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Modernizing resource management

Sustainable management of critical raw materials required for the low-carbon energy transition – Draft for discussion

Prepared by the United Nations Resource Management System Sub-group of the Expert Group on Resource Management

Summary

Critical raw materials are essential for producing various everyday goods and applications. They have a unique role in accelerating low-carbon energy transitions. Renewable energy such as solar, wind and geothermal energy and energy storage using batteries need critical raw materials (CRMs). They are inextricably linked to all industries across all supply chain stages. Critical raw materials are crucial for a solid industrial base in the global economy and an essential building block for the growth and competitiveness of industrialised countries. There are over 40 materials that have been identified as critical by Canada, European Union, Japan and US. This draft document sets out the rationale, background and possible directions for developing a United Nations Resource Management System-based CRMs information dashboard for the availability of socially, environmentally and economically referenced data on CRMs. A robust, sustainability-focused information dashboard will support the investment roadmap and business case for the assurance of CRMs and channelling climate and Environmental and Social Governance related finance for a pipeline of bankable projects.

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I. Introduction

1. The low-carbon energy transition, urgently needed to limit the severe negative impacts of climate change, implies a shift away from a fossil fuel-intensive economy. The shift will require several technology raw materials, some of which are defined as critical raw materials (CRMs). CRMs are those raw materials that are economically and strategically important for the economy, especially for energy transitions. They have a high-risk associated with their supply. The CRM list could differ from country to country. There are over 40 materials that have been identified as critical by Canada, the EU, Japan and US.[1] CRMs are essential for producing various everyday goods and applications. They have a unique role in accelerating low-carbon energy transitions. Renewable energy such as solar, wind and geothermal energy and battery storage all need vast amounts of CRMs. CRMs are also required in a variety of industrial applications.

2. Sourcing these raw materials responsibly is a crucial challenge for a sustainable future. CRMs have geographical dependencies, sustainability issues in production and use, and complex supply chains. These materials are usually associated with muti-metal deposits in low concentrations. They require harsh chemical processes in extraction and refining. Governments, industry, financial, academic, and civil society stakeholders need timely information on availability, production, use and reuse to properly manage critical raw materials.

3. Raw materials can be sourced from primary (mining), including extraction from geothermal brines and secondary sources (anthropogenic resources). Both offer specific advantages and face characteristic challenges. Primary sources are tied to geology, which dictates possible localities for production. Appropriate investment and framework conditions ensure these sources are found and developed, thus securing sufficient supply. Secondary sources are tied to the use of products containing the desired raw materials previously extracted from a primary source.

4. Recovery of raw materials through recycling often leads to lower environmental impacts than mining. Still, the quantities and quality available for recycling depend on the generation and appropriate collection and processing of residues such as scrap and materials that could be recovered from landfills. Quantitatively, mining supplies the majority of raw materials used by society today. This will continue in the following decades, despite efforts to increase recycling and reduce demand through efficiency and circularity measures. Most of the global non-fossil fuel industrial ecosystem has yet to be constructed. What has yet to be built cannot be recycled.

5. Besides increased supply from mining, there is the potential to extract CRMS from secondary sources such as mine tailings. Much work is still needed on the circular use of CRMs. On the one hand, the circular management of CRMs can substantially reduce greenhouse gas (GHG) emissions and other negative environmental impacts arising from mining and processing complex multi-metal deposits, as well as social and geopolitical issues related to primary supply. On the other hand, it can help to secure the CRM supply and reduce the pressure to mine more primary natural resources.

6. The World Bank estimates that over 3 billion tons of minerals and metals will be cumulatively needed to deploy wind, solar and geothermal power and energy storage required for achieving a below 2°C future.[2] The production, refining and use of these materials in low carbon technologies will require billions of dollars worth of financing and the collaboration between the private and public sectors to mobilise these resources. A significant increase in sustainability-focused investments for CRM development is crucial to ensuring the security of supply. Sustainable investments for CRM development which integrate circularity in their design necessitate accessibility to harmonized social and environmentally referenced information and knowledge. Such information encompasses aspects of:

[1] Department of Industry Innovation and Science, 2019. Australia's Critical Minerals Strategy.

[2] World Bank (2020) Minerals for Climate Action: The Mineral Intensity of the Clean Energy Transition https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

(a) Social contract on natural resources;

(b) Adherence to sustainable investment guidelines;

(c) Alignment to the principles of sustainable resource management;

(d) Life cycle transparency and traceability; and

(e) Strategic environmental management.

7. The world needs reliable, responsible, and sustainable supplies of critical minerals to help address climate change and progress on the Sustainable Development Goals (SDGs). One of the main problems for the sustainable supply of CRMs is a lack of socially, environmentally and economically referenced harmonized information on the global supply potential.

8. Even in today's digitalized environment, only partial data is available. In addition, making the data into practical information and knowledge for decision-making is the biggest challenge. Harmonizing the available CRM resource information using the United Nations Framework Classification for Resources (UNFC) is part of the solution. Such information will be helpfully in understanding the resource base and what part of it can be produced in the near-, medium- and long term. UNFC-based information must be combined with other production information, primarily social and environmental aspects. Supply chain information and data related to the use and reuse of other factors need particular attention. Integrating the information mentioned above is possible through the United Nations Resource Management System (UNRMS).

9. **This document sets out the rationale, background and possible directions for developing a UNRMS-based CRM information dashboard for the availability of socially, environmentally and economically referenced data on critical raw materials.** A robust, sustainability-focused information dashboard will support the investment roadmap and business case for the assurance of CRMs and channelling climate and Environmental, Social and Governance (ESG) related finance for a pipeline of bankable projects.

10. How data appears is often as important as data quality. Data that cannot be easily accessed or viewed is not usually of great use for comparative analytics. A dashboard is a visual display of the essential information needed to achieve one or more objectives, consolidated and arranged on a single screen so users can monitor the information at a glance. Informational dashboards serve the goal of unbiased information about a project or business. Strategic dashboards help users discover opportunities, create forecasts, drive strategy, and focus on high-level performance data. Analytical dashboards are detailed and allow users to drill down into the data. Operational dashboards give users insight into the operation's processes and other underlying functions.

11. As can be seen from available but challengingly difficult-to-extract information from many data sources, there is a significant difference between data and information. The CRMs dashboard tool will provide actionable information that can lead to better knowledge and improved decision-making regarding critical raw materials.

II. United Nations Resource Management System

12. Natural resources are parts of the natural capital used to produce goods and services in economic activities. Material resources such as minerals, petroleum, nuclear fuels, geological storage, anthropogenic resources, renewable energy resources such as geothermal, solar, wind, biofuels and water resources could be considered natural resources. While utilizing natural resources for society's benefit, the net natural capital could be enhanced by enhancing the environment and addressing the climate crises rather than depleted.

13. Sustainable resource management is defined as the total of policies, strategies, regulations, investments, operations and capabilities within the framework of public, public-private and civil society partnerships, and based on environmental-socio-economic viability and technical feasibility, which determine what, when and how resources are developed,

produced, consumed, reused and recycled by the society.[3] Sustainable resource management using UNRMS is intended for optimizing sustainable benefits to stakeholders within the people-planet-prosperity triad. UNRMS is based on the United Nations Framework Classification for Resources (UNFC). The approach emphasizes cross-sectoral nexus linkages and minimization of potential adverse impacts. The current climate crises and accompanied impacts such as heat waves, droughts, forest fires and floods make it imperative that action of sustainable resource management should have a sense of urgency.

14. UNRMS is a global voluntary resource management system for governments, industries, investors, and civil society. It is an innovative integrated resource management framework for resources such as minerals, petroleum, renewable energy sources, nuclear resources, anthropogenic resources, geological storage and groundwater to support the development of policies and regulations in the sustainable management and advancement of the Sustainable Development Goals (SDGs).[4]

15. UNRMS is a comprehensive information framework and methodology to support resource progression applicable for programme, portfolio, project and asset-level management. Importantly, it is a sustainability framework to aid the financing of resource sectors. It is a system for local and indigenous communities to evaluate and assess projects against stated environmental-social-economic objectives. It is also a scheme for long-term considerations of commercial and policy aspects of projects and the design of conditions for the industry to harness integrative dynamic capabilities. UNRMS can be a project support kit to help align with applicable regulations and support sustainability and financial reporting.

16. The fundamental principles of sustainable resource management are as follows:

(a) State rights and responsibilities in the management of resources;

(b) Responsibility to the planet;

(c) Integrated management of resources;

(d) Social contract on natural resources;

(e) Service orientation;

(f) Comprehensive resource recovery;

(g) Value addition;

(h) Circularity;

(i) Health and safety;

(j) Innovation;

(k) Transparency;

(l) Continuous strengthening of core competencies and capabilities.

17. Integrated management of resources is the key to overcoming social and environmental challenges. UNRMS embraces the critical concept of integrated resource management that considers complexity, multiple scales, and competing interests and brings these together to make informed decisions. For sustainable resource management to be holistic, i.e., respond to the complexity of all resources, time and space scales, and life cycles, it should be principles-based. Principles provide general guidance on the direction sustainable resource management should proceed. From the fundamental principles, requirements are established at a lower level.

[3] UNECE (2022) Draft UNRMS: Principles and Requirements https://unece.org/sed/documents/2022/04/session-documents/draft-unrms-principles-and-requirements

[4] See Draft United Nations Resource Management System: Principles and Requirements (ECE/ENERGY/GE.3/2022/6) https://unece.org/sites/default/files/2022-04/ECE_ENERGY_GE.3_2022_6.pdf

III. Critical raw material demand

18. Critical raw materials are essential for producing various everyday goods and applications, especially low-carbon energy, mobility and digital transitions.

19. CRMs are crucial for high-tech products and emerging innovations, including many related to climate mitigation and adaptation. Technological progress and quality of life depend on access to many raw materials. For example, a smartphone can contain up to 50 metals,[5] all of which have lightweight and user-friendly small-size properties. CRMs are essential in solar panels, wind turbines, electric vehicles and energy-efficient lighting. The implementation of low-carbon technologies is expected to increase demand for certain raw materials by a factor of 20 by 2035.[6] Likewise, the defence capability of industrialized countries is directly dependent on access to CRMs. It will contribute to an increase in demand. Night vision devices, communication technology, stealth for aeroplanes, gyrocompasses for guided weapons, etc. depend on access to Rare Earth Elements (REE) and CRMs.

20. As the economy becomes greener, CRMs become increasingly important. These solid minerals will dominate the future of energy production as it is today by oil and gas. If demand for CRMs continues to increase as expected, also the environmental impacts of their mining will become more and more important. New smart mining processes and recovery methods could help to secure supply and make it more sustainable. UNFC and UNRMS emphasize the importance of sustainable and integrated resource management, including progress towards a more circular economy.

A. Critical raw material applications

21. CRMs are essential for the energy transition and needed also needed for a variety of key industrial applications. The diversity of CRM applications complicates understanding the likely demand in the future. To assure a steady supply of CRMs, disaggregated information on their applications and the potential demand in various sectors are needed. Some of the key applications are summarized here.

22. *Electrical and Electronic Equipment:* The electrical and electronic equipment (EEE) sector depends on various CRMs, including antimony, beryllium, cobalt, gallium, germanium, indium, platinum group metals (PGMs), natural graphite, REEs, silicon metal, and tungsten. For example, gallium finds widespread use in integrated circuits and light-emitting diodes (LEDs) for lighting. Other essential product applications associated with the EEE sector include magnets, flat-screen displays, and optical fibres. The EEE sectors are the significant gallium users (95 per cent of the element is used in the EEE sectors), germanium (87 per cent), indium (81 per cent), and several REEs (e.g., used in lighting applications). Some CRM flows reach EEE indirectly, and statistics do not always capture these flows. For example, 52 per cent of the overall flow of antimony is used to produce flame retardant for plastics, afterwards used to manufacture EEE. Additional information on these flows is necessary to capture the final uses of CRMs.

23. *Batteries:* There are three types of batteries: portable, industrial and automotive. In the last decades, new battery chemistries have appeared on the market due to the development of new applications (e.g. electric vehicles, e-bikes). Depending on the battery chemistry, the main CRMs embedded in batteries are antimony, cobalt, lithium, natural graphite, nickel, indium, vanadium and some REEs. Antimony is mainly used for lead-acid batteries, and its use has declined due to new battery technologies. In contrast, in recent years, the battery market has seen a relative increase in the amount of cobalt: from 25 per cent of global end uses of cobalt in 2005 to 44 per cent in 2015. This increase is mainly related to specific

[5] See Smartphones, Smart Chemistry https://www.acs.org/content/dam/acsorg/education/resources/highschool/chemmatters/archive/chemmatters-april2015-smartphones.pdf

[6] OECD (2019), Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences, OECD Publishing, Paris, https://doi.org/10.1787/9789264307452-en

lithium-ion chemistries (e.g., lithium, nickel, manganese cobalt oxides suitable for new applications). Concerning natural graphite, almost 10 per cent of worldwide uses of graphite in 2010 was for the batteries sector. Graphite is widely used in several rechargeables and non-rechargeable batteries (both portable and industrial) as an anode, for example, in the quickly growing lithium-ion battery market. From 2010 to 2017, alkaline batteries accounted for about 5 per cent of indium consumption. Finally, 10 per cent of the worldwide lanthanum and 6 per cent of cerium are used for NiMH batteries among REEs.

24. *Automotive sector:* In the automotive industry, including conventional (combustion engine vehicles), hybrid electrical vehicles (HEVs), and electric vehicles (EVs), several vehicle components contain CRMs. Some examples are graphite (in brake linings, exhaust systems, motors, clutch materials, gaskets and batteries), cobalt (in lithium-ion batteries, especially for EVs), Platinum Group Metals (palladium, platinum and rhodium in auto-catalysts and particulate filters), niobium (as an alloying agent in high-strength steel and nickel alloys used in the body structure, engine system and structural components) and REEs (in permanent magnets, auto-catalysts, filters and additives). About 14 per cent of worldwide uses of graphite in 2011 refer to automotive parts. In 2012, the EU demand for palladium for petrol engines was 69 per cent, 70 per cent of platinum was used for light-duty diesel engines, and 80 per cent rhodium for 3-way catalytic converters used to reduce tailpipe emissions from vehicles. Concerning niobium, in 2012, 44 per cent of the EU demand was intended for the automotive sector. Among the REEs, neodymium, praseodymium and to a lesser extent, dysprosium and terbium are used in large high-performance neodymium-iron-boron magnets for HEVs and EV electric motors. These are also used in small electric motors and electronic sensors for the standard automotive industry, including starter motors, brake systems, seat adjusters and car stereo speakers.

25. Moreover, lanthanum and cerium are embedded in nickel-metal hydride (NiMH) batteries used in HEVs designs. Cerium is additionally used in auto-catalysts, which accounted for 35 per cent of consumption in 2013. Lithium-ion is the reference technology for EV batteries. Many different Li-ion chemistries are available and tested to improve performance and lower battery costs. For example, in recent years, Li-ion chemistries have shifted in favour of lower cobalt compositions. Natural graphite, in turn, is the reference anode material. In comparison to available alternatives, natural graphite had a market share of 64 per cent in 2014.

26. *Renewable energy:* Wind and Photo Voltaic (PV) energy technologies rely on various materials, including six CRMs, namely neodymium, praseodymium, dysprosium, indium, gallium, and silicon metal. The global and EU demand for these materials will evolve depending on the deployment rates of wind and PV energy technologies and the technology mix. For instance, most of the wind turbines currently installed in the EU do not use permanent magnet generators and thus do not require rare earths. However, the situation can significantly change in the next 10-15 years due to the sizing up of wind energy: the introduction of large and more efficient turbines, as well as more offshore wind power, may entail a higher use of permanent magnets.

27. *Defence industry:* The defence industry depends on various raw materials necessary to build a large spectrum of key defence capabilities. Thirty-nine raw materials have been identified as essential for producing high-performance processed, semi-finished materials (e.g., alloys, composites, etc.) needed to manufacture a large variety of defence-related components and subsystems. The aeronautic and electronic defence sub-sectors are the primary users of CRM (and the most vulnerable to potential material supply constraints).

28. *Chemicals and fertilizers:* The production of several chemicals and fertilizers relies on many CRMs, such as antimony, baryte, bismuth, borate, cobalt, fluorspar, hafnium, natural graphite, niobium, potassium, platinum-group metals (PGMs), phosphorus, REEs, silicon metal, tantalum, tungsten and vanadium. The main applications of CRMs in the chemical and fertilizers sectors include their use in the production of catalysts, fertilizers, polymers, pharmaceutics and dyes. Examples include: 86 per cent of phosphate rock is used in the production of fertilizers; 90 per cent of white phosphorus is used in the production of detergents and other chemicals; 60 per cent of bismuth is used in the manufacture of pharmaceuticals and other chemicals; 54 per cent of silicon metal is used for making silicones and silicates (final applications in, e.g., shampoos, fixing materials and insulating materials).

B. Assessment of future demand for critical raw materials

29. In their study, Monnet and Ait Abderrahim (2018) analysed the demand for the most important CRM for the future.[7] In the energy sector, the development of wind power (involving REE) and domestic energy storage (mainly cobalt and natural graphite) are expected to drive up the CRM requirements in the coming decades. On the contrary, the requirements for deploying PV panels (mainly silicon, indium and gallium) should become less critical by 2035, primarily thanks to material efficiency. Essential drivers in this sector include policies to reduce further CO_2 emissions, incentives for distributed power generation, and power and storage requirements related to EV deployment.

30. In the transport sector, the need to decarbonize mobility and reduce air pollution is closely tied to the emergence of hybrid and electric vehicles and the persistent dependence on autocatalysts for internal combustion engines. (ICE) vehicles. EV deployment is expected to drive most of the growth of CRM requirements (mainly REE, cobalt and natural graphite) in this sector by 2035. The search for better-performing materials to replace existing ones, especially in weight and performance in extreme conditions (ceramics for jet engines, aluminium-based alloys for car bodies), should also impact the sector: tantalum, magnesium, and niobium are the main CRMs concerned.

31. In the sectors of telecoms and electronics, the global expansion of digital networks and services implies that more people have access to the internet, thus fuelling the need for connected equipment and fibre optics that Europe could produce and export. Therefore, the demand for CRMs in this sector should reach either level off (indium for screens) or keep increasing (REE, tantalum, palladium for electronic devices and appliances, germanium for optic fibres). Important drivers to monitor in the future include the miniaturisation of components, measures against planned obsolescence and restrictions on exports of e-waste. In addition, the search for better-performing and cheaper materials or components of electronic appliances fosters substitution, making future demands more unpredictable in the sector.

32. In the agricultural sector, global population growth will foster the need for more efficient agriculture, thus increasing reliance on fertilisers. On the contrary, various sources of phosphorous are likely to be considered (animal manure, sewage sludge and food waste chain) to reduce dependence on phosphate rocks. At last, the emergence of precision agriculture, helped by new technologies, might improve the efficiency of using fertilisers in a context where agriculture tries to reduce its environmental footprint.

33. In 2017, the World Bank published a set of commodities demand scenarios up to 2050. Notably, these scenarios were based on the IEA's climate and technology scenarios.[8] The World Bank projections consider three technologies – wind, solar and batteries – under 2, 4, and 6-degree global temperature increase scenarios (2, 4, and 6 DS). They found that renewable energy generation (including hydropower and biomass) in the energy mix would increase from 14 per cent to a low of 18 per cent under 6DS and a high of 44 per cent under 2DS. Furthermore, the report found that low carbon technology requirements, and relevant metals demand, would increase rapidly between 4DS and 2DS. Batteries drive demand for aluminium, cobalt, iron, lead, lithium, and manganese, by more than ten times under the 2DS compared to the 4DS.

34. The European Commission (EC) DG for Internal Market, Industry, Entrepreneurship, and SMEs performs regular criticality assessments for the EU economy.[9] The latest analysis

[7] Monnet, A. & Ait Abderrahim, A. (2018): Report on major trends affecting future demand for critical raw materials.- European Union's Horizon 2020 research and innovation programme SCRREEN - Coordination and Support Action (CSA); Ref. Ares(2018)2641358 - 23/05/2018; www.scrreen.eu; http://www.lgi-consulting.com/wp-content/uploads/2018/10/D2.2-Report-on-major-trends-affecting-future-demand-for-critical-raw-materials.pdf

[8] Low Carbon Future, The Growing Role of Minerals and Metals for a Low Carbon Future. https://doi.org/10.1596/28312

[9] Critical Raw Materials for Strategic Technologies and Sectors in the EUL: A Foresight Study https://rmis.jrc.ec.europa.eu/uploads/CRMs_for_Strategic_Technologies_and_Sectors_in_the_EU_2020.pdf

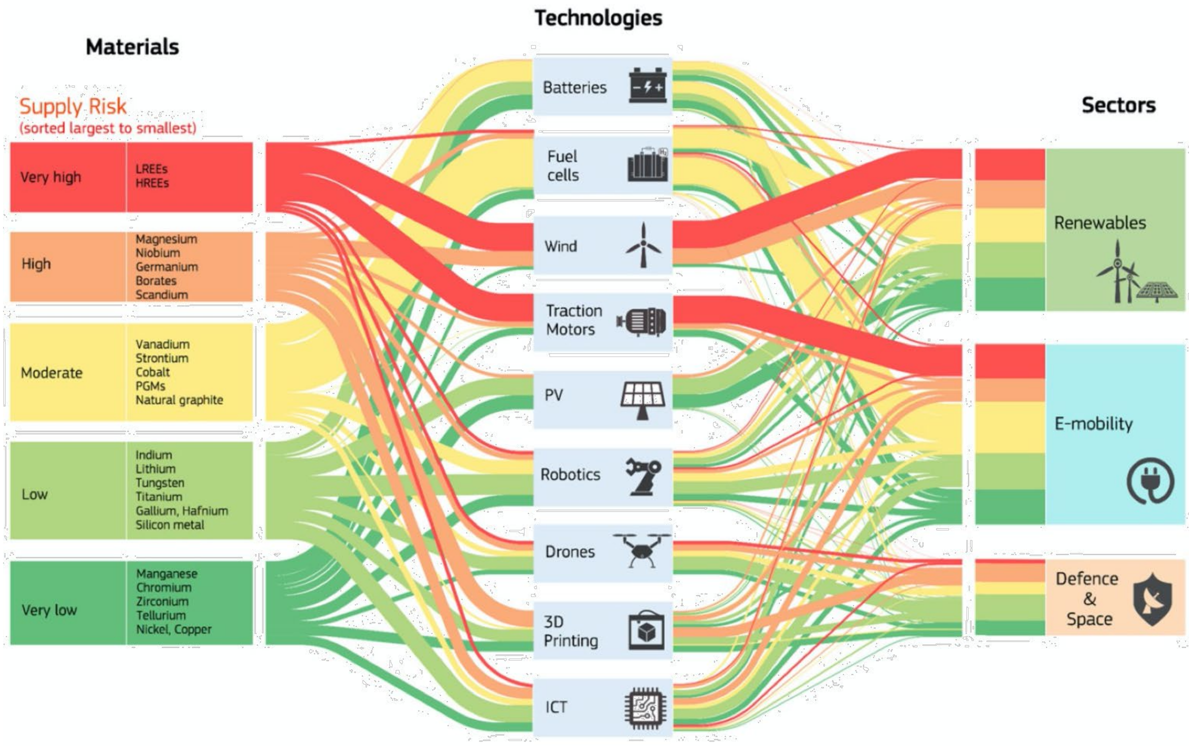
published in 2020 identified 30 critical raw materials. The EC is concerned about the supply of raw materials that is concentrated in a few countries only, such as rare earth elements (REEs) and magnesium from China, iridium from South Africa, niobium from Brazil, beryllium from the United States, but also a concentrated supply within Europe such as hafnium from France, and strontium from Spain.

35. The EC mapped the raw material used in important sectors such as (among others) aerospace/defence, electronics, mobility/automotive, energy-intensive industries, renewable energy, and digital technologies. A flow chart (Figure I) shows the use of CRMs in technologies within three strategic sectors: renewables, e-mobility, and defence and space. It visualises the complexity of the supply chains and technologies competing for critical materials (e.g., wind turbines and traction motors for rare earth elements). A missing screening component is the use of REEs in hard drives and electronics in the ICT sector.

36. In 2021, the International Energy Agency (IEA) published a bottom-up assessment of mineral demand for 2040 under various scenarios. It found that, compared to today, total mineral demand from clean energy technologies doubles by 2040 under the Stated Policies Scenario (STEPS, which assumes the implementation of current and planned policies) and quadruples under the Sustainable Development Scenario (SDS, which states that countries meet the Paris Agreement goals [climate stabilization at "well below 2°C global temperature rise"]). To achieve net-zero emissions by 2050, the IEA projects that the mineral demand will increase six times.[10]

37. The International Renewable Energy Agency (IRENA) examined the potential demand for a few critical minerals in 2050 under a 1.5°C scenario. The projection reveals the diversity in supply and demand among the critical minerals and differs significantly from, for example, the earlier World Bank estimates. By value in 2050, copper has the highest share of about a third, followed by lithium and nickel (a quarter each), graphite (10 per cent), and cobalt (7 per cement).[11]

Figure I
European Commission: Critical materials required for strategic technologies and sectors in the EU – a foresight study, 2020



10 IEA (2021): The Role of Critical Minerals in Clean Energy Transitions, International Energy Agency, World 500 Energy Outlook Special Report, World Energy Outlook Special Report.

11 IRENA, 2021. Critical minerals for the energy transition.

38. For the first time, the EC projected raw material needs by 2030 and 2050 (corresponding to the target of the Paris Agreement), which are relevant time scales to consider investments now. For applications in mobility and renewable energy, lithium demand is expected to increase by a factor of over 50 compared to the current total demand. Cobalt and graphite demand could increase by a factor of around 10. Also, the demand for REEs, which are currently mostly imported as semi-finished products, will enormously increase. Not only the criticality of raw materials was screened, but also of processed materials, components, and assemblies. In the case of lithium batteries, the EU is dependent on imports in all stages of the technology. Similar conclusions are valid for electric motors and generators.

39. The estimated total quantity of metals to manufacture one generation of renewable technology capacity to complete phase out fossil fuels (replace the existing system) is far more extensive than existing strategic thinking allows for. Conventional strategic planning in the circular economy states that the primary source of metals for the future will be recycling.[12, 13]

40. In 2020, there were 10,385 million electric passenger cars (0.7 per cent of the global transport fleet) registered globally,[14] and renewable power systems accounted for 11.7 per cent of global annual electricity production.[15] Most of the global non-fossil fuel industrial ecosystem has yet to be constructed. What has yet to be built cannot be recycled.

41. Each technology project harvests renewable energy (wind and sunlight), but they have a working life of a few years. An EV's working life is approximately 10-15 years, and solar panels and wind turbines retain operational effectiveness for about 20 years.[16] After each unit fatigues and is no longer effective, it must be decommissioned and recycled. If all the required renewable technology units to phase out fossil fuels were constructed in 2023, it would not be until 2033 that any of these units reach the end of their working life and be available for recycling. At least the first generation of technology units will have to be manufactured using minerals mining as metal feedstock.

42. The demand for minerals and metals will rise as the global population increases. In 2017, extraction reached 92 billion tons, compared with 27 billion in 1970. If current trends continue, the world will require 190 billion tons of material annually by 2060, including green technologies needed for a transition to a sustainable future. These trends make the need for an inclusive and circular economy increasingly urgent.[17]

43. The UN Policy Brief on Transforming Extractive Industries for Sustainable Development (2021)[18] highlights that some commodity-dependent developing countries, including low and middle-income countries, have a 20–30-year window of opportunity to potentially benefit from the green transition, as many are rich in the commodities needed for the renewables revolution and clean technologies, including lithium, graphite, manganese, cobalt, and CRMs. However, seizing these opportunities will first require ensuring that

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[12] European Commission (2019): Going climate-neutral by 2050 A strategic long-term vision for a prosperous, modern, competitive and climate-neutral EU economy, Directorate-General for Climate Action (European Commission), ISBN:978-92-76-02079-0, Catalog Number ML-04-19-339-EN-C

[13] European Commission (2019): REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS - on the implementation of the Circular Economy Action Plan, https://eur480 lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019DC0190&from=EN

[14] IEA (2021): Global EV Outlook, International Energy Agency report, https://www.iea.org/reports/global-ev503 outlook-2021

[15] BP (2021): BP Statistical Review of World Energy 2021, https://www.bp.com/content/dam/bp/business449 sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-r

[16] IEA (2021): Global EV Outlook, International Energy Agency report, https://www.iea.org/reports/global-ev503 outlook-2021

[17] UNEP (2019). UN Calls for Urgent Rethink as Resource Use Skyrockets. Available at www.unep.org/news-and-stories/press-release/un-calls-urgent-rethink-resource-use-skyrockets

[18] UN Policy Brief on Transforming Extractive Industries for Sustainable Development https://unece.org/sites/default/files/2021-05/SG%20Policy%20Brief%20Extractives%20NOemb.pdf

countries have adequate fiscal space and resources, including stable governments, reasonable security, and attractive regulatory and business frameworks, to invest in recovery and lay the groundwork for a resilient and sustainable future. The renewed push towards achieving net-zero emissions and the rapid decline in the costs of wind and solar technologies will eventually cause many existing fossil fuels assets – estimated to have a value between USD 900 billion and USD 1.8 trillion – to become "stranded" as investments shift towards critical rare earth and minerals needed for the renewables sector.[19]

IV. Critical raw material supply

44. Currently, mineral resource extraction plays a dominant role in the economies of 81 countries that account for a quarter of global GDP, half of the world's population and nearly 70 per cent of those living in extreme poverty.[20] This importance of mining will likely continue as the demand for the materials and critical metals needed as inputs to renewable energy and related technologies increases. The higher labour cost and stricter environmental standards in developed countries continue to make production in developing contexts attractive.

45. There is enormous potential in mineral resources for emerging economies in the current transition period, such as the contribution of mining to GDP, export contribution, exploration, and mineral rents contribution to government revenues. Among developing/middle-income countries, mining contributed the most to the national wealth in several countries. Over the years, during the period of the supercycle in the years 2000-2014 (when supply was lagging with rising demand), the importance of mining increased structurally.[21]

46. When a new super cycle starts, emerging economies could benefit. Presently the emerging economies in which mining contributes largely to national wealth have a minor contribution to global mine production. In 2018, coal mining contributed most to the value created at the mining stage worldwide. It could be problematic for emerging economies that rely on coal mining if future demand decreases. Diversification into metals and critical raw materials will help stabilize the industry and make the mining sector resilient.

47. To understand the CRMs used in batteries, it would be helpful to have an index. Such an index could be created based on the following factors:[22]

- Known resources in all countries of the world
- Current production
- Country exploration
- The mining contribution index, and
- The existence of established mining industry.

48. The countries with the most significant potential to benefit from increased demand for battery materials could be delineated from such an index. The index will show where resources are and how developed a particular country's mining infrastructure will immediately contribute to the rising demand. For an investment attractiveness index, see Fraser Institute Survey of Mining Companies 2021.

49. CRMs needed in the Information and Communication Technology (ICT) sector accounted only for 0.1 per cent of the total value obtained by mining in 2018 (excluding the rare earth elements). Current production of ICT metals such as beryllium, gallium,

[19] Carbon Tracker (2020). Fault Lines: How Diverging Oil and Gas Company Strategies Link to Stranded Asset Risk. Available at carbontracker.org/reports/fault-lines-stranded-asset

[20] UN Policy Brief on Transforming Extractive Industries for Sustainable Development https://unece.org/sites/default/files/2021-05/SG%20Policy%20Brief%20Extractives%20NOemb.pdf

[21] Magnus Ericsson, Olof Löf (2018) 3 Mining's Contribution to Low- and Middle-income Economies https://academic.oup.com/book/27405/chapter/197217134

[22] https://www.fraserinstitute.org/sites/default/files/annual-survey-of-mining-companies-2021.pdf

germanium, indium, REE, selenium, tantalum, and tellurium is dominated by the US, China, Australia, and emerging economies, providing a minor contribution.

50. Emerging economies can benefit from the unique opportunity of the expected growth of demand for metals and minerals in a low-carbon future by the increased need for mining while avoiding environmental and socio-economic pitfalls and difficulties. The European Union, the European Commission, and European countries have a role in transferring technologies and best practices to emerging economies. Mining should be further developed in developing countries (e.g., African countries) that can economically benefit from this.

51. One factor contributing to the lack of information could be the evaluation of "by-product materials", such as cadmium, germanium, and indium, present in the multi-metal ore. For example, indium is a by-product of sphalerite (zinc) ores. When zinc is mined, approximately 1 per cent of the value could be obtained from indium. But as the ore value will be determined mainly by zinc, the indium content is ignored. Cadmium, needed in specific solar panels, is seen as a toxic or impurity element, so the cadmium content is not reported with the same level of detail as other elements.

52. Currently, these CRMs are small markets with a comparatively low value in mining. They are supplied by only a handful of companies or countries. Therefore, there is a lack of recognition of CRMs in resources and mine products. This lack of data is often confused with a lack of supply potential. More global research is required to obtain more information about the supply potential of these CRMs.

53. As many of the CRMs are mined as by-products, there is little information about them in the primary deposits. However, based on data on the primary materials, which is relatively complete, estimates can be made about the potential supply of CRMs. In the "Werner method," geochemical relationships and information are used to establish correlations between reported primary materials and CRMs.

54. Given the nature of CRMs commonly reliant on primary minerals and their extensive global endowment, it is clear that the world has an equally vast endowment of CRMs. For example, regarding rhenium (a by-product of molybdenum), there is a linear correlation between rhenium content and molybdenum content in the economic reserves. Even though data is lacking on rhenium's availability, the information available on molybdenum can be used to extrapolate and estimate the availability of rhenium. Based on such relationships, large amounts of resources of gallium, germanium, hafnium, tellurium, selenium, indium, and strontium could be inferred.

55. Even when focusing on the main minerals, the amount of resources has been demonstrated to be dynamic. During mine production, reserve estimates become more accurate and sometimes increase, and additional resources are also identified. There is, however, a trend of declining ore grades for copper, nickel, lead, zinc, and many other metals.[23] How much can be recovered from a certain amount of ore depends on factors such as how refractory the ore is, possible processing technologies, impurities, and recovery rates. But in general, lower ore grades mean that an increasing amount of ore needs to be processed to obtain the required metals – increased mining and processing results in increased social and environmental impacts, which to a certain extent can be addressed by increased efficiencies of new mining and process technologies and financially, a diminishing-returns exercise for mining companies.

56. Studies on nickel deposits show that deposits should not only be evaluated based on the grades of the primary metal. The contents of copper, cobalt, and platinum group metals (PGMs) could have similar cumulated economic value if all the extracted metals are considered (known as "comprehensive recovery"). The economic profitability of mining is influenced by the grade and the type of mineralogy. Higher-grade mineral deposits could be sulphides or oxides, whereas lower grades could be granite or limestone. Extraction from

[23] Calvo G, Mudd G, Valero A, Valero A. Decreasing Ore Grades in Global Metallic Mining: A Theoretical Issue or a Global Reality? Resources. 2016; 5(4):36. https://doi.org/10.3390/resources5040036

these lower-grade deposits requires a much more considerable amount of energy. Skinner's Mineralogical Barrier indicates the change of mineral type.[24]

57. The principal CRM challenges are understanding recoverability, global market dynamics (especially rapidly evolving sectors like renewable energy, electric vehicles, speciality alloys, electronics, etc.), market power, trade flows, and implications.

58. The production of REEs, which are also increasingly used in modern technologies (defence, renewables), is currently dominated by China.[25] Australia now mines REEs from Mount Weld and Brown's Range. Other active projects are the production of REEs as by-products at Toongi or Heavy Mineral Sands (HMS). Australia has another large deposit of REEs, the Olympic Dam. This deposit is mostly sub-economic when CRMs are considered individually. Still, when viewed in the context of comprehensive recovery, the economics are more attractive (e.g., Olympic Dam is the world's largest single uranium resource, however, if uranium were considered alone, it would be sub-economic, but when considered in the context of comprehensive recovery as a by-product of copper mining, with gold and silver also recovered, Olympic Dam, is a significant global producer of uranium). Furthermore, the specific availability of REEs (heavy or light) is also relevant to determining economic feasibility.[26]

V. Secondary sources and circularity strategies

59. The mining sector plays a dominant role in CRM supply. However, primary production and global supply chains face critical environmental and social challenges and substantial political and financial risks (see Section IV). At the same time, the CRM stocks in our society are continuously growing. The most important streams are mining residues, landfilled residues, electric and electronic equipment, batteries, vehicles, renewable energy infrastructure, defence equipment, chemicals and fertilisers.

60. The sustainable management of CRMs benefits from a circular economy, which prolongs product lifetimes and recovers CRMs from secondary sources. This section introduces the relevance of the circular economy, explains fundamental principles of the circular economy for CRM management and draws a landscape in which several supportive elements already exist. It closes with a list of instruments national policymakers could explore to support the circularity of critical raw materials.

A. The relevance of circular economy for sustainable critical raw material management

61. On the one hand, the circular management of critical raw materials can substantially reduce GHG emissions and other negative environmental impacts such as air, water and land pollution due to mining and processing, as well as social and geopolitical issues related to primary supply. On the other hand, it can help to secure CRM supply and reduce the pressure to mine more primary natural resources:

- With circular economy strategies such as prolonged product lifetime or repairability, unnecessary wastages and losses are prevented, and raw materials are kept in the economic cycle as long as possible. The resource value is thus preserved, less primary and secondary production must occur, and the demand for new resources decreases

[24] Skinner, B. J. (2001, April). Exploring the resource base. In Proceedings of the Workshop on "The Long-Run Availability of Minerals", Resources for the Future (RFF), Washington, DC, USA (pp. 22-23).

[25] Kalantzakos, Sophia, 'How China Came to Dominate the Rare Earth Industry', China and the Geopolitics of Rare Earths (New York, 2018; online edn, Oxford Academic, 23 Nov. 2017), https://doi.org/10.1093/oso/9780190670931.003.0005

[26] Schmandt, D. S., Cook, N. J., Ciobanu, C. L., Ehrig, K., Wade, B. P., Gilbert, S., & Kamenetsky, V. S. (2017). Rare earth element fluorocarbonate minerals from the olympic dam Cu-U-Au-Ag deposit, South Australia. Minerals, 7(10), 202.

- End-of-life recycling of product parts, alloys or raw materials also helps to reduce environmental footprints: secondary sourced raw materials usually have a much lower environmental footprint than those mined from primary sources. At the same time, the inflow of recycled material adds to material supply, reducing dependencies on other countries and other risks related to primary mining. Supply chain risks that might impede the large-scale deployment of critical new technologies, such as low-carbon energy production and mobility, can thus be reduced.

62. Unfortunately, critical raw materials are often not preserved in the economic cycle. Discarding fully or partially functional products leads to material and value loss. Domestic recycling often does not occur: for example, only 40 per cent of European electronic waste is recycled in the EU.[27] If products reach proper end-of-life recycling, the critical raw materials are frequently not recovered. One reason is that the amount of specific CRMs in a product is often too low to be of economic interest. However, although the mass fraction of a particular raw material in a product might not be high, it is usually still substantially higher than in natural ores, making the "urban mine" an (although dispersed) high-quality ore.[28]

63. In the case of raw materials with a very high price (such as platinum group metals), there are solid financial drivers to preserve their value, even if they only can be recovered in minor amounts per product. Accordingly, these materials are already managed in closed loops in many applications. For other critical metals (such as rare earth elements), circular strategies – including recycling – are often not economically competitive. Accordingly, preservation and recovery rates for these raw materials are meagre, despite their crucial role in technological development and advancement.

64. Policy incentives are therefore needed to increase the circularity of materials where economic drivers for preservation are insufficient to fully address the strategic value of these resources, their limited accessibility, and the negative impacts often associated with their primary supply.

B. Spotlight on circular economy enablers

65. A central claim of a circular economy is that it keeps the value of products, materials and resources maintained in the economy for as long as possible.[29] Accordingly, whenever possible, the "inner loops" of the Ellen MacArthur circular economy system diagram ("butterfly diagram") should be used,[30] including the prolongation of the lifetime of products and closing material loops. Key enablers comprise circular product design, repair and recycling.

66. *Circular product design:* Product and systems design will play a key role in enabling the transition to a circular economy, keeping in mind that circularity is a means to support the transformation towards a more sustainable society operating within the planetary boundaries and not an end in itself. Given supporting the design of sustainable products, the European Commission proposes a sustainable product policy legislative initiative expanding the Ecodesign Directive beyond energy-related products to make the Ecodesign framework[31] applicable to the broadest possible range of products and deliver it on circularity. As part of this legislative initiative, the Commission will consider establishing sustainability principles and other appropriate ways to regulate aspects such as improving product durability,

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[27] https://www.europarl.europa.eu/news/en/headlines/society/20201208STO93325/e-waste-in-the-eu-facts-and-figures-infographic

[28] Bangs, C., Meskers, C., Van Kerckhoven, T., & Refining, U. P. M. (2016). Trends in electronic products—the canary in the urban mine. Proceedings of the Electronic Goes Green, 7-9.

[29] What is a circular economy? https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

[30] https://ellenmacarthurfoundation.org/circular-economy-diagram#:~:text=The%20circular%20economy%20system%20diagram,cycle%20and%20the%20biological%20cycle

[31] Ecodesign for sustainable products https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733524/EPRS_BRI(2022)733524_EN.pdf

reusability, upgradability and reparability, enabling remanufacturing. High-quality recycling, incentivising product-as-a-service or other models where producers keep the ownership of the product or the responsibility for its performance throughout its life cycle, and mobilising the potential of digitalization of product information, including solutions such as digital passports., design for the inner loops could use a modular approach which makes it easier for components to be separated, recovered, or replaced during repair, reuse, or remanufacturing. [32, 33, 34]

67. *Repair:* Repairing is a crucial strategy to extend the lifetime of a product and can often be done independently of the company producing the products: by consumers themselves or local professionals. Following a resolution of the European Parliament on a longer lifetime of products in 2017 and two different resolutions calling on a 'right to repair', the European Commission has announced the introduction of an effective right to repair for consumers in several of its strategic documents: the European Green Deal, the new circular economy action plan and the new consumer agenda.[35] First acts implementing this right exist, e.g. for washing machines, servers and data storage products or electronic displays. They require manufacturers to ensure, amongst other things, that (i) joining, fastening or sealing techniques do not prevent the disassembly for repair or reuse purposes, (ii) spare parts are available for a certain number of years after the last item has been placed on the market (e.g. seven years for electronic displays), (iii) the ordered parts are delivered within 15 days and (iv) maintenance information, including manuals, is made available to professional repairers. Repair is also considered in rules on the EU Ecolabel, a voluntary labelling scheme of 'environmental excellence' developed for a limited set of products and services. Establishing policies supporting increased product lifetimes would also reduce the demand for CRMs, provided potential rebound effects (e.g., increased consumption of other CRM-containing products) do not compensate for this.

68. *Recycling:* CRM recovery allows substituting primary supply, typically with lower environmental impacts. Given the relevance of CRMs for emerging technology applications with rapidly growing demand and the time lag between these applications being placed on the market and reaching end-of-life, the primary production of CRMs will remain dominant in the coming years. The recovery of CRMs comes along with challenges, including the strong influence of the primary raw materials price on the economic viability of recycling, collection and channelling of End of Life (EoL) products to the appropriate facilities, optimal recycling processes minimizing CRM losses, mass-based recycling targets focusing on bulk materials, or the availability of data on product composition, stocks and flows and CRM recoverability.[36]

69. Addressing these challenges will require the intensification of research and development activities about, amongst others, the provision of data on CRM along the product life cycle and under the inclusion of proprietary data (such as digital passports, distributed ledger technology), innovative, efficient and cost-effective technologies for the recovery of CRMs in a product-centric perspective,[37, 38] and factors determining the success

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[32] A new Circular Economy Action Plan. For a cleaner and more competitive Europe. COM (2020) 98 final. https://ec.europa.eu/environment/strategy/circular-economy-action-plan_en

[33] Commission 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

[34] Tercero et al. (2020) Greater circularity leads to lower criticality, and other links between criticality and the circular economy. Resources, Conservation & Recycling 159, 104718. https://doi.org/10.1016/j.resconrec.2020.104718

[35] Right to repair. Briefing for Members and staff of the European Parliament, https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698869/EPRS_BRI(2022)698869_EN.pdf

[36] https://weee-forum.org/projects-campaigns/futuram

[37] Loevik, A., Wäger, P. and Hagelüken, C. (2018) Improving supply security of critical metals: Current developments and research in the EU. Sustainable Materials and Technologies 15, 9-18. https://doi.org/10.1016/j.susmat.2018.01.003

[38] UNEP (2013) Metal Recycling: Opportunities, Limits, Infrastructure, A Report of the Working Group on the Global Metal Flows to the International Resource Panel. United Nations Environment Programme, Paris.

of business models and strategies towards circularity.[39] Concurrently, the integration of specific provisions related to the recovery of CRMs into the legislative framework, e.g., in the context of the foreseen revision of the rules for end-of-life vehicles,[40] will have to be pushed forward.

C. Supportive instruments to accelerate the transition to a circular economy

70. The supply of CRM faces several challenges in meeting the future demand for renewable energy transition (See Section IV). To overcome these challenges, instruments such as the European Action Plan on critical raw materials aim to reduce dependencies on third countries, diversify supply from both primary and secondary sources and improve resource efficiency and circularity while promoting responsible sourcing worldwide. The Circular Economy Action Plan (CEAP), one of the building blocks of the European Green Deal, will implement regulatory measures for specific products containing CRMs: e.g., electronics shall be designed for energy efficiency and durability, reparability, upgradability, maintenance, reuse and recycling. The EU's new regulatory framework for batteries was adopted in March 2022, aiming to secure the sustainability and competitiveness of battery value chains. It introduces requirements such as minimum recycled content for specific raw materials, durability criteria, and material recovery targets for critical raw materials such as cobalt, nickel, and lithium.

71. Such policies serve circular economy goals like preserving resource value and reducing the environmental footprints of CRMs with considerations of securing the critical raw materials base for the energy transition and other relevant technological deployments. These are essential steps toward more sustainable and resilient economies.

72. There is a large set of supportive instruments that can be encouraged, implemented and utilized by policymakers and regulators:

- National circular economy strategies and action plans focus on CRMs to extend product lifetimes and recover more CRMs from secondary sources
- Measures that unlock the full potential of sharing, repairing, remanufacturing and recycling with a particular focus on CRMs of electrical and electronic equipment
- Set up and strengthen separate collection schemes for Waste from Electrical and Electronic Equipment (WEEE) and enforce awareness-raising campaigns to inform consumers about proper waste separation
- Stop illegal waste shipments, especially WEEE and End of Life Vehicles (ELV). Strengthening waste inspections and border controls helps domestic recyclers access waste containing CRMs
- Assess the feasibility of CRM recovery from extractive industry residues in their country
- Implement legislation to increase product lifetime (such as the "right to repair")
- Industries must be encouraged to establish sustainable supply chains through responsible business conduct
- Green Finance mechanisms encourage national stakeholders to support CRM sourcing in the mining and recycling sector.

73. Countries should develop robust CRM e-waste supply chains based on the circularity principles and requirements of UNRMS. The strengths of the informal sector (collection) should be combined with the stability of the formal sector (advanced recycling technologies). Formalization does not have to imply a loss of jobs or revenues. Employees in the informal

[39] The role of industrial actors in the circular economy for critical rawmaterials: a framework with case studies across a range of industries. Mineral Economics. https://doi.org/10.1007/s13563-022-00304-8

[40] Commission Staff Working Document Evaluation of Directive (EC) 2000/53 of 18 September 2000 on end-of-life vehicles, SWD(2021) 61 final

sector can be incentivized to work in better environmental conditions, with fewer health risks and increased job security. Creating formal jobs can lead to safe recycling practices, higher income generation, and higher employment levels. Robust supply chains start in households. Increased awareness and access to collection points can help better waste separation. Here, PROs and local municipal governments play a role. There is also the opportunity for technology and knowledge transfer. India, for example, can learn from best practices in, example, Europe.

74. Resource policymakers, industry and recyclers would profit from systematic data sourcing and data-driven business models. It is recommended to support the global development of CRM data strategies, including foresight on future supply, product labelling through digital passports, blockchain technologies and new standards for sharing proprietary data. Countries and the industry should develop research and innovation programmes regarding circularity strategies, recycling technologies and new business models fostering resource conservation. Governments should also accelerate the implementation of sustainable product policies and specific provisions related to CRM recovery into national legislative frameworks.

VI. Improving transparency of critical raw material sourcing

75. A range of social issues often bogs down critical raw material projects. Challenges with large-scale mining, chemically intensive processing, vast quantities of waste created, rights of the indigenous populations, issues related to children and women and human rights make the projects socially unacceptable in many situations.

76. There is a need for companies and governments to better transparency regarding the origin of CRMs. Blockchain is an emerging technology that can improve transparency in the mining sector. The technology lets people know where the material comes from and under what conditions it has been produced.

77. Blockchain could be understood as a database used to make unique digital items. The items can store value as each item is unique and unchangeable (copies can be identified). This concept could be used to create digital certificates. These certificates can be linked together, gathering information from every supply chain actor to transfer supply-chain information.

78. Supply-chain traceability should start at the mine site and push data down the supply chain. Alternatively, one could begin with a downstream user that wishes to discover who operates in their supply chain and what data can be retrieved. Information could be traced about carbon emissions, policies, willingness to supply data, and documents that facilitate international trade could be generated. It goes beyond responsible sourcing; this strategy also allows companies to secure their supply, verify their purchases, and have confidence in the data.

79. The needs of supply chain participants are diverse: upstream suppliers are interested in market access, investment, and social license to operate, via the provision of data and differentiation of their products. Regulators and downstream companies mainly look for transparency and supply-chain security. The needs of traders in the middle are shifting from protecting supply-chain information to active participation in sharing information. The needs of upstream suppliers are often overlooked. The scalability of blockchain solutions towards better supply-chain transparency can be increased by demonstrating the value of traceability to producers, even if they participate on their own.

80. The Korean Mineral Resource Information System (KOMIS) is an example of government support for data allocation. The London Bullion Market Association (LBMA) aims to make a gold bar registry and is currently evaluating different authentication security features. The Institute for Forensic Geology (IFG) reported that the Swiss refiner Metalor, in collaboration with the Swiss Government, Innosuisse and the University of Lausanne, announced the development of a ‘Geoforensic Passport’ for responsibly sourced gold. Its success in gold value chains might indicate that blockchain is currently easier applicable to raw materials of high value.

81. Areas like carbon emission tracking, import document management, and incident reporting are not dependent on the value of the material tracked. Blockchain technology could be a breakthrough in fulfilling UNRMS needs regarding responsibility and transparency. (For more details, see Concept Note: UNFC and UNRMS - Systems approach to enabling the resource as a service paradigm through blockchain technologies ECE/ENERGY/GE.3/2022/5).[41]

82. As long as the supply of traceable materials is limited, encouraging the demand for these minerals only leads to shifting the problem to other value chains. Therefore, regulations and incentives are needed to increase responsible supply.

VII. Financing critical raw material projects

83. To attract investment, including private finance, into the sector, it is also critical to deploy Environmental, Social and Governance (ESG) funding based on common sustainable finance taxonomy and principles. ESG financing is increasing and is part of the solution to the challenge of transitioning to a low-carbon future. Such initiatives, though, run the risk of "greenwashing". At the same time, the mining and metals sector continues to underperform against most key assessment indicators.

84. The principles-based UNFC and UNRMS approach provide the proper framework for sustainable resource management that can help attract the necessary investments. To attract ESG and climate-related funding, robust socially and environmentally referenced information is required. Such information is also needed for strategic policy making and regulations. The CRM information dashboard could also link to the civil society groups concerned about the process's opaqueness. The CRM information dashboard module of UNRMS is intended to serve these purposes.

85. China is the largest producer of more than 20 CRMs. China is less reliant on international alliances and coalitions and more self-sufficient. One strategy of China is to develop its mining, processing and refining technologies. For example, China modified the Bayer process to refine lower-grade domestic bauxite. In contrast, western countries rely on the import of higher-grade bauxite. In the last few years, many research hubs and centres have been funded by the Chinese government at home and internationally, including in Africa.

86. The EU followed a similar strategy as China concerning the automotive industry, particularly the battery supply chain, by offering grants to manufacturers. One of the European Raw Materials Alliance aims is to access EU funding opportunities and financing sources for developing mining /refining projects inside and outside Europe. As some of the projects are technically challenging and investments may not yield returns, the term "aid" applies here. Such measures are a necessity to become self-reliant on critical materials.

87. Support is provided to the automotive industry in the EU and Canada, but mining companies also need aid. CRMs attract less than 5 per cent of the global exploration budget, and these projects are usually financed through capital markets. Canada has the highest number of listed companies exploring or mining CRMs, including lithium and graphite. However, most projects lack funding.

88. In Australia, Lynas Rare Earths Ltd successfully developed its rare earth project due to the support of Japan, more or less in line with the Chinese model. Japanese companies provide loans to Lynas and are incredibly patient and tolerant about the financial performance of Lynas and their ability to serve the loans. In the US, rare earth is mined by MP Materials and sent to China for further processing. Before MP Materials, the rare earth deposit was owned by Molycorp. This company went bankrupt because its creditors were not as patient as in the case of Lynas. Most such CRM companies are funded through the stock market. Only a tiny amount of the funding is spent on exploration, and the competition to receive this funding is high.

[41] https://unece.org/sed/documents/2022/02/session-documents/concept-note-unfc-and-unrms-systems-approach-enabling

89. Raw material processing facilities are direly in need of funding. Processing of critical materials is very complex and often energy intensive. This complexity and energy requirement makes it difficult for developing countries, which do not always have the necessary power infrastructure to support such projects. The capital expenditure (CAPEX) of material processing plants can be around a billion dollars, similar to the total size of the annual market of certain materials. With a typical, expected investment payback time of 4 years and an internal rate of return of 20 per cent, investing in processing critical raw materials is not always feasible.

90. Therefore, governments should collaborate to increase the discovery and advancement of critical materials worldwide, as envisioned by the US Energy Resource Governance Initiative (ERGI).[42] Especially international coordination is needed. Governments should collectively invest in infrastructure, as significant resources of critical materials are in remote areas, e.g., in Northern Canada and Africa.

91. Governments should collaborate to invest in mineral projects via low-interest loans, equity investment, grants, lower taxes, joint ventures, public-private partnerships (PPPs), etc. – the EU Raw Materials Alliance is an excellent example of PPPs. Global supply chains should be supported by offering aid to resource companies, refiners and processors, metal makers, fabricators, etc. Resource-rich countries should avoid resource nationalism, but more effort should be made to bring benefits to countries that are supplying minerals. Finally, investing in R&D and skill training centers is needed to build the required technical workforce and stay competitive.

92. The Paris Agreement includes a global goal for adapting to the effects of climate change. Trillions of dollars worth of investments are needed each year to achieve the rapid, far-reaching transformations required to address the impact of the climate crisis from the perspectives of mitigation and adaptation. Developed countries and private sector investors have yet to deliver on the annual USD100-billion commitment of climate finance agreed to in 2009, which was to be reached by 2020, and progress towards aligning all financial flows with the SDGs and Paris Agreement goals is nowhere near what is needed. At COP26, new financial pledges were made to support developing countries in achieving this goal. The Paris Agreement includes a global goal for adapting to the effects of climate change. At COP26, new financial pledges were made to support developing countries in achieving this goal.[43]

93. To deliver on climate change and sustainable development, the UNECE region must optimize the management of endowments of natural resources, including critical raw materials (CRMs). A resilient, sustainable and ethical supply of CRMs is essential for clean energy, mobility transitions, and digital transformation. Resiliency in resource supply requires careful attention to several important environmental, economic and social considerations. Governments, industry, the financial sector, and civil society must cooperate to share relevant social and environmental information and knowledge. As this will require massive investments, the mobilization of finance through public-private partnerships (PPPs) and the use of climate finance instruments, such as green bonds, will help secure access to the necessary capital, foster innovation, and support transfer expertise.

VIII. UNRMS-based critical raw materials information dashboard

94. Natural resource management is the field of activity that examines the physical, social, biological, environmental and economic implications that come from working with or using natural resources. It studies the utilization of natural resources and the consequences of those uses on natural and human systems. The new imperative to address the Sustainable Development Goals requires wise natural resources management, coming from collective analysis, benefiting from good decision-making, depending on good information, and the judicious use of quality data.

[42] https://www.state.gov/wp-content/uploads/2019/06/Energy-Resource-Governance-Initiative-ERGI-Fact-Sheet.pdf

[43] https://unfccc.int/process-and-meetings/the-paris-agreement/the-glasgow-climate-pact/cop26-outcomes-finance-for-climate-adaptation#eq-5

95. Sustainable resource management is enabled by an interdisciplinary data system that considers the physical, biological, economic and social aspects of working with natural resources. In the context of the SDGs and the UN Secretary-General's call to action included in the UN Policy Brief on Transforming Extractive Industries for Sustainable Development, the CRM information system should permit interested persons, companies, agencies and governments to view, extract, analyse, and interpret information concerning the opportunities and consequences of a natural resource activity. Multistakeholder evaluation will yield a much broader and often more inclusive and thorough assessment and can lead to proposals that constitute the best overall outcome.

96. An information system needs data. The need for quality data is crucial to making good decisions. Quality data requires structure and purpose. There is great diversity in the natural resource value chain participants, from business executives to labourers, from civil society volunteers to government agents. The strength of a robust and accessible data system will be most valued in the very diversity of the constituency of a system. A global natural resource information system has specific data quality needs and suitability to purpose.

97. Resource information, like much business information, currently resides in silos. These may be silos of activity (mining), silos of responsibility (regulation and standards), silos of use (water consumed), silos of impact (GHG emissions), silos of social responsibility (agencies), silos of national interest (governance) etc. There are many silos and many organisations responsible. Despite this level of complexity, most information management systems still operate autonomously. Without communication and coordination between siloes, global management actions can be misdirected or even missing. A decision that maximizes activity in one area may significantly impact the outcome of another and, without consultation, lead to a less-than-desired outcome.

98. The world is witnessing an evolution in the ability to communicate instantly. Yet there is an inability to access data. We are also seeing the consequences of such open and rapid communication manifested in both increased communication of global issues and increased miscommunication or false information presented as truth. This divergence leads to a lack of trust. This lack of confidence can seep into a lack of trust in technology systems and result in questions about how data is used. A global natural resource management system requires open, verifiable and secure data.

99. How data appears is often as important as data quality. Data that cannot be easily accessed or viewed is not usually of great use for comparative analytics. A dashboard is a tool that collects, organizes and displays data in a format that allows users to access, visualize and perform fundamental data analysis of single or multiple datasets. The purpose of a dashboard is to enable users to draw insights and drive action. A dashboard must tell the right story to the right audience to drive action. There are four types of dashboards designed for four types of audiences.

100. Strategic dashboards focus on reporting high-level metrics. They are enterprise-wide, broad in scope, and complex in creation. They track performance against long-term strategic goals and usually provide summaries over time frames of months, quarters, or years. The primary users of strategic dashboards are senior management. In a corporate setting, this would be individuals in senior management positions.

101. Tactical dashboards show information that supports monitoring the progress of strategic initiatives. Tactical dashboards help filter, segment, and include fewer data and more data visualisation than the following two dashboard types. In a corporate setting, tactical dashboards benefit those in vice-president positions in marketing, human resources, or communication, for example, evaluating higher-level activities.

102. Operational dashboards focus on real-time performance. They are aligned with key performance indicators and help users to understand an activity's current day-to-day or minute-to-minute status, to manage operations, and to monitor operational performance. Operational and process managers and directors use this type of dashboard.

103. Analytical dashboards can contain a vast amount of data from various sources that users can analyse to provide insights into historical results. They are often complex, using

modelling and what-if questioning. The users are area experts and business analysts – individuals tasked with understanding and evaluating causation.

104. It is conceivable that there could be at least three somewhat different initial user groups for global natural resource data presented in the form of dashboards. These three groups will work with the same data but view it differently.

105. The first users of a global natural resource management dashboard in UNRMS will likely be government policy officers. Their work includes drafting policy analysis, implementing projects and programmes of work, coordinating activities across departments and external stakeholders, and closely supporting decision-makers. They can examine global natural resource data to support programs such as the Sustainable Development Goals. They will benefit from a tactical dashboard reflecting information from the resource sector. The second group of global natural resource management dashboard users in UNRMS could participate in 'tabletop' or 'nexus' group activities. Multidisciplinary group exercises have already been trialled to evaluate natural resources in transboundary basins. The participants in this type of exercise will be domain subject experts from various disciplines and stakeholder groups. Resource analysis group needs will include accessing and drilling down through data quickly. The users will look to a dashboard to provide current, accurate, sufficiently complete, and reliable country data on global natural resources. They will need existing country resources and secondary materials data in UNFC. This group may be charged with tactical responsibility; however, their domain expertise presumes a professional knowledge of natural resources and suggests the need for an analytical dashboard.

106. The information should also be used by other stakeholders in the industry, financial institutions, academic researchers and social and environmental stakeholders for various applications and requirements (Table 1).

Table 1
Possible applications of UNRMS-based CRM information dashboard

Regional and global criticality studies
Resource availability
Supply-demand analysis
Optimize resiliency in production and supply
Metric on circular economy
Improving transparency and traceability
Climate finance and sustainability-focused investments
Environmental, social, and governance (ESG) compliance

IX. Conclusions and recommendations

107. There is still a lack of information on the main application of some CRMs, the expected demand, the resource available and the likely supply scenarios. Criticality is defined from the consumer perspective, considering supply risk and (economic) importance. With the ongoing low-carbon energy, e-mobility and digital transitions, it is essential to see how to balance the importance of this criticality with ESG and relations with developing economy-producing countries. There is a need to focus on the best initiatives to strengthen regional and global partnerships.

108. Therefore, criticality assessments should incorporate the third dimension of environmental and social impact analysis to guide priorities. Assessment is required to see how efficiently CRMs in question can contribute to the total material flows, such as dematerialisation, which is key in the low carbon economy challenge. In addition to country resource base, corporate resource base should also be measured and reported in a standardized and harmonized manner, as companies control production. It could be helpful

to consider ore grade decline over time concerning its effect on the cut-off market price per country and even globally in the long term. Such an analysis is possible only if accurate socially, environmentally, and economically referenced information is available.

109. Challenges to fulfilling CRM demand include the secure supply of CRMs in both the public and the private sector, lacking capability of the recycling system to keep up with increasing material demand, and the occurrence of CRMs in radioactive ores, which poses challenges for regulation regarding the environment and health and safety.

110. The social and environmental impacts, on the one hand, and societal opposition to mining, on the other hand, were named as the most significant challenges in many countries to increasing domestic mining activities. It is mentioned that, for materials such as tantalum, there is high variability in supply depending on currency markets and opacity in artisanal supply chains, combined with little exploration to determine resources.

111. It is suggested to investigate secondary applications of some CRMs when existing studies reveal a quickly growing application (e.g., storage application for cobalt and natural graphite). In these cases, even secondary applications could exacerbate the upward demand trend. Finally, in specific situations, a focus on some processing steps of the CRM value chain could bring valuable information since the criticality of some CRMs mainly depends on a particular form of a product, like high-grade silicon used for PV panels and electronic components. More circular business models need to be implemented. It is emphasized that many CRMs are highly diluted in applications. For example, niobium, due to its primary use in steel alloys, recycling can hardly help to support supply. Data on secondary resources are not captured in national databases. Therefore, the information system should include secondary resource data.

112. UNRMS provides the fundamental principles and requirements for the sustainable management of all resources, including critical raw materials. Comprehensive information on CRM resources, demand, and supply will ensure that the projects promote good social and environmental outcomes. Provenance information is of high importance, along with whether the material passed through conflict-affected or high-risk areas, information about the regulatory framework of the country of origin, as well as documents and data confirming compliance with this framework. Carbon emissions and other environmental impacts are of interest as well. Companies will have to share data and be more open regarding their products' Life Cycle (Sustainability) assessments and performance.

113. **It is recommended that an international UNRMS-based CRM information dashboard be established, which can be accessed by governments, industry members and anyone with information to share with others worldwide.** The CRM information dashboard could provide all the relevant social, environmental and economic data on CRM projects, which could be used for government policymaking, industry business models and financial capital allocation. Since the circular industry is an inevitable trend, knowing early about new practices, regulations and standards from other parts of the world is crucial to allow for a fast response. Also, the vital role of utilizing "waste" materials for sustainable supply is highlighted, such as mining waste, currently unused by-products (e.g., cadmium and rare earth elements from phosphate rock), and anthropogenic resources. Furthermore, innovative approaches such as resources as a service must be considered, as adopted by the platinum industry. (See ECE/ENERGY/2022/7 – Resources as a Service: A catalyst to accelerate the energy transition, safeguarding climate action targets within the circular economy.)

114. National inventory based on UNFC and UNRMS is required to track CRM**.** In the informal sector, tracking material flows and recovery rates is impossible. Anecdotal evidence suggests that recyclers only recover visible gold (0.18 g), silver (0.02 kg), and copper (0.018 tonnes) per tonne of printed circuit boards (PCB), which is only a fraction of the total quantity of recoverable metals. The remaining PCB waste is shredded and exported. The national inventory of mineral flows should be strengthened to understand what minerals can be recovered, current recycling rates, and current capacity utilization (which is currently low). Even though a current act mandates recyclers and dismantlers to maintain records of e-waste for the state and central pollution control boards in India, these reports are infrequent and not standardized and focus on the input flows rather than the flows of recovered materials. E-

waste flows could be mapped by triangulating information between recyclers, collection centres, and PROs (producers' responsibility organizations, which take over the responsibility of end-of-life products from OEMs).

115. Strengthening national policies aligned with UNRMS principles on recycling CRMs is urgently required. Current recycling targets are based on the collection rather than the recovery rate. Consequently, recyclers have focused on the mechanical separation of e-waste instead of chemical separation, resulting in low recovery rates. The import of electronic waste increased between 2015 and 2019 by 390 per cent globally. However, the refining capacity remained constant. Another recommendation is extending the scope of extended producer's responsibility (EPR), incentivizing OEMs' take-back of old equipment. This will stop waste from flowing into the informal sector.