for economies of scale should the trials be rolled out. Although trial partners have, where possible, estimated the potential efficiencies, new technology and the development of commercial partnerships may mean there are further improvements to be made.

Based on the key infrastructure recommendations resulting from the trials, a qualitative analysis has been undertaken on the impact the trial could have on countries outside of the EU. This section seeks to assess the impact from a consumer, business and a macroeconomic perspective. For example, it looks at the impact on other electronic manufacturing supply chains and the impact on countries that have historically imported WEEE, e.g. Thailand.

3. WEEE generation

Before determining the infrastructure required to increase the collection and recovery of CRMs, it is important to understand where we are currently in terms of WEEE generation and how this might evolve during the period to 2030. Therefore, this section looks in detail at recent trends in overall WEEE generation across the EU and for CRM-rich WEEE categories in particular.

The analysis also looks at trends on a country by country basis. In doing so we can begin to understand the various pressures in different countries, and importantly the various policy measures that might be appropriate to enable positive change.

Based on previous research and modelling undertaken by the United Nations University (UNU) on behalf of the European Commission, we are able to estimate the amount of WEEE generated for each country in the EU-28 by broad category[1], defined as follows:

WEEE generated in a Member State corresponds to the total weight of discarded products (waste) as a result of consumption within the territory of that Member State in a given reporting year, prior to any activity (collection, preparation for re-use, treatment, recovery (including recycling) or export) after discarding.

According to the methodology selected by the UNU study, the quantity of WEEE generated in a specific year is calculated by a collective sum of discarded products that were placed on the market in all historical years multiplied by the appropriate lifespan distribution, based on the probability of a product batch being discarded over time. The following sets were used, for each type of product and for each country:

- Historical EEE POM data for product type by weight (1980 to 2012), and
- Lifespan distribution per product type.

The model developed by UNU projects likely volumes of WEEE generated by category from 2014 to 2024. In the absence of the underlying model created by UNU, we have extrapolated the trend in WEEE generation, estimated between 2015 and 2024, and assumed growth at the same rate through to 2030 (Table 1). Based on these assumptions, the total WEEE generated in the EU-28 is projected to rise from 9.8Mt in 2015 to 11.1Mt by 2030 (an average annual increase of 0.8%).[2]

[1] Study On Collection Rates Of WEEE, by EC (2014): http://ec.europa.eu/environment/waste/weee/pdf/Final_Report_Art7_publication.pdf
[2] WRAP analysis

Table 1 : Projected WEEE generation, Mt

	2015	2016	2017	2018	2019	2020	2025	2030
Temperature exchange equipment	1.6	1.6	1.7	1.7	1.8	1.8	2.0	2.2
Screens	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.2
Lamps	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4
Large equipment	3.1	3.2	3.2	3.2	3.2	3.2	3.4	3.6
Small equipment	2.7	2.7	2.7	2.8	2.8	2.8	3.0	3.1
Small IT	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Total	**9.8**	**9.9**	**9.9**	**10.0**	**10.0**	**10.1**	**10.7**	**11.1**

UNU estimates from 2015-2020; WRAP estimates from 2025-2030

However, while aggregate WEEE generation is projected to increase, those categories of WEEE that are rich in CRM material (e.g. small IT) are projected to decline. Small IT equipment is expected to decline slightly (by an annual average of 0.7% per annum) in the period to 2030 to around 0.7Mt. This is mostly due to the decline of waste generation from desktop computers and telecommunications equipment. In contrast mobile phones, smartphones and printers show increasing WEEE generation in terms of units arising, but they represent a relatively small increase in terms of weight generated

Although total WEEE generation in the trial countries (Czech Republic, Germany, the UK and Italy) is expected to increase over the period to 2030, growth is expected to be highest in the Czech Republic and Italy (2.3% and 1.4% respectively per annum) while in the UK and Germany growth is likely to be much slower (less than 1% per annum). While small IT WEEE generation is expected to remain broadly stable in the Czech Republic and Germany, it is expected to decline in the UK (by 2.3% per annum) and Italy (by 0.6% per annum).

Table 2 below shows the expected annual growth in small IT WEEE generation by country across the EU-28 (based on UNU and WRAP analysis). Although the majority of countries are expected to see declining generation of small IT WEEE, there are some notable exceptions. In particular the Netherlands and Poland are large economies that are expected to see increasing small IT WEEE generation over the period to 2030.

Table 2: Annual growth in small IT WEEE generation

Croatia	3.3%		Cyprus	0.0%		European Union		-0.7%
Slovakia	2.0%		Finland	0.0%		Denmark		-0.8%
Hungary	1.3%		Latvia	0.0%		Norway		-0.8%
Poland	1.2%		Luxembourg	0.0%		France		-1.0%
Netherlands	1.2%		Czech Republic	0.0%		Romania		-1.1%
Germany	0.3%		Sweden	-0.5%		Belgium		-1.3%
Lithuania	0.0%		Austria	-0.6%		Slovenia		-1.4%
Estonia	0.0%		Italy	-0.6%		Ireland		-1.4%
Spain	-1.7%		Greece	-2.0%		United Kingdom		-2.3%
Bulgaria	-2.5%		Portugal	-4.0%				

Source: UNU estimates 2015-2024; WRAP estimates 2024-2030,

Total EU-28 WEEE generation is expected to continue to increase during the period to 2030. However, WEEE generation from CRM rich equipment (small IT) is expected to decline over the same period. This is an important distinction since infrastructure (both collection and recovery) will need to be configured to capture a higher proportion of a declining waste stream, at least on a tonnage basis.

Although small IT WEEE generation is likely to decline on an aggregate EU-28 basis the experience of individual countries may differ, and this may have important implications for policy design in individual member countries. For example, the Netherlands and Poland are large economies that are expected to see increasing small IT WEEE generation over the period to 2030. In these countries there may need to be a focus on reduce as well as on increasing recovery of small IT WEEE.

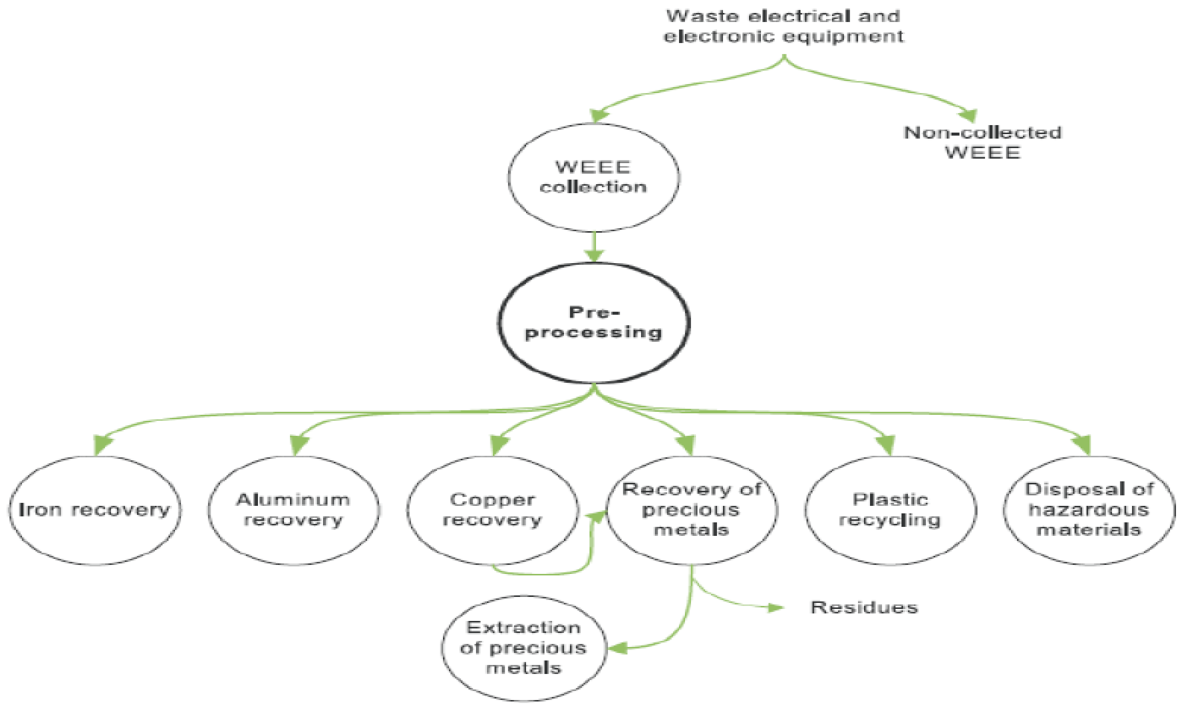
4. Current collection and recovery infrastructure in the EU

The WEEE recovery infrastructure in the EU is complex, involving several different parties (Figure 1). WEEE is captured from both consumer and business collections. Some WEEE will be processed through the secondary metals industry. This is often the case for large kitchen appliances such as dishwashers, cookers and temperature exchange equipment that have a high metal content. A significant amount of business-to-business products (in many cases equipment that could also be used in the household) are taken back directly by producers who have their own arrangements for dealing with it.

Not all of these arrangements are reported to Producer Compliance Schemes and Regulators and, are therefore not captured in the national statistics. Other studies have estimated EU WEEE flows unaccounted for in official statistics (e.g. ProSUM). This report will use some of those estimates where appropriate in the analysis.[3]

[3] Present and potential future recycling of critical metals in WEEE, Copenhagen Resource Institute (2014)

Figure 1 : Simplified recycling chain for WEEE



Source: Chancerel, 2009

4.1. WEEE / CRM collection

The capacity to collect WEEE is not limited in the same way as many other materials that are recycled. Most recycled materials are collected kerbside at the household where the limiting capacity factor is the volume of the bins and / or the size of the collection vehicle. In contrast most WEEE is collected through community waste collection sites where householders bring their WEEE and / or it is taken-back by retailers. Although there may be limiting factors to collection it is not clear that collectors are limited by a fixed volume.

Based on the latest data available from Eurostat (2014) we are able to identify the relative performance of EU Member States at recovery (recycling and re-use) of WEEE by country and by WEEE category. The EU collected 3.5Mt of WEEE from household and other sources in 2014, 38% of WEEE placed on the market in that year.

The EU's Waste Electrical and Electronic Equipment Directive (WEEE Directive) splits out WEEE into 10 broad categories. In terms of CRM content the most important category is IT and Telecommunications Equipment (ITE) which includes laptop computers, smartphones and e-readers, among other items.[4]

[4] These categories do not overlap exactly with the WEEE categories used by UNU in their WEEE generation analysis presented in section 1.

The EU collects almost 620Kt of WEEE under the ITE category for recycling and re-use, from both household and business sources, according to Eurostat data. This represents 49% of the total amount of ITE WEEE placed on the market in 2014. While most EU member states (particularly large economies) collect between 45% and 65% of the ITE placed on the market (this includes the UK, Germany and Italy from the trial countries), some countries appear to be collecting around 80% (Table 3).

At the other end of the performance scale there are other large economies that only collect around 25% to 40% (including the trial partner country the Czech Republic). If all of the countries in this poor performing group could raise their collection performance in line with the current EU average (49%) this would result in an additional 51Kt of CRM rich WEEE being collected. At an EU level this would increase collections from the current 618Kt to 669Kt (an increase of 8%).

Table 3: IT and telecommunications equipment collected by country , tonnes

Location	IT and Telecommunications Equipment Collected	Collection Rate
Liechtenstein	58	100%
Lithuania	3,144	100%
Portugal	11,218	86%
Hungary	8,995	79%
Slovenia	2,253	79%
Estonia	1,165	76%
Sweden	24,006	65%
Italy	59,582	65%
Austria	18,057	63%
Cyprus	493	63%
Bulgaria	2,549	62%
Norway	14,448	62%
Croatia	2,722	61%
Germany	144,476	59%
Finland	9,381	58%
Netherlands	29,699	51%
Slovakia	2,691	51%
European Union	618,088	49%
United Kingdom	127,093	49%
Iceland	715	48%
Poland	25,884	47%
France	67,731	45%
Malta	330	40%
Denmark	11,625	39%
Greece	5,191	37%
Romania	4,803	36%
Ireland	6,412	33%
Spain	20,205	31%
Latvia	528	27%
Belgium	18,364	26%
Luxembourg	678	26%
Czech Republic	8,813	20%

Source: Eurostat, 2014

4.2. Collections from business

Of the 620Kt of the WEEE collected under the IT and Telecommunications Equipment category around 500Kt (80%) comes from households with the remainder (around 120Kt) arising from businesses. Many business collections of WEEE comprise a large amount of ITE and therefore this waste stream is typically CRM-rich.

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Nevertheless, the amount of ITE collected across Europe varies significantly depending on whether it is collected from households or businesses. Although it is not possible to say how much is collected as a proportion of the total amount placed on the market for business use only (Eurostat data only shows total placed on the market by category), we are able to compare the proportion of ITE that is collected from households versus that of businesses.

Across the EU, around 81% of ITE collected is from household sources according to Eurostat. Of those countries that perform well in terms of the overall ITE collection rate, 3 of these countries collect a much lower proportion from households than is typical elsewhere in the EU; Sweden collects 71% from households, Norway 63% and Italy 43%.

This suggests that one way that countries could collect more CRM rich WEEE is to increase the amount of WEEE collected from business sources. Importantly, dual-use WEEE (which is the same type and quantity as would arise in a household) counts towards European and national targets and so can be collected from businesses (in some cases free of charge) by the Producer Compliance Schemes (PCS).

4.3. Collection processes within the trial countries

This section details the processes and systems operational in the trial countries.

Czech Republic

Extended producer responsibility applies to a number of WEEE groups, including ITE, consumer electronics, toys, monitoring and control devices, end of life vehicle, household appliances and more (CENIA, 2008). Producers, importers and distributers are obliged to take back used products from consumers free of charge (Decree 237/2002). They are also required to inform consumers about take-back facilities, types of products received, opening and closing times, and ensure that no charges are imposed (Decree 237/2002).

Producers are required to provide collection points in every city with more than 2,000 inhabitants. Only collection points or processors that are in a contract with a collective system or manufacturers are allowed to accept products from the consumers (Marusova and Mazal, 2018). Most WEEE is collected by collective systems. A list of collective systems, the groups of WEEE that they are permitted to handle, and finance available is published on the website of the Ministry of Environment.

United Kingdom

The Producer (referring to the manufacturers or importers who place EEE on the market, as well as the distributors who make products available) is the main stakeholder responsible for compliance with the Regulation. Producers are obliged to be part of a Producer Compliance Scheme (PCS) (although there are exemptions for small scale producers), which aims to support the implementation of the obligation for recovery, re-use and recycling of WEEE, and when selling a new item, distributors are required to take back the old household WEEE for free.

When purchasing new EEE items, stores are obliged to take back the same type of item from the customer for free. For small WEEE, stores have to take back the item regardless of whether a new item is bought or not. Stores, obliged to take back WEEE, have the possibility to join a PCS, who will organise the transport and arrange recycling or preparation of re-use at Approved Authorized Treatment Facility (AATF) or transport the waste themselves provided they comply with all the Regulations.

Retailers & distributors can opt out of taking WEEE back in-store, if they are members of the Distributor Take-back Scheme (DTS) which is the dominant model throughout the country. Retailers are obliged to inform the customer of where the closest Designated Collection Facility (DCF) is so they can return their WEEE there instead of in-store. This option entails a fee, which is used to support the recycling centres of the local municipalities.[5]

Italy

Under the WEEE & RoHS Decree (151/2005) the responsibility of collection, treatment and recovery of WEEE is given to the producer, including manufacturers, resellers, importers, internet retailers, and others (Valpak, 2015). Decree 121/2016 further obliges retailers to collect WEEE free of charge when a new similar product is purchased. Very small items must be collected regardless if any business is done or not.

Consumers can bring their WEEE to collection centres or collection sites. The former represents the majority of collection facilities and are operated by municipalities and businesses. Residents of the respective municipality can drop off their WEEE free of charge. Further collection points are drop-off places operated by distributors, private collection centers or collection sites, operated by installers and major users, though the latter two mainly target public and private entities (University of Leeds, 2018). An agreement signed in 2015 between National Italian Municipalities Association, WEEE Clearing House, EEE producers and Associations of Waste Collection Companies defines terms regarding collection and management of WEEE for a period of three years.

Germany

Divided Product Responsibility: The system in place is called the divided product responsibility. This mechanism describes the main obligations for electrical and electronic waste disposal as being the shared responsibility of public waste management authorities and electrical and electronic device manufactures (Umweltbundesamt, 2016).

Requirements by stakeholder (Umweltbundesamt, 2016, Grieger, 2018):

- **Public waste management authorities:** Establish municipal collection points for WEEE and acceptance of such waste free of charge.
- **Electrical and electronic device manufacturers:** Free to provide own collection mechanism. They are obliged to take-over the WEEE collected at municipal

[5] DCFs are municipal HWRCs permitted to take WEEE.

collection centers according to their market share in the respective product category if the public waste management authorities do not decide to recycle the collected WEEE on their own.

- **Retailers/ online traders:** Obliged to accept WEEE depending on the size of the sales floor/ storage and distribution area for electrical and electronic appliances. Retail stores with at least 400 m2 of sales area for electrical and electronic products are required, upon sale of a new piece of equipment, to take back a used device of the equivalent type (1:1 take-back obligation) free of charge as well as any waste electrical or electronic equipment in common household quantities as long as the external dimensions of such waste do not exceed 25 cm. In the latter case, take-back must not require the customer to buy new electrical or electronic equipment (0:1 take-back).
- **Other entities that like to work as a collection point:** Need to be mandated by municipalities, retailers or producers.
- **Consumer:** Obliged to bring back their electrical and electronic waste to collection facilities.

The collection system is based on a bring system, where the consumers are obliged to bring their WEEE to collection points. The disposal is free of charge. Currently there exist around 1,500 municipal recycling centres established by public sector recycling companies (Umweltbundesamt, 2016). While manufacturers are allowed to set up their own recycling mechanism, retailers are also free to implement take-back systems and are required to accept WEEE at their shops (Umweltbundesamt, 2016, Grieger, 2018).

4.4. WEEE recovery

According to Eurostat (2014) data, around 3Mt of WEEE are recycled or re-used in the EU each year. Germany, France and the UK account for 50% of total accredited WEEE recycling in the EU. However, taking account of recycling not carried out by accredited facilities and re-use of parts not accounted for in the official statistics, this may increase to around 4Mt (an estimated 950Kt of additional non-compliant collection and recycling of WEEE estimated to occur in the EU).[6]

Although estimates for the amount of ITE that is recycled or re-used are not available, official Eurostat data suggests that around 500Kt of ITE is recycled / re-used in the EU annually. Together, the UK and Germany account for just below 50% of the EU's accredited recycling and re-use of ITE (Table 4).

[6] Countering WEEE Illegal Trade Summary Report, EU (2015); non-compliant recycling in the EU estimated at 950Kt.

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Table 4: Recycling & re-use of ITE in the EU-28, Kt

County	Weight
UK	102
Germany	124
France	57
Czech Republic	8
Italy	47
Other	166
EU	**503**

Source: Eurostat, 2014

4.5. Recovery processes in the trial countries

The existing recovery process for WEEE in the trial countries is broadly similar and is largely determined by EU legislation.

Czech Republic

Waste management companies have processing capacities for all groups of WEEE and work with local processors for the further handling of collected WEEE.

UK

In the UK, currently WEEE is grouped into 5 categories at DCFs – LDA / COLD / SDA / DISPLAY / LAMPS. They are also treated in specialist plants according to their WEEE category. Some treatment facilities use shredding technologies while others first apply manual, automated or combined disassembly processes.

Italy

WEEE is grouped into 5 different categories: Products of refrigeration and air conditioning, other large household appliances, TVs and monitors, IT and consumer electronics, luminaires and lighting sources (Pellegrino, 2016). Distributors bring the household WEEE to authorized treatment facilities. Treatment facilities have the responsibility to register as a member in the National WEEE Clearing House and report their amount of WEEE treated.

Germany

Depending on the type of product and its composites different processes are used to recycle the materials. There are currently around 200 operators, though many of them work as storage places and only a few carry out treatment operations (Grieger, 2018). For certain components a dismantling step is applied in order to remove motherboards, plugs and other valuable components as well as pollutants prior to the recovery processes. These fractions, containing valuable CRMs, are further processed in larger treatment centres (Grieger, 2018).

4.6. CRM recovery

We understand that there are only four plants in Europe that extract CRMs on a commercially significant scale. Despite this the ability to process CRMs is thought to be limited to post-production scrap and end-of-life equipment obtained from industrial sources.

- The Umicore plant in Belgium was opened in 2011 and recovers 17 precious and speciality metals from a wide variety of materials from over 200 complex input streams. It is thought to have expanded its metal recycling capacity from 350Kt per year to 500Kt per year although it is not clear what percentage are devoted to CRM recovery.
- The Boliden facility based in Sweden opened in 2012; capacity is estimated to be around 120Kt per year.
- Aurubis has two facilities (copper smelters) in Germany that also extract CRMs; plants are based in Hamburg and Lunen and have a capacity of 450Kt per year and 210Kt per year respectively.[7]

It is not possible to say that there is a certain amount of CRM reprocessing capacity per year. The plant sizes above represent the capacity to reprocess all metals recovered from WEEE and other sources of metals, not their capacity to reprocess CRMs.

4.7. Economics of CRM recovery

The recovery and recycling of CRMs is not always economically feasible. Indeed, CRM recovery infrastructure for non-precious metals (e.g. lithium) is thought to be scarce in Europe, reflecting lack of extraction techniques that could be economically viable. The potential to improve recycling of materials depends on various factors such as recycling infrastructure, market prices, ability to disassemble products and associated costs, and the amount of material becoming available from products reaching their end-of-life.

High investments and operating costs for sorting and recycling technologies are likely to deter the private sector from investing in recovery infrastructure, particularly if high administrative burdens exist, such as complex processes of acquiring licenses and permits. Rapid product developments, new material and innovations result in a change in waste material composition. This poses a risk to those businesses that may be able to invest in a certain technology today, which might not be able to deal with the waste material in the future.

[7] Aurubis AG Environmental Statement (2015): Hamburg and Lünen Sites https://www.aurubis.com/binaries/content/assets/aurubis-en/dateien/responsibility/environmental-statement_2015.pdf

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A further risk and uncertainty is an unstable secondary product and material market, caused for example by a lack of demand for secondary material due to high costs, lower or inconsistent quality of secondary materials, and volatile market prices.

The closure of the Solvay plant in 2016 illustrates the risk of focusing too narrowly on the recovery of certain CRMs. Together with Umicore, Solvay developed an innovative recycling process to extract rare earths contained in low energy light bulbs. However when the price of rare earth metals declined the plant was no longer economical and was shutdown.

The lifetime of CRMs in EEE largely depends on the type of application and the end-use product. For example, the lifetime can vary from a few years (or even months) for lamps, up to decades in high efficiency motors. It is not possible to make assumptions with regard to the ease of disassembly (and hence of repair and re-use) of certain parts containing CRMs or therefore the costs associated, as this depends on the type of product and even its brand. It is observed that the trend of miniaturisation of electronics is generally making disassembly of components increasingly challenging.

At the same time, the recovery of CRMs contained in WEEE largely depends on the type of application and on the value of the raw materials. For example, precious metals in electronics (e.g. PGMs in printed circuit boards) are generally separated and recycled because this is economically viable. On the contrary, the recycling of materials such as gallium, germanium, indium, silicon metal, and rare earth elements (REEs) is more challenging because of their dispersed use in products.

There is limited data on the amount of EEE that is re-used. Re-use of EEE is generally not much established in the EU, except for some durable household products, e.g., washing machines and dishwashers, for which the re-use rate in certain EU countries can amount to 1% of the flow.[8]

The table below (Table 5) shows WRAP analysis on known CRM recovery capacity available in Europe broken down by CRM where possible and the trade routes that recovered CRMs take. Although there is limited capacity (at least in terms of number of operators) to recycle the CRMs within Europe (and even these primarily source from industrial sources) there are operators who aggregate different CRMs for export for reprocessing. Depending on how contracts are set up, it can be the case that the recovered CRMs are returned to Europe for re-use.[9]

[8] Report on Critical Raw Materials and the Circular Economy, EC (2008): http://ec.europa.eu/docsroom/documents/27348
[9] A study of the recycling and recovery infrastructure for materials critical to the UK, KTN (2011)

Table 5: European CRM recovery capacity assessment

CRM	Reprocessing locations in Europe	Comments	Country level data
Beryllium	UK for onward shipment to US	No reprocessing in Europe	Materion Brush Ltd (formerly Brush Wellman) is the major supplier of copper-beryllium alloys in the UK and will take back new scrap. This is returned to the US for reprocessing.
Cobalt	Belgium		Umicore (Belgium) have developed a closed loop solution for lithium ion batteries by which the cobalt, lithium and nickel components can be recycled, refined and transformed into lithium cobalt dioxide for manufacturer of new lithium-ion batteries.
Europium	None	Solvay plant in La Rochelle closed in 2016 due to drop in the price of europium	
Fluorspar	None	The nature of the products manufactured from or containing ceramic-grade fluorspar means that recycling of post-consumer waste is currently not a practical option due to the wide dispersion of the material.	

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Gallium	UK, Germany	Reprocessing infrastructure for production waste, not for post-consumer waste	Mining & Chemical Products Ltd recycle/ reprocess gallium compounds scrap from UK customers and materials obtained from other group locations in Europe. The principal sources are electronic waste and material that fails quality testing prior to manufacture of targets. MCP also refines indium, germanium and other metals. Recapture Metals Ltd, a Canadian company but with a European plant in Stade, Germany also recycle production waste from gallium compounds.
Germanium	UK, Germany, Belgium	Primarily post production scrap	Chemical and Technical Developments Ltd of Salisbury, Wiltshire, UK recycle germanium bearing material including germanium metal, germanium dioxide and other germanium compounds. The majority of the scrap (95%) is from obsolete optical sources with the balance from the machining of infra-red lenses and other infra-red system components. The company also purchases and processes powders and pastes containing germanium dioxide. PPM Pure (Germany) and Umicore (Belgium) also reprocess germanium containing components returned from the optical fibre manufacturing industries.
Indium	UK, Germany		AWA Refiners Ltd (UK) chemically refine and melt a variety of precious metals specialising in the refining of gold, silver, platinum, palladium, chromium, indium and ruthenium, but they process a number of other metals. Umicore Ltd (Belgium) (AV) and Recapture Metals (Germany) recover indium from spent targets used in the manufacture of solar cells. MCP Ltd (Wellingborough) recycles indium.
Magnesium	UK, Germany and Norway	EU recycling capacity estimated at 75,000 tonnes per annum.	Magnesium Elektron (UK) will recycle high-grade processing and have recently developed technology to process lower grade material such as magnesium swarf and dross. At their plants in Bottrop (Germany) and Porsgrunn (Norway) Norsk Hydro provide the largest volume of remelt magnesium to the European market, - 35,000 t per annum in 2004 (BY).

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Niobium		No evidence for the recycling of niobium in either the UK or Europe has been identified.	
Phosphorus	UK	The limited amount of addition to and the dispersive use of phosphorus-containing materials generally precludes recycling of phosphorus from original material.	Johnson Matthey (UK) offer a general refining service for electronic waste containing platinum-group metals. A service specifically for scrap computer boards is offered by AWA Refiners Ltd (UK) who chemically refine and melt process.
REEs		No indications of any post-consumer recycling of rare earth containing products were found.	
Tantalum	Germany	Reprocessing infrastructure for production waste, not for post-consumer waste.	H.C. Starck in Germany
Tungsten	UK		There are a number of companies in the UK that specialise in the recycling of tungsten and/or tungsten carbide scrap. These include Centaur Metals, UK Carbide Recycling, Mormet, and Wilbury Metals Ltd.
Terbium	None	Solvay plant in La Rochelle closed in 2016 due to drop in the price of terbium.	

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Yttrium	None	Solvay plant in La Rochelle closed in 2016 due to drop in the price of Yttrium.

Source: WRAP, CRM Recovery, 2018

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4.8. WEEE pre-processing and processing supply chain efficiency

The aim of WEEE pre-processing is the removal of hazardous and valuable components. This can be done manually or automatically before, during or after waste treatment. Although required by law, commonly not all hazardous and valuable components in Annex II of the WEEE directive (EU-Commission, 2002) are removed. The aim is to generate material streams that can go to the correct end-processing for final metal recovery.

Common pre-processing processes are liberation and sorting techniques such as manual dismantling, crushing, shredding and automated sorting. Pre-processing takes place at a regional or national level with various facilities all over EU-27. The technique applied largely depends on labour costs and has a major influence on further separation steps and thus on metal recovery efficiencies (Chancerel 2010). Many technologies for automatic size reduction are available on the market.

The degree to which CRMs are lost during pre-processing depend on whether manual or mechanically dismantling is applied. Data published in 2014 by the Copenhagen Resource Institute estimates that manual pre-processing can provide over 90% recycling rate for many of the selected products groups (i.e. those like mobile phones that contain higher concentrations of CRM), whereas the mechanical process for most metals only gives a recycling rate of between 0% - 60%. Although the recycling rate in end-processing (smelting) is very high (90% to 95%) for certain metals such as silver, cobalt, tellurium, gold, palladium and ruthenium, the rate is 0% (i.e. none of the material is recovered) for 7 of the selected 13 critical metals that were included in the study.[10]

The recycling rate of WEEE is poor for some of the metals because the whole recycling process (dismantling, pre-processing, end-processing) focuses and is tailored toward the extraction of bulk materials, and satisfactory dismantling, pre-processing, and end-processing technologies are not present. Meanwhile there are thermodynamic limits to the recycling of certain metals if jointly contained in complex mixes with other elements.

The CRM project recovery trials investigated the current barriers to recovering CRMs from WEEE. The most economical way of recovering CRMs is from PCBs (extracting materials like gold and silver) before they are shredded as part of a product (Table 6). Although it is technically possible to extract other CRMs, the difficulty in separating individual components (e.g. capacitors) and the range of material specifications (e.g. graphite) available make it significantly more challenging.

[10] Present and potential future recycling of critical metals in WEEE, Copenhagen Resource Institute (2014)

Table 6: Barriers to extracting CRMs from existing WEEE infrastructure

Element	Available recovery route	Limits in current WEEE processing
Au	Cu-fractions for smelter route extracted from PCB's	During shredding and separation process, amounts of Au end-up in fractions such as Steel, Aluminum, Plastics, dust: Au is not recovered.
Co	Specialized Li-ion battery treatment	No significant Co recovery from material fractions in WEEE processing except battery recycling.
Nd	Magnet recycling route	Once mixed with other material, even with other types of magnets, Nd recovery is not feasible
Pd	Cu-fractions for smelter route extracted from PCB's	During shredding and separation process, amounts of Pd end-up in fractions such as steel, aluminum, plastics, dust: Pd is not recovered.
Ag	Cu-fractions for smelter route extracted from PCB's	During shredding and separation process, amounts of Ag end-up in fractions such as steel, aluminum, plastics, dust: Ag is not recovered.
Ta	Specific recovery process for Ta wastes	No Ta recovery from any current WEEE fraction.
Y	Recycling of energy saving bulbs/ fluorescent tubes	No Y recovery from any current WEEE fraction.
Graphite	Graphite recycling (mostly on high level and knowledge about composition and origin)	No Graphite recovery from any current WEEE fraction.
Sb	SbO_3 e.g. recovered in Umicore process Creasolv © process can recover SbO_3 from plastics	No Sb recovery from current WEEE fractions installed
Pt	Recovered in Cu smelting process	Not very common in WEEE

Source: CRM Recovery, 2018

5. Potential increase in collection

This section starts with an overview of cost and performance from each of the collection trials. It then estimates what the potential impact could be if they were scaled up across the whole of the EU, where there is sufficient evidence to carry out this exercise. All estimates come with the caveat that these were trials which may become more efficient over time (capturing more material, at lower cost), while the seasonality of EEE purchases and WEEE disposal may mean that the collection figures are optimistic in relation to what would be captured over the course of a year. It is also challenging to understand what the counterfactual is, i.e. if these items of WEEE would have been collected elsewhere via a different route.

Italy

The collection trials in Italy involved three primary routes to collection. First, from September to December 2016 and from May to June 2017, in a series of public squares across Milan on consecutive Sundays in each square, a large blue collection container was placed to collect the citizen's WEEE. During the collection activities, the WEEE was sorted into 6 categories: flat screens (reusable/not reusable), high content of critical raw material (reusable/not reusable), low content of CRMs (reusable/not reusable). Two tonnes of WEEE were collected via this route with an average cost of €7.5 per Kg.

Two days of collections and awareness-raising about the issues surrounding CRMs were carried out in the Cormano (Milan) High School. Almost one tonne of WEEE was collected during this element of the collection trials with an average cost of collection of €7.5 per Kg.

Second, from June to December 2017, two WEEE bring banks were placed permanently indoors, in 2 Coop Grocery Stores in Milan. The design of the container was developed by ECODOM, specifically for the collection of small WEEE. Overall more than 2.5 tonnes of WEEE was collected with an average cost of collection of €3 per Kg.

Germany

The following collection trials provided the opportunity to raise awareness, reducing resources required for collections, and increasing the understanding of re-use:

1) 'Re-use Collection Olympics' for schools, rewarding the schools with the best collection outcome;
2) 'ReBag' collection bag for private households as an additional possibility to return WEEE (small household appliances/consumer electronics);
3) 'ReBox', a distribution of cardboard boxes for donors to store items for returning (small household articles); and
4) 'ReEnvelope' for WEEE mobile phones/smartphones (returning by regular post services).

Table 7: Aggregate results of collection trials in Germany by WEEE category

	Weight (Kg)	%	Quantity	%
TVs & Monitors	854.64	29.3	60	5.7
Consumer Electronics	425.04	14.6	209	19.9
ICT	948.03	32.5	422	40.2
Small Household Appliances	687.47	23.6	359	34.2
Total	**2915.17**	**100**	**1050**	**100**

Source: CRM Recovery, 2018

Excluding any revenue earned from the resale of items collected, the total cost of collection of the 'Re-Use Olympics' at schools trial was estimated at €5340.74 and captured just 2.63

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tonnes of WEEE. The cost of ongoing collection for ‘Re-Use Olympics’ at schools method (6 schools, one event per year) was estimated at €1,643 per tonne. It is not possible to compare the cost/benefit performance of the Re-Bag and Re-Box and Re-Envelope on the same basis since the first two involved a high initial capital cost and the second failed to capture sufficient amounts of WEEE. Due to the high cost of collection compared with other trials we have not sought to extend the analysis to a country or EU level.

UK

Trial 1: England

In England the collection phase was split into three separate trials to assess different means of engaging with and encouraging UK consumers to recycle their unwanted small IT WEEE as follows:

1) Retail take-back service with Dixons Carphone at five Currys PC World stores in Greater Manchester;
2) Charity donation trial with the British Heart Foundation at four furniture and electrical stores in Greater Manchester; and
3) Incentivised retailer take-back service at two John Lewis stores (Leeds and York).

As part of the collections phase, surveys were carried out with consumers in each of the trial partner’s stores at staggered intervals throughout the trial period. These surveys questioned respondents on their past handling of WEEE and their current preferences for disposal.

The trials at John Lewis and Dixons Carphone stores accepted items in any condition. The British Heart Foundation trials only accepted items that were of good enough quality to be re-used. Almost 0.7 tonnes of WEEE was captured across the collections, of which 86% was ICT.

Trial 2: Scotland

The collection models trialed were developed to provide consumers with the opportunity to drop-off unwanted electrical and electronic appliances (small IT equipment) at a time and place that suited them, to reduce hoarding of potentially valuable resources. These hubs were also designed to minimise product damage and encourage drop-off. The collections models involved establishing the following:

1) Re-use containers at two Household Waste Recycling Centres (HWRCs);
2) Employee amnesty collections at six businesses;
3) Two collection hubs at schools;
4) Six collection hubs at University Halls of Residences; and
5) Linking with two Social Enterprises, as collection partners.

Developing collection models to the point where a financial return would be realised requires the following:

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- A significant improvement in recycling value earned in the market-place.
- Improved marketing, screening of equipment to ensure that higher value ICT is collected.
- Market development to secure the highest possible level of functioning ICT as early as possible after it becomes redundant/surplus – thereby increasing resale income.

A total of 6.5 tonnes of WEEE was collected through the trial with 71% being ICT. Assuming a management collection costs of £5 per item (covering logistics, labour, licenses, etc.) then the cost of collection during the trials (829 items were collected) was £4,145.

Although re-use is a fundamentally sustainable approach for keeping CRMs in circulation in the economy for as long as possible, re-use collection schemes are challenging to sustain due to low levels of items donated. This is compounded by the age profiles of those items that are donated (which have no or limited re-use markets). It is therefore likely that increasingly innovative collection schemes should be accompanied by significant awareness raising campaigns, possibly at a national level.

Czech Republic

The collection model trialed the objective of getting as close to people as possible. Citizens in selected areas of Prague had the opportunity to drop off WEEE directly in front of their house. For these purposes, ASEKOL created two prototype mobile containers for co-joint collection of WEEE and textiles, and that could be placed whenever needed.

The trial phase of the project (placing the containers into the streets) started in the middle of March and continued until July 2017. Mobile containers were deployed in various municipal districts within the capital city of Prague. Containers were placed in each location for at least 2 days. The trial project was also accompanied by an awareness-raising campaign emphasizing the collection trials for, in particular, CRM-rich WEEE.

A total of 1.7 tonnes and 694 items of WEEE were collected during the trial. Only 3% of the collected items were suitable for re-use.

Lessons learnt from the activities:

- Collection trial via mobile containers was very time consuming and costly (this was actually the most expensive collection stream).
- The collection result is affected by an existing network of stationary containers. Mobile ones were added at the places where the stationary ones couldn't be placed (historical places, transition to underground containers etc.).
- The collection was supported by linking with another commodity (textile) and the Red Cross. Collection always works well with some charity involved as in this case. The Red Cross is credible institution and thus collection of worn clothes was felt to have convinced people to dispose of their WEEE as well.

- Other companies dealing with waste textiles started to be interested in WEEE collection.
- WEEE that is thrown into the containers and then transported is not conducive to re-use. Throwing or tossing of WEEE and subsequent (manual or machine) handling increases the risk damage. Only 3% of the items in the trial were chosen as a potentially suitable for re-use.

5.1. Scale-up of collection trials

One of the key insights from the trials was that retailers and charity shops typically offer a convenient way to increase collection of WEEE. Retailers that are part of consumers' everyday habit (e.g. at small convenience stores) offer an economical way to collect small WEEE from consumers. Trusted retailers may also give consumers confidence to hand over appliances where data security issues are greatest (e.g. smartphones). This also increases the potential economic returns on collections since items returned are likely to be of relatively high value.

WRAP analsysis suggests that if the 'WEEE bring banks in stores' trial that took place in Italy were scaled up to the EU level (based on the number of outlets as the scaling factor) then this could result in the collection of an additional 600Kt of small WEEE each year. Given that an estimated 700-750Kt of small WEEE is generated in the EU each year this would represent a collection rate of 80%-85%. Based on the costs presented in the trials the cost of collection would be around €1.8 billion, before resale values are taken into account. However, as collections become more efficient over time it is likely that the collection cost could decline.[11]

Grocery shops are one of the places that are part of everyday living for all members of the public. Elderly people often prefer to shop in the morning, while young people and workers tend to shop during the evening or on the weekends. However, it is very likely that setting up an initiative in a grocery store would reach a very wide and diverse demographic. One observation from the trial was that it is important that there is parking nearby so that people can easily transport heavier forms of CRM rich WEEE, e.g. computer monitors.

One of the main costs to a retailer is the loss of floor space taken up by the WEEE collection bin, space that could be used to stock products or be used as storage space. Although retailer brand loyalty may increase by virtue of collecting small WEEE it's not clear what the value of this would be if the collections were rolled out on a national basis to all retailers.

[11] Retail Index registers and published data on food retailers globally. It estimates that there were 240,000 grocery store outlets in the EU in 2012 with an approximate turnover of €3 trillion https://www.retail-index.com/Sectors/FoodRetailersinEuropeandworldwide.aspx

6. Recovery trials

Italy

The ECODOM recovery trials aimed to increase recovery of the target CRMs and develop a new hydrometallurgical process to recover Cobalt and Graphite from batteries. The recovery trials aimed to achieve four main goals:

- Test and prepare for re-use the products having re-use potential;
- Implement recovery activities to increase current CRM recovery;
- Perform a new hydrometallurgical process to recover cobalt and graphite from batteries and;
- Analyse the overall increase in CRM recovery throughout the entire recycling chain.

Although it was not easy to evaluate the recovery results, especially regarding the Precious Metal Recycling (PMR) process and the treatment of batteries, some general considerations can be proposed linking the success of the collection and recovery trials. Almost 20% of the collected screens were reusable. It confirms that attention has to be given to the WEEE collection and transport phase, promoting clustering of disposed appliances and avoiding damage. Meanwhile, the quality of the collected WEEE (high CRM content) was a crucial aspect of the treatment performance. Both of these results suggest the need to further invest in the promotion of effective and rational collections that target high CRM-rich WEEE, but that is also collected and handled correctly.

Germany

The recovery trials focused on bio-leaching of Tantalum from capacitors as well as the generation of homogeneous Neodymium-based magnet material from computer hard disks by hydrogen decrepitation and melt spinning.

Even though the operational costs of bioleaching are considered a little higher than the cost of traditional recovery processes and conventional mining, more metal can be extracted using bioleaching especially from low-grade material. For example, conventional copper mining can extract 60%-65% from an ore/material whereas 90%-95% can be extracted using bioleaching.

The cost of recycled material is equal to the assumed costs of scrap magnets in Germany of about 4 €/kg *. As shown in Table 8, the costs of producing 1Kg magnet material from used magnets from HDDs (Hard Disk Drives) are about 15€.

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Table 8: Cost of recovery per Kg, Germany trials

Process Step	Explanation	Cost per Kg of Magnet Material Produced (€)
Purchase of Recycled Material	Cost of recycled material is equal to the assumed cost of scrap magnets in Germany of about €4/Kg. Since 55% magnet powder could be recovered after Hydrogen decrepitation and sieving	7.3
Powder Processing	Hydrogen decrepitation (HD), grinding, pressing, characterisation	3.0
Strip Casting	Production of flakes from powder by melt spinning	3.0
Adding Nd	2.5% Nd to be added to the melt	1.5
Total Cost		**14.8**

Source: CRM Recovery, 2018

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UK

Trial 1: England

The trial in England focused on recovering specific components from circuit boards to concentrate CRMs from smaller volumes of material. This was achieved through three trials:

1) **Item disassembly:** Disassembly of WEEE and recovery of circuit boards, measuring circuit board recovery rates as a proportion of item weight and speed of dismantling.
2) **Component depopulation:** Depopulation technology utilised to remove components from the circuit boards.
3) **Component separation:** Mechanical separation techniques applied (size, magnetism, density) to separate components into different fractions.

Dismantling was carried out at close to full scale so these costs per Kg could only be reduced slightly as operators became more familiar with the types of equipment dismantled. A figure of £100-110 per tonne (£1.00-1.10/Kg) of WEEE items may be appropriate.

Previous work by ITRI has indicated that a larger scale component depopulation process may have processing costs of approximately £250 per tonne (£0.25/kg) of circuit boards. This would translate to an approximate cost of £32 per tonne (£0.03/kg) of WEEE items. Large scale screening and magnetic separation processes have minimal operating costs and did not contribute significantly in comparison to the other stages.

Industrial scale density separation processes have operating costs in the region of £200-£300 per tonne (£0.20-0.30/Kg), which would translate to an approximate cost of £0.50 - £0.70 per tonne (<£0.01/Kg) of WEEE items. Overall, a scaled-up process could have costs of approximately £150 per tonne (£0.15/kg) of WEEE items.

Gold and copper are found in large quantities across almost all fractions, with no correlation between composition and fraction and/or category. There were very few fractions where there was a significant concentration of other CRMs. Additionally, given the number of components remaining on the circuit boards after the depopulation trials it is likely that partially depopulated boards still contain relatively high proportions of gold and copper. It is probable that every one of these fractions would be sent to the traditional processing route for recovery of gold and copper; therefore it is unlikely that a specialist processing plant to treat these fractions and recover other CRMs would be viable.

The trial demonstrated that collections need to be structured with the end recovery/re-use process in mind. The collection trial focused on ensuring that items that were donated which were not suitable for re-use would remain whole in order to aid the dismantling process. Items were carefully placed in secure containers during the collection phase to ensure minimal damage to the items. This meant that it was possible to manually dismantle the items and extract the intact circuit boards.

The trial also focused on data bearing devices that had a high level of CRMs within the components of the printed circuit boards, which meant that useful CRM-containing WEEE could be sent to the recovery trials.

Trial 2: Scotland

The aim of this recovery trial was to develop “proof of concept” benchtop experiments that would use biological and chemical separation techniques to extract gold, silver and cobalt from PCBs. The gold (Au), silver (Ag) and cobalt (Co) enriched solutions, would then be passed through a proprietary ElectroChemical Cell (EC Cell), manufactured by the University of the West of Scotland (UWS) to recover the elements of interest. The laboratory work strands are summarised below:

1) **Biological separation:** Three different types of microbe were selected (acidophiles, fungus and cyanogenic) to determine whether they would selectively extract gold, silver and cobalt from ground PCBs. Selected PCBs were prepared and processed using innovative biological, chemical and electro-chemical methods - for the extraction of gold, silver and cobalt.
2) **Chemical separation:** Three chemical separation techniques were explored to extract gold, silver and cobalt, these were:
    a. Acid dissolution
    b. Sulphide precipitation, and
    c. Particle size distribution.

   A fourth extraction method which used hydroquinone to extract solely gold was also considered.
3) **EC Cell:** Fourteen proprietary EC Cells were manufactured for the recovery of gold, silver and cobalt from reference solutions.
4) The initial aim was to wholly carry out the experiments on PCBs collected during Phase One. However, this methodology was subsequently refined for the EC Cells and hydroquinone experiments. For the former, reference solutions of gold, silver and cobalt of a known concentration were produced in order to calculate hypothetical recovery rates and help to determine the success of the concept. Reference solutions of gold were also produced for the hydroquinone experiments.

The costs associated with the recovery techniques carried out as part of this project were prepared by the trial partners, however because the work was being carried out on a laboratory, proof of concept basis, extrapolating beyond this to understand the costs and benefits at an industrial scale is extremely complex and does not form part of the scope of work.

Equipment sourced from the collection trials was first considered in terms of its potential for re-use and resale. Those which were suitable for reprocessing only were stored separately, with the target PCBs extracted and stored for the research to be carried out in the recovery trials. The type of WEEE used for the recovery processes was WEEE that was too old, uneconomical to repair or low specification. The type of products that it could be considered will have particular value to focus on for the CRM recovery processes highlighted in this trial include laptops and PCs, mobile phones (not smart phones) and flat screens (computer monitors, TVs).

Based on the recovery systems trialed, it would appear to be economically and environmentally sound to ensure that collection schemes enable as many items as possible to be processed for re-use markets, prior to recovery/ recycling.

Czech Republic

The aim of the recovery phase was to develop maximum recovery of CRMs from the fractions. Three fractions with the highest potential for recovery were chosen for development of methods. Precious metals, rare-earth elements (Ce, Dy, Ho, La, Nd, Pr, Sm) and copper were categorised among elements of interest. Trials were based on classical physical methods using different particle sizes, density, conductivity and electromagnetic properties.

Three fractions for each of the collection trials were chosen. Each of the output fraction material was evaluated focusing on amount, particle size and contents of elements of interest. Plastic fractions < 0.5mm and plastic fractions 0.71-1.5mm from both of the collected material streams were chosen for the recovery trials and focused to increase concentration of precious metals. The highest concentrations of rare-elements (mainly Nd) were contained in fine ferrous fractions, and these were chosen for those laboratory trials focused on rare-earth elements.

6.1. Linking collection to recovery

The overall aim of the trials was to ascertain whether there was a demonstrable link between the collection phase and the recovery phase of the trials and the lessons this may give for a wider rollout across Europe.

There is an argument that collecting greater amounts of WEEE increases the chances that it will be captured, rather than it being hoarded by households or end up in landfill. However, the corollary of this is that if you don't collect WEEE in an appropriate manner for the end process then many of the products that could have been re-used will be too damaged and CRMs that could have been extracted if they had been sorted and disassembled at an early stage are more likely to be lost due to WEEE shredding. And so the quality of the collection is just as important as the quantity that is collected.

Based on the recovery systems trialed, it appears to be economically and environmentally sound that collection systems enable as many items as possible to be processed for re-use markets, prior to recovery. If re-use is the final form of CRM recovery then the evidence from the trials is that collections need to target newer, high specification items with a relatively high resale value.

However, depending on the CRM recovery process it may be optimal to target older WEEE that have a high concentration of components used, e.g. PCBs. Development of a product database including knowledge of embedded CRM content will produce sorting criteria that could be used much earlier in the collection stage, for example in the marketing of the collections, encouraging citizens to just bring CRM-rich WEEE for collection and reminding them of the need to handle their products with care.

6.2. Economic assessment of collection and recovery trials

In order to assess the up-scaling potential of the different trials, costs and benefits related to the collection scheme innovations have been analysed. Costs, revenues and wherever possible necessary investments have been estimated based on:

- Data by the trial hosts as part of their reporting obligations;
- Interviews with responsible managers for the different steps of the trials; and
- Additional sources from the literature (especially on general framework conditions etc.).

Based on these data this section compares:

- The economic viability of the different approaches in their specific national/ regional contexts; and
- Potential cost saving potentials by increased economies of scale and learning curve effects.

Table 9shows the costs and revenues for the different trials, in total as well as relative figures per collected Kg of CRM-rich products for the trials in Italy, the income figures have been estimated using the data from Germany. For the trials in UK by ReTek average costs for the different trials have been indicated by the trial host.

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Table 9: Overview on costs and revenues from the different trials

		Asekol	Recyclingbörse			Ecodom		Axion		ReTek
			Re-use Olympics	*Re-Box*	*ReBag*	*Market Squares*	*Grocery Shops*	*John Lewis*	*BHF*	
Costs (€)	Investments/ permits	7000		5400	5000	410			200	
	Media	3000	800	930	300	2000	7236	300	4000	
	Labour costs	32000	4600	1600	6000	2590	4963	200	200	4660
Revenues (€)	Re-use	304.78	417.5	55	270	78	258	1633	1240	1338
	Recycling	146.99	201.35	5	15	38	125			
Collection (Kg)		1570	2134	95	163	399	1321	66	349	3477
Costs per kg, in Euro		**26.75**	**2.53**	**83.47**	**69.33**	**12.53**	**9.23**	**7.58**	**12.61**	**1.34**
Revenues per kg, in Euro		**0.29**	**0.29**	**0.63**	**1.75**	**0.29**	**0.29**	**24.74**	**3.55**	**0.38**

Source: CRM Recovery, 2018

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Analysis from only one of the trials shows a positive net economic benefit, for all other trials significantly higher costs than revenues have been indicated. This trial (the incentivised retailer take-back service at two John Lewis stores located in England) was economically viable for two primary reasons: extremely high value products that could be resold were collected; and labour costs were low due to cooperation with the external partner (whose costs were not included in the analysis).

Collection costs differ significantly between the different trials - ranging from €1.34 per kg to €83.47 per kg. These differences can be explained by:

- **The share of necessary costs borne by innovation:** The trials by RecyclingBörse in Germany required significant investments in new equipment leading to higher costs per kg. This might indicate possible cost reductions if the trials are continued in the future and economies of scale are developed.
- **How costs were shared across the trials:** For the Czech trials, necessary efforts have been recorded very thoroughly and the trials were handled as separate projects. Lower costs have been indicated wherever it was possible to include the trial activities into on-going projects.
- **The role of expenditures for awareness raising activities:** For example the trials in Italy were accompanied by very detailed information campaigns, raising significant awareness for the issue of CRM recovery and related environmental benefits. To some extent these are one-off costs which might be expected to fall over time if the trials are scaled up.

The revenues per collected Kg also differed significantly between the trials:

- **Newer, valuable items:** Those trials with high income streams managed to collect relatively new products that still have a high resale value. In total it can be stated that the key success factor is the sale of second hand products that is based on the extension of the use phase of products.

With regard to other key success factors, the analysis shows that economic viability clearly depends on successful coordination with other collection activities (e.g. the combined collection of WEEE and textiles) or the cooperation with existing infrastructures (e.g. household recycling centres) or the retail sector. Additional collection infrastructures just for CRM-rich products will be difficult to establish due to insufficient economic viability. The adoption of best practices might lead to more positive effects in the long run. At the same time it should be taken into account that the average value of products might decrease if the “good products” were returned in the beginning perhaps motivated by the communication on positive environmental benefits.

7. Infrastructure recommendations

7.1. Increasing awareness through improved information / data provision:

A European wide accreditation scheme that requires WEEE reprocessors to provide annual estimates of their capacity could reduce the information barrier to further investment in the sector. Creating transparency in the sector will provide a signal to companies as to whether there is a need for further investment in processing / sorting, both for different WEEE streams and on a geographical basis.

This could be similar to the requirement under the UK's packaging regulations to which accredited reprocessors have to register (including providing capacity information) in order to be able to issue Packaging Recovery Notes (PRNs). WRAP understands that the WEELABEX organisation may also provide a framework for how this accreditation could take place. [12] Importantly this must be a public transparent database that provides clarity on the feedstocks that are reprocessed. In turn this will give investors' confidence in understanding where there is a lack of capacity.

7.2. Harmonised collections that are smarter at targeting CRM rich WEEE:

The very first step to ensure CRMs are recovered (or kept in the economic loop through preparation for re-use activities) is to secure their separate collection. However, this isn't enough to ensure that CRM-rich WEEE achieves its optimal end-of-life value. In order to achieve this high value CRM-rich WEEE needs to be collected and sorted from older less reusable WEEE, and in turn needs to be collected separately from bulkier lower value WEEE with little or no CRMs embedded.

The trials demonstrate that, due to convenience and data security issues, local retailers that are trusted could be a strong partner in the collection process. Collections are most effective near major conurbations. They are best placed where there are downstream logistics close by (e.g. repair, re-use and recovery facilities) to avoid transport costs.

Harmonising collection schemes across Europe will reduce the cost of collections (e.g. through consistent collection messages). Harmonising the collection of CRM-rich material will also give reprocessors and other parts of the supply chain confidence in the amount and composition of feedstock they are likely to receive, and so they will be able to design and operate their plants more efficiently.

[12] (WEEELABEX ('WEEE label of excellence') is the acronym of a project (2009-12) co-financed by LIFE, the environmental programme of the European Community (LIFE07 ENV/B/000041), http://www.weeelabex.org/weeelabex-organisation/

7.3. Financial incentives to collect and re-use CRM rich products or otherwise recover CRMs:

To incentivise the recovery of CRMs from WEEE there is a case for introducing a separate mechanism that would provide a financial incentive to recover CRMs. This could be modelled on the Packaging Recovery Note in the UK. In the UK accredited reprocessors receive a PRN note (whose value reflects the likelihood of meeting annual targets for recycling packaging) whenever they recycle one tonne of packaging. This operates alongside the existing targets for overall recycling.

In the same way a CRM recovery note could operate to provide a separate incentive for collectors to capture more WEEE overall but also in a way that allows the CRM fraction to be captured.

8. The wider implications of increased CRM recovery for countries outside the EU.

This section considers the impact of infrastructure recommendations on countries outside of the EU, specifically the impact on consumers, businesses and broader ex-EU economies.

Increased collection of WEEE, particularly small WEEE will reduce the EU's reliance on legal and illegal exports of WEEE. According to the CWIT report on trade in WEEE an estimated 1.4Mt of WEEE are exported outside of the EU each year. The benefit of reducing this trade will be a reduction in the risk that WEEE ends up being exported to countries with poor waste management practices.[13]

In mid-2018 the Thai government announced that they were going to temporarily ban the import of WEEE due to poor waste management practices. If other countries follow suit or at least introduce more stringent restrictions / inspections, then there will be greater demand on WEEE reprocessing capacity in the EU.[14]

Increased collection of small WEEE in the EU and greater recovery of CRMs could be a potential benefit to multi-national companies sourcing CRMs, reducing their supply risks. In turn it may prompt some companies to establish manufacturing bases in the EU, or close by, if they could be confident that the supply of CRMs (both price, volume and quality) will be stable enough in the future.

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[13] Countering WEEE Illegal Trade Market Analysis Recommendations roadmap - Summary Report, EC (2015)

[14] Thailand bans import of plastic and WEEE waste, Recycling & Waste World (July 2008): http://www.recyclingwasteworld.co.uk/news/thailand-temporarily-bans-import-of-plastic-and-weee-waste/175854/

It may also provide a source of export revenue to companies exporting recovered CRMs to where they are required elsewhere in the world. A greater Corporate Social Responsibility (CSR) focus on the traceability of CRMs may result in the EUs future exports of CRMs to manufacturers elsewhere in the world receiving a premium relative to other suppliers.

Used electrical electronic equipment (UEEE) is often exported abroad, typically to less developed countries. Lower exports of usable technology to less developed countries may adversely affect economic activity in those destination countries by reducing the number of jobs required in electrical repair. It may also reduce the supply of technology to people who may not be able to afford more expensive new equipment.

9. Conclusion

The overall objective of the trials was to ascertain whether there was a demonstrable link between the collection phase and the recovery phase of the trials and the lessons this may give for a wider rollout across Europe. Although collecting more WEEE reduces the likelihood that CRM-rich equipment will just be hoarded by households or end up in landfill, if you don't collect WEEE in an appropriate manner for the end process then many of the products that could have been re-used will be too damaged and CRMs that could have been extracted if they had been sorted and disassembled at an early stage are more likely to be lost due to WEEE shredding. The quality of the collection is just as important as the quantity that is collected.

Based on the recovery systems trialed, it appears that collection systems should be designed and marketed with the end recovery process in mind – whether that is re-use, CRM recovery etc. If re-use is the final form of CRM recovery then the trials suggest that collections need to target newer, high specification items with a relatively high resale value. However, depending on the CRM recovery process it may be optimal to target older WEEE that has a high concentration of components used, e.g. PCBs.

A key insight from the trials is that retailers and charity shops are a great opportunity to increase collection of WEEE. Retailers that are part of consumers' everyday habits (e.g. small convenience stores) offer an economical way to collect small WEEE from consumers. Trusted retailers may also give consumers confidence to hand over appliances where data security issues are greatest (e.g. smartphones). This also increases the potential economic returns on collections since items returned are likely to be of relatively high value.

In this report we estimate that if the 'WEEE bring banks in stores' trial that took place in Italy was scaled up to the EU level (based on the number of outlets as the scaling factor) then this could result in the collection of an additional 600 thousand tonnes of

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small WEEE each year. If citizens are given the right guidance then much of this material may be available to be resold, with WEEE that cannot be resold being more likely to see its CRMs recovered.

In order to bring about this change we recommend that smarter collections are introduced - systems that specifically target CRM-rich WEEE for either re-use or recovery. For this to happen, collectors need to know what products (both new and old) are rich in CRMs and be able to educate citizens on how they should handle their items to secure the best returns. CRM re-use/recovery businesses need to understand their current and potential feedstock in much greater detail in order to give confidence that investments can generate the desired return. For this to happen there needs to be much greater transparency right across the supply chain, right from the CRM content of appliances to the current levels of reprocessing infrastructure and finally on to the potential size and sustainability of the end market.

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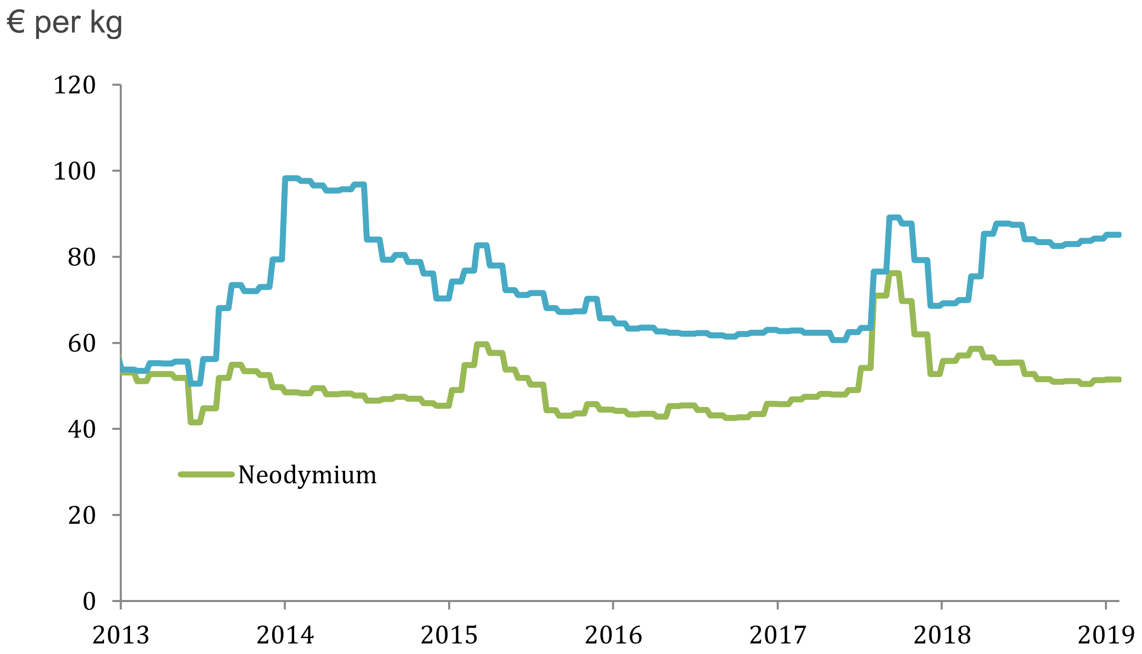
11. Appendix: CRM price volatility

The price of CRMs is particularly volatile, even when compared with other commodities. The data source for these metals only starts from 2013. This means that the spike in CRMs (specifically rare earth metals) in 2010/11 does not feature in the chart below. Chinese export restrictions on these metals resulted in the price of many of them multiplying several times over the course of 1-2 years. The price of these metals subsequently fell sharply as demand fell and alternative sources of supply became available.

Nevertheless, the volatility remains. Between June and August 2017 the price of neodymium and praseodymium increased by 50%. Just four months later almost all of these gains had been given back with prices returning close to mid-2017 levels.

CRM prices are particularly volatile since they are a typically a by-product from the mining of another major commodity, for example iron ore. This means that the supply of the CRM does not respond to higher prices, since the mine operator is primarily incentivised by the price of the major commodity – not the by-product.

Chart 1 : Price of neodymium and praseodymium



Source: Reuters