CEWASTE

Voluntary certification scheme for waste treatment

ROADMAP FOR THE LONG-TERM SUSTAINABILITY OF THE SCHEME

DELIVERABLE 4.4

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NOTICE

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ACRONYMS AND ABBREVIATIONS

Ag	Silver
ASI	Aluminium Stewardship Initiative
Au	Gold
BAT	Best Available Technique
Bi	Bismuth
Ce	Cerium
CFL	Compact Fluorescent Lamps
CRM	Critical Raw Material
CRT	Cathode-Ray Tube
Dy	Dysprosium
EC	European Commission
ECOS	Environmental Coalition On Standards
EEE	Electrical and Electronic Equipment
EERA	European Energy Research Alliance
EFTA	European Free Trade Association
ELV	End-of-life Vehicle
Eu	Europium
EU	European Union
ERMA	European Raw Materials Alliance
HDD	Hard Disk Drive
KCC	Key CRM Component
KCE	Key CRM Equipment
La	Lanthanum
LA	Lead auditor
LFL	Linear Fluorescent Lamp
LTP	Linked Third Party
MSX	Membrane Solvent Extraction
MtM	Magnet-to-Magnet
Nd	Neodymium
PWB	Printed Wiring Board

Pd	Palladium
PGM	Platinum Group Metals
POM	Put On Market
Pr	Praseodymium
PRO	Producer Responsibility Organisations
RE	Rare Earth
REO	Rare Earth Oxalate
RMI	Raw Materials Initiative
Sb	Antimony
SMART	Specific, Measurable, Achievable, Realistic, Timely
SMEs	Small and Medium-Sized Enterprises
Tb	Terbium
TRL	Technology Readiness Level
UNU	United Nations University
VAT	Value Added Tax
WEEE	Waste Electrical and Electronic Equipment
WP	Work Package
WRFA	World Resources Forum
WSR	Waste Shipment Regulation
Y	Yttrium

SUMMARY

Raw materials are crucial to Europe's economy. They play a crucial role in the European industrial base, producing a broad range of goods and applications widely used in modern technologies. However, Europe has restricted access to certain raw materials and relies heavily on foreign supply. This is a growing concern, both within the European Union (EU) and across the globe. To address this challenge, the European Commission (EC) drafted a list of critical raw materials (CRMs) for the EU, combining raw materials of high importance to the Eurozone economy, and of high risk associated with their supply.

To ensure a more secure and sustainable supply of CRMs, the EC developed its own action plan. The plan proposes measures to reduce Europe's dependency on other countries and regions, diversifying supply from both primary and secondary sources of CRMs, while improving resource efficiency and circularity. Some initiatives are already in place, providing tools to support resilient and sustainable value chains, such as the Raw Materials Initiative (RMI) and European Raw Materials Alliance (ERMA).

Moreover, the CEWASTE project is a two-year initiative funded by the EU's Horizon 2020 research and innovation programme. The CEWASTE project aims to improve the recycling of valuable and CRMs from waste electrical and electronic equipment (WEEE), waste batteries and end-of-life vehicles (ELVs), and thereby feeds into the EC's Action Area 3.2 Circular use of resources, sustainable products and innovation.

In the years leading to 2025, considering the context of the EU27+3 countries (including the UK, Switzerland and Norway), a significant decrease in the stock and WEEE generation of CRMs in fluorescent powders found in lamps is expected. This decrease will be mainly due to technological changes in production processes. Regarding CRM and precious metals in printed wiring boards (PWBs) in desktops, laptops, mobile phones and tablets, it is expected that stock is going to increase slightly in 2025 in comparison to 2018 levels, while WEEE generation will slightly decrease in the same period due to the miniaturisation and integration of components in and on PWBs for this type of equipment. Similarly to PWBs, the stock and WEEE generation of CRMS in magnets increases up to the years 2014 (in the case of stock) and 2017 (in the case of WEEE generation), and then decreases slightly over the following years.

Regarding the recovery process, some technologies are currently established, such as the recycling of palladium and other precious metals from printed circuit boards and recycling of antimony and cobalt

from batteries. The recycling of rare earth elements from cathode-ray tubes (CRTs) and fluorescent lamps could potentially be established if a stable investment climate and economic environment of the recycling operations is in place. The fluorescent powders from lamps are currently removed but are not recycled for commercial reasons. Other technologies are new or being tested, such as membrane solvent extraction (MSX) and magnet-to-magnet (MtM) technologies for magnets.

The main barriers to recovery identified by recyclers are: lack of market drivers (and, therefore, lack of economic viability of CRM recycling); lack of information on where CRMs can be found; and (in the case of some specific CRMs) the absence of recycling and recovery technology. Furthermore, although regulations are not a main barrier, they can play a significant role in the regulated market for CRM recovery, provided that the complete policy circle of policy making, regulation, implementation, enforcement, reporting and evaluation is in place. Unfortunately, this is not the case in Europe yet. The fact that on average only 50 percent of the WEEE is collected and treated in the EU, while the target in the WEEE Directive since 2019 is 65 percent, is an indication that the policy circle is not functioning well.

In the current business model for recycling WEEE and waste batteries, producers are required, among others, to organise and finance the collection (from the collection facilities) and recycling. Producer Responsibility Organisations (PROs) can be established in order to meet the take-back obligations on behalf of individual producers. In most cases, recyclers bid for logistics and recycling tenders from PROs, providing one quote for the logistics services and one for treatment. In Europe, the Terms of References (ToRs) for these tenders in different countries (and between PROs) can vary significantly. In some cases, reference is made to standards, but that is more of an exception rather than the rule. Furthermore, although some countries have quality requirements in place for the collection and transport of WEEE (such as the German Electrical and Electronics Equipment Act), it is not a widespread rule and can lead to bulk transport of mixed WEEE. This type of transport is economically the most cost-effective approach, but has a cost increasing effect in further downstream treatment, especially when components containing key CRM components (KCCs) need to be removed.

On the legal side, collection and treatment is required by the EU WEEE Directive, EU Battery Directive (including the new proposal for the Battery Regulation) and (partially) the ELV Directive that is currently being revised, with a proposal expected for Q2 2022. These directives, with the exception of the Battery Regulation proposal, do not have specific requirements focusing on recovery of precious metals or CRMs. or any specific material, and the overall mass-related recycling target does not create drivers to ensure a proper recovery of precious metals and CRMs.

On the economic side, recycling is not economically attractive for most CRMs. This is due mainly to the complex and expensive technology required, relatively low and volatile prices of CRM minerals, and challenges associated with achieving high-quality secondary materials that are suitable to be incorporated into new products.

Other challenges related to the process of CRM recovery include, but are not limited to, the difficulty in accessing components containing CRMs (due to product design, miniaturisation and increasingly complex material mixtures in electrical and electronic equipment), resulting in a knowledge gap of where CRMs are concentrated. Furthermore, due to the fact that CRMs are in very low concentration in products, it is important to consolidate material from a larger amount of WEEE: consider the example of REE from fluorescent powder in lamps: to recover 600 t of fluorescent powder, 30,000 tons of waste lamps are required.

From an economic perspective, to make the recovery of REE from lamps viable, the introduction of a recovery fee of 1.31 € per 1,000 lamps collected or 0.31 € per 1,000 lamps placed on the market is needed. Alternatively, the extra gate fee required is, on average, 8.75 €/t of waste lamps, with an average incidence on the recycling cost of waste lamps per ton of 1.2%. In 2019 the EU28 + Switzerland and Norway generated approximately 91,000 tons of waste lamps, which potentially justifies three plants across EU, even though the latest available data on Eurostat (year 2018) shows only 31,000 t of waste lamps were collected, meaning, at present, the lamps should be channelled to a single installation from all over the EU.

Several solutions are proposed to specifically ensure more efficiency and feasibility of the recovery process of CRMs (Table 1). The pre-condition for these solutions is that the legal requirements of applicable directives are properly implemented and enforced. The solutions include regulatory alternatives: legal obligation to recover CRM; mandatory recycled content of KCEs; removability of CRM-rich components in key CRM equipment (KCEs) and KCCs; and enforcement of European regulation to fight illegal waste export from the EU. Economic alternative incentives include: gate fees; tax credits; subsidies; value added tax (VAT) exemption; eco-modulation fee; and the creation of new markets for CRMs. Industrial processes alternatives include the improvement of critical infrastructure for recycling, and digital alternatives include: new collection models/grouping of CRM-rich products; inclusion of information in Digital Product Passports; increased use of digitisation and artificial intelligence; and the development of solid criteria to assess CRM presence in products.

Legislation	Implementation	Monitoring & Reporting	Enforcement
1. Legal obligation to recover CRM	10. Creation of a market for CRMs	13. Inclusion of information in Digital Product Passport	4. Enforcement of European rules to counter illegal waste export of KCE from the EU
2. Mandatory recycled content of KCEs including CRM, such as batteries	11. Improve critical infrastructure for recycling of specific CRMs and products	14. Increased use of digitisation and artificial intelligence	
3. Removability of CRM rich components in KCEs and KCCs	12. New collection models/grouping of CRM-rich products	15. Development of solid criteria to assess CRM presence	
5. Gate Fee			
6. Tax credits or Subsidies to recyclers			
7. Tax credits or Subsidies to producers			
8. VAT exemption			
9. Eco-modulation Fee			

Table 1: Proposed potential solutions to increase CRM recovery

Given that the recovery of CRMs is a political priority for the EU, the CEWASTE standard should be made mandatory. Voluntary standards could only have a minor impact, meaning low or no recovery of CRMs. Mandatory CENELEC standards are a precondition for the successful recycling of CRMs. Doing so would result in an expected increase in the collection rate of materials rich in CRM. Furthermore, the roadmap also envisages the creation of a market pull to promote the use of recovered components, facilitate the creation of demand for these components, push the need for more research into the economics of CRM recovery to ensure economic viability of the processes, and push for development of new technologies.

In terms of ownership, it is recommended that the CEWASTE normative requirements should be submitted with CEN-CENELEC, thereby transferring ownership to CEN-CENELEC. Verification of conformity with the CEWASTE normative requirements should be in the hands of the Prague-based WEEELABEX Organisation.

1 The CRM in WEEE and the intrinsic economic value

Critical raw materials are usually concentrated in specific products, known as Key CRM Equipment (KCE), and in specific components, known as Key CRM Components (KCC). Table 2 indicates the KCCs and KCEs together with the specific CRMs of each, as well as the current economic feasibility of the recovery process.

	WASTE TYPE	Valuable and Critical Raw Materials	Required/Viable Input for End-processing	Current Business Practice
PCBs Desktop computers, professional IT Laptops Mobile phones Tablets External CDDs/ODDs, devices with internal CDDs/ODDs	WEEE	Au, Ag, Bi, Pd, Sb	PCBs (shredded and unshredded), CuPM granulates, mobile phones w/o. batteries	✓
Li-ion BATTERIES Laptops Mobile phones Tablets Li-ion batteries in other WEEE (battery packs from e-bikes, tools, ...)	WEEE	Co, Li	Batteries	✓*
BEV, (P)HEV	ELV			
LEAD-ACID BATTERIES Uninterruptable Power Supplies Other WEEE (e-scooters without seats, ride-on toys,...)	WEEE	Sb**	Batteries	✓
Cars containing LABs, other vehicles (e-scooters with seats, ...)	ELV			
FLUORESCENT POWDERS Fluorescent lamps	WEEE	Eu, Tb, Y, Ce, La	Fluorescent Powder	✗
CRT monitors and TVs		Y, Tb, Eu, Gd, La, Ce		
Nd-MAGNETS Laptops (HDD) Desktop computers, professional IT (HDD) E-bikes	WEEE	Nd + Dy, Gd, Pr, Tb	Magnets	✗
BEV, (P)HEV (electro engine)	ELV			

BEV - Battery Electric Vehicle
CDDs - Compact Disk Drives
CuPM – Copper Precious Metal
HDD - Hard Disk Drive
ODDs - Optical Disk Drives
PCB - Printed Circuit Boards
(P)HEV - (Plug-in) Hybrid Electric Vehicle

The current business practice of recycling CRMs from the Key CRM Equipment is deemed to be achievable with current or foreseeable technologies if the economic and/or legal framework conditions for collection, sorting and treatment are adapted.

*Current business practice does not (yet) include recycling of Li
**Current feasibility refers to recycling with lead (Pb)

Table 2: Components in KCE containing valuable materials and CRMs

It is possible to estimate the amount of CRM present in the WEEE generated (WG) and stocks of KCE. For that, it is considered the data of WG Eurostat for the years 2000-2018, which is then compared with the results obtained adopting the EU common methodology.[1] For the years 2019-2025, projections and extrapolations were carried out based on trends from previous years, and from analysis conducted in various publications and national studies (such as Global E-waste Monitor 2020, the Future E-waste Scenarios[2], etc.). To better visualize the flow information of the KCE (for example, flows of composition of components in stock and WEEE generation), they were divided by the source of components in different products.

Figure 1 and Figure 2 illustrate the stock and WEEE generation of CRMs in fluorescent powders found in lamps in the EU27+3 (including UK, Switzerland and Norway) for the years 2000-2025. Yttrium (Y) is the main CRM in these lamps, followed by Lanthanum (La), Cerium (Ce), Terbium (Tb) and Europium (Eu). Overall, it can be seen that both flows of CRMS (stock and WEEE generation) found in fluorescent powders in lamps are decreasing over time, mainly due to a technology change. Taking into consideration uncertainties due to extrapolation in stock calculations, it is estimated that by 2025, an approximate 307 tonnes of CRMs found in fluorescent powders will still be in stock (Ce: 33 tonnes, Eu: 14 tonnes, La: 43 tonnes, Tb: 14 tonnes and Y: 203 tonnes respectively). When comparing the CRMs found in fluorescent powders of waste lamp generated in 2018 and 2025, a reduction of 58 percent can be seen. In the case of stocks, a reduction of 68 percent can be observed for the same period.

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[1] Magalini, F., et al., (2016): Study On Collection Rates Of Waste Electrical And Electronic Equipment (WEEE), possible measures to be initiated by the Commission as required by Article 7(4), 7(5), 7(6) and 7(7) of Directive 2012/19/EU On Waste Electrical And Electronic Equipment (WEEE). EU WEEE Directive Study

[2]Parayuli et al. 2020. Future E-waste Scenarios.

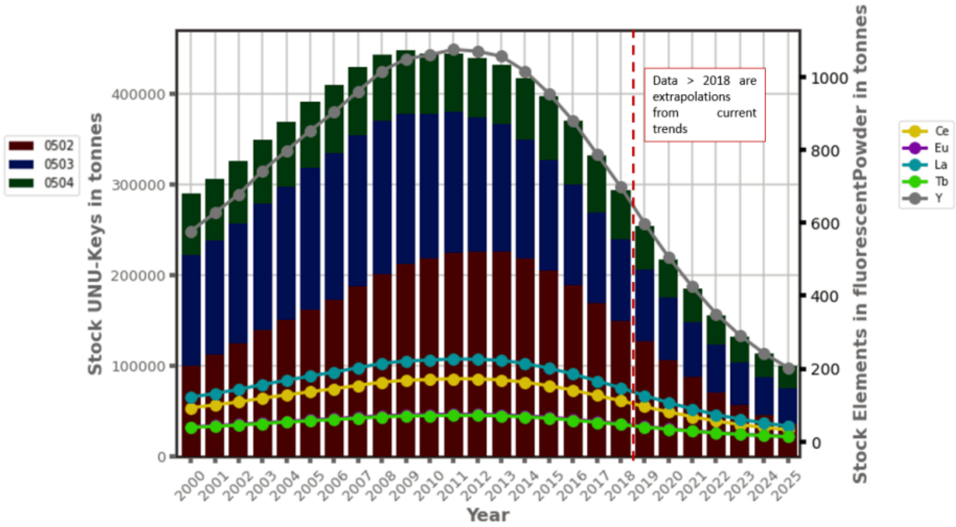

Figure 1: Stock of fluorescent powder in compact fluorescent lamps, straight tube fluorescent lamps, and special lamps (source: Urban Mine Platform, Eurostat and Global E-waste Monitor 2020)

In total, 220 tonnes of CRMs in fluorescent powders from lamps were generated in 2018 (Ce: 23 tonnes, Eu: 10 tonnes, La: 31 tonnes, Tb: 10 tonnes and Y: 146 tonnes respectively). By 2025, it is estimated that, 92 tonnes of CRMs will be generated (Ce: 10 tonnes, Eu: 4 tonnes, La: 13 tonnes, Tb: 4 tonnes and Y: 61 tonnes respectively).

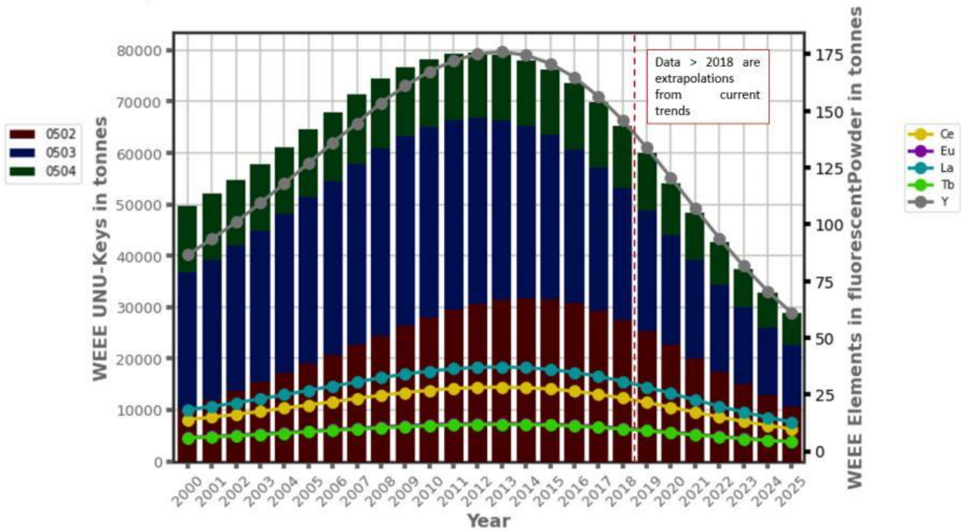

Figure 2: WEEE generation of fluorescent powder in compact fluorescent lamps, straight tube fluorescent lamps, and special lamps (source: Urban Mine Platform, Eurostat and Global E-waste Monitor 2020)

Figure 3 and Figure 4 illustrate the stock and WEEE generation of CRMs (Gold (Au), followed by Silver (Ag), Antimony (Sb), Palladium (Pd) and Bismuth (Bi)) in PWBs found in desktops, mobile phones, laptops and tablets in the EU27+3 (including UK, Switzerland and Norway) for the years 2000-2025.

The highest concentration of precious metals and CRMs in PCBs is Sb, followed by Ag, Au, Pd and Bi. It is estimated that, for the year 2018, a total sum of 852 tonnes of Sb, Ag, Au, Pd and Bi found in PCBs from computer desktops, mobile phones and laptops remained in stock. For 2025, the concentration it is estimated to be 884 tonnes.

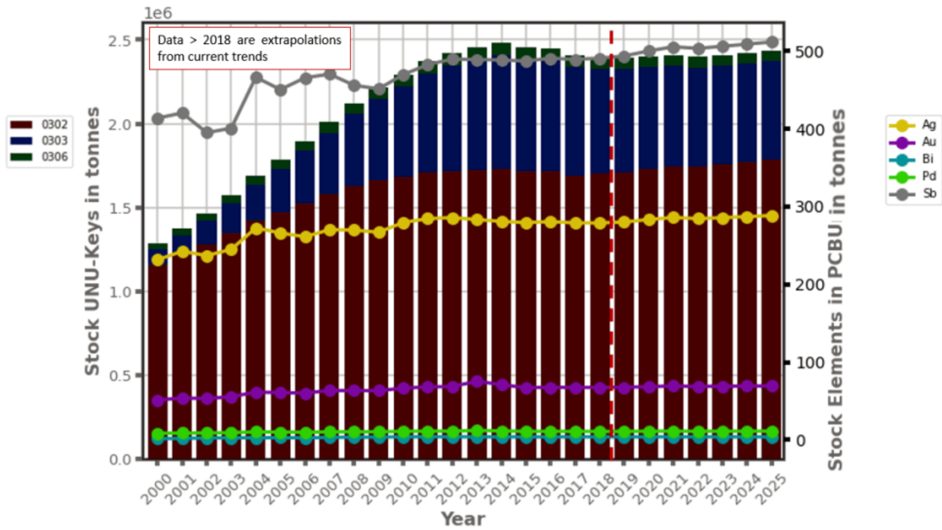

Figure 3: Stock of PCBs in desktops, mobile phones, tablets and laptops in EU27 (+UK, CH, NOR) (source: Urban Mine Platform, Eurostat and Global E-waste Monitor 2020)

Up to 2018, these products had an incremental trend, and for the following years slightly decreased. This decrease was mainly due to miniaturisation and integration of components in (and on) PCBs for this type of equipment.

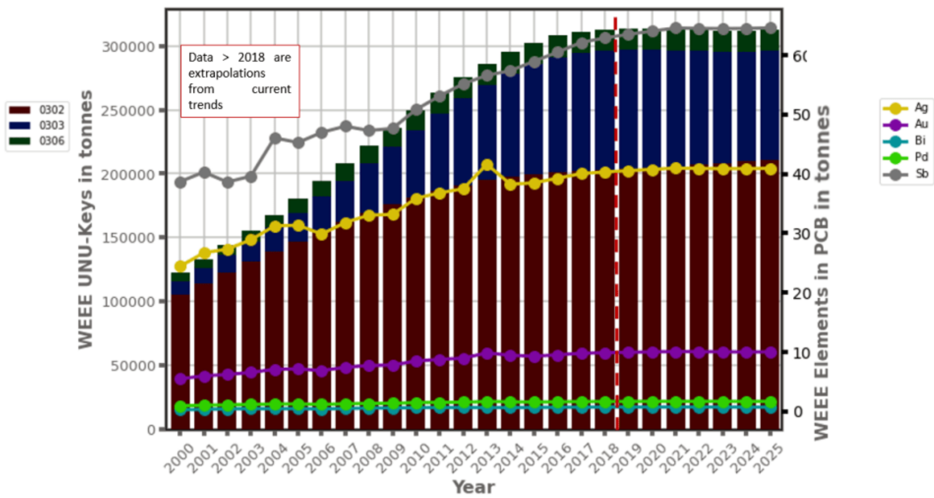

Figure 4: WEEE generation of PCBs in desktops, mobile phones, tablets and laptops (source: Urban Mine Platform, Eurostat and Global E-waste Monitor 2020)

It is estimated that, in 2018, approximately 115 tonnes of Ag (40 tonnes), Au (10 tonnes), Bi (1 tonnes), Pd (2 tonnes) and Sb (63 tonnes) were generated from the WEEE of PCBs found in desktops, mobile phones, laptops and tablets. By 2025, this number is expected to be approximately 118 tonnes of Ag (41 tonnes), Au (10 tonnes), Bi (1 tonnes), Pd (2 tonnes), Sb (65 tonnes).

The amount of stock and WEEE generation of the CRMs (Dysprosium (Dy), Neodymium (Nd), Praseodymium (Pr) and Terbium (Tb)) in magnets from magnets from computer desktops, Leisure equipment (e.g. sports equipment, e-bikes), laptops and tablets in the EU27+3 (including UK, Switzerland and Norway) for the years 2000-2025 are illustrated in Figure 5 and Figure 6. Similarly, to PCBs, the stock and WEEE generation of CRMS (Dy, Nd, Pr and Tb) in magnets increases up to the years 2014 (in the case of stock) and 2017 (in the case of WEEE generation) and slightly decreases over the following years. Overall, it can be seen that Nd has the highest concentration, followed by Pr, Dy and Tb. For the year 2018, it is estimated that a total of 1,515 tonnes of CRMs from magnets found in desktops, laptops and tablets remained in stock. For 2025, that number is estimated to be 1,560 tonnes.

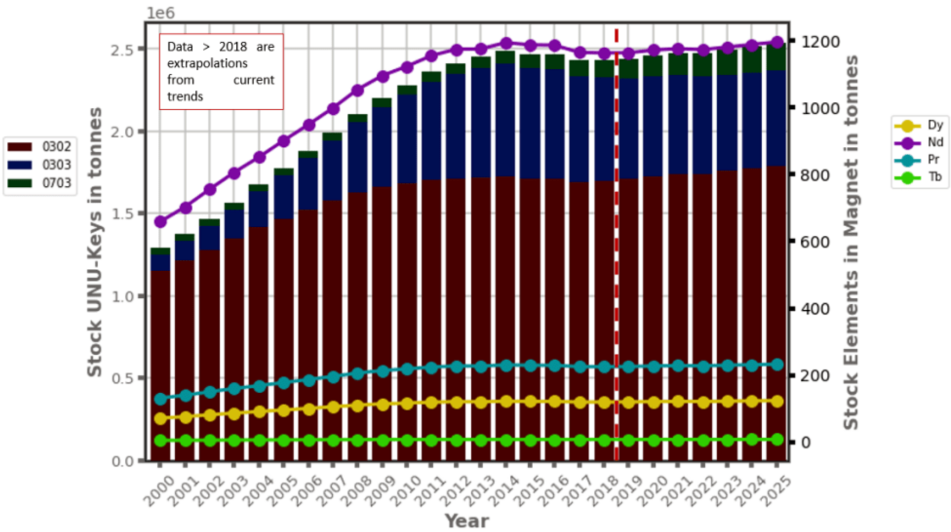

Figure 5: Stock of magnets found in computer desktops, leisure equipment (e.g. sports equipment, e-bikes), laptops and tablets (source: Urban Mine Platform, Eurostat and Global E-waste Monitor 2020)

The WEEE generation of CRMs (Dy, Nd, Pr and Tb) found in magnets from desktops, Leisure equipment (e.g. sports equipment, e-bikes), laptops and tablets in 2018 was 188 tonnes (Dy: 15 tonnes, Nd: 145 tonnes, Pr: 28 tonnes and Tb: 1 tonnes, respectively) and it is expected to be of 190 tonnes in 2025.

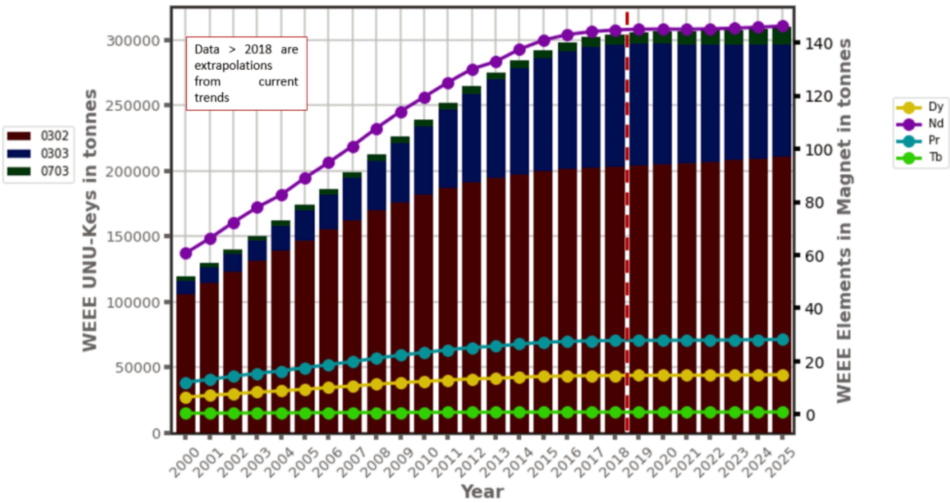

Figure 6: WEEE generation of magnets found in computer desktops, leisure equipment (e.g. sports equipment, e-bikes), laptops and tablets (source: Urban Mine Platform, Eurostat and Global E-waste Monitor 2020)

Table 3 illustrates that the CRMs contained in KCE analysed in CEWASTE for certain elements (such as Ce, La, Pr, Tb and Y) are key for defining the recovery of material, tracing and mapping of their flows in the EU. Their recovery would represent more than 65 percent of their average CRM composition in the defined KCEs.

List of CRMs analysed in CE-waste	Sum of the precious metals and CRM contents (tonnes) in KCE	Sum of the precious metals and CRM contents (tonnes) for other (non-KCE) products	Percentage of CRMs in CEWASTE KCEs compared to all products
Ag	57	64	47
Au	14	11	55
Bi	1	9	6
Ce	28	2	92
Dy	16	34	20
Eu	10	47	18
La	31	1	98
Nd	175	905	17
Pd	2	24	9.3
Pr	37	1	98
Sb	56	16,325	0.3
Tb	10.9	0.04	99.7
Y	146	0.5	99.7

Table 3: Comparison of average CRM contents in KCE and other EEE for 2018

There is a significant amount of precious metals and CRMs in the KCEs analysed to justify their recovery:

- A total of 220 tonnes of CRMs in fluorescent powders were generated from waste lamps in 2018 (Ce: 23 tonnes, Eu: 10 tonnes, La: 31 tonnes, Tb: 10 tonnes and Y: 146 tonnes).
- From waste desktop/laptops, a total of 116 tonnes was arising in 2018, mainly from PCBs (Ag: 40 tonnes, Au: 10 tonnes, Bi: 1 tonnes, Pd: 2 tonnes, Sb: 63 tonnes).
- From magnets, a total of 189 tonnes were found (Dy: 15 tonnes, Nd: 145 tonnes, Pr: 28 tonnes and Tb: 1 tonnes).

Figure 7 illustrates the number of batteries in newly registered vehicles (1 unit) and the amount of batteries spent (approximately 2.3 units) in End of Life passenger Vehicles (ELV) with lead acid batteries and their Sb content in tonnes. In 2018, newly registered passenger vehicles with lead acid batteries content of Sb were of 891 tonnes, and of approximately 1000 tonnes in ELV. For 2025, it is estimated that 1,775 tonnes of Sb will be generated from lead acid batteries in combustion engine ELVs, and 1059 tonnes of SB will be contained in lead-acid batteries for newly registered vehicles.

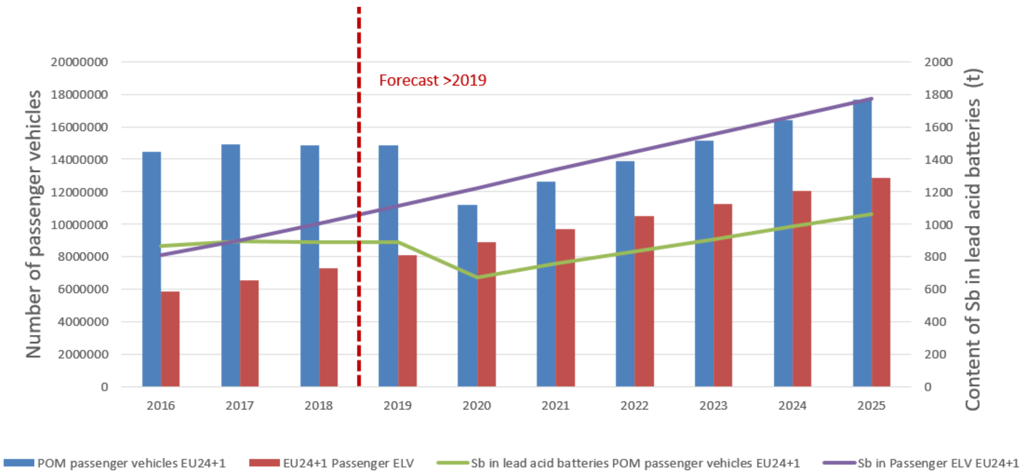

Figure 7: Number of passenger vehicles POM and ELV using Lead acid batteries, and content of Sb in lead acid batteries (tonnes) of passenger vehicles POM and ELV

In the case of electric passenger vehicles, in 2018, it is estimated that the content of Co in Li-ion batteries was of approximately 3,588 tonnes, while approximately 1,775 tonnes were found in ELV. For 2025, it is estimated that 7,910 tonnes of Co will be generated from Li-ion batteries in electric ELVs, while 13,860 tonnes of Co will be contained in Li-ion batteries for newly registered electric vehicles. It can be seen that Li-ion and lead acid batteries provide a great source for secondary raw materials, for both Co and Sb respectively.

There is, unfortunately, not extensive information about NdFeB magnet in passenger EV traction motors. Some estimations[3] at a global scale state that, between 2019 and 2020, there was a 35 % increase of the content of NdFeB. Assuming a constant throughout the years with a linear forecast, by 2025 approximately 23,100 tonnes of NdFeB in Motors in electrical vehicles will be found (Figure 8 and Figure 9).

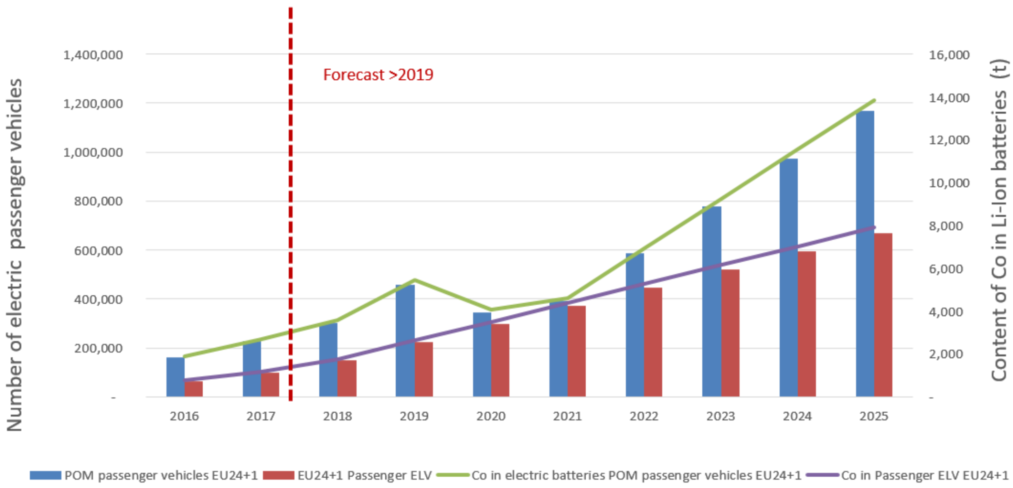

Figure 8: Number of Electric passenger vehicles POM and electric passenger ELV vehicles, and content of Co in Li-ion batteries (tonnes) POM and in electric passenger ELV vehicles

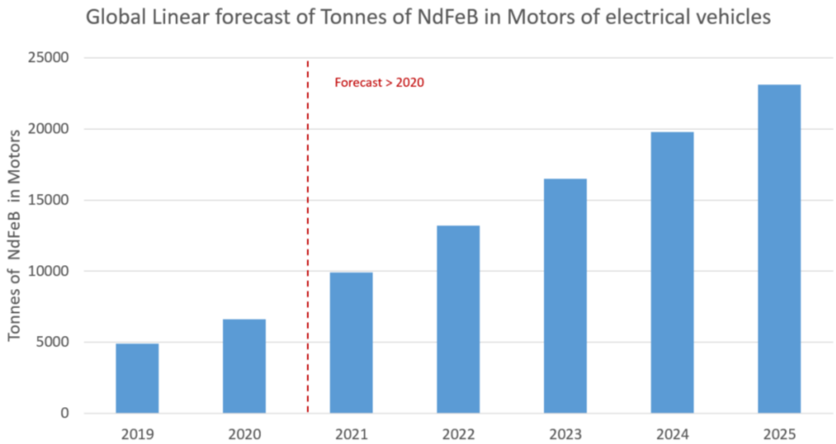

Figure 9: Global Linear forecast of tonnes of NdFeB in motors of electrical vehicles

[3] Adams Intelligent Report *"Rare Earth Elements: Small Market, Big Necessity".*

2 Current technologies for recovery of CRM

Recycling of CRMs from key CRM equipment requires final treatment processes on an industrial scale, and pre-treatment steps which can prepare the input fractions from which the final treatment can recycle the CRMs. This chapter will give insights into the status of the recycling processes, and foreseeable technological developments in the sector, as well as its current barriers.

2.1 Recycling technologies

2.1.1 Established recycling technologies

Recycling of palladium and other precious metals from printed circuit boards

The high prices of precious metals are the strongest economic driver of the WEEE recycling business. The pre-treatment of WEEE containing printed circuit boards to prepare them for final treatment, as well as the final treatment, are established standard techniques and commercial practice.

Recycling of antimony and cobalt from batteries

Recycling of antimony from lead-acid batteries and of cobalt from lithium-ion and nickel-metal-hydride batteries is economically viable under the current economic framework conditions and is already practiced on an industrial scale.

Recycling of rare earth elements from CRTs and fluorescent lamps

The WEEE Directive stipulates the selective treatment of CRTs[4] and of gas discharge lamps like fluorescent lamps. The fluorescent powders are removed, but currently not recycled for commercial reasons. Technically, the florescent powders can be treated by dedicated REE hydro-refining processes (Solvay). This treatment was practiced in industrial scale until Solvay suspended its refining operation in La Rochelle in France, when REE prices dropped after 2011. The processes could be reestablished for the recycling of REEs – from fluorescent powders from gas discharge lamps and from

[4] C.f. Annex 7 of the WEEE Directive.

CRTs – if a stable investment climate and economic environment of the recycling operations can be established.

2.1.2 NEW AND PILOT-SCALE RECYCLING PROCESSES: RECYCLING OF NDFEB MAGNETS

For the liberation of NdFeB-magnets from HDD and other equipment, several pre-treatment options were developed by private companies and in projects.[5]

The final treatment of NdFeB-magnets includes two different processing routes:

1. The recycling of REEs from the NdFeB-magnets.
2. The production of new NdFeB-magnets from old NdFeB-magnets (mangnet to magnet (MtM) recycling).

REE recycling from NdFeB-magnets is technically feasible, but the technology readiness level of end-treatment is probably below 9. Hitachi Metals uses molten Mg as an extraction method to recycle Nd and Dy from NdFeB-magnets. In 2012, Santoku Corporation is said to have started a recycling route for neodymium and dysprosium from magnets of air conditioner motors and magnet production scrap.[6] Another process is Momentum's hydrometallurgical MSX technology process, which is able to recycle more than 99 percent of the REE content from hard disk drives (HDDs) dissolved in acid while operating at room temperature and pressure.[7] Finally, the Ames Laboratory's acid-free dissolution recycling technology is described as having the potential to recycle Nd from shredded HDD samples without pre-concentration of the magnet contents, even though a pre-concentration is desirable to reduce the amounts of chemicals needed.[8] Several EU-projects address recycling of REEs from magnets, including REE4EU, pilot scale plant[9], REEcover[10], and others[11].

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[5] See Hitachi process (CEWASTE Deliverable D1.1, page 28) and the EU REMANENCE project.
[6] SCREEN (2016): Production technologies of CRM from secondary resources (page 126) and Urbanminingco.
[7] iNEMI: Value Recovery Project 2 report.
[8] iNEMI: Value Recovery Project 2 report.
[9] REE4EU project video.
[10] REEEcover project factsheet.
[11] For an overview of EU and international developments, see REE Recovery from End-of-Life NdFeB Permanent Magnet Scrap.

The US-based Urban Mining Company[12] and EU-based MagREEsource[13] claim to produce NdFeB-magnets from waste NdFeB magnets (MtM processing[14]). Further on, the EU ReproMag[15] and SusMagPro[16] projects have been developing the patented 'Hydrogen Processing of Magnetic Scrap' (HPMS)[17] as an MtM process. Other alternatives include the reuse of NdFeB-magnets from HDDs in applications others than HDDs, or the reuse of NdFeB-magnets from HDDs in newly-produced HDDs.[18]

2.2 Barriers perceived by recyclers on the recovery process

Barriers refers to issues leading to inefficiencies in the recovery process of CRMs. After the evaluation of audits conducted with 11 recycling companies in six countries, the main bottlenecks perceived on the process were identified. According to the audits and interviews, the main bottlenecks are:

- **Lack of market drivers making CRM recycling economically unviable**. The exception is the recycling of PWBs, where the content of precious metals Ag, Au and the CRM Pd are driving the business. Without proper economic and market incentives, the recycling of CRMs makes no economic sense. In order for the recovery of CRM to happen, an attractive market environment must be created so that investments are profitable and risks acceptable.
- **Lack of information on where CRMs can be found**. The lack of information indicating that a product contains CRMs can lead to wrong disposal of materials by consumers, which means products do not reach the correct recovery facilities. The lack of information can also lead to incorrect recovery by recyclers, as they are unaware of where or which CRM can be found in the disposed items.

[12] Urban Mining Company, https://www.urbanminingco.com/

[13] MagREEsource, https://www.magreesource.org/

[14] A more detailed description of the process can be found on page 31 of iNEMI: Value Recovery Project 2 report.

[15] ReproMag project.

[16] Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnets in a Circular Economy (SusMagPro project), and SusMagPro Solutions.

[17] REProMag EU-H2020 project: SDS, a new resource efficient production route for Rare Earth magnets

[18] See Demonstrators 1 and 2 in the iNEMI: Value Recovery Project 2 report.

- **Absence of recycling and recovery technology for specific CRMs**. Despite the fact that recovery of CRMs is technologically possible, few techniques have gone beyond the proof-of-concept stage, due to several reasons. In some cases, like fluorescent powders, the technology works on a pilot scale, but due to marketing problems in the final treatment, development has stopped. Specific final treatment technologies, for instance of NdFeB magnets and Li, are not yet available for pre-treatment operators. Therefore, recovery of these materials is not yet happening. The main issues behind recovery challenges are the lack of development of specific technology, the complexity and the high costs behind it.

Furthermore, although regulations are not the main barrier, they can play a significant role in the regulated market for CRM recovery, provided that the complete policy circle of policy making, regulation, implementation, enforcement, reporting and evaluation is in place. Unfortunately, this is not the case in Europe yet, as an average of only 50 percent of the WEEE is collected and treated in the EU, while the target in the WEEE Directive is 65 percent since 2013. This provides an indication that the policy circle is not functioning optimally.

3 THE BUSINESS MODEL FOR CRM RECOVERY

3.1 THE CURRENT BUSINESS MODEL FOR RECYCLING OPERATIONS

Most operators active in Europe work in the context of WEEE legislation and according to the Extended Producer Responsibility principle: producers are, among others, required to organise and finance collection from collection facilities[19] and recycle the collected WEEE. Producer Responsibility Organisations (PROs) were established in order to meet the take-back obligations on behalf of individual producers. Activities carried out by PROs include: the identification of service providers for

[19] Article 12(1) of the WEEE Directive states that the collection is required only of “WEEE from private households that has been deposited at collection facilities”. Art. 12 (2) of the WEEE Directive states that the collection from private households is only voluntary. Art. 13(2) of the WEEE Directive states that, for B2B, other solutions are possible.

collection and treatment services; definition of contractual obligations; and payment for take-back services.

In most cases, recyclers bid for logistics and recycling tenders from PROs, providing one quote for the logistics services and one for treatment. In Europe, the ToRs for these tenders in different countries and between PROs can vary significantly. In some cases, reference is made to standards, but this is more of an exception than the rule. Although some countries have quality requirements for collection and transport of WEEE in place (such as the German Electrical and Electronics Equipment Act), it is not a widespread rule and can lead to bulk transport of mixed WEEE. This type of transport is economically the most cost-effective approach but has a cost-increasing effect in further downstream treatment, especially for components containing CRMs where KCCs need to be removed.

In the great majority of cases, quotes are usually expressed as €/tonnes and depend on where waste is picked up from or is based on specific requirements. While the logistics always represents a cost for the PRO (and thus an income for the service provider), the situation might be different for treatment services carried out by recyclers (pre-treatment operators in particular but to certain extent also by end-processors).

One of the key elements in current operational mode is that collection activities are carried out by municipalities and retailers, and there is little control from the PROs on the material collected and handed over. 'Scavenging' occurs often, particularly of the most valuable material/fractions containing CRMs. A 2018-2019 survey conducted by EERA highlighted the main products (particularly mobile phones) and components scavenged across the EU during the collection phase: batteries (up to 9 percent), HDD (up to 29 percent), and printed circuit boards (up to 20 percent). For 2018, the total cumulated losses related to materials and components were estimated at almost €92 billions of diverted material value, and more than 64,000 tonnes of material.

Pre-treatment operators usually quote the net costs for proper treatment, including disposal of hazardous fractions and the main operating costs for each plant (labour costs, energy costs, depreciation of capital investment, and other costs related to the functioning of the plant itself). The operating revenues come from waste being processed in the plant resulting in different fractions, which might include CRMs or components including CRMs. These fractions are sold downstream in national or international commodities markets. In such models, the ownership of the fractions obtained from the recycling process rests with the recycler, even if more recently some PROs are adopting contractual models where they own the fractions. Some fractions have positive value (representing a revenue) while others have a negative value for disposal or further treatment or disposal (representing a cost), as shown in Figure 10. The evaluation of the net treatment cost is based on a straightforward economic balance of all costs and revenues.

Net treatment costs = Fractions positive value – Operating Costs (labour, energy, depreciation, others) – Fractions negative value – Profit Margin Plant

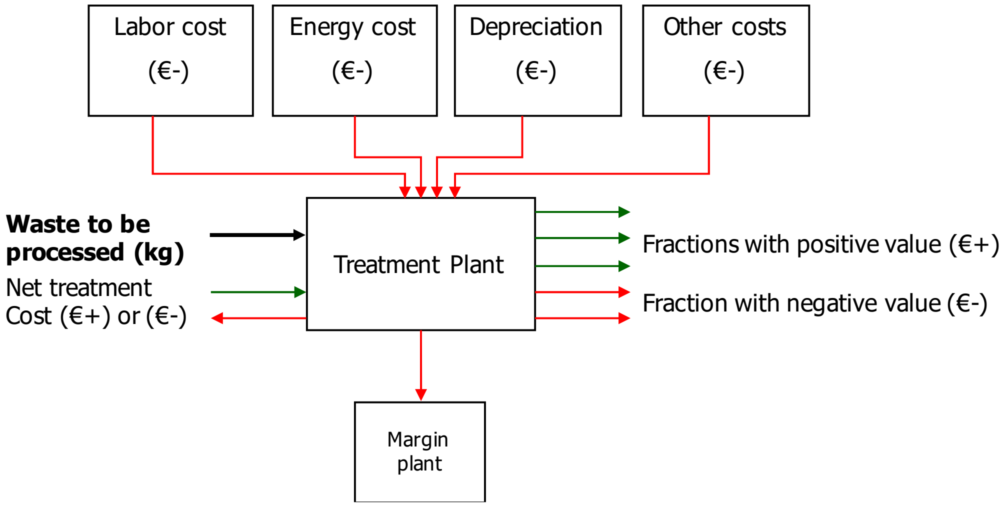

Figure 10: The net treatment cost principle

When the revenues generated in downstream markets are not sufficient to offset the costs for proper disposal of negative value fractions, or when the operating costs are particularly high, the net treatment cost is negative. If specific fractions, including CRMs, are too costly to recycle, or the downstream acceptors are not available, the overall economic balance for the pre-processing operators is affected. In these instances, operators might not carry out specific activities to not compromise the competitiveness of their price towards the PROs.

In some cases, particularly in final-processing steps, some recyclers adopt the so-called 'toll-recycling' model. Here, the recycler is charging for the recycling process, but the ownership of fractions obtained is with the PRO, or the entity delivering the waste for treatment. In this case, the financial risk related to economic fluctuation of commodities is with the waste holder, and not with the recycler. This model is sometimes used by smelters for batteries and printed circuit boards.

There are important elements to be considered in the current scenario, as detailed below.

LEGAL FRAMEWORK

Collection and treatment of WEEE and waste batteries is legally regulated by EU WEEE Directive, EU Battery Directive (including the new proposal for the Battery Regulation) and (partially) the ELV Directive, which is currently being revised. Since these directives are non-harmonised legal instruments in the EU that share only certain requirements (e.g., depollution and recycling targets), the implementation of the requirements varies from EU Member State to Member State, with the result that collection and pre-treatment operators have different costs structures and, therefore, different business models. The only market power to which all EU operators are exposed to is the commodity market for secondary raw materials.

None of these directives contain any specific requirements focusing on recovery of CRMs or any specific material, with the exception of the proposal of the EU Battery Regulation that presents proposed recycling efficiency targets for cobalt, copper, lead, lithium and nickel. The recycling and recovery targets for CRMs and precious metals are mass-based, because of their very low concentration. Previous studies[20] had already identified how, despite their criticality, a weight-based recycling target does not represent a trigger for their recovery. Even though precious metals – such as platinum group metals (PGMs) – are recovered, from a legal compliance perspective, the recycling target does not create a binding instrument to ensure a proper recovery of precious metals and CRMs.

In addition, the current legal collection targets are, for the great majority of EU Member States, currently not met. Various studies[21] have highlighted how, particularly for small appliances and IT products, the effect of low collection rates, scavenging of valuable components, and consumer bad habits (disposal with unsorted waste, hoarding, etc.) are major causes for dissipation of natural resources, including CRMs, as – in most of the cases – only very few metals are targeted in scavenged components.

Also, transboundary shipment rules and the requirements to ensure equivalent conditions for treatment happening outside the EU do not focus on CRMs, meaning the risk of dissipation when materials leave the EU is even higher. Furthermore, for appliances that are (legitimately) leaving the EU as reusable products, the risk of treatment in countries where lower standards might be applied should be considered. This is even more relevant when bearing in mind the share of appliances that might be illegally exported because of low levels of enforcement.

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[20] Study on WEEE recovery targets, preparation for re-use targets and on the method for calculation of the recovery targets, BiPRO 2015.

[21] CWIT, EERA Scavenging, ProSUM, WEEE Forum WEEE Flows.

Economics of recycling

Recycling is not economically attractive for most CRMs, for several reasons:

- The prices of CRM minerals are relatively low. There is currently a very low demand for CRMs from recycling, particularly while primary mining still represent a convenient source of materials.
- CRM mineral prices are volatile, as they depend on market demand. This makes recovery a risky business, as cost of processes to recover CRM through recycling cannot follow the same market fluctuations.
- The technology used for the recycling and recovery of specific components is not yet widely available at an industrial level, and is also complex. In many cases, the risks related to low demand are hampering the development process and the investment in new processes.
- The technology used for the recycling and recovery is usually expensive.
- It is difficult to achieve high-quality secondary materials that are suitable to be incorporated into new products. This is due to market challenges, such as ensuring economic feasibility of the process, and proper market conditions for the supply and demand of materials, and technological challenges, such as the difficulty in separating different components in the recovery process.
- The present economic framework conditions (i.e., market demand for CRM obtained from recycling, volatility of prices and difficulties to concentrate enough input fractions to obtain economies of scale for CRM recovery) make the recycling of CRMs other than PGMs not viable or attractive. Most modern waste management would not be economically feasible if it was not financed by taxes, fees paid by consumers, or by producers in the course of obligations arising from extended producer responsibility as stipulated (such as the management of WEEE in the WEEE Directive).

Technical, technological and organisational limitations

The process of CRM recycling faces technical, technological and organisational limitations, such as:

- Difficulty accessing components containing CRMs in products due to (for example) the design of products not considering the end-of-life and resulting in, for instance, glued components. This might also be linked to trends like miniaturisation and increasingly complex material mixtures which make separation inefficient or even technically impossible.

- Insufficient separate collection of KCE further dilutes the CRMs over collected WEEE. It should be noted that usually CRMs are present in very low concentration in individual products, so it is paramount to consolidate KCE and the resulting fractions for the end-processing.
- Difficulty for some CRMs to achieve high-quality secondary materials suitable to be incorporated in new products.
- Access to a comprehensive knowledge base. Such knowledge might not only be linked to recycling operations (i.e., where are the CRM and in which concentration) but also for planning investments in recycling infrastructures.
- Lag between use of CRM in products and availability for recycling (long-life assets) that might sometimes influence the time to market for technological innovations.

3.2 Business cases for recovery of CRMs

For most of the CRMs included in electronic products, the economic feasibility of the recovery process is not proven. We have analysed the two cases of rare earths, in particular:

- Recovery of Ce, Eu, Gd, La, Tb and Y from fluorescent powders coming from lamps.
- Recovery of Nd, Pr and Dy from magnets present in consumer electronics (in particular laptops and desktops).

Recovery of rare earths from Fluorescent Powders

In the recycling process of waste lamps, the fraction containing CRM is the fluorescent powder extracted after the removal of glass and other parts. The powder goes through sieving and other hydrometallurgical treatments, resulting in the recovery of Rare Earth Oxalates (REOs). To analyse the feasibility of the recovery process, first the business plan must be assessed. Seen from the treatment facility perspective, the business of recycling of waste lamps is determined and influenced by the following factors:

- Input stream of fluorescent powders recovered from compact fluorescent lamps (CFL) and linear fluorescent lamps (LFL) from various WEEE treatment plants. This is a net profit for the treatment plants, as it represents a gate fee for anyone with fluorescent powder to dispose of. The value has been estimated considering as benchmark the current landfill cost after deducting the cost of logistics to deliver the powder to the treatment plant, and is considered equal to €150/tonne.

- Sieving to remove glass residues. This is a cost incurred by the treatment facility and is set at €180/tonne. The cost of sieving is applied on 20 percent of the total amount of fluorescent powder for treatment.
- Operational costs for each tonne of fluorescent powder treated, including operational costs, but also the depreciation of the initial investment, is equal to €1,040/tonne.
- Revenues from selling the REOs. The revenues are highly variable over time and determined by the price set by the CRM market. There was a significant variation of price between 2012 and 2021, with minimum price in the period set at €1,860/tonne and maximum price set at €3,241/tonne (average value of €2,550/tonne). A 20 percent discount is applied to the market value due to losses for lower purity. The price may also suffer a selling depreciation due to sales to a single end-user.
- Selling depreciation associated with number of end-users to purchase the REOs' mixture. This value is variable, and here was considered ranging from 10 percent to 80 percent in different scenarios.

Based on these factors, different scenarios can be elaborated, assessing the impact of market price variations for the downstream sale of CRM recovered during the process (Table 4 and Figure 11). The scenarios consider 600 tonnes of inputs as fluorescent powders and a target annual cash flow to justify the initial investment of €150,000.

Scenarios	1	2	3	4	5
Selling price, depreciation	Minimum market value, 80%	Average market value, 80%	Maximum market value, 80%	Minimum market value, 55%	Average market value, 55%
Cash flow	€(287,941.00)	€(234,894.00)	€(181,847.00)	€(109,367.00)	€9,989.00
Target cash flow	€150,000	€150,000	€150,000	€150,000	€150,000
Gap to target	€437,941	€384,894	€331,847	€259,367	€140,011
Financial contribution needed per tonne of fluor. powder	€729.90	€641.49	€553.08	€432.28	€233.35

Scenarios	6	7	8	9	10
Selling price, depreciation	Maximum market value, 55%	Average market value, 35%	Minimum market value, 10%	Average market value, 10%	Maximum market value, 10%
Cash flow	€129,345	€205,895	€212,066	€450,778	€689,490
Target cash flow	€150,000	€150,000	€150,000	€150,000	€150,000
Gap to target	€20,655	€(55,895)	€(62,066)	€(300,778)	€(539,490)
Financial contribution needed per tonne of fluor. powder	€34.43	€(93.16)	€(103.44)	€(501.30)	€(899.15)

Table 4: Business plan scenarios for REOs from lamps

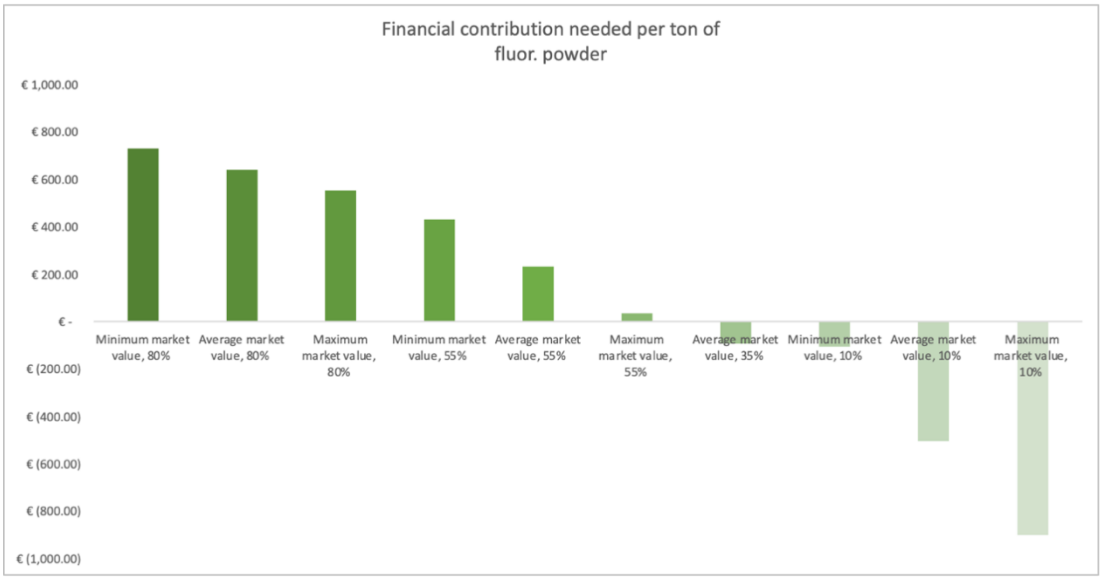

Figure 11: Financial contribution needed for recovery process of lamps under different scenarios

As the table and figures above show, the recovery of CRMs can be – from the perspective of a recycling company – a profitable business or not, depending on significantly volatile market variables. There are specific scenarios under which the process can prove viable, but the volatility and the uncertainty linked to the downstream market does hamper operations.

The introduction of a financial mechanism to de-risk the business, ensuring financial viability even under less favourable conditions is one of the possible alternatives. To evaluate those alternatives, it should consider the average recycling cost of lamps, equal to approximately €750/tonne, an average weight of 150 grams per lamp and 0.005 grams of fluorescent powder per lamp. The conversion factor of lamps to powder is 2 percent, meaning for CRM extraction, it is necessary for 30,000 tonnes of waste lamp as input to the recovery process to obtain 600 tonnes of fluorescent powder. In 2019 alone, the EU27+3 (including UK, Switzerland and Norway) has generated approximately 91,000 tonnes of waste lamps. This potentially justifies approximately three recovery plants across EU. However, the latest available data on Eurostat (year 2018) shows only 31,000 tonne of waste lamps have been collected, meaning fluorescent powder from all over EU is channelled to one single installation at the moment.

To ensure the target cash flow of €150,000 from recovery, considering the 600-tonne input of fluorescent powder, it would require the introduction of a recovery fee of €1.31 per 1,000 lamps, or €0.31 per 1,000 lamps placed on the market[22]. Alternatively, the extra gate fee required is, on average, €8.75/tonne of waste lamp entering the plant, with an average incidence on the recycling cost of waste lamp per tonne of 1.2 percent. These numbers can be significantly lower if the total fee to be shared over all the lamps generated as waste in the EU27+3. The recovery fees under each scenario are available in Table 5 below.

Table 5: Lamp recovery fees under different scenarios

Recovery fee (€/1,000 waste lamps)	
Scenario 1	€2.19
Scenario 2	€1.92
Scenario 3	€1.66
Scenario 4	€1.30
Scenario 5	€0.70
Scenario 6	€0.10

Recovery fee (€/1,000 lamps POM)	
Scenario 1	€0.53
Scenario 2	€0.46
Scenario 3	€0.40
Scenario 4	€0.31
Scenario 5	€0.17
Scenario 6	€0.02

Extra gate fee (€/tonne of waste lamp entering the plant)	
Scenario 1	€14.60
Scenario 2	€12.83
Scenario 3	€11.06
Scenario 4	€8.65
Scenario 5	€4.67
Scenario 6	€0.69

[22] Considering a return rate of 24 percent for lamps (Official clearinghouse Italy).

Another financing alternative is to introduce value added tax (VAT) exemption for the plant recovering the CRM. In this way, the value collected with the tax would be directly converted into financing the process of recovery. Considering a VAT rate of 20 percent, as currently in place in several European countries, the VAT exemption on products/services sold by the recycling plant is indicated in Table 6 below. For the reference scenario is approximately 1,3 M€.

Scenarios	€/tonne of fluor. powder	Total financial contribution required (€)	VAT exemption (value of products)
Scenario 1	€730	€437,941	€2,189,705
Scenario 2	€641	€384,894	€1,924,470
Scenario 3	€553	€331,847	€1,659,235
Scenario 4	€432	€259,367	€1,296,835
Scenario 5	€233	€140,011	€700,055
Scenario 6	€34	€20,655	€103,275

Table 6: VAT exemption for lamps under different scenarios

RECOVERY OF RARE EARTHS FROM MAGNETS

The FP7-funded REECover Project was developed with the objective of promoting WEEE recycling for the recovery of CRMs.[23] In the recycling process of magnets contained in hard drives of laptop and desktops investigated in REEcover, the material goes through pyrometallurgical and hydrometallurgical treatments, having as final result the obtainment of Neodymium (Nd), Dysprosium (Dy) and Praseodymium (Pr). To analyse the feasibility of the recovery process, the business plan for this process is assessed as seen from the treatment facility perspective. The main variables affecting the REECover Project are:

- Operational costs and depreciation from machinery, equal to €47,984/tonne.

[23] EC: Recovery of Rare Earth Elements from magnetic waste in the WEEE recycling industry and tailings from the iron ore industry.

- Revenues from selling the rare earth elements. The revenues are variable, and the market price of materials can reach up to three times higher than the value of €50.144/tonne proposed in the business-as-usual scenario.

Based on these factors, a sensitivity analysis was developed, exploring the possibilities of market price variations for the sales of CRMs. The scenarios consider 100 tonnes of RE output and a target cash flow of €5 million (Table 7 and Figure 12).

Scenarios	1	2	3
Market price	Business as usual	2x market price	3x market price
Cash flow	€216,048	€5,230,488	€10,244,928
Target cash flow	€5,000,000	€5,000,000	€5,000,000
Gap to target	€4,783,952	€(230,488)	€(5,244,928)
Financial contribution needed per tonne of RE	€47,839.52	€(2,304.88)	€(8,741.55)

Table 7: Business plan scenarios for REs from WEEE

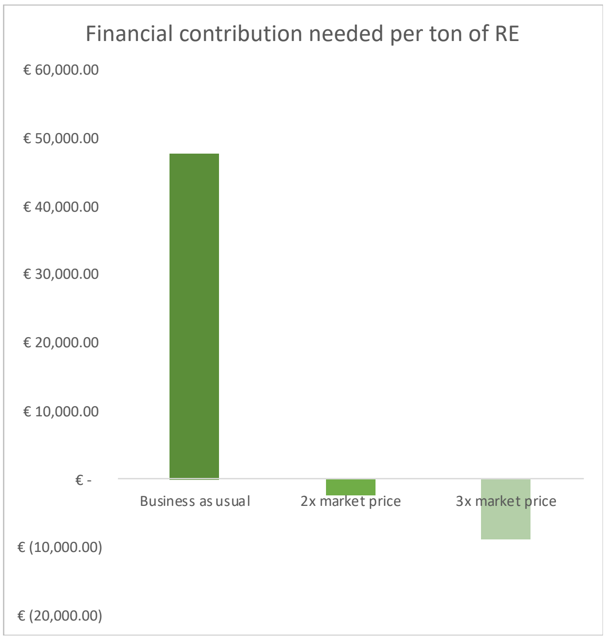

Figure 12: Financial contribution needed for recovery process of WEEE under different scenarios

As indicated in the case of RE recovery from fluorescent powder, the recovery of CRMs can be a profitable depending on significantly volatile market variables. The financial alternatives for economic feasibility include the introduction of a recovery of CRMs with the fee included in the WEEE price. The introduction of a recycling and recovery of CRMs fee included on the electronics' (laptops and desktops) price is one financing option. Considering an average recycling cost of WEEE of €30/tonne and a weighted average weight of 6.4kg per product, with 0.003kg of RE per appliance, the introduction of a recycling fee of €0.19/WEEE unit would be needed.

The conversion factor of WEEE to RE is 0.05 percent. Therefore, for CRM extraction, 195,390 tonnes of WEEE are necessary to obtain 100 tonnes of RE. According to EERA, the total amount of WEEE in Europe is estimated at 11.6 million tonnes per year. To reach a cash flow target of €5 million from recovery (considering an output of 100 tonnes of RE), would require the introduction of a recovery fee of €16.14/tonne of WEEE or of €16.99/tonne of EEE POM. Alternatively, to reach the same cash flow target, a gate fee could be introduced in recycling facilities of €24.53 per tonne of waste appliances entering the plant facility under Scenario 1, with an average incidence on the recycling cost of WEEE per tonne of 82 percent.

As for lamps, the introduction of VAT exemption can also be applied to encourage CRM recovery from magnets. If put into force, the value collected with the tax would be directly converted into financing the process of recovery. Considering a VAT rate of 20 percent, under Scenario 1 the VAT exemption on products/services sold by the recycling plant would be €23.9 million.

3.3 SUGGESTED SOLUTIONS TO INCREASE THE RECOVERY OF CRMS

Despite being part of the European strategic objective, in practice the recovery of CRM is currently not implemented largely due to the combination of factors outlined in previous sections. For those reasons, a series of options to increase the likelihood of recovery – and to foster the creation of a conducive legislative, operational and economic framework – are presented below. The solutions are grouped in main themes, and the likelihood of adoption, pros and cons of each option are briefly described. The qualitative potential impact of adoption is also indicated.

These solutions should not be considered as stand-alone measures, but as a framework that combines several policies and actions needed to achieve a strong outcome. The prioritisation of solutions and conditions for success are presented afterwards.

Several solutions are interconnected, as the implementation of some proposals may be dependent or strengthened by the implementation of other measures. Furthermore, there is no single answer for what should be done regarding all CRMs and precious metals assessed in the CEWASTE standard, and some solutions may be more relevant or applicable to a selected range of materials only. Further assessment for individual CRMs/KCEs can be carried out for better identification of relevance. These solutions were mapped according to their relation to different areas of the policy cycle, where legislation is identified in blue, implementation in yellow, monitoring and reporting in pink, and enforcement in purple.

THEME: REGULATIONS

1. Legal obligation to dismantle KCC and recover CRM	
Description	The inclusion of a legal obligation to recover CRMs as part of EU Directives (such as WEEE Directive and ELV Directive) or, even better, as Regulations (such as the proposal for the new Battery Regulation), or as a mandatory standard that would require recovery of a target percentage of the CRMs contained in appliances placed on the market and could be monitored via the adoption of the CEWASTE standard. In this way, it would promote better recovery rates of CRMs. This could also be part of the EU Implementing Act, laying down ambitious minimum quality standards for WEEE treatment, collection, logistics and preparation for re-use, based on the CENELEC EN 50625 standards. In the case of legally binding recovery of CRM, the cost of recovery would have to be integrated into the fees currently paid by producers, unless an alternative financing mechanism would be adopted. Legal requirements create a regulated market. However, the complete policy circle of policymaking, regulation, implementation, enforcement, reporting and evaluation must be in place.
Likelihood of adoption	Medium to high.
Pros	It is, in principle, realistic at EU level, considering the constant growth of extended producer responsibility regulations. The legal requirements could be adopted, in principle, by amending the WEEE Directive or as a new mandatory standard. Article 8 of the WEEE Directive gives the opportunity for the European Commission to adopt “implementing acts laying down minimum quality standards based in particular on the standards developed by the European standardisation organisations” in order to support WEEE proper treatment.

	The recent study carried out for the EC points out the enormous environmental benefits that implementing CENELEC standards would bring about, including enhancing the recovery of CRM from WEEE.[24]
Cons	Experience with other waste standards (like the CENELEC EN 50625) that give Member States the freedom to decide on implementation and enforcement, has so far not led to a level playing field and implementation of high-level standards across all of the EU. Only some EU Member States have made the standards mandatory, and governmental authorities represent a bottleneck for implementation. To implement a target percentage the amount of CRM in WEEE would be required, which is currently unknown.
Potential impact if adopted	In case of adoption and proper enforcement, this solution would yield a high impact, as it would significantly increase the effort for collection and recovery of CRMs. Also, adoption of mandatory standards would ensure a wider, coherent and harmonised application of their requirements throughout the EU, which will directly support CRM recovery.

2. Mandatory recycled content of KCEs including CRM, such as batteries	
Description	In its European Green Deal, the EC envisaged mandatory recycled content in manufacture (i.e., a requirement to be fulfilled by producers). This plan was materialised in the draft Battery Regulation published on 10 December 2020, first through an information requirement on the recycled content of cobalt, lead, lithium or nickel in industrial, electric vehicle (EV) and automotive batteries, and then mandatory minimum shares of these CRMs recovered from waste (initial targets from 2030 and higher targets from 2035). The implementation should be completed by a European legal act that lays down the methodology for the calculation and verification of the amount of CRM recovered from waste. It should use a batch-level mass balance approach (to assess the recovery rate in each product model and batch per manufacturing plant). This method should then be homogeneously applied throughout the EU, to allow for comparable accounting, relying on third party certification to ensure trustworthy claims.
Likelihood of adoption	Medium.
Pros	This theme serves as a means of boosting the market of secondary raw materials, for example for the manufacturing of batteries.
Cons	It requires track and tracing methods to ensure the material is really coming from recycling, and requires EU standardisation and a legal act in place.
Potential impact if adopted	The potential impact would be high, as it creates a market pool and ensures the recovered CRMs will be integrated in new batteries through a mandatory requirement. However, its scope might be reduced if it only applies to certain categories of batteries, if the targets are low, or if the chain of custody model is not credible.

[24] Publications Office of the European Union: Study on quality standards for the treatment of waste electrical and electronic equipment (WEEE).

3. Removability of CRM rich components in KCEs and KCCs	
Description	Product policy regulations, such as the draft Battery Regulation or Ecodesign Regulations should require that the KCE (e.g., the battery) and/or the KCC shall be readily replaceable during its lifetime and easily removable at the end of life. This will also ensure the KCE can be replaced with a similar substitute, without affecting the performance of the product, and is conducive to making the recovery of materials feasible. Ideally, the separation/separate collection of KCEs would ensure they are being sorted in the early stages of the chain. Removability could also be ensured during the treatment phase, allowing recyclers to develop technologies or approaches fit for purpose.
Likelihood of adoption	Medium.
Pros	For KCEs, it is already enshrined in several Ecodesign Regulations (e.g., the clause on “dismantling for material recovery and recycling while avoiding pollution” requires that “manufacturers, importers or authorised representatives ensure the products are designed in such a way that the materials and components can be removed with the use of commonly available tools”) and in the proposed Battery Regulation. It could be included as an overall objective in the European Sustainable Product Policy Legislative Initiative, for which the EC had a public consultation in Autumn 2020. Once the KCE is removed, the recyclability of KCC should be ensured.
Cons	It should not be seen as a voluntary measure. If only a few producers are engaged, it is not feasible. Removability does not guarantee the recovery of materials, unless it is channelled downstream towards a recycling partner capable of recovering CRMs. Therefore, the design requirement should always be complemented by the dismantling obligation (as suggested in Solution 1).
Potential impact if adopted	Medium to high impact expected, as the removability of KCE can ensure a better access to CRM and facilitate their recovery, although it does not ensure removability of KCC. The impact will be higher if combined with a recovery obligation.

4. Enforcement of European legislation to counter illegal waste export of KCE from the EU	
Description	Even though exports of WEEE is restricted by the EU Waste Shipment Regulation (WSR), which transposes the Basel Convention, it continues to happen because of weak enforcement. This would consequently prevent the recovery of CRM available in those products. Reuse is sometimes used as a pretext to ship WEEE to developing countries, even when its second life cannot be guaranteed. The WSR reinforcement, and in particular stronger enforcement, will help counter such illegal exports.
Likelihood of adoption	Medium.
Pros	The EC consulted on the options to reinforce and better enforce the EU WSR over the summer 2020 and an amended WSR proposal should follow in 2021. The EC has also commissioned a study on quality standards for the treatment of WEEE, which brings up equivalent conditions.

Cons	Article 10.3 from the WEEE Directive stating: "*The Commission shall, not later than 14 February 2014, adopt delegated acts, in accordance with Article 20, laying down detailed rules supplementing those in paragraph 2 of this Article, in particular the criteria for the assessment of equivalent conditions*" has never been fulfilled.
Potential impact if adopted	Medium impact expected, as it would increase the potential of recovering CRM by ensuring higher amounts of KCE available in Europe, but is likely to have a low impact on KCC.

THEME: ECONOMIC ALTERNATIVES

5. Gate fee at recycling plant	
Description	Introduction of a recycling and/or recovery gate fee charged by recycling facilities per tonne of waste collected, or per quantity POM. The fee is to be paid by the PROs, or by the waste-holder (depending on legal obligations related to financing) and could be used to cover the extra cost of the process to recover CRM.
Likelihood of adoption	Low.
Pros	An economic incentive that can directly impact the feasibility of the CRM recovery process.
Cons	Requires the creation of a legal framework (making the recovery of CRM mandatory and with costs included) or it should leverage a voluntary approach (but in this case the likelihood of having the necessary EU-wide impact would be very low).
Potential impact if adopted	It is expected that this solution would yield a medium impact, as it would potentially finance the operations of the recyclers.

6. Tax credits or subsidies to recyclers	
Description	Tax credits and/or subsidies to recyclers could be introduced to stimulate the recovery of CRM components. Although both are forms of financial incentives, tax credits would reduce the amount paid by recyclers to the government, whereas subsidies would transfer money from the government to the recyclers.
Likelihood of adoption	Low.
Pros	An economic incentive that can directly impact the feasibility of the CRM recovery process.
Cons	The implementation of financial incentives and tax credits would require unanimity in the European Council in order to be adopted.
Potential impact if adopted	It is expected that this solution would yield a medium impact. While it has the potential to help recyclers in making CRM recovery more economically feasible, it would require a sufficiently high level of tax credits/subsidies. However, this solution does not impact the potential to recover certain components or the availability of materials.

7. Tax credits or subsidies to producers	
Description	Tax credits and/or subsidies could be introduced to producers for the use of recycled CRM components. Although both are forms of financial incentives, tax credits would reduce the amount paid by producers should they use recycled components in its products, whereas subsidies would transfer of money from the government to those producers using recycled components.
Likelihood of adoption	Low.
Pros	It is an economic incentive that can directly impact the feasibility of the CRM recovery process.
Cons	In order to be adopted, the implementation of financial incentives and tax credits requires European Council unanimity. Furthermore, it requires the track and trace of components to ensure recycled materials are being used in determined products.
Potential impact if adopted	It is expected this solution would have a medium impact. While it has the potential to incentivise companies to use recycled materials, this would only be for as long as the amount of tax credits or subsidies was sufficiently high.

8. VAT exemption	
Description	VAT is a mechanism under which the value that would be paid out as VAT in products and services is instead directly converted into financing the process of recovery. In this way, there is an exemption in paying the VAT to the government, and the recycler is exempt of this cost.
Likelihood of adoption	Medium.
Pros	An economic incentive that can directly impact the feasibility of the CRM recovery process.
Cons	Although the EU law requires Member States to levy a standard VAT rate, each country can decide on its levels and rules for exemption.
Potential impact if adopted	If adopted, the VAT exemption could yield a medium impact, as it offers a direct economic alternative for recyclers to make the recovery process feasible, and the exemption would be converted into investments in the process.

9. Eco-modulation fees	
Description	Within the framework of Extended Producer Responsibility schemes, the financial contributions paid to PROs can be modulated to take into account the level of recycled content in the manufactured KCC (e.g., in the battery, considering also its rechargeability).
Likelihood of adoption	Low.
Pros	The eco-modulation criteria can be laid down at the EU level (e.g., in the new EU Battery Regulation) as required by the new Waste Framework Directive. It can incentivise design that allows for the easier recovery of CRMs and recyclability.
Cons	The specific decision on eco-modulation is left to the national producer responsibility organisations (e.g., as the case in France).

Potential impact if adopted	It is expected to have a low impact, as the fee may depend on other criteria than the level of recycled content (e.g., the rechargeability of the battery, its reuse capacity, the consideration of small and medium-sized enterprises, etc.), which would compromise the impact.

10. Creation of a market for CRMs	
Description	The creation of new markets for CRMs can incentivise trading of recovered materials. This could include the development of a platform where recyclers that recover CRMs could sell smaller quantities of the recovered components in the EU, opening up the space for the supply of small quantities, fulfilling demand from the market and improving market dynamics. An example of this is the website secondtrade.com. Furthermore, there could be a tool inside the platform to allow for trading of 'recycling credits', which could also be beneficial to the economic viability of recovery processes.
Likelihood of adoption	Low.
Pros	This solution would increase the demand for recycled components and facilitate the trade of such components.
Cons	It requires engagement among several partners and strong collaboration. Creating of new markets entails several market risks, and success can be uncertain depending on market conditions.
Potential impact if adopted	If adopted, such a platform has the potential to yield a low to medium impact in the recovery of CRMs, as it could make it easier for suppliers (recyclers) to find demand that fits their quantities. In this way, it could make business models more feasible by increasing demand and revenues. However, the amount recovered still depends on available collection systems and existing industrial technology.

THEME: INDUSTRIAL PROCESSES

11. Improve critical infrastructure for recycling of specific CRMs and products	
Description	The recycling of some CRMs is not viable, because the infrastructure required for the process is either not available or it is considered too risky, too complex and too expensive. Therefore, research and innovation should be directed to improving critical infrastructure to enable the recycling of specific CRMs and products.
Likelihood of adoption	Medium.
Pros	The European Raw Materials Alliance (ERMA) – a multi-stakeholder platform to co-ordinate EU funding among an array of stakeholders in the value chain of projects around recovery of CRMs – could be a tool to facilitate this solution by channelling money into recycling. The German BMU/UBA offers an environmental programme for demonstration facilities which implement an innovative environmental technology for the first time.
Cons	New technologies are complex and expensive to develop. They require a great deal of research and innovation that is not easily or rapidly achievable. The implementation of industrial scale facilities is therefore a bottleneck.
Potential impact if adopted	In cases where the development of new technology makes the recovery process more efficient or viable for certain materials, the impact would be

	considered high, as it would allow for higher recovery of CRMs and/or recovery of materials that are currently discarded.

THEME: AWARENESS AND DIGITALISATION OF INFORMATION

12. New collection models clustering CRM-rich products	
Description	Piloting new collection and logistics models and/or new grouping of CRM-rich products (for example re-clustering products in the collection phase). Priority should be given to technologies recovering CRMs having a higher technology readiness level (TRL), if CRMs have technological bottlenecks). Clustering of CRM-rich products in dedicated collection categories should be coupled with large scale awareness-raising campaigns, possibly funded by the EU, targeting consumers and waste-holders, explaining the strategic relevance of CRM recovery. Examples of similar campaigns include the annual E-waste Day organised by the WEEE Forum and the #WEEE4Future campaign organised by EIT RawMaterials.
Likelihood of adoption	Medium.
Pros	This solution would raise consumer awareness and make the collection of CRM-rich products into clusters easier to monitor and trace. This would potentially increase the amount of CRMs recovered.
Cons	It would involve designing, restructuring and piloting new models, which would include investments and potential disruption of the current flow of collection (as an example, very few EU Member States implemented the collection category for Small IT equipment). Furthermore, there would be a cost associated with raising consumer and recycler awareness of the new model.
Potential impact if adopted	Medium impact expected. The new models could be helpful for better collection and would provide higher potential of recovery of CRMs. However, technological advancements may still be required, as well as proper awareness raising regarding the new model.

13. Inclusion of information in Digital Product Passport	
Description	Legislation should require the value chain to meet certain transparency requirements to ensure that there are no knowledge gaps throughout the whole supply chain. • Designers of products need to provide evidence they use recycled content. • Manufacturers need to be able to tap into information around the content of components, materials and parts; • Treatment operators and recyclers need to know whether the waste product contains hazardous substances or substances of concern, and where and how they can be extracted; • Consumers need to be able to interrogate the OEM on the product's materials; and • PROs need to be able to communicate throughout the value chain. Blockchain technology should be the digital solution enabling the Digital Product Passport. There are tools and platforms already available in the

	market that could be used support this requirement, or serve as a benchmark for the development of a new platform, such as the I4R, WF-RepTool and Reeecyclab.
Likelihood of adoption	Low to medium.
Pros	This solution would make it easier to access information and help create a more efficient recycling process.
Cons	It involves several actors in the supply chains and increasing the need for more advanced and widespread technology for traceability. It also requires definition of confidentiality of the information shared.
Potential impact if adopted	If adopted, this solution would potentially have a medium impact as it would make the process of recovery of CRMs more efficient and assertive but has no direct impact in the costs or requirement of recycling.

14. Development of solid criteria to assess CRM presence	
Description	The development of solid criteria for green/mass balance claims would allow producers to make clear and accurate statements about the amount of recyclable content in products, facilitating the work of collection and recovery of CRMs. It is necessary, however, to have monitoring and reporting requirements in place, and to have a clear definition of the methodology to be used in a standardised way by all producers. One example methodology is blockchain, which could be used to track CRM presence in all materials in a standardised and protected way.
Likelihood of adoption	High.
Pros	The methodology is already in place in several supply chains (e.g., Circular Economy Action Plan points out the importance of creating a methodology for assessment, and an assessment of how it could be implemented in different sectors).
Cons	The criteria need to be updated to promote higher accuracy in the determination of components' amount in each specific product, and to encompass the specificities of individual CRM markets.
Potential impact if adopted	If adopted, this solution would be expected to have a medium impact on CRM recovery and the CRM supply chain. It has the potential to improve worthiness and transparency in claims of recycled content, as well as to incentivise recycling of materials (if associated to batteries requirements of recycled content). However, it does not have a direct influence in the recovery process.

PRIORITISATION OF SOLUTIONS

As mentioned before, these solutions are not to be seen as stand-alone. Instead, they should be considered as a framework, where several solutions could have a significant impact in the adoption of the CEWASTE standard, and improving of recovery of CRMs.

Those solutions with a higher potential impact, likelihood of adoption, or chance to stimulate changes at the EU level have been clustered in four main themes (Figure 13):

- **Legislation**: the EU's strategic priority to recover CRM cannot be hampered by the lack of harmonisation of measures aimed at ensuring an effective recovery of CRM from end-of-life products. Therefore, regulations (preferred over directives) should be implemented and request the mandatory recovery of specific CRM. This should be coupled with the creation of market incentives for the use of CRM, including the definition of minimum percentages of CRM use of obtained from recycling into new products, where possible. Given the current lack of economic viability for the technical processes of CRM recovery, the introduction of dedicated fees, to be paid by extended producer responsibility schemes (if CRM recovery is mandatory) or specific fiscal incentives (such as VAT exemption) should ensure economic viability for recyclers.
- **Implementation**: recovery of CRMs should leverage the consolidation of fractions of CRM-rich products, as well as channelling of material to those plants/processes capable of recovering such materials. The availability of recycling processes, coupled with a suitable logistic infrastructure, is paramount to achieving economies of scales. Implementation should be supported by a dedicated clustering of products already in the collection phase, also for monitoring purposes, and the facilitation of EU-wide platforms (e.g., through ERMA, or REIA) to channel the material recovered to downstream acceptors.
- **Monitoring and reporting**: the current lack of detailed, consistent and readily available information on the presence of specific CRMs in products on the market also makes it difficult to identify products and components rich in CRMs. The inclusion of minimum content information (e.g., presence, main components, average content) in the Digital Product Passport could facilitate the monitoring (such as the total amount put on the market) and the control of actual recycling performances (including the checking of recovery performances achieved).
- **Enforcement**: there is absolute need of enforcement for any of the measures implemented. Enforcement should target the transboundary shipment of CRM-rich fractions outside the EU (ensuring the destination could guarantee an acceptable level of material recovery), and also the adoption of technical standards along the entire collection and recycling chain.

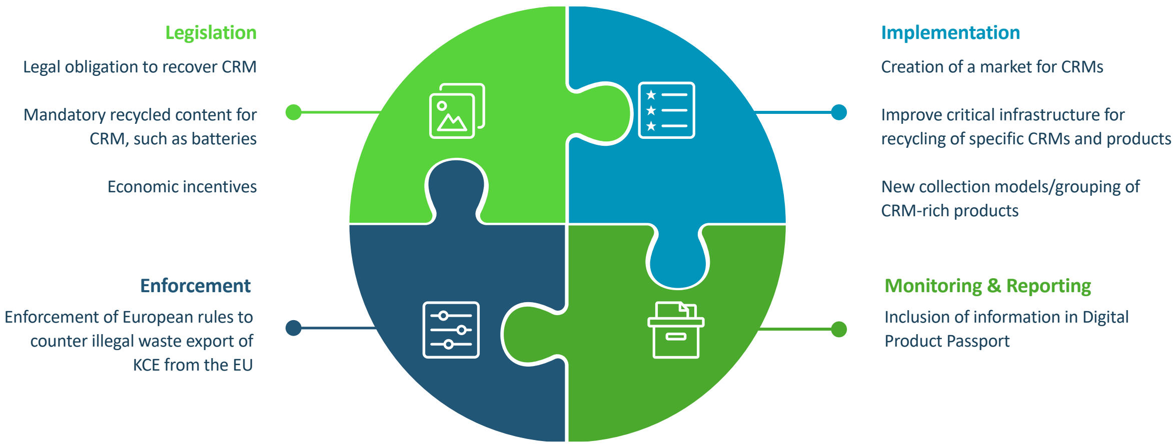

Figure 13: Clustering of options to increase CRM recovery across the EU

4 Recommendation for adoption of CEWASTE

4.1 Key points and roadmap

Piloting of CEWASTE requirements carried out during the project, as well as the summary of readiness level described in D4.3[25], highlighted the following key aspects:

- Generally speaking, the maturity varies along the chain. Most pre-treatment and final treatment operators met the majority of requirements. However, the lack of implementation of the EN 50625-4 standard for collection facilities across Europe poses the biggest challenge.
- In those cases where requirements were not met, the main underlying cause was the current absence of the process aiming at ensuring recovery of fractions rich in CRM mainly linked to (1) absence of a downstream market, or (2) absence of financial incentive to recover the CRM. In the great majority of cases, minor to medium organisational and/or process changes could be implemented by the audited companies.

[25] CEWASTE Deliverable 4.3 – Piloting Reports and Maturity Level Assessment

One of the key assumptions behind the development of the CEWASTE standard is linked to the strategic aims of the EU and, in particular, to the set of policies addressing raw materials, namely:

- To safeguard the EU's strategic assets, interests, autonomy, or security, and namely to increase EU resilience in raw materials supply chains for EU industrial value chains and strategic sectors; and
- To enable their green and digital transition, and to reduce current EU over-dependence on a few countries for critical raw materials, by boosting domestic production of secondary raw materials.

For these reasons, the adoption of CEWASTE is seen as a coherent step towards the achievement of such goals and the recommendations for its adoption can be divided into three main groups: (1) pre-requisites for the adoption, (2) conditions for success and (3) roadmap.

PRE-REQUISITES FOR ADOPTION

The main pre-requisite for the adoption of CEWASTE is to update the EN 50625 standards to best available techniques (BAT), and to have resource efficiency integrated, followed by making the standards legally mandatory. After this has been accomplished, the CEWASTE standards should also be made mandatory. Given that the recovery of CRMs is a political priority for the EU, the standard should not remain voluntary. This is mainly because, voluntary standards would only have a very minor impact, meaning low or no recovery of CRMs.

CONDITIONS FOR SUCCESS

There are three main conditions necessary for the achievement of a successful CEWASTE standard.

1. **Make the CENELEC[26] standard legally binding**

[26] CENELEC is one of 3 European Standardization Organisations and is responsible for publishing standards in the electrotechnical engineering field. CENELEC maintains close relationships with the International Electrotechnical Commission (IEC) and the European Committee for standardization (CEN). Through its Technical Committee TC 111X "Environment", CENELEC addresses the generic environmental standardization needs of the electrotechnical sector, especially in support of European legislation.

The reasons behind this recommendation are:

- Directive 2012/19/EU on WEEE, transposed in each EU Member State, enables standards to be developed (Article 8.5) that cover the treatment, including recovery, recycling and preparing for re-use of WEEE and reflect the state of the art.
- The EC mandated CENELEC to develop the standards in 2012 (M/518 EN).

These aims of the CENELEC EN 50625 series are to:

- Assist operators in fulfilling the requirements of the WEEE Directive by using SMART goals.[27]
- Give additional guidance to operators.
- Cover the treatment of all products within the extended scope of the WEEE Directive.
- Cover the collection and logistics of WEEE to allow for proper treatment.

At present, close to 200 processes of treatment operators are certified according to the CENELEC standards.

The cornerstone of CEWASTE requirements, as described in WP2, are EN 50625 CENELEC standards. Currently, the CENELEC standards are only mandatory in a few EU countries, and the experience in these countries is that mandatory implementation creates a level playing field for all operators where fair competition can take place in the regulated market.

It is unfortunate that the EC so far has not updated and made use of the possibility to make the standards mandatory by an implementing act as described in Article 8 of the WEEE Directive.[28] Making the standards mandatory can prevent large volumes of secondary raw materials being lost due to

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The members of CENELEC are the 33 national standardization bodies and national committees of 28 EU member states, 3 EFTA countries, and Turkey and Macedonia. In addition, there are 29 affiliates. CENELEC acts as a platform of experts from national committees and affiliates who develop European standards (EN) and technical specifications (TS). Over 20,000 standards have been published so far.

The process of making standards is transparent and consensus based. The ENs are reviewed every 6 years and the TSs every 3 years, thereby reflecting the state-of-the-art of technologies and market needs, and they can be used to support legislation. Standards have a harmonizing effect and can remove trade barriers and enhance economic growth.

[27] SMART goals: Specific, Measurable, Achievable, Realistic, and Timely.
[28] Article 8.5: In order to ensure uniform conditions for the implementation of this Article, the EC may adopt implementing acts laying down minimum quality standards based in particular on the standards developed by the European standardisation organisations.

illegal deposition and trade, as well as poor quality recycling. It is, therefore, important to have the EN 50625 standards becoming mandatory at EU level, to ensure a non-jeopardised implementation of CEWASTE.

2. **Increase the collection rate of materials rich in CRM and in accountability**

At present, most CRMs are lost due to low collection efforts by EU Member States. Therefore, a 'call to action' is necessary in this regard, especially for small products that are not currently being collected.

3. **The normative references of the CEWASTE standard must be based on the EN 50625 standards.**

After having analysed all standards that are available for the recycling of WEEE and waste batteries, the CEWASTE project has formed the opinion that the EN 50625 standards are the most state-of-the-art recycling standards. It is for this reason that most normative references in the CEWASTE standard are articles in the CENELEC standards.

During the pilot audits, it became clear that those companies complying with CENELEC standards, were also compliant with all CEWASTE management, sustainability and traceability requirements. In cases where the economics of CRM recycling worked, most of the CEWASTE technical requirements were also met, meaning that the gap between existing recycling practices and the aim of CEWASTE to recover CRMs from the urban mine is nominal. If the economic drivers are in place (as discussed in Chapter 4), bridging the gap of compliance with CENELEC is also close to being in place.

4.2 Ownership of the CEWASTE scheme

The project has identified and analysed different WEEE treatment verification schemes. The owners of these schemes are in the best position to become an accredited body for ensuring conformity verification in the short term for CEWASTE. This sub-section provides an overview of the six different companies identified (Table 8) and an analysis of their suitability for becoming a CEWASTE verification scheme.

No.	Name of verification scheme	Type of scheme	Type of scheme	Product or material focus (+ detail)
1.	WEEELABEX	Private	Accredited certification scheme	WEEE
2.	R2:2013 Checklist	Public	Verification scheme (not accredited)	WEEE
3.	e-Stewards	Private	Accredited certification scheme	WEEE
4.	Recycler Qualification Program (RQP)	Private	Verification scheme (not accredited)	WEEE
5.	EPEAT	Public	Verification scheme (not accredited)	EEE
6.	AS/NZS 5377-2013	Public	Accredited certification scheme	WEEE

Table 8: List of verification schemes

According to the research conducted in WP1, R2 is the verification scheme with the most certified facilities. In February 2019, R2 listed 856 facilities on its webpage in 12 different geographical areas around the world.[29] R2 is followed by WEEELABEX, which listed 188 facilities in Europe,[30] e-Stewards counts 51 facilities in five countries (USA, Canada, Mexico, Singapore and UK)[31], RQP follows with 47 facilities in Canada,[32] and AS/NZS 5377:2013 counts 45 certified facilities in Australia and New Zealand.[33] EPEAT counts a total of 18,941 products registered in 33 countries across the world[34].

While most schemes have verified facilities in many countries, RQP and AS/NZS 5377-2013 mostly focus on Canada, and Australia and New Zealand, respectively (Table 9).

Scheme	Total number of certificates issued for 2018	Number of countries with certified/verified facilities	List of countries
WEEELABEX	188 (source: WEEELABEX office)	16	Austria, Belgium, Czech Republic, France, Germany, Greece, Ireland, Italy, Lithuania, Netherlands, Poland, Portugal, Romania, Serbia, Spain and United Kingdom
R2:2013 Checklist	856 (source: Sustainable Electronics	33	Argentina, Australia, Belgium, Brazil, Canada, Chile, China, Colombia, Costa Rica, Czech Republic, Ecuador, France,

[29] Sustainable Electronics: recyclers.
[30] WEEELABEX: Operators List.
[31] e-Stewards: Find a recycler.
[32] EPRA: RQO Approved Recyclers.
[33] Mousa Sharif, Certification Manager, Global Compliance Certification.
[34] Epeat registry.

Scheme	Total number of certificates issued for 2018	Number of countries with certified/verified facilities	List of countries
			Germany, Hong Kong, India, Indonesia, Ireland, Japan, Korea, Malaysia, Mexico, New Zealand, Peru, Philippines, Singapore, South Africa, Spain, Sweden, Taiwan, Thailand, The Netherlands, United Kingdom and United States
e-Stewards	51 (source: e-Stewards)	5	Recyclers: Canada, Mexico, Singapore, United Kingdom and United States Enterprises: USA
RECYCLER QUALIFICATION PROGRAM	47 (source: EPRA)	12	Belgium, Canada, China, Germany, Hong Kong, Japan, Mexico, Malaysia, North Korea, Sweden, United Kingdom and United States
EPEAT	Servers: 467, Computers and Displays 2018: 4287, Imaging equipment: 5209, Mobile phones: 44, TVs: 298 (Source: Epeat)	33	US, Canada, New Zealand, Bulgaria, Belgium, Austria, Australia, Brazil, China, Czech Republic, Denmark, Finland, France, Greece, Germany, Hungary, Italy, Japan, Latvia, Lithuania, Bulgaria, India, Mexico, Netherlands, Norway, Sweden, Switzerland, Poland, Portugal, Romania, Slovakia, Spain, Taiwan and United Kingdom
AS/NZS 5377-2013	45 (source: GC Certificates)	2	Australia and New Zealand

Table 9: Number of companies certified in verification schemes and their locations

All schemes are covering treatment of WEEE in their verification schemes. The main difference in the scoping of the activities audited seems to be in collection activities. Three of the schemes identified seem to be covering collection: WEEELABEX, R2 and AS/NZS 5377-2013. It is unclear whether any of the schemes cover final treatment activities, but information collected so far does not identify any of the schemes as going that far in the chain (Table 10).

No.	Part of value chain affected	Who is certified/verified?	Standards of reference	Scope of the certificate
1.	Collection, logistics, pre-treatment	Collection companies, logistics operators and WEEE pre-treatment operators	CENELEC WEEE Standards	Per facility, per WEEE stream
2.	Collection, pre-treatment, downstream treatment, preparation of re-use	Collection companies, WEEE pre-treatment and downstream treatment operators, preparation for re-use operators	R2:2013 Standard	Per facility (for pre-treatment), for materials (downstream treatment)
3.	Logistics, pre-treatment,	Logistics operators, pre-treatment operators,	e-Stewards Standard for Responsible Recycling	Per company

No.	Part of value chain affected	Who is certified/verified?	Standards of reference	Scope of the certificate
	downstream treatment, Preparation for re-use	downstream operators, preparation for re-use operators	and Reuse of Electronic Equipment	
4.	Pre-treatment, downstream treatment	Pre-treatment operators, downstream operators	Electronic Recycling Standard (ERS)	Per facility (for pre-treatment), for materials (downstream treatment)
5.	Product design, product manufacturing	Manufacturers of IT devices	NSF/ANSI 426-2018, NSF/ANSI 426-2017, IEEE 1680.1-2018, IEEE 1680.2-2012, IEEE 1680.2a-2017, EEE 1680.3-2012, IEEE 1680.3a-2017, UL 110 Edition 2 2017.	Per product
6.	Collection, logistics, pre-treatment, disposal, preparation for re-use, storage	Collectors, logistics operators and WEEE pre-treatment operators, re-use operators	AS/NZS 5377-2013	Per facility

Table 10: Characteristics of verification schemes

WEEELABEX, e-Stewards and AS/NZS 5377-2013 are accredited verification schemes. The certification body must be accredited to offer CEWASTE certification.

The criteria for identifying the best suited company for adopting the CEWASTE scheme are:

1. Coverage of activities. Provision of global services is preferable.
2. Scope of the WEEE value chain covered. Verification experience covering the whole value chain from collection to final treatment for WEEE is expected.
3. Shows expertise with CENELEC requirements, as these are the basis of the CEWASTE standard. Assessing verification against CENELEC requirements will speed up the process of implementing the scheme.
4. Should be an accredited certification scheme.
5. Financial stability and good market penetration.

While the first four criteria are summarised in Table 11, information on financial stability is more complex to collect. It is assumed that getting accredited for the CEWASTE certification scheme will require an initial investment that will not be returned in the short term, given that the market for CRMs is still emerging. The main benefit of operators getting CEWASTE certified will most likely be gaining competitiveness in the market. If the market is not yet fully developed, competitiveness may not be a benefit good enough for obtaining certification. This means the market seeking certification will expand timidly in the short term, and financial support may be required for ensuring the accredited body holding the CEWASTE scheme does not encounter serious financial issues. Alternatively, a scenario in which CEWASTE compliance becomes legally mandatory will radically change the situation, as the company holding the CEWASTE scheme will be required to be a 'front-runner' and adapt quickly for covering market needs (i.e., extensive training programmes, sufficient pool of auditors, etc.).

No.	Name of the verification scheme	Coverage of activities	Scope of WEEE value chain	Expertise in CENELEC?	Accredited
1.	WEEELABEX	Global (mostly EU)	Collection, logistics, pre-treatment	Yes	Accredited certification scheme
2.	R2:2013 Checklist	Global	Collection, pre-treatment, downstream treatment, preparation of re-use	No	Verification scheme (not accredited)
3.	e-Stewards	Global (mostly America)	Logistics, pre-treatment, downstream treatment, preparation for re-use	No	Accredited certification scheme
4	RQP	Mainly Canada	Pre-treatment, downstream treatment	No	Verification scheme (not accredited)
5.	EPEAT	Global	Product design, product manufacturing	No	Verification scheme (not accredited)
6.	AS/NZS 5377-2013	Australia and New Zealand	Collection, logistics, pre-treatment, disposal, preparation for re-use, storage	No	Accredited certification scheme

Table 11: Summary of criteria per scheme identified

Therefore, the recommendation is that the CENELEC would be the owner of the CEWASTE standard, while WEEELABEX would be the owner of the certification.

4.3 ROADMAP

The proposed roadmap for implementation of the CEWASTE standard is outlined in Figure 14:

1. **Make the CENELEC standard mandatory:** revise CENELEC standards and update BAT to include aspects related to resource efficiency. Make the CENELEC standard mandatory to ensure effective impact in CRM recovery and full alignment with the EU's priorities.
2. **Incorporate the CEWASTE normative requirements into CENELEC's EN 50625 series**, making them equally legally binding.
3. **Call to action for EU Member States:** request EU Member States to increase collection of CRM-rich materials, particularly enforcing dedicated collection clusters and conducting awareness raising campaigns. This is expected to increase the supply of CRMs available for recovery.
4. **Create market pull:** promote the use of recovered CRM materials via regulations requiring the minimum number of recycled components in products, similar to what the proposed Battery Regulation aims to achieve.
5. **Facilitate CRM demand:** create platforms of demand for recycled components or materials easing the trade process for companies recovering CRMs.
6. **Stimulate economic viability of recovery:** investigate how dedicated policies and measures can ensure the economic viability of CRM recovery processes, including dedicated incentive schemes for recyclers (or producers using CRMs from recycling).
7. **Stimulate research on effective technologies**: invest in research, development and the transfer of technologies for better and more efficient processes.

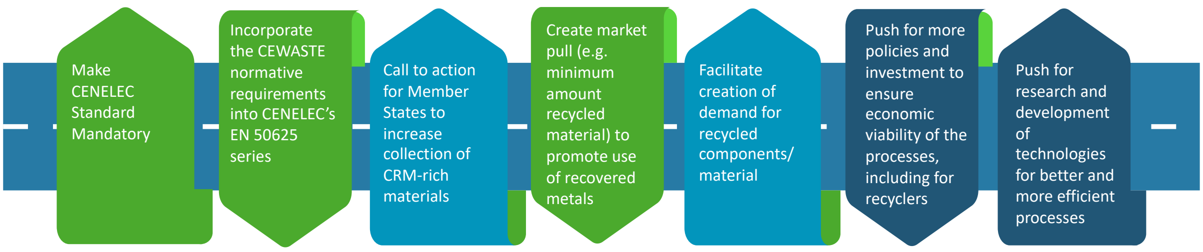

Figure 14: Roadmap for adoption of CEWASTE