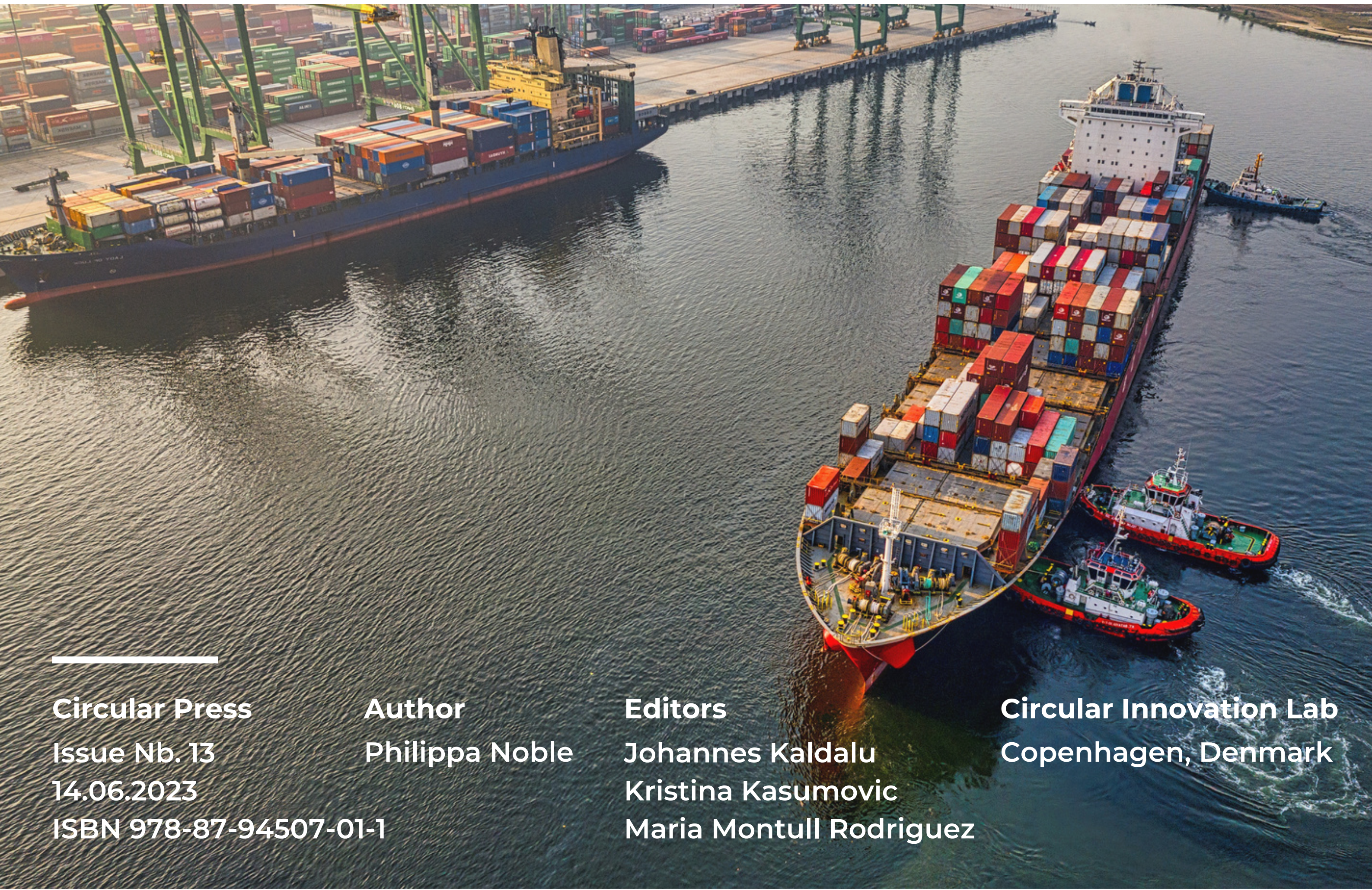
A CIRCULAR EUROPEAN CRITICAL RAW MATERIALS MANAGEMENT SYSTEM: THE 2023 PLAYBOOK

A CIRCULAR ECONOMY VISION



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ABSTRACT

This paper follows a previous analysis of the ECRMR's potential effects on developing economies. In this paper, the focus is turned to the EU's domestic CRM markets, revealing how the current hyperfocus of the policy on extraction, processing, and recycling is not applicable to all identified CRMs. Through an analysis of the limits of the ECRMR as it stands, it will be shown that a supporting structure of circular economy legislation could promote a successful ECRMR for all CRMs, not just those that could benefit from recycling infrastructure. The paper provides detailed policy recommendations for each CRM where data allows.

1. Introduction

1.1 The European Critical Raw Materials Regulation

The European Commission published the European Critical Raw Materials Regulation (ECRMR) on the 16th March 2023 to continue its plans to tackle major global supply risks in increasingly important critical raw materials (CRMs). The Regulation first divides these identified materials into CRMs (those with supply risks and increasing economic importance) and strategic raw materials (SRMs - those with more significant or pressing supply risks due to increasing demand or high import reliance on a single or multiple foreign countries) - (European Commission, 2023c).

The green and digital transition are key drivers of risk for many CRMs. The shift towards electric vehicles for the green transition is already boosting lithium demand far above our global extraction capacity. The 180% increase in lithium production in the five years after 2017 still could not match lithium demand in 2022 (IEA, 2023). In the same year, 60% of global lithium demand was from the electric vehicle battery market. Other CRMs, such as cobalt and nickel, were also heavily demanded for electric vehicle batteries in 2022, covering 30% and 10% of global demand for each CRM respectively. The developing battery market has already overtaken supply and shows no signs of stopping. Therefore, the ECRMR aims for a sustainable supply chain for CRMs, tackling supply risks due to overuse or overreliance on imports by developing domestic capacities in extraction, processing, and recycling.

1.2 The Circular Economy

The circular economy is a re-imagination of our current take-make-waste economic system. By looping downstream goods into upstream supply chains, the CE aims to circulate the remaining value in goods back into the economy, rather than allowing it to fall into landfill as products often do.

A CE society imagines the economy extending initial product use-life, reusing products, repairing goods in their initial form, remanufacturing goods more extensively, and finally recycling its materials for new goods. This process aims, therefore, to reduce waste streams to a minimum - where goods are no longer reusable, repairable, or recyclable.

The CE, therefore, represents an innovative leap forward for our economic systems, bringing with it significant changes in behaviour and business. Although the cycles of the CE refer mostly to downstream use, preparation for the CE looks further upstream.

The CE transition requires redesign of products to enable easy reuse, repair, remanufacture, and recycling - including concepts such as modularity and new choices in materials.

Consumer education on how to consume and later dispose of their products is crucial to extending product life and ensuring goods are redirected away from landfill. Finally, the CE demands heavy investment into infrastructure at every cycle of the value chain.

1.3 CE in the EU

Over the past decade, the European Union (EU) has been a leader in CE policies. The European Commission (EC) released 'Towards a Circular Economy: A Zero Waste Programme for Europe' in 2014, beginning its journey towards a CE shift (European Commission, 2014). In 2015, the EC published its first Circular Economy Action Plan (CEAP), which set out initial plans to transition towards a circular system across the Union (European Commission, 2023b).

Since then, the EU has developed a set of strong legislation for the circular transition. The 2020 European Green Deal strategy was launched to improve energy- and resource-efficiency and the environmental impacts of the EU through a dual shift: towards a sustainable and circular economy. Developing this further, the EU published a new CEAP in 2020 (European Commission, 2023b).

Three EU Directives also support the circular transition: the Waste Framework Directive (2008/98/EU), WEEE Directive (2012/19/EC), ELV Directive (2000/53/EC). The Waste Framework Directive encourages Member States (MS) to develop their collection and recycling capacities to a defined level, although whether this is legally binding is left to the MS's discretion. The WEEE Directive looks at end-of-life electrical and electronic equipment (EEE), encouraging eco-design requirements for MSs. The ELV Directive refers to end-of-life vehicles, their components, and materials. It aims to ensure reuse, recovery, and recycling of these vehicles to close the loop as far as possible. The WEEE and ELV Directives also introduce an extended producer responsibility (EPR) scheme to help finance the development of recycling infrastructure.

1.4 Scope

The last paper in this series focused on possible impacts and opportunities the ECRMR could hold for developing economies. Here, the issue of enabling a circular ECRMR will be discussed. This paper aims to set out the ways in which the ECRMR itself, and supporting legislation within the CRM industry, could create a circular value chain. The paper will first analyse the policies promoted in the ECRMR, then follow the circular value chain to cover the remaining policies for: reuse, repair, remanufacture, and consumption reduction. In section 4, a matrix of policy recommendations for each CRM in the EU will be constructed.

Key CRM uses have been taken from the EU-funded SCRREEN (2023) CRM profiles to give descriptive insights into which policies are relevant for each material. Recycled Input Rates have been taken from the 'Study on the Critical Raw Materials for the EU 2023' to give further descriptive reasoning why recycling policies cannot be applied to all material markets and uses (European Commission, 2023g).

2. Under the ECRMR

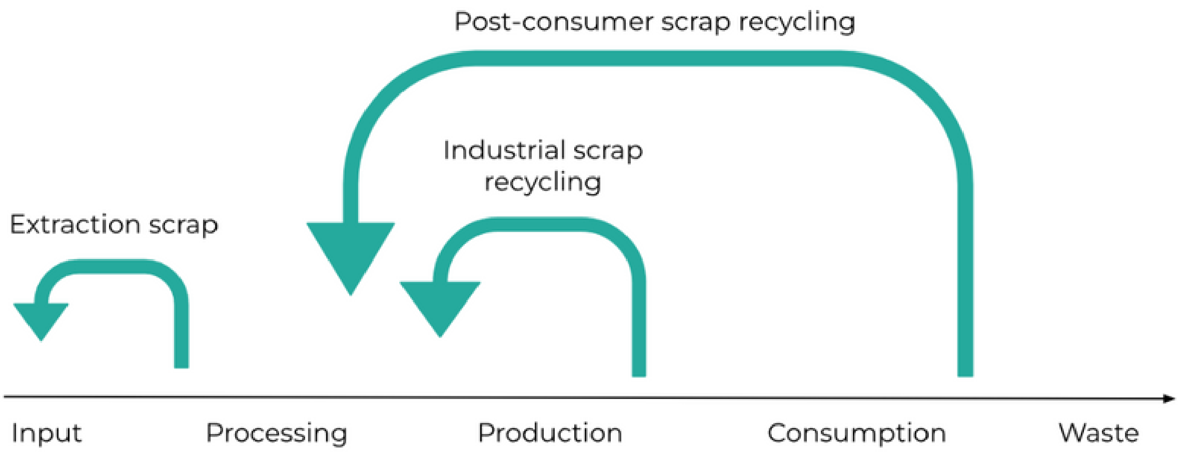


Figure 1: The ECRMR Value Chain

The ECRMR could be seen by some as a piece of circular economy (CE) legislation. However, its main provisions only acknowledge recycling to retain value along a product's life cycle. There are some circular additions to goals within the Regulation, requiring: Member States to encourage reuse by 2026, CRM management labour to be trained in circularity (although there are limited criteria for what this encompasses), and for more overt labelling of permanent magnet make-ups (between Neodymium-Iron-Boron, Samarium-Cobalt, Aluminium-Nickel-Cobalt, or Ferrite) - (European Commission, 2023e).

The main focuses, however, follow the four key goals of the ECRMR:

- 10% of EU consumption covered by domestic extraction of CRMs;
- 40% covered by domestic processing;
- 15% covered by recycling;
- A maximum of 65% of the EU's annual consumption of a single SRM should originate from a single third (non-EU MS) country (European Commission, 2023e).

2.1 Inputs

Inputs, particularly at the extraction level, are the only aspect of the value chain afforded direct policy solutions within the ECRMR supporting documents. Nevertheless, even these are limited. The EC report reveals that improved provision for EU consumption by domestic extraction will, by definition, necessitate increased extraction infrastructure. As shown in Table 1, this shifts input streams from imports towards domestic trade, yet has an ambiguous effect on output streams. An increase in domestic extraction infrastructure could highlight the costs to the economy and the environment of extracting CRMs, reducing consumption.

There could be no impact if demand is fully and only shifted towards domestic supply. Or, consumption and waste of CRMs could increase due to improved ease of trade.

A more minor policy mentioned in the ECRMR is the use of extraction by-products as an initial step towards shifting EU CRM demand away from imports (European Commission, 2023e). Producers will first use primary CRMs from waste stockpiles in pre-existing extraction sites. In doing so, input streams are shifted away from imports, and output streams are slowed. Previously, this would have been considered waste alongside post-consumer goods. However, with sufficient effort, underutilised primary extractions should be properly harnessed.

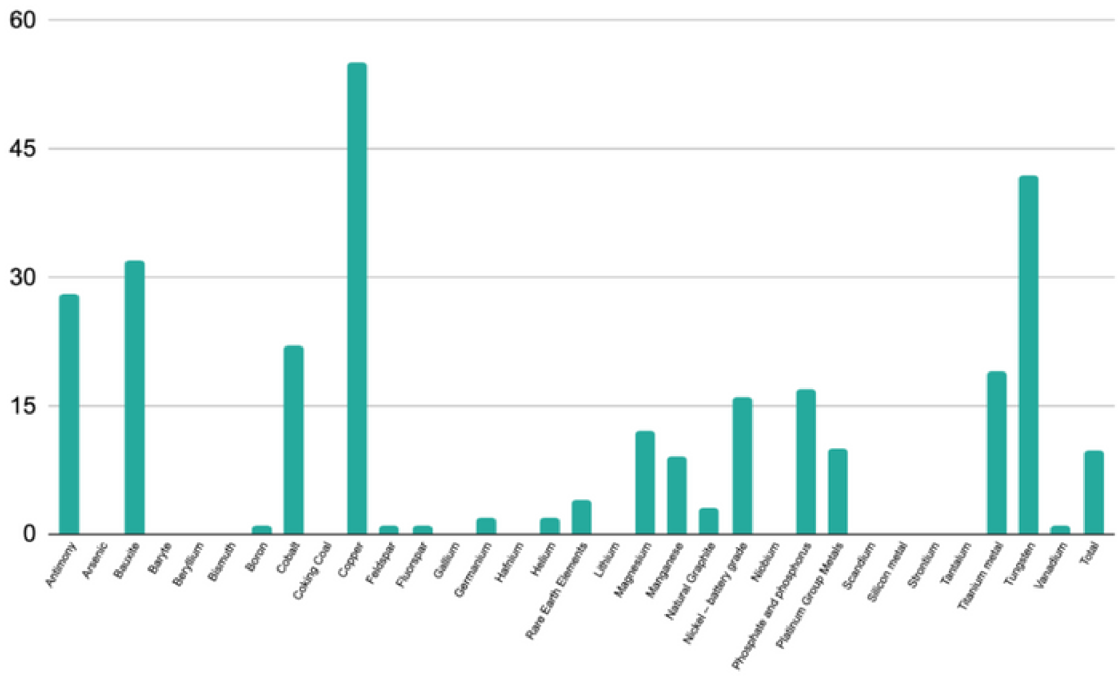
	Effect on output streams	**Circular**
Increase in extraction infrastructure	*Ambiguous*	N
Use of extraction by-products	*Slows*	Y

Table 1: Input policies under the ECRMR

2.2 Recycling

As it stands, the ECRMR will aim to cover 15% of European consumption of CRMs through recycling. As seen below in Figure 2, 8 CRMs already surpass this goal, although many still have an estimated Recycled Input Rate (RIR) of less than 1%. The RIRs of copper (55%) and tungsten (42%) skew the overall proportion of EU consumption covered by recycling (European Commission, 2023g). Although, when weighted by annual estimated EU consumption (taken as an average over 2016-2020 by SCRREEN), the overall consumption covered by recycling stands at only 9.75%.

As with any goal, it must be ambitious to achieve results. However, when the specific obstacles to high CRM recycling rates are understood, there are significant barriers to achieving the 15% average RIR targeted by the ECRMR. Even more importantly, these CRMs have been identified due to the EU's high import reliance, the economic importance, and the potential supply risks facing these materials. An average RIR of 15% across the CRM list does not ensure that all CRMs will be sheltered from these risks.



** Bauxite's RIR represents the RIR of aluminium, as bauxite is consumed fully in its creation of aluminium.*

Figure 2: End-of-Life Recycled Input Rate (%) of CRMs

Figure 3 below provides a breakdown of recycling capabilities per CRM value chain. Data constraints mean that heavy and light rare earth elements have been consolidated. Further, platinum group metals and the original division of elemental phosphorus and phosphate rock have also been brought together under grouped terms.

"Limited possible methods" refers to value chains where recycling faces insurmountable barriers - for example, where there is no process to recycle the material. Therefore, innovation is required to either move away from the material, or test new recycling methods. Non-existent recycling capacities include CRM value chains with no current recycling (RIR is equal to <1%). There is, however, no physical barrier to recycling as above. Nascent recycling infrastructure refers to CRMs where there are limited RIR levels, but there is evidence to suggest growth in the future. "Growing" is assigned to CRMs with either substantial RIR levels (5-10%), or where there is significant evidence for future growth such as promising pilots in progress. Well-developed recycling capacities produce RIR levels of 10% or more. These are established pathways for end-of-life materials.

12 out of 32 of these materials face currently impossible recycling methods, rendering their RIR near or at 0%. These materials account for 47.0 megatonnes of EU CRM consumption, or 69.9%. Only 1 CRM is categorised as "growing", with demonstrated evidence for improvements in RIRs in the near future. 9 out of 32 CRMs are "well-developed", corresponding mainly with CRMs currently operating past the ECRMR goal.

Some of these “well-developed” CRMs already have an RIR of over 40%. For example, copper’s 55% RIR and its standing in public knowledge suggest that major gains here will not be achieved by 2030; a critical mass has been reached. Combined with the barriers faced by “limited possible methods”, this leaves only 9 “nascent” and “growing” recycling capacities as candidates for a successful transformation in RIR levels under ECRMR policies.

Nikulski et al.’s 2021 study on LED lamp recycling reveals the complexities of recycling for many CRMs. The estimated 14% collection rate of LED lamps reveals the first issue: there is limited infrastructure for currently unrecyclable materials even to be collected as waste. Secondly, Nikulski et al. explain that, through different material retrieval methods, some CRMs could be extracted while others are lost. Grouping compatible metals, it is shown that the following could be retrieved together: indium-gallium, rare earth elements, precious metals (including palladium). Following their calculations, it is estimated that there will be 212.38kg of gallium waste in LED lamps between 2017 and 2030. Assuming a consistent recycling rate of 50% and a collection rate of 14%, the authors estimate that 13.49-14.84kg of gallium could be retrieved. In a more ambitious scenario, with an increasing recycling rate from 50% to 80% and an increased collection rate from 14% to 85%, between 90.59-99.65kg of gallium could be retrieved from LED lamp waste by 2030. However, this would mean that, even with improvements in collection and recycling infrastructure for gallium, all other incompatible metals in the lamp (rare earth elements and precious metals) would be lost. Therefore, we can see that a simple policy on recycling will not be enough to achieve a sustainable CRM supply chain, and certainly does not qualify as a circular system.

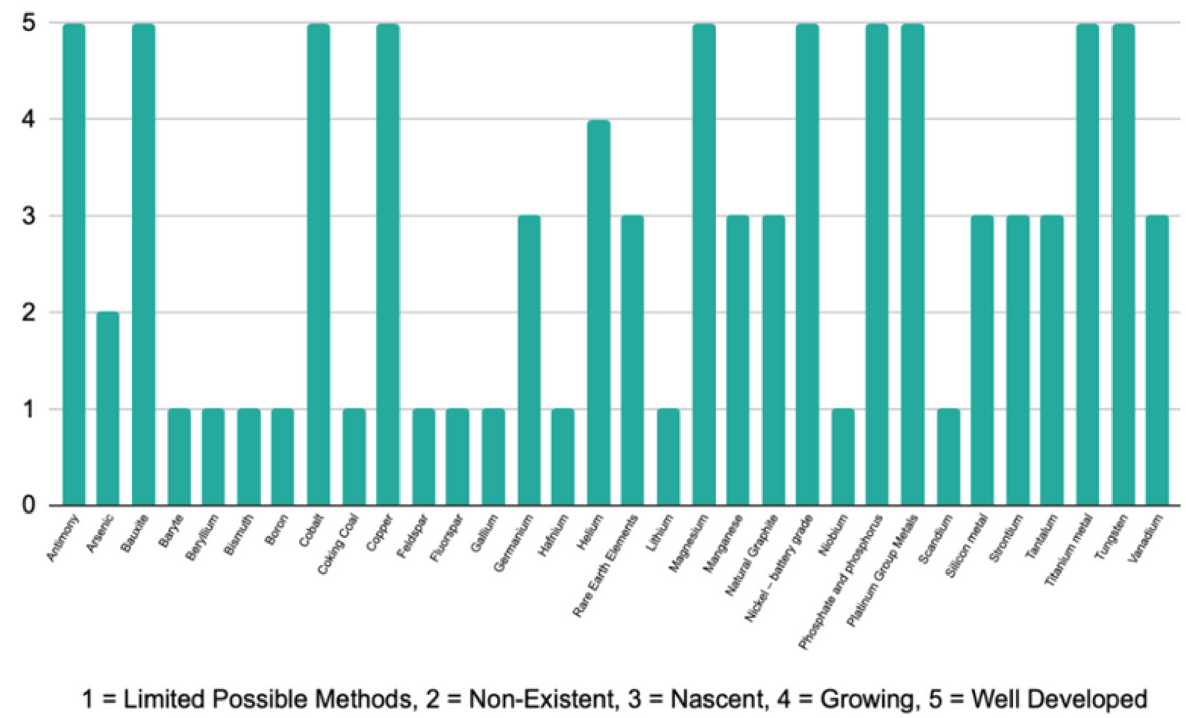


Figure 3: The current state of recycling capabilities and infrastructure across CRMs

Given the limits of recycling laid out above, the ECRMR must pursue supporting circular policies to ensure sustainable supply of CRMs and a reduced environmental impact. The assumption that improved recycling will solve the value chain issues faced by the varied markets of different CRMs is unfounded.

Recycling is the final stage of the circular value chain, where the product has the lowest value before waste, so is by no means the priority for a CE transition. However, the ECRMR is right to target this for specific CRMs, alongside a more integrated system approach of reuse, repair, and remanufacturing infrastructure. Where CRMs could benefit from increased focus on recycling systems, there are a variety of policies that could be harnessed for improved RIR levels.

The recycling segment of the value chain is host to many obstacles. Recyclate must pass from consumers to some form of collection system and then be distributed to processing centres. Here, recyclate is separated into different materials, processed into an acceptable quality for reuse, then redistributed to producers. Therefore, CRMs in the consumption phase require:

- A valid collection system,
- Separability from other materials,
- Processes to renew CRMs to a sufficient quality,
- Established processing infrastructure.

With this in mind, there are three key policies directly related to recycling infrastructure needed to implement the system imagined by the ECRMR:

- Innovation in recycling processes where CRMs are not currently able to be recycled,
- Investment in collection infrastructure,
- Investment in processing infrastructure.

Collection infrastructure is required in particular for bauxite, baryte, manganese, platinum group metals, and tantalum - where post-consumer collection issues have already been identified. Collection systems should further be focused on post-consumer goods, where recycling levels are significantly lower as consumers can misunderstand recycling requirements, some collection infrastructure is not available for consumers, or there is simply a lack of economic incentives for consumers to exert effort. Typically, new-scrap (or industrial scrap) has a much higher reported recycling rate.

Finally, there still remain major hurdles in understanding the needs of CRMs due to a lack of recycling data. Arsenic, coking coal, battery-grade nickel, niobium, and vanadium suffer from limited data, which in turn restricts the effectiveness of policy recommendations. Thus, the EU should also aim to collect more recycling data, including information on issues faced during the process.

	Effect on output streams	Circular
Collect more recycling data	-	Y
Innovate in recycling processes	*Slows*	Y
Develop collection infrastructure	*Slows*	Y
Develop processing infrastructure	*Slows*	Y

Table 2: Potential recycling policies under the ECRMR

3. Towards a Circular CRM Supply Chain

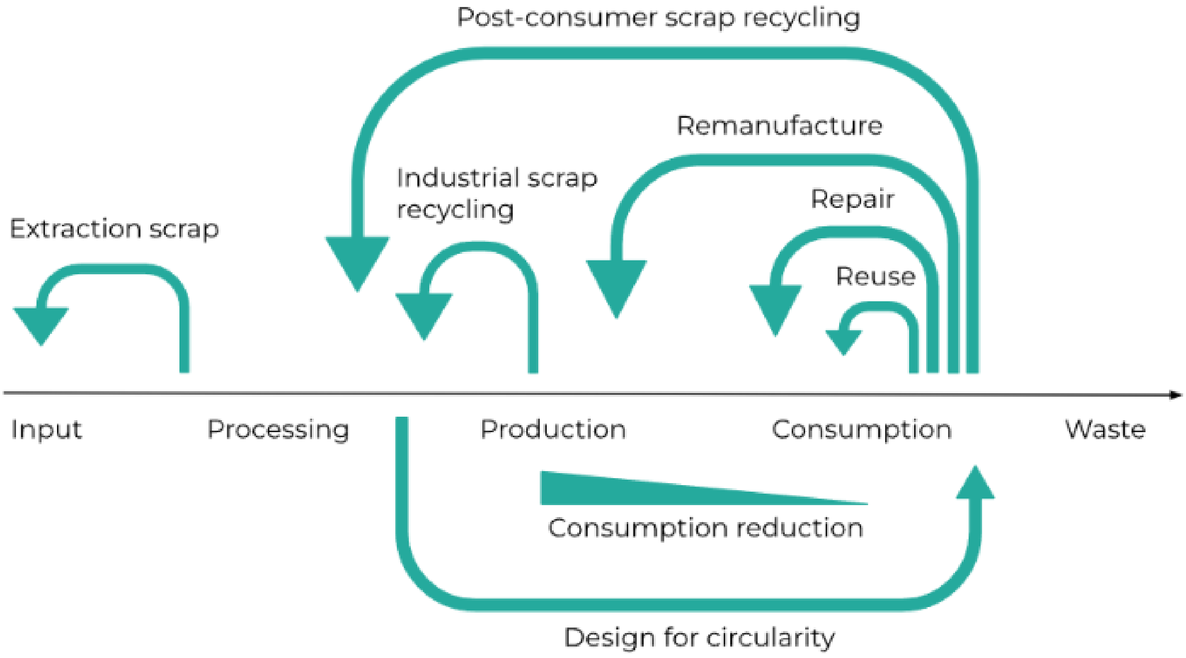


Figure 4: The Circular ECRMR Value Chain

CE principles are fully aligned with the goals of the ECRMR, although only very briefly discussed in the Regulation's supporting documents. The CE attempts to narrow, slow, and regenerate value streams (Bocken et al., 2016). Inputs are narrowed and slowed, while output streams are regenerated, ensuring that waste streams are stopped. The ECRMR searches for a sustainable supply chain, which is only possible with regenerative output streams. It looks to reduce its reliance on CRM imports, which can equally be limited by recycling secondary material into the value chain.

The ECRMR does, however, lay out plans for improvements in recycling: the final stage of the circular system with the lowest value retention. To ensure this is effective, upstream circular design principles must be upheld - to ensure separability of materials for recycling, or that materials can even be recycled in the current system. If this is impossible, then circular principles encourage redesign away from problematic and harmful materials.

Below, the 2023 playbook begins, answering the questions: how can the European Commission implement the ECRMR effectively and why is a CE lens required?

3.1 Design for circularity

For many of the CRMs that score 1 (or have “limited possible methods” for recycling) and even some between “non-existent” and “growing”, circular design principles could be the missing piece of the puzzle - substantially reducing EU reliance on primary materials. Where recycling is possible, some CRMs are still at a low RIR level because of how they are used within a product. CRMs that are dispersed or used in thin layers or wafers make recycling processes incredibly difficult, rendering the process uneconomic.

Most concerningly, this includes many applications of CRMs in electronic goods. The green and digital transition will only increase reliance on these goods and materials, so it is crucial that design solutions are developed before output streams skyrocket. Beryllium is used chiefly in electronic and communications equipment and components in aerospace and defence goods (SCRREEN, 2023). As beryllium is contained mostly in very small components, making up only a tiny portion of the goods’ materials, it is not physically or economically feasible to retrieve the metal as it stands. However, there are no chemical barriers to recycling beryllium. According to Freeman (2016), 94-100% of new scrap is returned to producers and recycled. Industrial waste, therefore, is perfectly recyclable and faces few barriers in infrastructure or chemistry. The only thing left is to improve final product design to enable post-consumer recycling with modularity.

More extensive policies for design for circularity include: modularity, separability of materials or flexible design, proper material choice, material consumption at the producer stage, and product life extension.

Where recycling systems only have “limited possible methods”, this is often because CRMs in this category are dissipative. For example, a significant proportion (23%) of boron consumption is accounted for by fertilisers, chemicals, preservatives, and fire retardants (European Commission, 2023g). In these uses, boron cannot be retrieved - which eliminates any possibility of recycling under the ECRMR or of any other supporting circular processes. Some platinum group metals are used in medical applications, often ending life as contaminated goods that cannot be reused or retrieved (SCRREEN, 2023). CRMs must be designed out of these products. There is no possibility here of sustainable consumption, so all circular and ECRMR efforts are hindered by physical possibilities.

Producer consumption reduction and product life extension often work in opposite directions. The former aims to reduce material usage per good produced, therefore reducing the overall quantity of a material utilised during the production process of a batch of goods. The latter, however, aims to prolong the life of the product, reducing the amount of times production of each batch of goods is required.

This often requires more initial material input to improve the durability of, for example, a washing machine. Commercial washing machines are much larger, more durable, and last longer. If the goal was to move to economy-wide communal washing practices, then durability is much more desirable. However, if each household still requires a washing machine, then a reduction in producer consumption could have much greater net benefits, especially when combined with designing for repair and recycling.

	Effect on output streams	**Included in the ECRMR**
Material Choice: design away from CRMs, recycled input rate requirements	*Shifts*	N
Redesign for circularity: modularity requirements, material separability requirements, recyclability requirements	*Slows*	N
Producer consumption reduction (upstream)	*Narrows*	N
Product life extension	*Slows*	N

Table 3: Design policies across the circular economy and the ECRMR

Case Study: Designing away from Lithium use

Designing away from any material requires significant investment in research and innovation, but it is often possible, even in a market facing one of the highest predicted demand expansions: lithium. In 2022, 60% of global demand for lithium came from the electric vehicle battery market (IEA, 2023). Set to grow exponentially over the next decade, the battery market will become even more important for lithium demand and prices. In the same year, lithium was used in 90% of batteries (both lithium nickel manganese cobalt oxide types and lithium iron phosphate). However, nickel cobalt aluminium oxide types made up 8% of the market.

Li-ion batteries are being challenged by other chemistries, such as Na-ion (sodium-ion) batteries. As the, currently, only viable alternative to lithium-based batteries, Na-ion batteries represent a clear way forward, away from CRM reliance in this market. Harnessing this chemistry fully could stabilise prices of batteries in the long run as demand increases. Na-ion batteries are even currently sold at lower prices than Li-ion batteries. Nevertheless, Na-ion batteries face more limited energy densities and require more research (IEA, 2023).

From the above, it is obvious that trading off one battery type for another shifts demand for CRMs internally, not outside of strategically and economically important materials. For example, if lithium iron phosphate types represented the entire battery market, they would utilise almost 1% of agricultural uses of phosphorus (IEA, 2023). Designing away from CRMs is not always a catch-all, but research focus on these markets can bring about new methodologies that could solve some pressing issues facing CRMs.

3.2 Reuse

Reuse is the beginning of the downstream circular value chain. This is the first cycle of the CE, preserving the greatest possible value in the product's life cycle. Consumers pass on goods that are still functional in their primary function - maintaining all value added from the production process. It calls for consumer sharing, following human traditions of passing on goods to extend their life.

Consumer re-education can begin the reuse cycle locally, through personal connections, or within the reaches of a postal system, through online resale platforms. To capture the full potential of reuse, however, the CE must be formalised.

Three reuse models that could be of use here:

- Consumer ownership - where a single consumer owns a good and uses a reuse system to rent it to others (this often extends product life through back-to-back use);
- Community ownership - where a community owns a good and members of the group can use the good (this often improves utilisation through simultaneous use);
- Producer ownership - where the producer of a good maintains ownership and consumers rent the good (this often improves utilisation through simultaneous use).

At the national and international level, reuse under consumer and producer ownership has proven results. Community ownership works well with strong personal ties and requires commitment from all parties - which is difficult to generate with top-down policy making. However, if this theory can be extended to communities at the local authority level, there is room for EU policy making.

Besides encouraging and educating on these circular business models, the EU could support reuse systems by improving finance for reuse start-ups and developing property rights legislation in line with new concepts of ownership. Reuse infrastructure, such as a well-developed postal system and collection schemes are also crucial here.

Reuse systems work best when collection and redistribution is easy. B2B shipping would provide an excellent, so far untapped, opportunity for reuse as processes are almost identical every time. The same reusable packaging could be sent back to the original producer to then be used on another shipment of the same good to the same business. As transport links are also already developed B2B, CRMs in these situations could see improvements in retention in the near future.

	Effect on output streams	**Included in the ECRMR**
Consumer education on reuse business models	*Slows*	N
Improved finance for reuse start-ups	*Narrows*	N
Property rights for new concepts of ownership	*Narrows*	N
Reuse infrastructure: postal system development, collection schemes	*Narrows and slows*	N

Table 4: Reuse policies across the circular economy and the ECRMR

Reuse is a priority for goods containing CRMs that cannot currently be recycled but can be retained in its original form. CRMs dissipated within a good (not through use like fertiliser) could benefit from reuse to maintain the CRM as far as possible. Feldspar, for instance, could be retained through reuse of its glass forms. CRMs with low RIR levels due to their dispersion within goods could also be retained through reuse.

Reuse could also slow output streams in CRM value chains with long product lives. For example, aluminium (or bauxite on the CRM list) could benefit from reuse in its longer term uses: consumer durables, building materials, or (in its compound form, aluminium hydroxide) in waterproof fabrics.

In contrast, CRMs, such as silicon metal, used in high-innovation industries could be better utilised in its original metal form, making reuse unsuitable until product turnover slows.

Overlapping product sharing, seen in the case study below, could be more beneficial in these industries - improving utilisation, not necessarily product life.

Case Study: Car Sharing in Copenhagen

LetsGo in Copenhagen is a good example of a producer ownership model - where customers rent a car as needed, without ever owning it. LetsGo attempts to solve the issue of vehicle underutilisation. 40% of their customer base stated they would own their own car if not for the service, when surveyed (LetsGo, 2023).

While the company handles repairs, parking, and taxes, its customers simply pay for a membership to access the cars. For each trip, customers reserve a car according to their needs - from a standard small car or an SUV, to a van or 9-person bus. Cars can be rented for a few hours or up to a few weeks at a time. After reserving, customers find their car in a specific parking spot - allowing the company to keep track of available cars, and for customers to have a guaranteed spot when they return from their trip.

This ownership model not only solves issues of owning a car in a city for the consumer, but also for wider society. Over-demanded parking spaces are avoided by improving per unit utilisation, leaving more urban space for social use. A reduced stock of cars allows for easier transition to greener technologies (such as electric cars) as they become economical, reducing CRM turnover. Even the central ownership model improves the likelihood of repairs. As the stock of cars now translates into profit, economic incentives are aligned with timely repairs - which help preserve the vehicle at its highest value, rather than reduce the car to scrap through misuse and procrastinated repairs.

Plenty of CRMs could be reused by scaling this car-sharing model. In electric vehicles, CRMs found in batteries (lithium, nickel, cobalt, and potentially phosphorus) could be retained for far longer. More generally, copper and aluminium could be preserved in a longer use-life.

Nevertheless, this requires sufficient stock to cater to time-sensitive demand - such as commutes to and from work. In cities without robust public transport infrastructure, for instance, the necessary stock level of cars is much higher, which could prove uneconomical.

3.3 Repair

Repair is part of the use-life of a product that has been neglected for many everyday goods. Cars and bikes, for example, are regularly repaired, yet products such as clothes, televisions, and mobile phones are often thrown away at the first sign of decline. The CE aims to bring all goods back under the repair umbrella.

Repairing a good is cost-efficient by restoring a good to functionality at a much smaller price than purchasing a new product. It also saves on repairing more significant issues later in the good's use-life. Repairing shoe heels, for instance, in the short run could stop the sole from wearing through completely.

To bring repair to the forefront of the EU economy, infrastructure must be developed. A repair system crucially needs collection points, trained labour, and social awareness of what can and cannot be repaired. The development of local repair shops is required to provide services at a base level. This could be supported in the private and public sector, through education or mutual aid schemes. Given the economic pressure on CRMs (especially on SRMs) and the lack of mainstream repair examples for key CRM markets, the EU should aim to incorporate education and repair infrastructure at the local authority level. This will utilise public sector leadership to break through consumer and producer mental barriers.

However, there are plenty of obstacles in this value chain. Incentives to differentiate products and encourage greater consumption in recent years have created an economy rife with planned obsolescence and obstructive repair requirements. The EU must take a strong stance on repair legislation - pushing forwards a Right to Repair and more robust intellectual property framework to allow repairs of strategic goods.

The ECRMR already includes a call for Digital Product Passports (DPPs) in permanent magnets. The CE extends this to industries with a need for product information. For other parts of the CE life cycle, DPPs could provide helpful recycling information or allow monitoring of RIR levels for taxation. In repair, DPPs are critical in passing on repair information - such as repair histories and producer instructions. The current conception of DPPs includes blockchain, which could allow producers to protect sensitive product information from competitors while enabling specialised repair.

	Effect on output streams	**Included in the ECRMR**
Digital Product Passport	*Slows*	Y
Local Authority leadership in repair schemes	*Slows*	N
Strong Right to Repair legislation	*Slows*	N

Table 5: Repair policies across the circular economy and the ECRMR

As before, CRMs with dissipative uses cannot be supported by repair systems. Many other CRMs could benefit from Local Authority leadership in repair schemes. Although, this policy sits at the consumer level, so will likely have the greatest impact in small, non-complex, consumer goods.

DPPs are more useful for CRMs incorporated into complex goods that are outside of reparable infrastructure with developed human capital and often more homogeneous components to restore - for example, permanent magnets, complex technology, and aeronautical products. Tantalum is often used in capacitors for EEE and super alloys (SCRREEN, 2023). Therefore, it is unlikely the component containing tantalum will be repaired directly. However, it is crucial that the whole good is repaired to retain tantalum which is so far uneconomic to recycle.

Right to Repair legislation will also likely impact CRMs in more complex goods. Competition and intellectual property rights are likely strongest in developed EEE markets, so will see the greatest shift in behaviour following a more robust legal structure to support repairs.

Case Study: The new EU Right to Repair Proposal

The EU is continuing to develop its CE legal framework with a Right to Repair proposal. The proposal includes requirements to shift producer guarantees towards repair instead of replacing goods with new products. Under this, producers would also have to provide options for repair after the length of guarantee policies. The proposal overall is focused mainly on household electronics: from washing machines to vacuum cleaners, and in the future phones and tablets (European Commission, 2023f).

This is a great step forward in legislating for the CE - pushing producer behaviour through legal requirements instead of underestimated economic incentives. However, the proposal does not cover anti-repair practices, which can include the use of obscure tools for construction or the intentional avoidance of modularity in design. Right to Repair legislation must be strengthened, especially in industries using CRMs, to close the loop. Out-of-industry repair shops are critical in providing one-stop-shop repair services, which improve the likelihood of consumers opting-in to this CE cycle and shift consumer preferences away from companies that intentionally obstruct repair. Therefore, the EU's Right to Repair proposal must look to include more private sector solutions, supporting external repair shops and not simply internal guarantee procedures.

Right to Repair EU also highlights that the proposal does include an acknowledgement of the costs of repair, especially in underdeveloped markets with limited economies of scale (Right to Repair EU, 2023).

With repairs still reliant on the producer, companies could make repairs prohibitively expensive to circumvent the EU proposal. Greater access to finance through EU loans and/or grants could help to tackle this issue, allowing new entrants to afford high set-up costs and bargain down prices through competition.

Beyond the legislation, however, the EU have also proposed a set of new rights including: producer obligations to inform consumers of what they are required to repair themselves and repairer obligations to provide information on quotes. This stands alongside two new information services: an online matchmaking service between consumers and repairers, and a European quality standard for repairs (European Commission, 2023f).

3.4 Remanufacture

Once goods have passed through a reasonable use-life, individual repairs might no longer be sufficient for a working good. Remanufacturing aims to restore goods and their components to an "as-new condition" (Ellen MacArthur, n/d).

To achieve "as-new condition" for a specific good, more system-based policies are required to cover the entire value chain and consumer base. Although very similar to repair, remanufacture could also be supported by Product as a Service (PaaS) business models. Consumers here purchase the service, not the product from the producer.

	Effect on output streams	Included in the ECRMR
Product as a Service finance support	*Slows and narrows*	N

Table 6: Remanufacture policies across the circular economy and the ECRMR

The same CRMs that could benefit from repair could also see greater supply stability from remanufacture policies. The only extension in PaaS models is that it requires a concrete good that will be required long term. This could provide key benefits in the battery market: where, although innovation and turnover is high, the battery itself will be used over a long time horizon. PaaS could therefore allow continued innovation while old components are remanufactured into new products. The EU can encourage this private sector shift with improved financial support for start-ups or for companies adapting a product line.

Case Study: Philips Light-as-a-Service

For example, one of Philips' products provides the service of light, not just a single lightbulb. As bulbs require repair or complete remanufacture, Philips retrieves the product and replaces it with one in an "as-new" condition. Their Light-as-a-Service reduces maintenance costs by 60% and ensures no waste ends up in landfill - instead recycling all luminaries at their end-of-life avoiding consumer confusion, mistakes, or inconvenience (Signify, n/d).

3.5 Consumer Behaviour

Consumption reduction could still generate further benefits for the EU in CRM management: both in creating a streamlined input demand and in achieving greater circular-based behaviours. The CE aims for a narrowed, slowed, prevented, and regenerated value chain (Bocken et al., 2016). The simplest way to narrow, slow, and prevent waste streams is to reduce consumer demand. Oger and Watkins (2023) highlight the lack of focus on consumption reduction in the ECRMR. Worryingly, the Regulation attempts to stabilise supply chains without attempting first to stabilise consumption levels, which are set to increase dramatically in the near future.

DPPs can be used here to support circular consumer decisions. Labelling requirements (including criteria such as recyclability, recycled material content, reparability, and hazardous substance content) could be stored within DPPs and inform consumer decisions. Combined with consumer education, this can help drive private sector behaviour through market preferences.

Although less specifically for CRM use, Pay-As-You-Throw charges on household waste, which will be implemented in Slovakia in 2024, could further develop circular consumer behaviour (European Environment Agency, 2023). By realising the realities of waste costs in per-unit taxes, the EU could shift consumers away from waste streams and into other circular cycles.

	Effect on output streams	Included in the ECRMR
Consumption reduction education	*Slows and narrows*	N
Labelling requirements	*Shifts*	Y
Tax on household waste	*Narrows*	N

Table 7: Input policies across the circular economy and the ECRMR

Consumer behaviour focuses, however, solely on consumer goods in mainstream society. For CRM uses in the public sector and academia, tailored consumption education must be carried out. For example, where titanium is used in aeronautics, individuals cannot influence the speed or volume of CRM use, so consumer education will have minimal effects.

4. Policy Recommendations

While the ECRMR's recycling initiatives could yield greater supply chain stability in the future in some CRMs, it is clear that this will not be the case for many. The varied nature of the CRM list - from materials used in dissipative fertilisers, to metals with complex technological uses, to more common metals used in a variety of goods and infrastructure - means that a one-size-fits-all policy will not succeed. With this in mind, the tables below set out key policy recommendations for each CRM, with ECRMR policies supplemented by more rigorous CE practices.

Table 8: Circular Economy Policy Recommendations by CRM

	CRM	Antimony	Arsenic	Bauxite	Baryte	Beryllium	Bismuth	Boron	Cobalt
	End-of-Life Recycled Input Rate (%)	28	0	32	0	0	0	1	22
	Main use	Flame retardants Defence applications Lead-acid batteries	Semiconductors Alloys	Lightweight structures High-tech engineering	Medical applications Radiation protection Chemical applications	Electronics equipment automotive, aero-space, defence	Medical applications Low-melting point alloy Solid rocket propellant	High performance glass Fertilisers Permanent magnets	Batteries Super alloys Catalysts Magnets
DESIGN	Design away from CRM				X		X	X	X
	Redesign for circularity	X	X	X		X		X	X
	Producer consumption reduction					X			
	Product life extension	X	X	X				X	X
REUSE	Consumer education on reuse business models	X	X	X		X			X
	Finance for reuse start-ups		X	X		X			X
	Property rights for new concepts of ownership		X	X				X	X
	Reuse infrastructure: collection schemes, developed postal system	X	X	X		X			X
REPAIR	Digital Product Passport		X	X		X		X	X
	Local authority repair schemes		X	X					
	Strong Right to Repair legislation		X	X		X			X
REMANUFACTURE	Product as a Service finance support	X	X						X
CONSUMER BEHAVIOUR	Consumption reduction education	X	X	X					X
	Labelling requirements		X	X					
	Tax on household waste		X	X					
RECYCLING	Produce recycling data		X						
	Innovation in Recycling Processes	X	X					X	
	Recycle - processing infrastructure								X
	Recycle - collection infrastructure	X		X	X	X			X

	CRM	Coking Coal	Copper	Feldspar	Fluorspar	Gallium	Germanium	Hafnium	Helium
	End-of-Life Recycled Input Rate (%)	0	55	1	1	0	2	0	2
	Main use	Coke for steel Carbon fibres Battery electrodes	Electrical infrastructure	Glass including fibreglass Ceramics	Steel and iron making Refrigeration and Air-conditioning Aluminium making	Semiconductors Photovoltaic cells	Optical fibres and Infrared optics Satellite solar cells Polymerisation catalysts	Super alloys Nuclear control rods Refractory ceramics	Controlled atmospheres Semiconductors MRI
DESIGN	Design away from CRM	X		X	X			X	
	Redesign for circularity					X	X		
	Producer consumption reduction								
	Product life extension		X	X		X	X		
REUSE	Consumer education on reuse business models			X		X			
	Finance for reuse start-ups			X		X			
	Property rights for new concepts of ownership			X		X			
	Reuse infrastructure: collection schemes, developed postal system			X		X			
REPAIR	Digital Product Passport					X	X		
	Local authority repair schemes			X		X			
	Strong Right to Repair legislation					X			
REMANUFACTURE	Product as a Service finance support					X	X		
CONSUMER BEHAVIOUR	Consumption reduction education			X		X			
	Labelling requirements					X			
	Tax on household waste			X		X			
RECYCLING	Produce recycling data	X							
	Innovation in Recycling Processes								
	Recycle - processing infrastructure						X		X
	Recycle - collection infrastructure		X						X

	CRM	Rare Earth Elements	Lithium	Magnesium	Manganese	Natural Graphite	Nickel – battery grade	Niobium	Phosphate and phosphorus
	End-of-Life Recycled Input Rate (%)	4	0	12	9	3	16	0	17
	Main use	Permanent Magnets Lighting Phosphors Catalysts Batteries Glass and ceramics	Batteries Glass and ceramics Steel and aluminium metallurgy	Lightweight alloys for automotive, electronics Desulphurisation agent in steelmaking	Steel-making Batteries	Batteries Refractories for steelmaking	Batteries, Steel making, Automotive	High-strength steel and super alloys for transportation and infrastructure High-tech applications	Mineral fertiliser Phosphorous compounds Chemical applications Defence applications
DESIGN	Design away from CRM		X	X				X	X
	Redesign for circularity	X	X			X	X		
	Producer consumption reduction		X		X	X			
	Product life extension	X						X	X
REUSE	Consumer education on reuse business models		X		X	X	X		
	Finance for reuse start-ups		X		X	X	X		
	Property rights for new concepts of ownership	X	X		X	X	X		
	Reuse infrastructure: collection schemes, developed postal system	X	X		X	X	X		
REPAIR	Digital Product Passport	X	X		X	X	X		
	Local authority repair schemes	X							
	Strong Right to Repair legislation	X	X		X	X	X		
REMANUFACTURE	Product as a Service finance support	X	X		X	X	X		X
CONSUMER BEHAVIOUR	Consumption reduction education		X						
	Labelling requirements								X
	Tax on household waste		X						
RECYCLING	Produce recycling data						X	X	
	Innovation in Recycling Processes		X			X		X	X
	Recycle - processing infrastructure	X			X	X			X
	Recycle - collection infrastructure				X				X

	CRM	Platinum Group Metals	Scandium	Silicon metal	Strontium	Tantalum	Titanium metal	Tungsten	Vanadium
	End-of-Life Recycled Input Rate (%)	10	0	0	0	0	19	42	1
	Main use	Chemical and automotive catalysts Fuel Cells Electronic applications	Solid Oxide Fuel Cells Lightweight alloys	Semiconductors Photovoltaics Electronic components Silicones	Ceramic magnets Aluminium alloys Medical applications Pyrotechnics	Capacitors for electronic devices Super alloys	Lightweight high-strength alloys for aeronautics, defence Medical applications	Alloys for aeronautics, space, defence, electrical technology Cutting, mining tools	High-strength-low-alloys for e.g. aeronautics, nuclear reactors Chemical catalysts
DESIGN	Design away from CRM	X		X	X				X
	Redesign for circularity	X	X	X		X	X		
	Producer consumption reduction	X		X					
	Product life extension					X	X	X	X
REUSE	Consumer education on reuse business models	X			X	X			
	Finance for reuse start-ups	X			X	X			
	Property rights for new concepts of ownership	X			X	X			
	Reuse infrastructure: collection schemes, developed postal system	X			X	X			
REPAIR	Digital Product Passport	X	X	X		X	X	X	X
	Local authority repair schemes								
	Strong Right to Repair legislation	X		X		X			
REMANUFACTURE	Product as a Service finance support	X	X	X					
CONSUMER BEHAVIOUR	Consumption reduction education				X	X			
	Labelling requirements				X				
	Tax on household waste				X				
RECYCLING	Produce recycling data								X
	Innovation in Recycling Processes		X	X	X	X			
	Recycle - processing infrastructure			X	X	X	X	X	X
	Recycle - collection infrastructure	X		X	X	X	X	X	

5. Conclusion

This paper has shown that the ECRMR as it stands is insufficient in achieving sustainable consumption and in achieving its less abstract, measurable goals. An awareness of the variety of the CRMs and their uses is not exhibited anywhere within the Regulation's supporting documents, fundamentally harming its potential for large-scale impact. Its focus on recycling as the be-all and end-all of sustainable CRM supply chains leaves significant economic value on the table, and resigns many currently non-recyclable CRMs to landfill.

With this gap in policy identified, the Regulation must provide tailored policies for the realities of individual CRMs and harness the CE as a means of achieving sustainable consumption and supply chains. This paper has attempted to begin this process.

Section 3 sets out five critical policy spaces for a circular ECRMR: design, reuse, repair, remanufacture, and consumption reduction. Outside of the more common CE value streams, a reduction, not a displacement, of consumption is required to engender sustainable supply through sustainable demand. Further, this paper calls for EU-wide support for CRM innovation in use, recycling processes, and ownership models.

While the ECRMR makes some headway in closing the loop for CRMs, an integrated approach to the CE is crucial. The Regulation does not include the policy commitments laid out in the CEAP or the new CEAP of 2020. Going forwards, policy makers should ensure that regulations in any way related to sustainable consumption utilise the policy structure of the CEAPs as far as possible.

The CRM and SRM list is constantly in flux, following new industries and supply risks. With ever-increasing demand and developing economic trends, there are more at-risk materials on the horizon and it is clear that recycling cannot always be the answer. Therefore, it is critical that the EU develops CE infrastructure as a priority to manage the 2023 CRM list and prepare for the future.

A sustainable supply chain for CRMs cannot exist in a world where global primary resource extraction grew by 400% between 1970 and 2010 (Oberle et al., 2019). It is clear: we need systemic change.

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