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TACKLING THE EU'S DEPENDENCY ON RAW MATERIALS FROM CHINA

A Case Study on Rare Earth Elements and Potentials of the Circular Economy

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Executive Summary for Policy Makers

The demand for raw materials is ever-rising. Increases in general consumption levels and technological developments in IT, green tech and energy generation have boosted international competition for some scarce resources. However, while possible applications are plentiful, supply is tight and concentrated in the hand of few players. Chinese companies in particular have gained an overwhelming market position that allows them to virtually dominate the supply side as monopolies. Given current experiences on the energy market, due to Russia's failure to comply with its contractual deeds, western democracies, and the EU in particular, are assessing new supply chains and possible strategies that might allow them to reduce their dependency on raw material imports from China. The findings presented by the authors of this study take an inventory of the main options that the EU currently has to counterbalance pressure related to growing dependencies. These options include:

→ **diversification** of trading partners and increased **domestic mining activities;**

→ **stock accumulation** and **consumption adaption;**

→ **technological innovation,** allowing for **substitution** and an increase in **resource efficiency;**

→ **restructuring of value chains,** from a linear towards a **circular economy.**

In general, it is reassuring to learn that the EU ultimately has significant potential to become more self-sufficient, and build leverage as a future provider of alternative supply chains. In-stead of relying on ever-new resource inputs for the production of goods, just for them to be discarded at the end of a product's lifetime, the circular approach intends to reuse objects or at least recycle the built-in components or materials wherever possible. However, this potential still requires significant investment in order to be transformed into actually resilient macrostructures, besides the difficulty to achieve political consensus on the matter. Neither is easily achieved. To exemplify the challenges required for such system change, this paper places its focus on the transformation processes towards a circular economy. It suggests to trust in the economic gain that a circular economy, once in place and functioning, promises to deliver for the EU. In the EU alone, a European circular economy could increase resource productivity by 3 percent already by 2030, while generating cost savings of €600 billion a year, alongside the generation of another €1.8 trillion in other economic benefits. Thus, apart from the expected positive effect on resource dependency, there are considerable economic benefits to an increasingly circular economy all across various products' lifecycles as well. Liberal approaches to reducing dependency should bear this benefit in mind and weigh out the long-term stability that circularity brings with it against the short-term costs of having to redesign existent infrastructures and investing heavily into innovation. Simultaneously, liberals will also be aware that considerable challenges have to be taken into account during the transformation process. There is a strong pricing argument that currently favours virgin materials over recyclates, also from a tax perspective. Additionally, there are cultural and regulatory barriers hindering a widespread application of circular methods, at least for the time being. Consequently, strong economic mechanisms are needed in order to buffer short- to mid term costs and delayed benefits. Liberals can build leverage proactively by looking into feasible solutions now to bridge this phase, and place strategic suggestions to set incentives for relevant industries that can deliver the necessary innovation. At both the EU and national level, there already exist numerous legislative initiatives and political goals, which aim to achieve higher degrees of circularity within the economic system. While large successes have yet to materialize, this study discusses some positive examples of viable circular approaches, which target savings in the usage of rare earths. These include, in particular:

→ **Reduce:** By sharing equipment within the society, the need for single units of said equipment decreases. Thus, the amount of rare resources, needed to fulfil a society's needs is also reduced. The growing car-sharing sector may serve as a suitable example.

→ **Reuse:** By repairing or modernizing equipment, the overall lifespan of said equipment can be prolonged. This means that less additional resources are needed, in order to replace a product in its entirety. Instead, only the raw materials needed for the adaptions have to be utilized. Some companies lease and refurbishment services are already taking this approach further towards the circular economy.

However, there are also approaches that allow recovery of the materials utilized after a product's lifespan.

→ **Recycle:** Using modern and innovative technologies, recycling efforts may very well be more fruitful and less costly in the future. Thus, future industries might have access to much higher quantities of reclaimed resources, instead of solely relying on virgin materials.

With the global power balance shifting and dependencies increasing also in all other sectors, the EU prepares itself best giving leeway to the broadest possible variety of measures to counterbalance dependency. Whether or not the EU economy is already well set up to meet the EU Commission's circularity targets until the mid-2030s in their intended scope, a strong case for more circularity is indicated already now to take pressure off classic supply chains and thus free up political space for manoeuvre simultaneously.

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1. The Big Picture: Raw Material Dependency in the EU

1.1 Steady Supply Guaranteed by Global Markets

For many years, the EU and its member states, or rather, its companies have successfully satisfied their demand for raw materials on global markets. Other strategies to meet demand and increase raw material security have been pursued with limited ambition. They have been politically unpopular and/or complex and costly, which was considered unfavourable in the political environment of the past. The EU has benefited from this strategy, with a prospering economy while at the same time largely outsourcing the negative side effects of its high raw material consumption, such as the environmental damage arising from mining and processing of primary raw materials. The price paid are high levels of raw material dependencies. Over the last decades, the EU has continuously had a trade deficit for raw materials, both in value and in weight.[1] The trade deficit is highest among metals and minerals (€32 billion),[2] and particularly high for several raw materials that are critical to the EU economy.

The problem is not all new: rising and more volatile commodity prices due to strong economic growth between 2002 and 2008 have sparked policy initiatives in the EU and some of its member states.[3] The EU Raw Materials Initiative of 2008, for example, aimed to set the right framework conditions to foster supply from European sources, reduce consumption, and decrease relative import dependency through efficiency increases and recycling. Most importantly, its goal was to tackle unfair trade practices and ensure access to raw materials under the same conditions as industrial competitors.[4] While the new mineral policies showed positive effects, such as an increase in productivity for most member countries' mineral sectors,[5] it can be argued that it was not enough to increase raw material security. To illustrate, the first ever list of critical raw materials,[6] which dated back to 2011, included 14 raw materials, while the fourth list, published 2020, included 30 critical raw materials. This increase is partly due to a larger number of materials being covered in the assessments over the years.[7] However, it also represents an increase in quantity and variety of materials needed for modern high-tech products, which was not matched with efforts to increase EU raw material security. All of this combined shows an increase in the EU's vulnerability concerning raw material supply. "Criticality" is thereby mainly determined by economic importance, supply risk, and a strongly restricted variability of sources:[8] or seven to up to eleven of those critical raw materials, China is one of the main suppliers to the EU, according to the list of critical raw materials from 2020.[9]

For single EU member countries, criticality can be even more significant: the German Raw Materials Agency (DERA), for example, counts 27 high-risk raw materials, 25 of which being imported from China as the biggest producer.[10] This dependency is expected to rise even further in the future due to global green energy transitions.

1.2 China's Strategic Raw Materials Policy

The European development stands in stark contrast to China, which has large raw material deposits and a strong mining industry. A study showed that between 2002 and 2018, China kept 14.5 percent of the total global extraction of eight different types of base metals. During the same time, the EU's own percentage shrunk from 4.1 to 2.6 percent.[11] China's production efforts become even more impressive when looking at its refining capacities: for the abovemen-tioned raw materials, refinery production rose from 17.7 to 44.5 percent between 2002 and 2018. Meanwhile, the EU's decreased from 15.9 to 9.1 percent. Today, China holds around half of the world's refinery capacities[12] and is strategically well positioned for the expansion of renewables and the development of technological key sectors.

Furthermore, Chinese-owned companies have invested heavily in mining in Africa and elsewhere in the last two to three decades to secure metals and minerals for their economic, climate and development goals. While China's control of African and global mining may not be as big as media coverage may indicate,[13] its investments have been very targeted to raw materials needed for future technologies. For example,

1 Eurostat 2022. Extra-EU trade in raw materials. Link: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Extra-EU_trade_in_raw_materials&oldid=562723#Raw_materials_by_product_group (retrieved on 09.08.2022).
2 Ibid. Eurostat publishes "Rubber, metal and minerals" in one category, with imports amounting to almost 60 billion Euro and exports 27.7 billion Euro.
3 Policies were first introduced by Germany, Finland, (the United Kingdom), Portugal and Greece.
4 European Commission 2008. Communication "The raw materials initiative – meeting our critical needs for growth and jobs in Europe", COM(2008) 699, p. 5f.
5 Janikowska, Olga / Kulczycka, Joanna 2021. Impact of minerals policy on sustainable develop-ment of mining sector – a comparative assessment of selected EU countries, in: *Mineral Economics* 34, 305-314, p. 305.
6 European Commission 2011. Communication "Tackling the challenges in commodity markets and on raw materials", COM(2011) 25, p. 21f.
7 83 individual materials in the 2020 assessment in comparison to 41 analysed for the first assessment 2010/2011. See *European Commission 2014*. Communication "On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative", COM(2014) 297, p. 2.
8 European Commission 2020. Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability, COM(2020) 474, p. 2.
9 For seven of the critical raw materials (CRM) China is listed as a main EU supplier, for five of the 30 CRM, there is no data of the main EU sourcing countries, but China is for four of those one of the main global producers.
10 DERA – Deutsche Rohstoffagentur in der Bundesanstalt für Geowissenschaften und Rohstoffe 2021. DERA-Rohstoffliste 2021. DERA Rohstoffinformationen 49: 108, S. 5.
11 Perger, Johannes 2020: Wirtschaftsmächte auf den metallischen Rohstoffmärkten. Ein Vergleich von China, der EU und den USA. DERA Rohstoffinformationen 46: 33 S. 9. The raw materials considered in that study are the base metals aluminum, lead, copper, nickel, zinc, tin, iron and steel.
12 Presentation at BGR Rohstoffkonferenz.
13 Ericsson, Magnus, Löf, Olof, Löf, Anton 2020. Chinese control over African and global mining – past, present and future. Mineral Economics, 33:153-181.

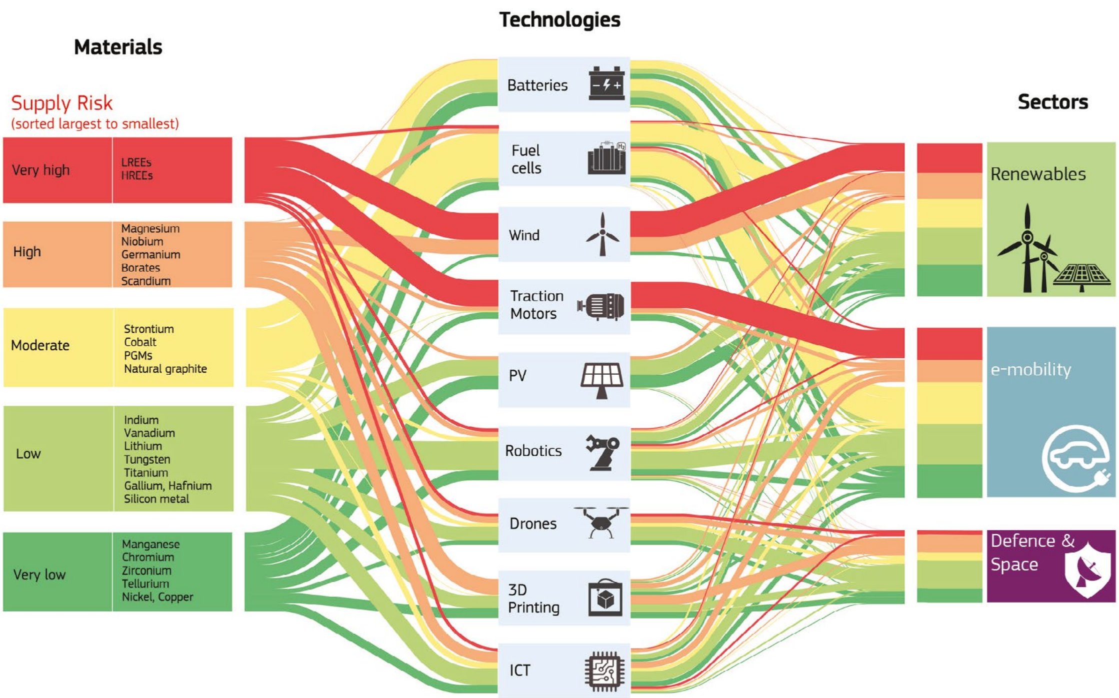
Chinese-backed companies have owned or had financial involvement in 15 out of a total of 19 cobalt mines in the Democratic Republic of Congo at the beginning of 2022.[14]

1.3 Supply Concentration: A Risk to Commodity Supply and Prices

The Covid-19 pandemic has already exposed supply chain bottlenecks in global raw materials supply, but in general, dependency may at any time become a political weapon in case of a conflict. Europe's vulnerabilities, arising from its dependencies on fossil fuels supplied by Russia, have been painfully exposed in the wake of Russia's war against Ukraine. The threat of supply disruptions for critical raw materials were already looming in the 2019 trade conflict between the USA and China.[15] In 2020, China introduced its "Export Control Law" for sensitive materials and technologies. While the latter was widely understood to be a response to the expanding export controls of the USA, some analysts already saw the potential for a rare earth elements ban.[16] In 2021 this law was followed by a draft regulation on the management of rare earth elements, which led the European Commission to submit comments "recalling that any measures to be taken should comply with China's obligations and commitments un-der the World Trade Organisation".[17] A decade ago the US, the EU and other governments had still been able to successfully challenge export limits imposed on rare earth elements by China in a WTO complaint. However, even back then it took it three years until quotas were successfully scrapped.[18] In the meantime, the WTO has been weakened and its dispute settlement is currently not fully functioning.[19] This makes conflict settlement via the WTO a lot less likely. Without doubt, dependencies would become a significant problem for the EU and the entire Western world in a possible major conflict over Taiwan.

But even in a scenario where all geopolitical conflicts were solved diplomatically, the unbalanced concentration of supply sources and dependencies would pose a major risk. Increases and volatilities in prices, or actual supply shortages, are major threats to the EU economy, especially with regard to future technologies. Critical raw materials, including light and heavy rare earth elements (LREEs and HREEs[20]), are needed in everything from smartphones, to 3-D printing, and robotics. They also form the basis of a variety of key products and technologies that are essential for the European Union's transition to a green economy, such as electric vehicles and renewable energy technologies.[21]

Figure 1 | Material Flows through Key Technologies



Source: European Commission 2020. Critical materials for strategic technologies and sectors in the EU - a foresight study.

14 The New York Times 2022. Chinese Company Removed as Operator of Cobalt Mine in Congo. Link: https://www.nytimes.com/2022/02/28/world/congo-cobalt-mining-china.html; The Economist 2022. How Chinese firms have changed Africa. Link: https://www.economist.com/special-report/2022/05/20/how-chinese-firms-have-changed-africa.

15 Forbes 2019. China Threatens To Cut Rare Earths Supplies To The U.S. -- Bad Idea. Link: https://www.forbes.com/sites/panosmourdoukoutas/2019/05/16/china-threatens-to-cut-rare-earths-supplies-to-the-us-bad-idea/?sh=3f75821d7486.

16 Nikkei Asia 2020. China passes export control law with potential for rare-earths ban. Link: https://asia.nikkei.com/Politics/International-relations/US-China-tensions/China-passes-export-control-law-with-potential-for-rare-earths-ban.

17 European Parliament 2021. Parliamentary Question E-002460/2021(ASW). Link: https://www.europarl.europa.eu/doceo/document/E-9-2021-002460-ASW_EN.html#def1.

18 The New York Times 2015. China Drops Its Export Limits on Rare Earths. Link: https://www.nytimes.com/2015/01/06/business/international/china-drops-its-export-limits-on-rare-earths.html.

19 BDI 2022. The Crisis of the WTO. Link: https://english.bdi.eu/article/news/the-crisis-of-the-wto/.

20 **L**ight **R**are **E**arth **E**lements (LREE); **H**eavy **R**are **E**arth **E**lements (HREE).

21 European Commission 2022. Second indepth review of strategic areas for Europe's interests. Link: https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/european-industrial-strategy/second-depth-review-strategic-areas-europes-interests_en (retrieved on 01.08.2022)

In the following we want to present strategies to reduce raw material dependency in the EU (chapter 2) zooming in on the role the circular economy can play (chapter 3). In the final chapter, we will present a few concrete examples of how the EU can reduce its rare earth elements dependency on China with a focus on reducing, reusing, and recycling solutions (chapter 4).

2. Decreasing Dependencies: Strategies for the EU

The main strategies to decrease raw material dependency are diversification, mining, substitution, increasing efficiency, building up reserves, sufficiency, and the circular economy.

In the EU, raw material supply is mainly in the hands of the economy, meaning that **diversification** is also mainly the responsibility of companies. Raw materials are traded on the market, and as long as the market functions, this is the preferred state by companies. They know their raw material demand and the procurement markets better than governments.[22] However, diversification of supply is difficult for companies: for many materials, the market is highly concentrated, but even if different suppliers exist, diversification of suppliers is time-consuming and costly,[23] which would reduce companies' competitiveness. Supply chain disruptions in recent years have led to a greater discussion about the role the EU could play. The EU added an Action Plan to their last List of Critical Raw Materials which included two related actions: the launching of an industry-driven European Raw Materials Alliance (ERMA)[24] that should "work on diversifying supply" and the development of strategic international partnerships.[25] Partnerships with Canada and Ukraine were established in 2021, and partnerships with Africa are being fostered,[26] with the use of Horizon Europe Funding.[27]

Experts have long argued that Europe needs to increase its **mining** capacity to reduce raw material dependencies, leading to the 2nd pillar of the EU raw material initiative "sustainable supply of raw materials within the EU."[28] While Europe is resource-rich, not all critical raw materials can be found on the continent and known deposits could not satisfy full demand. Nonetheless, 11 of the 30 critical raw materials on the EU list (2020) can be found in European deposits, including lithium, natural graphite, and rare earth elements,[29] with further materials recoverable as by-products. However, in the past, Europe has seldom mined its riches – partly because European sites are smaller and harder to exploit and environmental standards are high, adding to the costs, but often also due to the resistance of civil society to mining – or even exploration.[30]

Building up reserves is yet another tool in the box. While it may not solve the problem at its roots, it smoothes out temporary supply shocks or buys time in case of supply stops. Stock keeping increases costs and is not an easy option for some materials (base metals, e.g. oxidise or corrode quickly), companies have therefore focussed on just-in-time production in the past.[31] Some countries – China and the USA, but also France and Great Britain among others – have reserves of strategic metals. The European Commission is currently examining options for strategic stocks.[32]

Raw material **substitution** is primarily understood as the replacement of one material with another. Substitution often takes place as alternative materials become cheaper or provide specific functions. Next to material substitution, technological and functional substitution are other types of substitution. With regard to critical raw materials, substitution is viewed as an important strategy to reduce dependency and is receiving and has received research funding in the EU in recent years.[33] High raw material prices and additional factors, such as the problematic reputation of mining certain materials, have also brought companies to invest heavily in the search for alternatives, e.g. for cobalt. Panasonic, which is Tesla's main battery cell supplier, has been reporting great advances toward the "cobalt-free battery".[34]

22 Matthias Wachter, BDI cited from Düngefeld, Leonie 2022. Kritische Rohstoffe: Sollte Europa Reserven anlegen? Link: https://table.media/europe/analyse/kritische-rohstoffe-sollte-europa-reserven-anlegen/?utm_source=capital&utm_medium=rekoop&utm_campaign=et_capital_koop_4ub&utm_content=kritische_rohstoffe__sollte_europa_reserven_anlegen_.
23 Financial Times 2020. Why supply chain diversification isn't all that easy. Link: https://www.ft.com/content/0e34387f-2a52-47f7-837d-a429ff555ea6.
24 European Raw Materials Alliance 2022. Link: https://erma.eu/workstreams/.
25 European Commission 2020. Action Plan on Critical Raw Materials. Link: https://ec.europa.eu/docsroom/documents/42852.
26 European Commission – Joint Research Center (no date). Africa Knowledge Platform. Raw Materials. Link: https://africa-knowledge-platform.ec.europa.eu/topic/Raw-Materials.
27 European Commission 2021. Building EU-Africa partnerships on sustainable raw materials value chains (CSA). Link: https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/topic-details/horizon-cl4-2021-resilience-01-05.
28 European Commission 2021. Sustainable supply of raw materials from EU sources. Link: https://single-market-economy.ec.europa.eu/sectors/raw-materials/policy-and-strategy-raw-materials/sustainable-supply-raw-materials-eu-sources_en.
29 Lewicka, Ewa, Guzik, Katarzyna, and Galos, Krzysztof, "On the Possibilities of Critical Raw Materials Production from the EU's Primary Sources", Resources, vol. 10, no. 5 (2021): 50, p. 1. The source counts 29 CRMs.
30 Ibid. pp. 12f.
31 Düngefeld, Leonie 2022. Kritische Rohstoffe: Sollte Europa Reserven anlegen? Link: https://table.media/europe/analyse/kritische-rohstoffe-sollte-europa-reserven-anlegen/?utm_source=capital&utm_medium=rekoop&utm_campaign=et_capital_koop_4ub&utm_content=kritische_rohstoffe__sollte_europa_reserven_anlegen_.
32 Ibid.
33 European Commission 2022. DG GROW homepage – Critical raw materials. Link: https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en
34 Panasonic Group 2022. Evolving Energy Solutions to Contribute to a More Sustainable Society. Link: https://news.panasonic.com/global/stories/1011.

However, some materials, such as Lithium, have proven difficult to substitute, and often a substitution will affect other materials. Substituting rare earth elements in wind turbines, for example, leads to a higher demand for copper. Substitution of abiotic materials with biotic materials will often increase pressures on land use and biodiversity.

Sufficiency can be understood as "a strategy of introducing hard limitations to unsustainable trends"[35] and is discussed and promoted mainly by civil society actors, e.g. within the degrowth movement. The sufficiency discourse is closely connected to questions of over-consumption and environmental as well as distributional justice, between countries, social groups and among different generations within a society.[36]

Increasing **resource efficiency** has long been the key resource strategy in Europe, reflected in policy initiatives such as the "Flagship initiative resource-efficient Europe" and the "Roadmap to a Resource Efficient Europe" (2011) or on the German Resource Efficiency Programme "ProgRess". Increasing resource efficiency means improving benefits in relation to an effort. Since 2011 resource productivity, measured as GDP/Domestic Material Consumption (DMC),[37] has been the lead indicator for resource efficiency in the EU. Increasing resource efficiency does not necessarily mean a reduction in resource dependency, as resource use may still grow, albeit slower than economic activity ('relative resource decoupling'). If resource use declines, absolute resource decoupling occurs. Other discussions, led by the International Resource Panel, go further, arguing to shift focus to decoupling economic activity and wellbeing from resource use and environmental impact.[38]

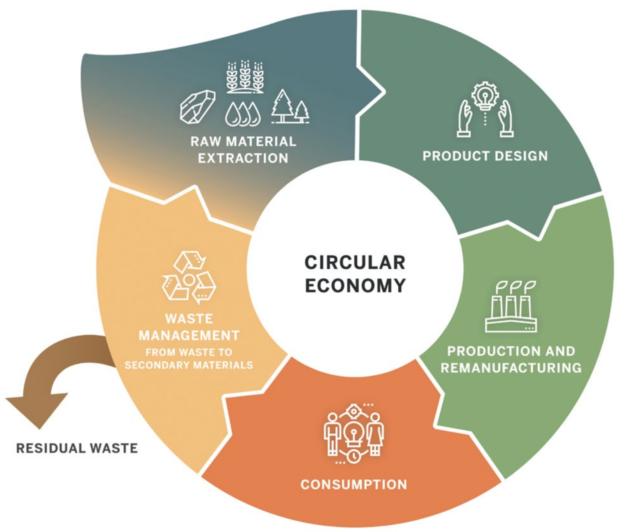
In the following chapter we will zoom in on the circular economy as another important but still underused tool to decrease resource dependency.

3. Zooming In: What Is the Circular Economy?

The circular economy aims to reduce the primary raw material input into the economy, keep raw materials in the loop ("slow down the circle") and recycle materials at the end of a product's lifetime. The reduction of primary raw material input into the economy can be achieved through more sufficient lifestyles, as well as new product designs and circular business models, such as sharing concepts. In the circular economy, materials are kept in the circle for as long as possible by increasing quality, longevity and repairability. At the end of a product's lifetime, the focus lies on the recovery of the materials. These "secondary raw materials", can help reduce demand for scarce primary materials, and in the long run, make the EU less dependent on imports.

In 2013, the Ellen MacArthur Foundation defined the circular economy as *"[…] an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models."*[39] This definition highlights a shift in the perception of the term "circular economy", from the 'end-of-life' concept to a more systematic approach that encompasses the earlier stages of production.

Figure 2 | Key Stages of the Circular Economy



Source: Beata Vargova, Ecologic Institute

The shift to a circular economy is more complex than it may seem at first sight, as the focus in debates is still often on the end-of-life phase and the recycling of materials. Waste treatment legislation is long established in the EU, and the waste hierarchy of the Waste Framework Directive – prevention, preparing for re-use, recycling, recovery, and disposal – may at first glance even look similar to the loop of the circular economy. In Germany, the term "Kreislaufwirtschaft" is the literal

35 Mathai, Manu 2018. Approaching Sufficiency in the Global South, in: Sufficiency. Moving beyond the gospel of eco-efficiency, p. 33.
36 Ibid.
37 DMC is an indicator for resource use, measured in weight. It sums up materials extracted from the domestic territory and physical imports minus physical exports.
38 International Resource Panel 2019. Global Resources Outlook 2019. Summary for Policymakers, p. 9. Early discussions of the Global Resources Outlook 2024 suggest that the shift to focus on wellbeing will be emphasized even further.
39 Ellen MacArthur Foundation 2013. Towards the Circular Economy – Economic and business rationale for an accelerated transition, p. 7. Link: https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an (retrieved on 08.07.2022).

translation of "circular economy", but is still often understood only as recycling.[40 41] Recycling and increasing the use of recycled materials is important and the policy framework must shift in favour of the recycling industry. But more importantly, for the circular economy to have a major effect on the EU's raw material dependency, a shift in focus to the reduce and reuse stages is necessary.[42] This also requires changes in the economic system and behaviour: despite the (slight) increase in attention to the circular economy in the EU since 2015[43] the economic system is still organised for the linear economy: Many business models rely on cheap raw materials to produce products of lower quality that are meant to be replaced at high rates. Repair is, at least in high-wage countries, often still more expensive than buying new products and ownership is still predominant over sharing models, even for products that are rarely used.

With the European Green Deal, the European Union has given itself a roadmap to a sustain-able economy. Its key goals are climate neutrality until 2050 and decoupling economic growth from resource use, which can only be achieved with a functioning circular economy.[44] This will require fundamental changes in the way we design, produce, use, and dispose of products. It will require innovative circular business models, appropriate financing models and research. And it requires a supportive policy framework.

The good news is – a lot of what is needed for the circular economy is already there, and despite the challenges, the circular economy brings also a lot of economic opportunities.

3.1 Economic Opportunities of the Circular Economy

It has been estimated that the circular economy could increase Europe's resource productivity by 3% by 2030 while generating cost savings of €600 billion a year and €1.8 trillion more in other economic benefits, such as a reduction of negative externalities.[45] Additionally, business models that use zero-waste approaches are estimated to create 30 to 200 times more jobs than linear models that centre around landfilling and incineration.[46] An increasing number of firms are incorporating circularity in their business models as its benefits are becoming more and more evident.[47]

In other words, the circular economy not only increases the sustainability of an economy but also provides economic opportunities at different phases of the lifecycle of a product.

The *design phase* decides on business models and materials used, how well a product can be repaired and recycled, and influences strongly how long it will last, how it will be used and how much energy it will need during its use phase.[48] And obviously, it decides about aesthetics – which will often determine if a product is being bought. Some experts estimate that the design phase determines "over 70% of a product's lifecycle costs and environmental footprint".[49] Business examples for new circular designs are manifold and range from, for example, the production of compostable packaging products from mushroom roots[50] to beer brewed from old bread.[51] Circular principles can also be included in the *production phase*, helping companies to reduce costs and improve resource efficiency. General Electric, for example, has transitioned to using 3D printing in its manufacturing, thereby saving material and costs while still being able to meet the needs of companies in the aerospace, automotive, and medical industries. By shifting its business model and becoming more circular, GE has become one of the world's leading 3D service companies and expects ongoing growth in the next years.[52]

The design phase is also crucial when played out with the *use or consumption phase*, especially when connected to a circular business model. Many examples exist already today – especially new kinds of sharing services are on the rise. Think, for example, of furniture rentals, where customers rent their furniture and return it when no longer needed. This in-centivises the production company to provide long-lasting repairable products, while customers are encouraged not to waste furniture bought at a high price.[53] Similar business models exist already for many products, or rather services, from consumer electronics, lighting, and household appliances, to flooring,[54] with car sharing or carpooling services possibly being the most prominent examples.

40 While the authors of this paper could not find a survey that investigated the understanding of circular economy or Kreislaufwirtschaft, the reduction of Kreislaufwirtschaft to recycling (industry) frequently shows in the discourse. To give two examples, the "Statusbericht der Kreislaufwirtschaft 2020" acknowledges that there are new meanings, but still looks at the sector almost exclusively from a recycling perspective. The German Wikipedia article to the Kreislaufwirtschaft is accompanied by a picture that presents the linear economy and then the circular economy, in which the linear economy is presented in a circle and recycling is added.
41 acatech, Circular Economy Initiative Deutschland, and SYSTEMIQ 2021. Circular Economy Roadmap for Germany, p. 24. Link: https://www.circular-economy-initiative.de/s/Circular-Economy-Roadmap-for-Germany_EN_Update-Dec-2021_DOI.pdf (retrieved on 11.07.2022).
42 Presentation Janez Potocnik at the G7-Workshop "Resource Efficiency and Circular Economy", 22.03.2022; the argument was mainly built on data from the Global Resource Outlook 2019 and the ongoing work for the upcoming Global Resource Outlook.
43 Google Trends 2022. "circular economy". Link: https://trends.google.com/trends/explore?date=all&q=%2Fm%2F0gtxxx2.
44 Supporting studies: Circle Economy 2019. The Circularity Gap Report 2019; Diaz-Bone, Harald et al. 2021. Circular Economy as a Cornerstone for Meeting the Goals of the Paris Agreement, Ellen MacArthur Foundation 2019. Completing the picture: How the circular economy tackles climate change. Link: https://emf.thirdlight.com/link/dcijanpohgkd-oblthh/@/preview/5.
45 McKinsey & Company 2017. Mapping the Benefits of a Circular Economy, p. 1. Link: https://www.mckinsey.com/business-functions/sustainability/our-insights/mapping-the-benefits-of-a-circular-economy (retrieved on 11.07.2022)
46 GAIA. Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solu-tions, p. 4. Link: https://zerowasteworld.org/wp-content/uploads/Jobs-Report-ENGLISH-2.pdf (retrieved on 11.07.2022)
47 PwC. The Road to Circularity, p. 27.
48 Widmer, Simon (no date).. Design and the circular economy. Link: https://ellenmacarthurfoundation.org/articles/design-and-the-circular-economy.
49 Radjou, Navi / Prabhu, Jaideep 2015. Frugal Innovation. How do to more with less, p. 12.
50 Ecovative Design, see: https://www.ecovative.com/.
51 Knärzje, see: https://www.knaerzje.de/.
52 Ibid., p. 36.
53 Ahrend, see: https://www.ahrend.com/en/.
54 Electronics (e.g., Grover), lighting (e.g., Signify), household appliances (e.g., Bundles), flooring (e.g., Desso). Examples from Ellen MacArthur Foundation (https://ellenmacarthurfoundation.org/explore?contentType=CircularEconomyExample) and Langsdorf, Susanne et al. 2022. Kreislaufführung und Sekundärrohstoffe Praxisbeispiele und Potenzia-le. Hrsg.: Hessen Trade and Invest, Wiesbaden.

Note that sharing models aside, the current market system does not set enough incentives for circular business models, apart from a positive marketing effect. This, however, is less important to non-brand companies. Companies care about resources and production costs but, in general, have limited stakes after a product is sold. This can lead to unfavourable results: Adidas, for example, has created an innovative running shoe (Futurecraft.loop) made from a single material (thermoplastic polyurethane-TPU) in which no glue is used, which makes it significantly easier to recycle.[55] However, Adidas is still fully relying on virgin plastic to create the shoe, as currently no clean TPU recyclates are available.

Finally, a circular economy provides improved economic opportunities in the repair and refurbishment sectors, as well as in the **end-of-life phase of a product**, especially in the recycling sector.

Apart from the business opportunities the reduction of raw material dependency also helps improve the resilience of the economy overall, as it reduces the risks of supply disruptions.

3.2 Key Barriers to a Thriving Circular Economy In the EU

As mentioned above, the circular economy offers significant opportunities and stronger resilience to external shocks. Despite these advantages, there are a broad variety of barriers that stand in the way of its implementation and success. A growing research body has been looking at these barriers, and sorted them into different categories, including cultural, market-related, technological, and regulatory.[56] Others include lack of infrastructure, or business models unfit for circularity.[57] In this section, we present selected barriers in order to illustrate the complexity of the shift towards a circular economy.

Cultural barriers refer to impediments to a transition toward a circular economy that includes consumer interest and awareness as well as company culture. These can be an issue where circular solutions cannot replace products of the linear economy with the same qualities (e.g., convenience of throw-away products) or if the circular solution requires new habits and skills (e.g., the use of smart devices to access sharing products). In an analysis of barriers to the circular economy by Kirchherr et al. cultural barriers were estimated to be the most pressing barriers, matched only with key market barriers.[58]

Market barriers consist of two main challenges, namely, 1) low virgin raw material prices and 2) high upfront investment costs.[59] Lower virgin raw material prices put recycled materials at a competitive disadvantage, where circular products end up being more expensive than products made from virgin raw materials.[60] While prices for many virgin raw materials have gone up in the past, they can fluctuate significantly. In comparison, secondary raw material prices have been relatively stable. This makes it difficult to guarantee a steady consumer demand for the latter material group as soon as virgin alternatives go down in price. This financial risk could present as a deal-breaker for potential investors into the recycling industry, which already faces high upfront costs.[61]

Additionally, **regulatory barriers** affect the transition towards a circular economy. Barriers occur in all phases of the circular economy cycle. In general, as the regulation of the linear economy differs strongly from what a circular economy requires. Some regulations have already come under scrutiny in the EU, for example, those that limit the repairability of products. Still, a lot remains to be done, and setting the right policy framework is highly complex. Regulating the sharing economy, for example, has already proven to be truly challenging. While sharing models can help reduce raw material use per capita, some sharing business models have been operating under poor regulatory frameworks. This has led to debates about, for example, tax fairness and labour rights. Waste regulation and defining the end-of-waste are also an issue: In many EU countries, Germany for example, special licenses are required to treat waste. Some companies may have a demand for a certain end-of-life material, as well the capabilities to treat that material. However, this does not grant the company permission to go ahead and process the material, if it classifies as 'waste' in legal terms. Another challenge may concern cross-country waste trading, when certain materials cannot be transported across borders in order to be recycled.[62] Different implementations between single EU member states can also cause classifications of certain materials or wastes to differ. This ultimately poses a large barrier to a successful circular economy. At the same time, a lack of specific export regulations leads to a steady outflux of critical raw materials out of the EU. A common example would be end-of-life vehicles exported as 'used vehicles', with a high amount of valuable materials being lost for future purposes within the EU.[63]

Technological barriers include complex product designs, which can hinder the separation and subsequent recycling into secondary raw materials. Furthermore, inadequate recycling technology and a lack of large-scale recycling facilities

55 PwC 2019. The Road to Circularity, p. 35. Link: https://www.pwc.de/de/nachhaltigkeit/pwc-circular-economy-study-2019.pdf (retrieved on 11.07.2022).
56 Kirchherr, Julian et al. 2017. Breaking the Barriers to the Circular Economy, p. 6.
Link: https://circulareconomy.europa.eu/platform/sites/default/files/171106_white_paper_breaking_the_barriers_to_the_circular_economy_white_paper_vweb-14021.pdf (retrieved on 18.07.2022)
57 Stanislaus, Mathy 2018. Barriers to a Circular Economy: 5 Reasons the World Wastes So Much Stuff (and Why It's Not Just the Consumer's Fault).
Link: https://www.wri.org/insights/barriers-circular-economy-5-reasons-world-wastes-so-much-stuff-and-why-its-not-just (retrieved on 15.07.2022).
58 Kirchherr et al. Breaking the Barriers to the Circular Economy, p. 8.
59 Ibid, p. 7.
60 Ibid.
61 Boulding, William / Christen, Markus 2001. First-Mover Disadvantage. Link: https://hbr.org/2001/10/first-mover-disadvantage (retrieved on 18.07.2022)
62 Kirchherr et al. Breaking the Barriers to the Circular Economy, p. 8.
63 Technopolis Group et al. 2016. Regulatory barriers for the Circular Economy: Lessons from ten case studies, p. 17.
Link: https://circulareconomy.europa.eu/platform/sites/default/files/2288_160713_regulary_barriers_for_the_circular_economy_accepted_hires_1.compressed.pdf (retrieved on 20.07.2022)

contribute to recycling rates for critical raw materials that are well below what is technically feasible.[64]

But besides technological barriers alone, recycling often stays below what is technologically feasible: low virgin raw material prices make recycling unprofitable and recycling markets are complex. A prominent example is plastic recycling: despite high and continuously increasing plastic use and plenty of plastic waste, plastic recycling remains in its infancy. In Germany, for example – which is often portrayed as a model recycler - , it has been estimated that less than 3% of total plastics in use are recycled materials.[65] Recycling of e.g. compound plastics indeed hits a technological barrier. However, in general competing against virgin plastics made from cheap – tax free[66] – oil has been the bigger barrier for recycled plastics and now, as companies ask for recyclates for marketing reasons not enough high-quality recyclers are in business. More complex markets and regulations, - which recyclates can be used for what where (e.g. regarding the use in food containers or in construction) – put plastic recycling at a further disadvantage[67]

3.3 The Political Landscape of the Circular Economy In the EU

The circular economy has been on the political agenda of the EU for several years: its first **Circular Economy Action Plan (CEAP)** was set up in 2015, but a related strategy on the sustainable use of natural resources had already been published in 2005. The European Green Deal of 2019 and its goals to become climate neutral by 2050 and decoupling economic growth from resource use has since given a new dynamic to the latest developments.[68] In 2020, a new **CEAP** followed.[69] In part, the new plan builds on the actions imple-mented since 2015, predominantly focusing on objectives such as sustainable product design and consumer empowerment. Furthermore, it focuses on a number of specific sectors, namely electronics and information and communications technology (ICT), batteries and vehicles, packaging, plastics, construction and buildings, food, water and nutrients, as well as textiles.[70] CEAP lays out a transition to a circular economy and aims to add to a "regenerative growth model that gives back to the planet more than it takes".[71] However, it remains a mere strategy, with its only quantitative goal being to "double the circular material use rate in the coming decade",[72] that is, from 12.8% in 2020 to 25.6% in 2030.[73] The impact of CEAP will depend mainly on the implementation of its goals via legislation.

Indeed, in the wake of CEAP, several **key legislations** have been reviewed or developed. At the end of 2021, the European Commission put forward a **proposal for a new regulation on waste shipments**. Globalisation and economic growth have led to an increasingly large amount of waste being shipped across borders, which can cause significant harm to the environment. The new proposal is set up to help reduce illegal waste shipments and facilitate the transport of waste for recycling and reuse within the EU, which would not only help to prevent pollution elsewhere but also to keep valuable secondary raw materials on the continent.[74]

In March 2022, the **EU Sustainable Products Initiative** was put forward alongside a "Communication on Making Sustainable Products the Norm" and a proposal for a framework regulation on ecodesign requirements for sustainable products set up to repeal the Ecodesign-Directive (2009/125/EC).[75] The proposal for a framework regulation expands the scope of the Ecodesign-Directive from 2009 and will apply to a broad range of products. It will not only promote energy efficiency, but also circularity through product-specific regulation, and will include rules to make products more durable, reliable, reusable, upgradable, reparable, easier to maintain and refurbish, as well as energy and resource-efficient.[76] In addition, the Initiative aims to help consumers make more sustainable choices through more stringent information requirements through the implementation of Digital Product Passports.[77] For example, products could be ranked "A to G" in terms of their performance and efficiency to enable comparisons between different makers.

While the above proposals are, at the time of writing of this study, not yet adopted, some of the rules have already been included into specific product regulations or proposals thereof. For example, in December 2020 the European Commission adopted a proposal for a (new) regulation on batteries and waste batteries. At the time of of writing of this study, the pro-posal is in the trialogue between the Council, Parliament and Commission. A final text is expected to come into force at the end of 2022 or the beginning of 2023.[78] The proposal includes the requirement of minimum shares of cobalt, lead,

64 European Environment Agency 2021. Emerging Waste Streams: Opportunities and challenges of the clean-energy transition from a circular economy perspective. Link: https://www.eea.europa.eu/publications/emerging-waste-streams-opportunities-and/emerging-waste-streams-opportunities-and (retrieved on 20.07.2022)
65 Heinrich-Böll-Stiftung 2019. Abfallentsorgung: Hinter den Kulissen der ungelösten Plastikkrise. Link: https://www.boell.de/de/2019/05/27/abfallentsorgung-hinter-den-kulissen-der-ungeloesten-plastikkrise.
66 In Germany, fossil energy sources are not taxes if used in materials.
67 Polyproblem Report 2021. Wertsachen. Warum der Markt für recycelten Kunststoff nicht rund läuft und wie sich das ändern könnte, p. 11, p. 44 ff.
68 Tamma, Paola et al. 2019. Europe's Green Deal plan unveiled. Link: https://www.politico.eu/article/the-commissions-green-deal-plan-unveiled/ (retrieved on 20.07.2022)
69 European Commission 2020. Communication "A new Circular Economy Action Plan for a cleaner and more competitive Europe". Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN
70 European Commission. Circular economy action plan.
71 Ibid. p. 4.
72 Ibid. p. 4.
73 Eurostat 2021. EU's circular material use rate increased in 2020. Link: https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20211125-1.
74 European Commission. Waste shipments. Link: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-shipments_en; SMART WASTE 2022. EU Proposal for a new Regulation on waste shipments. Link: https://projects2014-2020.interregeurope.eu//smartwaste/news/news-article/13710/eu-proposal-for-a-new- regulation-on-waste-shipments/.
75 European Commission 2022. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. On making sustainable products the norm. COM(2022)140 final; European Commission 2022a. Proposal for a regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC. COM(2022) 142 final; Langsdorf, Susanne/ Duin, Laurens 2022. The circular economy and its impact on developing and emerging countries. An explorative study. Link: https://www.ecologic.eu/18561.
76 European Commission 2022. Questions and Answers: Sustainable Products Initiative. Link: https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_2014
77 Ibid.
78 EEB et al. 2022. EU-Batteries Regulation: Four-Position-Paper. Link: https://eeb.org/library/eu-batteries-regulation-four-position-paper/.

lithium and nickel recyclates in batteries. The right to repair is already implemented in legislation on electronic displays,[79] which includes demands on the availability of spare parts and the requirement that repairs must be possible with commonly available tools.[80]

Eleven other initiatives and actions implemented as part of the CEAP have been initiated by the European Commission to date (autumn 2022), including a strategy for sustainable and circular textiles and a proposal for a revised construction products regulation.[81]

The Waste Framework Directive, the key European waste legislation, is in the process of being revised. In January 2022, the European Commission published a Call for Evidence, with an overarching aim to improve the holistic environmental outcome of waste management in line with the waste hierarchy[82] and the implementation of the polluter pays principle.[83] This is motivated by the reality that, despite existing legislation, municipal waste generation has been increasing over the last decade. Inefficient waste collection systems have especially led to low recycling rates and lower quality recyclates.[84] Many responses to the Call for Evidence from the public have highlighted the need to address consumption and encourage direct reuse and design for circularity. They also highlighted the importance of packaging waste in relation to the idea that separate collection is a prerequisite for improving reuse and recycling.

In the final chapter we will present concrete circular economy solutions to reduce raw material dependency, with a focus on rare earth elements.

4. Practical Solutions: How the Circular Economy Can Help Reduce Dependency On Rare Earth Elements

4.1 Why Rare Earth Elements Are Key

Rare Earth Elements (REEs) are a group of 17 heavy metals that can be split into two groups, Light Rare Earth Elements (LREE) and Heavy Rare Earth Elements (HREE). Despite having chemical properties that are virtually indistinguishable from one another, REEs have different electronic and magnetic properties, which make them suitable for different applications.[85] They are critical to modern technology in general and to the realization of a low-carbon economy specifically, as they are needed, for example, in permanent magnets for electric engines or wind turbines. Other key usages include catalysts, metal alloys (nickel-metal hydride batteries) and polishes. Subject to the level of climate action and technological evolution, it is estimated that the demand for REEs will increase three to seven-fold by 2040, relative to 2020.[86] In particular the market for magnets is expected to grow, which would specifically increase the demand for neodymium and dysprosium, among others. Growing battery usage is expected to increase demand for lanthanum.[87] On the other hand, the use of some REEs, such as europium in lighting, is expected to decrease.[88]

4.2 Reasons for and Ways Out of Dependency

Even within the field of critical raw materials, which, by definition, are characterised by a high supply risk, rare earth elements stand out: in the latest EU list of Critical Raw Materials (2020)[89] China's share in EU sourcing for rare earth elements stood at almost 100 percent,[90] opposite a total of 44 percent of imported critical raw materials from China overall. Whilst China dominates the rare earth elements market(s) globally, other countries have followed a number of counterbalancing strategies, from mining, to diversification or stockpiling, in order to reduce dependency to some extent. The USA, for example, increased its production from zero in 2017 to 43,000 tonnes in 2021. Of its imported rare earth metals compounds and metals "only" 78 percent were imported from China, and additionally, the US has stockpiled strategic rare earth metals. Substitution of rare earth

79 European Union 2019. Commission Regulation (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and re-pealing Commission Regulation (EC) No 642/2009.
80 Langsdorf, Susanne/ Duin, Laurens 2022. The circular economy and its impact on developing and emerging countries. An explorative study. Link: https://www.ecologic.eu/18561.
81 European Commission 2022. Circular Economy Action Plan. Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN.
82 See: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en.
83 European Commission. Waste Framework Directive.
84 European Commission 2022. Call for Evidence: Revision of the Waste Framework Directive. Link: https://environment.ec.europa.eu/news/waste-framework-directive-revision-2022-02-14_en#:~:text=The%20revision%20of%20the%20WFD,the%20drivers%20of%20these%20problems.
85 Massachusetts Institute of Technology 2016. Rare Earth Elements: A comprehensive back-ground. Link: https://web.mit.edu/12.000/www/m2016/finalwebsite/elements/ree.html (retrieved on 08.08.2022)
86 International Energy Agency 2022. The Role of Critical Minerals in Clean Energy Transitions, p 52. Link: https://iea.blob.core.windows.net/assets/ffd2a83b-8c30-4e9d-980a-52b6d9a86fdc/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf (retrieved on 01.08.2022)
87 BGR 2021. Seltene Erden. Informationen zur Nachhaltigkeit, p.3. Link: https://www.bgr.bund.de/DE/Gemeinsames/Produkte/Downloads/Informationen_Nachhaltigkeit/seltene_erden.pdf;jsessionid=EC2172DB42C9D8C6D9131B395B2215FE.1_cid292?__blob=publicationFile&v=3.
88 DERA (no date). Rohstoff Seltene Erden. Link: https://www.deutsche-rohstoffagentur.de/DERA/DE/Downloads/m-seltene-erden.pdf?__blob=publicationFile&v=3.
89 Ibid.
90 EU sources 99% of its Light Rare Earth Elements (LREE) and 98% of its Heavy Rare Earth Ele-ments (HREE) from China.

elements is also possible for various applications, but this is in general associated with inferior functionality.[91]

Consequently, it can be argued that European dependency is, at least to a certain extent, a decision. As geologists do not tire to point out: rare earth elements are not rare in the earth's crust, but in fact relatively abundant,[92] and mining in the EU would be possible.[93] However, "minable concentrations are less common than for most other mineral commodities"[94] and the environmental impacts that arise from the mining of REEs are considerable. One study sums up: "for every tonne of REEs produced, 13kg of dust, 9,600 - 12,000m^3 of waste gas, 75m^3 of wastewater, and 1 tonne of radioactive residue"[95] are generated. During mining, toxic chemicals are used to separate the REEs from the ore. This process results in "leaching pools" that contain environmentally hazardous solutions and need to be properly sealed and handled with due diligence.[96] Mining companies need to follow high environmental standards in the EU – which add to the costs of extracting raw materials. Furthermore they mostly face strong resistance by local communities, all of which has resulted in the current state of complete dependency with regard to REEs.

To sum up: strategies to reduce the dependency are available to the EU, but some of the barriers that apply to them are high. All the more reason to make better use of the opportunities that arise from implementing the circular economy. In the remainder of this study we present a number of examples that hopefully help to illustrate the variety of how the circular economy can help making the EU less dependent.

4.3 Practice Examples: Reduce, Reuse, Recycle

4.3.1 Reduce: Car Sharing

Current state of the automotive industry and REEs: The automotive industry is a key driver of the European economy, but it also contributes ~12% of the EU's CO_2 emissions[97] and, with an average weight of almost 2,000kg per car,[98] has a high resource demand. With the shift to electric vehicles (EVs), emissions in the use phase will decline sharply, which is why material emissions are calculated to account for 60% of a car's total life cycle emissions by 2040.[99] At the same time the raw material mix in cars will shift, with an increase in the demand for copper, nickel and critical raw materials, including REEs[100] such as neodymium, praseodymium, and dysprosium.[101] These materials are mostly used in a few key components of EVs, such as lithium-ion batteries and electric traction motors. Like wind turbines, most hybrid and electric vehicles use electric traction motors with Neodymium-Iron-Boron (NdFeB) permanent magnets. The compact size and high-performance capability of these magnets make them crucial for the production of EVs.[102]

Business model: Car sharing is an example of a "product-as-a-service" business model where customers purchase the service that a product provides, while the provider maintains their ownership of the good.

Benefits and Opportunities: By substituting private vehicle ownership, car sharing can be beneficial for consumers who may want some flexibility in terms of their mobility but prefer not to bear the large, fixed costs associated with car ownership. There are several positive outcomes of this business model, including economic and environmental benefits. Global consumer spending for car-sharing has been accounted for approximately $4-6 billion in 2019.[103]

The environmental benefits of large-scale car sharing can be substantial, and include reductions of mileage, land use (due to a reduction in stationary cars), car ownership and therefore resource consumption.[104] Research has focussed mainly on the reductions in greenhouse gas (GHG) emissions, with studies estimating reductions from 30 to up to 70% of GHG emissions resulting from a shift from car ownership to car sharing, including the impacts of modal shifts.[105] While only few studies exist on the effects on resource consumption and thusly REE consumption, it is clear that the key indicator is the amount of private cars that car sharing will replace. Again, study results are inconclusive, ranging from 4-6 cars replaced in Belgium, 5-7 in Sweden and 7-10 in Germany.[106] One study

91 USGS 2021. Rare Earths Statistics and Information. Link: https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information.
92 USGS 2021. Rare Earths Statistics and Information. Link: https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information; DERA 2 Rohstoff Seltene Erden; Horizon, the EU Research and Innovation Magazin 2015. Europe's rare earth deposits could shore up tech industry. Link: https://ec.europa.eu/research-and-innovation/en/horizon-magazine/europes-rare-earth-deposits-could-shore-tech-industry.
93 Horizon, the EU Research and Innovation Magazin 2015. Europe's rare earth deposits could shore up tech industry. Link: https://ec.europa.eu/research-and-innovation/en/horizon-magazine/europes-rare-earth-deposits-could-shore-tech-industry.
94 USGS 2021. Rare Earths Statistics and Information. Link: https://www.usgs.gov/centers/national-minerals-information-center/rare-earths-statistics-and-information
95 Ibid.
96 Nayar, Jaya 2021. Not So "Green" Technology: The Complicated Legacy of Rare Earth Mining. Link: https://hir.harvard.edu/not-so-green-technology-the-complicated-legacy-of-rare-earth-mining/
97 European Commission 2021: CO_2 emission performance standards for cars and vans. Link: https://ec.europa.eu/clima/eu-action/transport-emissions/road-transport-reducing-co2-emissions-vehicles/co2-emission-performance-standards-cars-and-vans_en.
98 Statista 2022. Durchschnittliches Gewicht neu zugelassener Personenkraftwagen in Europa nach Marken¹ in den Jahren 2019 und 2020. Link: https://de.statista.com/statistik/daten/studie/238004/umfrage/gewicht-von-pkw-nach-autoherstellern/.
99 World Economic Forum/Systemiq 2021. Paving the Way: EU Policy Action for Automotive Cir-cularity, p.9. Link: https://www3.weforum.org/docs/WEF_Circular_Cars_Initiative_Paving_the_Way_2021.pdf.
100 EEA 2018. Electric vehicles from life cycle and circular economy perspectives TERM 2018: Transport and Environment Reporting Mechanism (TERM) report. Link: https://www.eea.europa.eu/publications/electric-vehicles-from-life-cycle/download.
101 European Environment Agency 2018. Electric Vehicles from Life Cycle and Circular Economy Perspectives, p. 15.
102 IDTechEx. Electric Motors for Electric Vehicles 2022-2032. Link: https://www.idtechex.com/en/research-report/electric-motors-for-electric-vehicles-2022-2032/842
103 McKinsey&Company 2021. Shared mobility: Where it stands, where it's headed. Link: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/shared-mobility-where-it-stands-where-its-headed.
104 Harris, Steve et al. 2021. Sharing is daring, but is it sustainable? An assessment of sharing cars, electric tools and offices in Sweden, Resources, Conservation and Recycling, Volume 170.
105 Ibid.
106 Ibid.

from Germany calculated a high replace rate of nine cars for one station based car, but fails to find an impact of car sharing on the car market.[107]

While more research is needed to clarify effects and verify results, the current body of research shows that the potential effects are highly positive. However, especially with regard to resource consumption, the actual replacement of private ownership is key. If one shared car replaces four private cars (the lowest estimate from the studies above), raw material use for mobility is reduced by 75 percent. While this is naturally a simplification, as the effects of car sizes, lifetimes due to heavier use and replacement rates are ignored, it can nevertheless be argued that reductions of this magnitude cannot be easily achieved through other instruments.

Challenges: The inconclusive results regarding the actual replacement of private car ownership also indicate that car sharing as a circular business model requires a supportive political framework to succeed. In fact, car sharing without a reduction in car ownership would actually worsen raw material dependency. While no policy instruments can be analysed in depth in this study, other studies have suggested that adjusting the business model to the city, and supportive local regulations, for example, regarding priority parking, can help car sharing businesses to succeed. At the national level, other instruments, such as taxing the second or third car of a household higher in places where car sharing is available, would likely support the shift to car sharing and help reduce private car ownership.

The car sharing example shows the high potential to reduce raw material dependency via this circular business model, but it also sheds light on the need for systemic changes to over-come the barriers (see also chapter 3.2) to a circular economy. Socio-cultural aspects, such as the high prestige of car ownership, appear to be changing already, with younger generations less interested in private car ownership.[108] Technological barriers have been overcome with the advance of digitalisation, sharing apps and the near-full rollout of smartphones. Market and regulatory barriers have been reduced, with many successful sharing businesses already operating in the EU. However, in a true circular economy, the market would have to be organised in a way in which companies can make better business by offering sharing services rather than by simply selling products.

4.3.2 Reuse: Philips Equipment Leasing and Refurbishment

Medical devices, electronics and REEs: Modern medical devices contain high amounts of critical raw materials, including REEs. The high demand stems partly from digitalisation processes, e.g., for screens, processors, or memory, but it also includes demand from specific high-tech medical devices such as magnetic resonance imaging (MRI) systems, which contain permanent magnets that use REEs. Other applications include medical laser technologies which require erbium, yttrium and neodymium, or medical mass products such as such as medical hearing aids, which also contain neodymium.[109]

Business model: Philips, a global leader in healthcare technology with a net sale of €19.5 billion in 2020[110] has set the circular economy as one of the key pillars of its sustainability goals. Philips aims to generate 25 percent of its revenue from circular economy solutions and to make sure that 100 percent of the products meet the company's ecodesign principles.[111] Healthcare providers face significant costs to replace equipment with high residual value, given the rapid pace of technological advancements within the medical field. Philips has therefore been developing business models that tackle these challenges, namely, product-as-a-service, take-back schemes, and upgrade and refurbishment programmes.[112] In particular, the refurbishment programme (Philips Refurbished Systems) allows hospitals or specialty practices to trade in their used equipment in exchange of an upgraded new equipment at a discounted price. Imaging equipment such as MRI devices and computed tomography (CT) scanners are examples of products that are covered in this programme.[113]

Product-as-a-service is another business model used by Philips to extend the life of its products while retaining competitiveness in the market. In this business model, customers pay to access the service for a limited time while the provider maintains ownership of the product and remains responsible for the delivery, maintenance, upgrade, and treatment at the end of the product's use.[114]

Benefits and Opportunities: The benefits of these business models are manifold. Customers get access to high quality equipment at lower costs because of the tradein or leasing schemes. In addition, performance and access-based models that are a part of these services reduce upfront costs. In the context of healthcare systems, upgradability is an important benefit for customers as they keep up with the latest technology.

107 Kolleck, Aaron 2021. Does Car-Sharing Reduce Car Ownership? Empirical Evidence from Germany. Sustainability 2021, 13, 7384.
108 Forbes 2019. The Reasons Why Millennials Aren't As Car Crazed As Baby Boomers, And How Self-Driving Cars Fit In. Link: https://www.forbes.com/sites/lanceeliot/2019/08/04/the-reasons-why-millennials-arent-as-car-crazed-as-baby-boomers-and-how-self-driving-cars-fit-in/?sh=5a9dead63fc5.
109 MDDI 2013. A Rare Earth Metal Shortage Could Spell Trouble for Medtech Firms. Link: https://www.mddionline.com/materials/rare-earth-metal-shortage-could-spell-trouble-medtech-firms.
110 Ellen MacArthur Foundation. Pioneering Circularity in the Healthcare Industry. Link: https://ellenmacarthurfoundation.org/circular-examples/pioneering-circularity-in-the-healthcare-industry-royal-philips
111 Ellen MacArthur Foundation. Philips.
112 Ellen MacArthur Foundation. Pioneering Circularity in the Healthcare Industry.
113 Board of Innovation. 10 Circular Business Model Examples. Link: https://www.boardofinnovation.com/blog/circular-business-model-examples/
114 Hvid Jensen, Henrik. 5 Circular Economy Business Models That Offer a Competitive Advantage.

On the other hand, this business model also offers benefits for Philips as the supplier. As more and more customers consider the environment in their procurement strategies, service providers will experience increased competitiveness in the long run.[116] Besides, leasing and refurbishing business models often require stronger relationships between the seller and buyer. The customer loyalty established here can lead to recurring business and more recurring revenue.

Environmental benefits are also significant, as Philips achieved 50-90% material reuse through its refurbishing activities which includes the reuse of 940 tonnes of refurbished medical imaging equipment in 2016.[117] This does not only contribute to Philips' circular economy targets, but it also decreases its demand of primary REEs and reduces the amount of waste that ends up in landfills. Finally, it also leads to improved supply security.

Risks and Challenges: One of the challenges of this business model from Philips' perspective would be the uncertainty surrounding customer acceptance. Even if the potential customers are aware of the environmental impacts of the products they are purchasing, there is still a misconception among customers that reused, refurbished or recycled products are potentially of a lower quality.[118] This false perception could hinder Philips' advancement into the lease and refurbished markets and it is therefore crucial to effectively remarket the products showing its ability to provide high quality services. Finally, the pricing of these services can be challenging from an economic perspective. This is because it can be difficult to predict the price level that would allow coverage of the fixed and variable costs of the product in a consumption-based leasing model.[119]

4.3.3 Recycle: Stena & Neodymium Permanent Magnets

In the circular economy, the first steps of the circle – especially reducing the input of raw materials and keeping materials in high value use – is essential. Reuse, remanufacturing, and redistributing strategies preserve the value of materials, rather than devaluing them, as it happens in recycling processes.[120] When all other options have been exhausted, however, recycling is still a crucial component of the circular economy, especially in the current days, where options to reuse, repair, or remanufacture may still be limited.[121]

Business Model: Stena Recycling is Sweden's leading recycling company. It is heavily in-volved in projects relating to the recovery of neodym (NdFeB) permanent magnets. Its parent company, Stena Metall AB operates in seven European countries, focusing on the recy-cling of waste from electrical and electronic equipment (WEEEs), end-of-life vehicles, and many other types of industrial waste that contain permanent magnets. Stena has participated in several continentwide projects such as REE4E, REMANENCE[122]; and most recently, SUSMAGPRO (see info boxes on pp. 16 and 17).[123] These projects aim to increase the re-cycling of these metals by developing new and sustainable solutions

SUSMAGPRO

Sustainable Recovery, Reprocessing and Reuse of Rare Earth Magnets in a European Circular Economy

Duration: 2019 to 2023; Budget: ~ 5 Mio. EURO

SUSMAGPRO builds on EU research projects, including the REMANENCE project. Its key objective is to develop a recycling supply chain for rare earth magnets. Furthermore, the recycled magnets shall be piloted in electronics, wind turbines and the automotive sector.

The recycling and recovery process involves new sensing and robotic sorting lines to efficiently identify, sort and extract NdFeB from waste. The magnetic scrap is processed into powders using Hydrogen Processing of Magnetic Scrap (HPMS), before being reprocessed into magnetic components. Mobility is also a focal point with the line being designed in a transportable manner to allow on-site segregation of waste. Furthermore, pilot-scale facilities with the potential to process 50 tonnes of clean NdFeB powders per year are being developed in the United Kingdom and Slovenia.

Researchers have conducted market analysis to identify the main sources of waste material containing NdFeB and created business plans for these recycling and reprocessing solutions to meet the goal of producing 15 percent of EU demand (450 tonnes per year) for NdFeB magnets within 5 years of the project commencement.

115 Philips. Circular Products and Services. Link: https://www.philips.com/a-w/about/environmental-social-governance/environmental/circular-economy/circular-products-and-services.html
116 Ellen MacArthur Foundation. Pioneering Circularity in the Healthcare Industry.
117 World Business Council for Sustainable Development. Leasing. Link: https://www.ceguide.org/Strategies-and-examples/Sell/Leasing
118 Murphy, Michael 2021. Electronics Can Trigger a More Circular, Sustainable World – Here's How. Link: https://www.weforum.org/agenda/2021/05/electronics-can-trigger-a-more-circular-sustainable-world-here-s-how/ .
119 Slavchova, Kameliya / Georgiev, Denis 2019. Pay-Per-Use: The challenges for consumption-based leasing in a tech-driven world. Link: https://www.codix.eu/en/company/stories/world-leasing-yearbook-2020.
120 Lemille, Alexandre 2019. For a True Circular Economy, We Must Redefine Waste. Link: https://www.weforum.org/agenda/2019/11/build-circular-economy-stop-recycling/.
121 Zero Waste Scotland. Recycling and the Circular Economy. Link: https://www.zerowastescotland.org.uk/circular-economy/recycling.
122 European Commission 2017. Rare Earth Magnet Recovery for Environmental and Resource Protection: Final Publishable Report, p. 3. Link: https://cordis.europa.eu/docs/results/310/310240/final1-remanence-final-report-v1.pdf
123 Stena. Neodymium Magnets. Link: https://www.stenametall.com/research-and-development/current-projects/neodymium-magnets/

Benefits and Opportunities: In the face of high REEs dependence and demand growth recycling presents a significant opportunity both economically and environmentally. Economically speaking there are benefits at various levels and scales of production. Recycling companies can benefit from the increased demand for secondary rare earth elements while consumers can benefit from more price stability. Furthermore, as more efficient technology is deployed in the recycling process, firms could benefit from economies of scale. Thus, by recycling in larger volumes, a firms´ average costs per unit would decrease. This of course could in turn improve the competitive position of recyclates in comparison to virgin materials. From an environmental standpoint, the recycling of permanent magnets could significantly reduce climate change effects. Data analysis of pilot trials in the REE4EU project indicated a reduction of climate change impacts by 50 percent and primary energy consumption by 35 percent when compared to the current scenario that relies on primary rare earth elements from China.[124]

REMANENCE

Rare Earth Magnet Recovery for Environmental and Resource Protection

Duration: 2013 to 2016; Budget: ~ 5 Mio. EURO

REMANENCE had the aim of increasing the amount of REE magnets that are recovered from waste streams. The project developed sensing and separation technology to recover REE magnets from electronic equipment. The materials were then processed to convert the NdFeB magnets into a hydrogenated powder, before being mechanically extracted from the devices and processed further to manufacture sintered or bonded REE magnets.

This project has implemented the process into a virtual production line and produced magnets, that are comparable to and competitive with magnets made from primary raw materials.

Risks and Challenges: The main factors that currently still block the recycling of rare earth elements in the EU are inefficient waste collection, high costs, and the complexity of dismantling and retrieving the magnets. Recycling neodymium magnets is a challenging task due to their brittle and magnetic nature, which can cause them to get stuck in the equipment.[125] However, dismantling and removing the magnets by hand would be too time consuming and costly, and could even be harmful to human health. A lack of recycling in the EU is also a challenge and there are no prior examples of realising a permanent magnet value chain using recycled material.

The approaches in these two projects have shed light onto how recycling can play an important role in Europe's green transition. Technical advancements, as seen with sensing, sorting, and hydrogen processing are important components of a circular economy, and require much more attention. At the same time, an important aspect of these projects has been to raise awareness of these business models. The question of customer acceptance of permanent magnets made from recycled material, regarding its magnetic properties and potential supply chain bottlenecks need to be addressed before its implementation at a wide scale.

124 European Commission 2020. Recycled Permanent Magnets Provide a Source for Rare Earth Elements. Link: https://cordis.europa.eu/article/id/415387-recycled-permanent-magnets-provide-a-source-for-rare-earth-elements.

125 Stena. Neodymium Magnets. Link: https://www.stenametall.com/research-and-development/current-projects/neodymium-magnets/.

Political Takeaways

At present, Europe remains in a relationship of structural dependency on authoritarian regimes. Whether it is Russia's dominant position as a provider of fossil fuels or China's monopoly on strategically relevant elements that are necessary for modern and ecologically sustainable technologies – Europe has to cut itself loose, at least to a certain extent, if it is to maintain true political autonomy. Therefore, this study has suggested possible strategies to to achieve a higher degree of independence in the realm of raw materials.

Scientific and technological advancements might allow for higher rates of substitution and increased resource efficiency. New recycling technologies can help to improve the sorting and recovery of materials. However, technological innovation can only help to a certain extent – at least, within a short timeframe. Consequently, one much-needed additional tool could be a more conscious approach towards the usage of rare materials. This includes both the establishment of more sustainable and reuse-friendly design processes, to be introduced by companies, as well as the adaption of more mindful consumption patterns, to be implemented by the wider public. Undoubtedly, from a sourcing perspective, Europe and the West will also have to investigate new sources of rare earth elements. This includes domestic mining activities as well as increased international trade within a network of reliable, democratic partners. Yet, progress is not achieved in a vacuum. There is a great need for political incentives and regulatory framework schemes that favour the aforementioned adaptations.

1. In order to incentivize the creation of innovative and resource-saving, technological solutions, intellectual properties have to be guaranteed to inventors and innovators. One way to achieve this is via a clear and innovation-friendly patenting process. In this context, innovation agencies can help potential founders and developers with patent applications and their subsequent enforcement.

2. At the same time, regulatory barriers in the way of the transformation towards a sharing economy have to be lowered. This might include policy measures such as tax benefits for users of sharing services or the easing of regulatory requirements for providers of such services. However, irrespective of potential political support, the transformation can only work at a somewhat organic pace and has to be endorsed by its users.

3. Finally, international cooperation with reliable partners that share similar values will increase in importance even further. This includes both the sourcing of critical resources and the exchange of technologies. The geopolitical challenges of this century can only be solved through collaboration and shared goals. Thus, it is in Europe's best interest to further strengthen and diversify its trade networks and support international free trade with reliable partners.

Considering the enormous industrial relevance of the continuous and reliable availability of scarce materials, Europe's regulatory framework has to adapt to new realities. Resource- and trade policies must incorporate a stronger focus on circularity – not only for the sake of our planet's climate and environmental sustainability but also in order to guarantee the West's lasting political and economic sovereignty. Thus, current funding programs on EU and national levels are good first steps. However, the pace and commitment has to increase in order to become less susceptible to potenial political blackmailing by China and other competitors in an environment of everrising geo-economic tensions.

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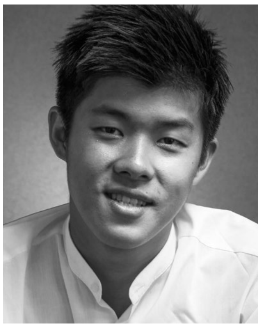

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