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TECHNOLOGY CRITICAL ELEMENTS AND THE GEF

Technology Critical Elements and the GEF

A STAP Advisory Document
November 2020

STAP SCIENTIFIC AND TECHNICAL ADVISORY PANEL
An independent group of scientists that advises the Global Environment Facility

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The Global Environment Facility (GEF) was established on the eve of the 1992 Rio Earth Summit to help tackle our planet's most pressing environmental problems. Since then, the GEF has provided close to $20.5 billion in grants and mobilized an additional $112 billion in co-financing for more than 4,800 projects in 170 countries. Through its Small Grants Programme, the GEF has provided support to nearly 24,000 civil society and community initiatives in 133 countries. http://www.thegef.org

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Uganda: Wolframite (Tungsten) mining. Alex Tyson

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TECHNOLOGY CRITICAL ELEMENTS AND THE GEF

INTRODUCTION

1. Technology critical elements (TCEs) include rare earth elements, the platinum group elements and other relatively scarce metals,[1] which are used in emerging and green technologies. However, the extraction of TCEs can have potentially harmful effects on ecosystems and human health when released into the environment. Products containing TCEs include electric cars, wind turbines and solar cells, which are important for dealing with climate change, but the unsustainable mining, processing and disposal of TCEs could adversely affect the objectives of the Global Environment Facility (GEF) in chemicals and waste, land degradation, forestry and biodiversity. The Scientific and Technical Advisory Panel (STAP) paper on novel entities recommended that managing the risks and harnessing the opportunities of TCEs should be a focus for the GEF.[2]

2. A number of GEF projects concern mining and its environmental impacts, mainly under the Minamata Convention, and the adoption of cleaner techniques for artisanal and small-scale gold mining, which uses mercury for amalgamation purposes. The GEF has invested in country-level capacity-building, which can also be applied to the mining of TCEs.

3. The GEF's global E-Mobility and Cleantech Innovation Programs both involve the use of TCEs and address issues such as battery recycling and the management of end-of-life products and components. The mining of TCEs is also relevant to the Congo[3] and Amazon Basin Impact Programs.

4. This paper summarizes the benefits and costs of TCEs as well as mitigation measures, policies and practices, and it makes recommendations for future interventions.

THE BENEFITS AND COSTS OF TCEs

Benefits

5. TCEs have many uses in renewable energy, energy security, energy storage, electronics, urban development and agriculture. TCEs facilitate communication and transportation and provide other socioeconomic benefits:

- TCEs are used in high-tech products and everyday consumer products such as mobile phones, thin-layer photovoltaics, lithium-ion batteries, fibre-optic cable and synthetic fuels.
- Many advanced engineering applications, including clean energy production, energy storage technologies, communications technologies, computing, wind turbines and solar panels, use numerous TCEs.
- TCEs are also being used in transportation, for example in the manufacture of electric vehicles and in aerospace, particularly in electric motors and batteries, both of which contain lithium.
- Many electric motors use high-powered magnets containing TCEs.
- Emerging technologies such as the Internet of Things, automation and robotics use TCEs in the data networking of smart devices, vehicles and buildings.
- Automation and robotics will be used increasingly in artificial intelligence, which will involve the use of TCEs.[4]

Table 1. Example applications of rare earth elements[5]

Area	Applications
Electronics	Television screens, computers, mobile phones, silicon chips, monitor displays, long-life rechargeable batteries, camera lenses, LEDs, compact fluorescent lamps, baggage scanners, and marine propulsion systems
Manufacturing	High strength magnets, metal alloys, stress gauges, ceramic pigments, colourants in glassware, chemical oxidizing agents, polishing powders, plastics creation, additives for strengthening other metals, and automotive catalytic converters
Medical science	Portable X-ray machines, X-ray tubes, MRI contrast agents, nuclear medicine imaging, cancer treatment applications, genetic screening tests, and medical and dental lasers
Technology	Lasers, optical glass, fibre optics, masers, radar detection devices, nuclear fuel rods, mercury-vapour lamps, highly reflective glass, computer memory, nuclear batteries, and high temperature superconductors
Communication	Energy efficiency communication through fibre-optic signal amplification
Renewable energy	Permanent magnets in wind turbines, eliminating the need for gear boxes and improving reliability (particularly important for offshore wind power generators) and facilitating larger wind power generator designs
Electric vehicles	Magnets in electric motors (mitigates CO_2 from the transport sector)
Energy storage	Nickel-metal hydride batteries for electric and hybrid vehicles and rechargeable electronic devices
Lighting	Energy-efficient lighting (fluorescents and LEDs)
Transport and energy	Hydrogen storage alloys for clean energy and transport, and ceramics for hydrogen fuel cell vehicles and power generation; an estimated 1 kg of rare earth elements can be found inside a typical hybrid automobile
Greenhouse gas mitigation	Catalytic converters to reduce harmful emissions in exhaust gases
Other	Europium: identification of legitimate euro bills to discourage counterfeiting Holmium (highest magnetic strength of any element): creation of extremely powerful magnets, reducing the weight of many motors

6. Greenhouse gas emissions from agriculture may be reduced through improved agricultural practices such as the application of TCEs, particularly rare earth elements, minimizing fertilizer use and reducing the amount of land required for food production.

7. Avoided CO_2 emissions attributed to the transition to renewable energy in the power sector were estimated to be 215 Mt in 2018.[6]

Electric vehicle charging station.
3D rendering. Nerthuz

Costs

8. The costs of TCE mining include loss of biodiversity through direct land clearance and deforestation, leading to direct habitat loss and land degradation. One study found that up to 300 m^2 of vegetation and topsoil were removed for every tonne of rare earth oxide extracted.[7]

9. Mining in forested areas poses more direct challenges to biodiversity and ecosystem integrity. Figure 1 shows mining areas, many of which are for TCEs, within protected areas or within 50 km of protected areas. Several TCE projects are in forested areas with high biodiversity, in particular in the Amazon and the Democratic Republic of the Congo.

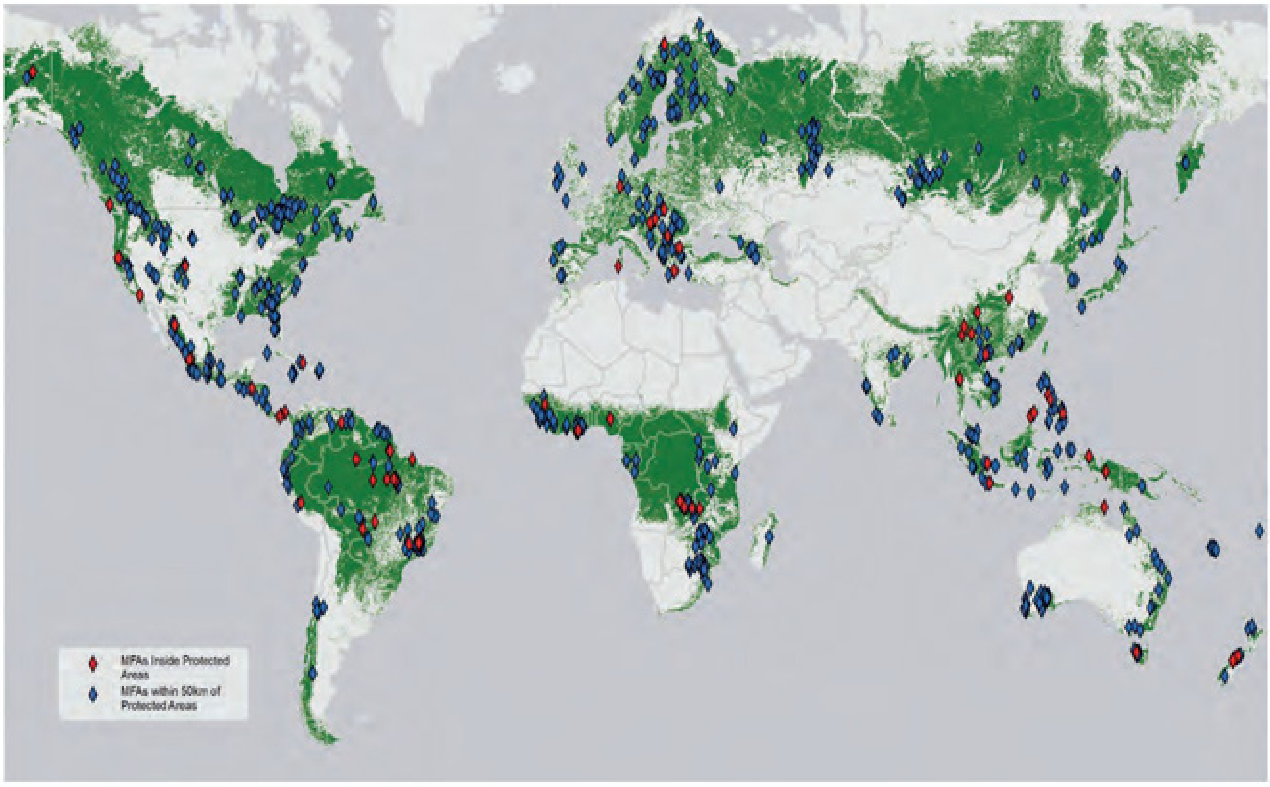


Figure 1. Mining in forested areas (MFAs) inside, and within 50 km of, protected areas.[8]

COLTAN MINING IN EASTERN DEMOCRATIC REPUBLIC OF THE CONGO FORESTS

The case study illustrates the challenge of introducing forest-smart mining solutions to remote, largely self-governed, vulnerable artisanal mining communities and offers a few practical suggestions.

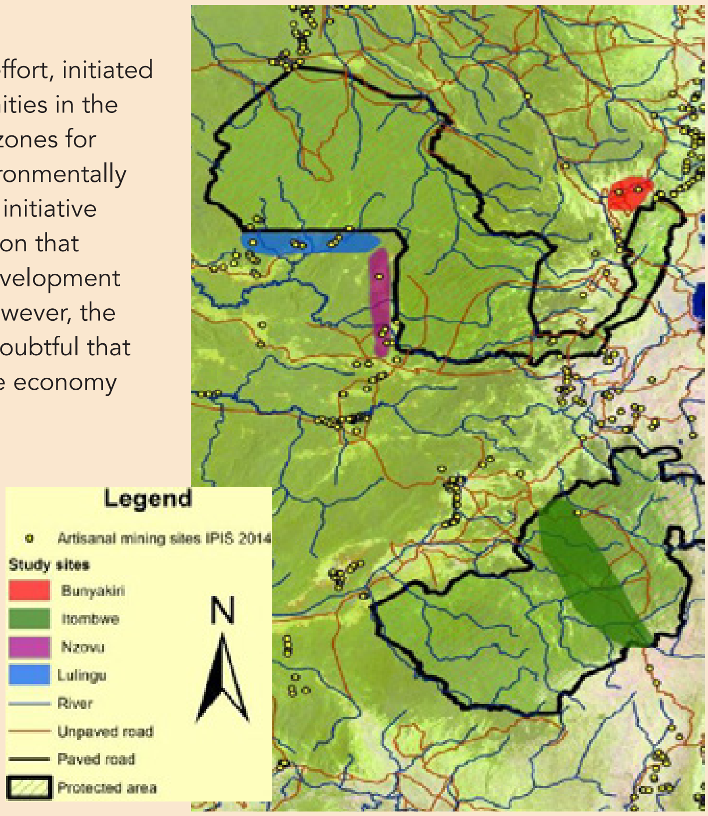
Columbite-tantalite ("coltan") deposits are located within and around two high biodiversity areas in South Kivu Province: the 6,000 km² Kahuzi-Biéga National Park, which is a World Heritage Site, and the 12,000 km² Itombwe Natural Reserve. The daunting loss of 95% of the elephant population and 50% of the gorilla population in the highlands of Kahuzi-Biéga in the four years of the coltan rush, from 1999 to 2003,[9] has been widely attributed to the skyrocketing prices of tantalum at that time.[10] In fact, the real driver was the economic elasticity of artisanal mining – its ability to react promptly to global demand. Since the area hosts only 9% of the world's known deposits but yields 62% of global production,[11]* we should rather see the ecological cost as a global market failure.

Compliant cassiterite mining sites near the Kahuzi-Biéga National Park (certified by OECD-derived initiatives) risk becoming points for laundering non-compliant production from ecologically fragile areas into responsible supply chains. This adds a new layer of complexity for monitoring.

Practical initiatives launched to combat the negative environmental effects of artisanal coltan mining include:

- An integrated land-use planning effort, initiated with local chiefdoms and communities in the Itombwe Reserve, which delimits zones for integral conservation and for environmentally friendly economic activities.[12] The initiative is grounded on the local assumption that ecozones will attract economic development that can compete with mining. However, the remoteness of the area makes it doubtful that ecotourism could become a viable economy there, even in the long term.

- The provision of alternative livelihoods to local miners through microfinance schemes.[13] But with a mean monthly income of US$116 for miners against US$62 for non-miners, this initiative does not bear hopeful prospects.



Map artisanal mines around the Kahuzi-Biega National Park and Itombwe Natural Reserve. Source: Kirby et al. 2015

COLTAN MINING IN EASTERN DEMOCRATIC REPUBLIC OF THE CONGO FORESTS, CONT.

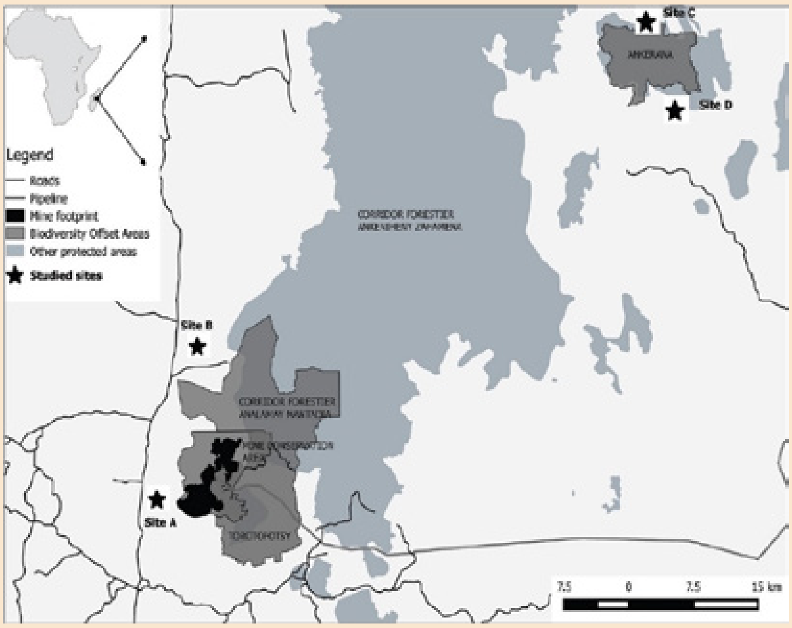
Although somewhat effective, these solutions do not address the root cause of the problem: the relationship between artisanal coltan mining and deforestation. All studies agree that the direct impact of artisanal mining on forests, the removal of trees to expose the mineralized substrate, is far less damaging than the indirect impacts caused by mining-related economic activities.[14] These activities include bushmeat hunting to feed the miners; timbering and tree de-barking to build pans and sluices; the collection of timber and branches to build camps or to cook and provide heat; slash and burn agriculture; secondary migration; and human waste.

Ultimately, local market-driven solutions can complement the value chain requirements of OECD-derived models, land-use planning or "zoning" solutions, or community engagement schemes between large- and small-scale miners, like in the cassiterite site of Bisie,[15] to make artisanal and small-scale mining of coltan more forest smart. In remote communities, the improvement of existing techniques will always garner more buy-in, increasing the scope for the gradual adoption of more forest-smart mining policies and practices.

Note: OECD = Organisation for Economic Co-operation and Development.
* The official figure for production origin is 42%. However, most studies suspect that a lot if not all of the production declared by Rwanda (20% of global production) actually comes out of the eastern Democratic Republic of the Congo as well.

CASE STUDY: AMBATOVY NICKEL AND COBALT MINE IN MADAGASCAR[16]

The Ambatovy nickel and cobalt exploitation operation, which includes open cast mining, is close to the ecotone between lowland eastern and montane forest, near Moramanga, Madagascar. It is a forest mosaic of largely intact to heavily disturbed patches. The key biodiversity components of this forest matrix include structurally distinct forest types (azonal, transition, zonal) linked to different substrates, streams and seasonal ponds. The zone is biotically diverse, with at least 1,367 flora species and 214 vertebrate species, including 13 confirmed lemur species.[17]



Location of the Ambatovy mine and its biodiversity offset portfolio.
Source: Bidaud et al., 2017.

CASE STUDY: AMBATOVY NICKEL AND COBALT MINE IN MADAGASCAR, CONT.

The impacts on biodiversity come from progressive forest clearing. To minimize this environmental footprint, the Ambatovy Project has implemented a stringent biodiversity management plan for the area surrounding the mine, which also overlaps the Torotorofotsy Ramsar site. The plan is based on International Finance Corporation Performance Standard 6 on biodiversity conservation and sustainable natural resource management. It commits the project to avoiding species extinction, minimizing impacts to natural resources, realizing a net increase in the conservation of rare habitats, assuring the viability of priority habitats by maintaining or increasing habitat connectivity, and linking project actions in support of biodiversity with other regional biodiversity initiatives.

To that end, the project has adopted a landscape approach to forest management that considers both the high level of biodiversity and the local population's dependence on natural resources as a means to sustain their livelihoods. The programme includes a biodiversity offset initiative with projected conservation outcomes leading to no net loss to biodiversity through impact avoidance and minimization and through reclamation measures.

Impact avoidance was achieved by creating a forest conservation zone that includes two tracts of distinctive azonal forests overlying the ore body. Impact minimization was attained through paced and directional forest clearing associated with taxa-specific salvaging and monitoring activities. Specific management programmes for plants, lemurs, frogs and fish were designed and implemented.

In parallel, a multifaceted biodiversity offset programme was developed with the establishment of a large conservation zone, with biodiversity components similar to the impacted site. Other offset activities include buffer zone protection with joint Ambatovy community management of forest corridor linkages, wetland protection, and a progressive revegetation process, which re-establishes a multifunctional replacement forest with restored biodiversity values.

Preliminary results suggest that activities implemented using the landscape approach can be an effective means of decreasing human pressure on areas of high conservation importance.

10. Improperly disposed of objects containing TCEs may leach elements into the environment.

11. Mining TCEs may lead to acid mine drainage. Such acidification can destroy marine and freshwater organisms, disturb aquatic biodiversity and harm ecosystems.[18] Furthermore, processing TCEs generates huge amounts of wastewater. It is reported that for every tonne of rare earth oxide extracted, up to 1,000 tonnes of contaminated wastewater and 2,000 tonnes of tailings are generated. These wastes may be discarded into adjacent valleys and streams, contaminating surface and groundwater, and could also be washed into international waters.

12. Desert ecosystems have traditionally been more resilient to mining. However, deserts are often water scarce, and the need for water for processing of mineral ores poses a range of challenges for such regions.[19]

13. In addition to the impacts on soil and land associated with TCE extraction, dumping

Next generation residential VRFB manufactured by StorEn Inc and recently arrived in Australia" (Courtesy: Freedom Energy Pty Ltd: 100% subsidiary of Multicom Resources Limited)

e-waste releases significant quantities of TCEs, together with other toxic elements, into subsoils and groundwater.[20] (At present only about 20% of e-waste is recycled.) The increased demand for electronic goods and services will increase the amount of e-waste generated and hence the amount of TCEs released into the environment.

14. Mining of TCEs involves cutting, drilling, blasting, transportation, stockpiling and processing, all of which can release dust containing TCEs and other toxic metals and chemicals into the air and surrounding water bodies, with adverse effects on local soil, wildlife, vegetation, and human beings.[21] TCEs and other waste compounds may be released by open burning of e-waste.[22]

15. TCEs are an essential element for decarbonization,[23] but relatively scarce, and therefore their extraction often involves processing large amounts of material, which results in the emission of greenhouse gases from burning fossil fuels, the removal of large areas of forest, and ore processing.[24]

16. Human health:

    — Waste disposal areas exposed to weathering have the potential to pollute air, soil and water.[25]
    — Some TCEs contain significant amounts of radioactive elements (e.g. uranium), which can contaminate air, water, soil and groundwater.[26]
    — Some studies indicate that chemicals used in TCE ore processing, extraction and refining processes have been responsible for health hazards to workers and local communities, and for water pollution.[27]
    — Exposure to rare earth metals has been reported to increase the risk of respiratory and lung-related diseases, such as pneumoconiosis.[28]
    — Exposure to selenium is hazardous and may cause selenosis.[29]
    — Cadmium is a heavy metal with the potential to bioaccumulate in the human body and in the food chain, leading to acute and chronic intoxication due to biomagnification.[30]
    — Beryllium is classified as a carcinogen that can be inhaled as dust, fumes or mist and that may cause lung cancer. Short exposure may lead to several diseases.[31]

17. There are gaps in our understanding about of the anthropogenic level of TCEs, their fate and behaviour in the environment (biogeochemical or anthropogenic cycling), and their adverse effects on human health. Their individual and additive toxicological effects require further study.[32]

MITIGATION MEASURES, POLICIES AND PRACTICES

18. In May 2019, the World Bank launched the **Climate-Smart Mining Initiative** to "help resource-rich developing countries benefit from the increasing demand for minerals and metals, while ensuring the mining sector is managed in a way that minimizes the environmental and climate footprint."[33]

19. **Forest-smart mining**[34] is mining in ways that protect forests and forest values. Mining can be understood as forest smart when miners behave in ways that recognize that forests have "significance for sustaining growth across many sectors" and that "changes in forest cover affect other land uses as well as the people living in that landscape". Forest-smart mining involves "identifying opportunities for mutual benefit and creating practical solutions that can be implemented at scale."[35]

20. The World Bank's PROFOR (Program on Forests) trust fund commissioned studies that examined what forest-smart mining might mean, where examples of forest-smart and not-so-smart mining might be found, and what key lessons could be learned to make mining more forest smart in the future.[36] The studies considered forest-smart mining across all scales – from artisanal to mega-mines – and diverse geographies: 44 case studies in 20 countries. One outcome of the

work was the definition of 14 **forest-smart mining principles** (annex 1) to support the development of context-specific forest-smart mining approaches across all scales.[37] (For further details, see the World Bank's report on artisanal and small-scale mining.)[38]

21. STAP's paper *Plastics and the Circular Economy* described the **circular economy** thus:

"The circular economy is an alternative to the current linear, make, use, dispose, economy model, which aims to keep resources in use for as long as possible, to extract the maximum value from them whilst in use, and to recover and regenerate products and materials at the end of their service life."[39]

The circular economy[40] promotes a production and consumption model that is restorative and regenerative by design.[41] It is designed to ensure that the value of products, materials and resources is maintained in the economy at the highest utility and value, for as long as possible, while minimizing waste generation, by designing out waste and hazardous materials.[42] The circular economy applies both to biological and technical materials.[43] It embraces systems thinking and innovation to ensure the continuous flow of materials through a "value circle", [44] with manufacturers, consumers, businesses and government each playing a significant role.[45] (For more on the circular economy, see also STAP's paper *A Future Food System for Healthy Human Beings and a Healthy Planet.*)[46]

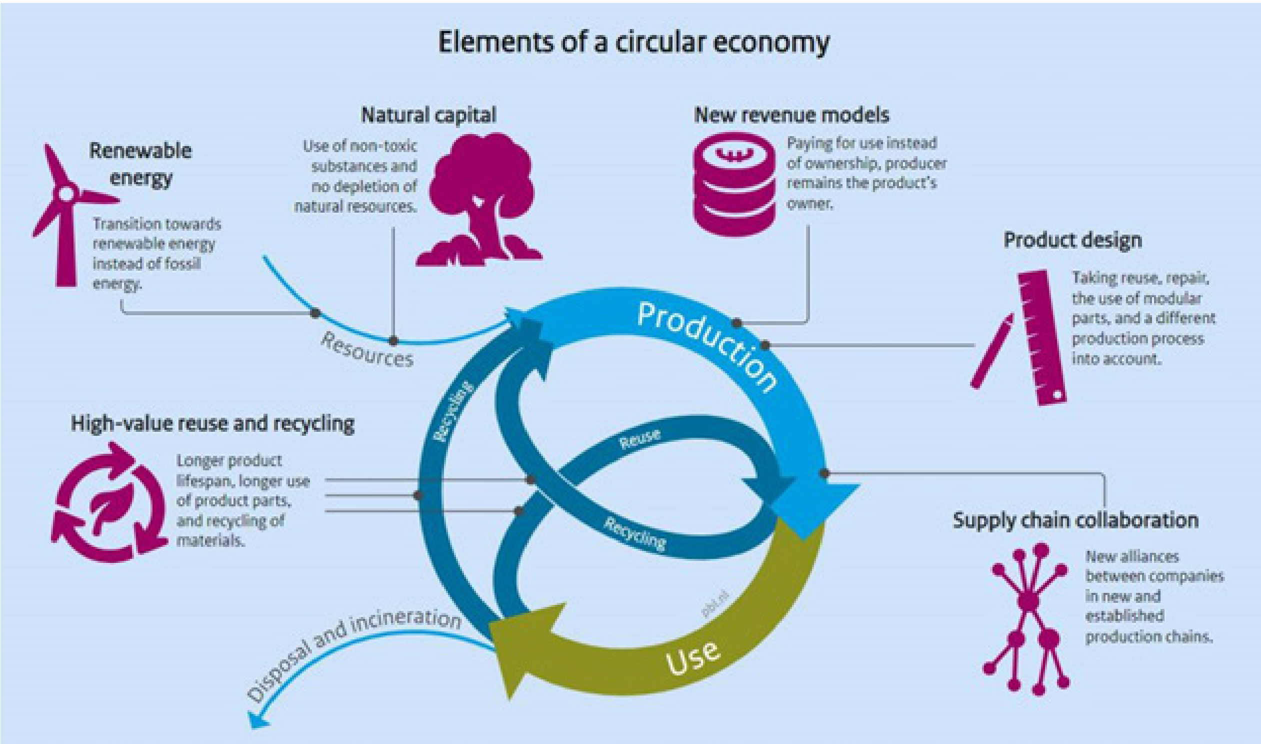


Figure 2. Elements of the circular economy.[47]

22. **Application of the circular economy concept to TCEs** may focus on making products using TCEs more durable; easily repairable; able to be remanufactured or reused; from recycled materials; more energy and resource efficient; easier to separate into recyclable components; without toxic or problematic components (or, if present, with only such components as can be easily replaced or removed before disposal); and with a reduced need for packaging.[48]

23. Increasing the rate of **recycling** is a manifestation of the circular economy approach and can play an important role in reducing the demand for virgin materials, thereby reducing the environmental impacts. Recycling TCEs should be a preferred option to reduce environmental impacts, but recycling rates for TCEs are low (e.g. less than 1% in rare earth elements),[49] despite the TCEs present in consumer goods composing 4–20% of the annual mine production of TCEs.[50]

24. There are three key challenges in recycling TCEs: insufficient stock available for recycling to meet demand; low concentration of TCEs in materials to be recycled compared with mined ores; and dissipative applications, where the critical element is a minor piece in a complex material matrix with many other metals and plastics. For example, waste electrical and electronic equipment has dissipative concentrations of critical metals like palladium and indium. Typical e-scrap, like circuit boards, contains a spectrum of metals such as copper, tin, cobalt, gold, silver, indium, palladium and platinum. This makes e-scrap a really challenging task for recycling technologies because of its complexity.

25. By contrast, there is immense potential for **battery recycling** as e-mobility infrastructure and vehicles gain traction worldwide.[51] The World Economic Forum has launched the Global Battery Alliance to provide cleaner recycling options for the battery industry.

26. Some TCEs are by-products or co-products of other mined materials: secondary production could decouple supply from the primary metal source. And there are recycling opportunities in upstream mining activities, for example small-scale reprocessing of tailings or bioleaching (i.e. the biological conversion of an insoluble metallic compound into a water-soluble form).[52]

27. **Green mining** is defined as technologies, best practices and mine processes that are implemented to reduce the environmental impacts associated with the extraction and processing of metals and minerals. Examples include reducing greenhouse gas emissions and using selective mining approaches to reduce ecological footprint as well as chemical and water use.

28. **Efficient use of water.** The extraction of TCEs uses large quantities of water in a range of activities, including ore processing, dust suppression, slurry transport and employee requirements. (For every tonne of rare earth oxide extracted, up to 1,000 tonnes of water is used, often in areas where water is scarce.) Heavy usage of water is a major concern for communities living near mining sites, particularly when mining operations also pollute water sources.[53] For example, water control and recycling involves the measurement and control of water inputs to a plant, the use of high-efficiency thickeners to decrease water losses to tailings, the recovery of water infiltration from tailings for reuse in the process, the recycling of tailings run-off, and water substitution (i.e. using wastewater and grey water in the process).

29. Work is under way on **alternative materials and technologies** that can reduce the demand for virgin TCEs to ensure a more secure supply, improve efficiency, and lower costs.

30. For example, biometallurgical processes using hyperaccumulator vegetation have the potential not only for metal recovery of some TCEs for recycling but also for the restoration of contaminated land. **Phytomining**[54] (or agromining) entails

producing an economically viable metal-rich biomass of plants from which to derive high-purity metals. Hyperaccumulators are plants that can accumulate metals into their shoots up to hundreds, or even thousands, of times greater than "normal" plants. The application of hyperaccumulated plants for the remediation of contaminated soils is a new technology called **phytoextraction**, which can remove hazardous metals from the soil in a cost-effective way and can potentially create revenue from metal recovery.

31. The high price of metals such as cobalt, nickel, selenium and thallium and other rare earth elements make them of interest for phytomining. For nickel and cobalt, phytoextraction can be applied to low grade and agriculturally unproductive soils that naturally contain high concentrations of these elements. Abandoned mining waste left without sufficient remediation is also a raw material for phytomining. The harvested biomass is usually incinerated to ash to obtain "bio-ore", which increases the concentration of metals. The economic feasibility of phytomining depends critically on the ability to recover the metals of interest from their harvested biomass. Most of the work to date has focused on nickel recovery. Phytoextraction and phytomining have been trialled in experimental settings and require testing at field scale to assess their commercial potential.

32. **Oceanic minerals.** The increasing demand for minerals and declining ore reserves on land, and the ecological impact of terrestrial mining, has led to greater interest in the potential of marine resources for minerals. Coastal marine mining for diamonds and other mineral sands has been undertaken for decades, but deep-sea mining is still in the early stages of development.

33. The United Nations Convention on the Law of the Sea has established the International Seabed Authority (ISA) to issue licences for mineral exploitation. ISA is developing a range of environmental regulations for mining of the deep sea, with a focus on critical metals such as cobalt, manganese and nickel. A key feature is a requirement for all private ventures to partner with a country that is a party to the Convention.

34. The environmental impact of oceanic mining is hotly contested. The ISA regulations will pay particular attention to the following issues: the impact of mining on sediment dislocation and plumes generated by mining; the impact on biodiversity attributable to the expanse of mining activity and to noise generation; the potential release of deep-sea carbon through extractive activity; and the impact on fisheries and livelihoods. Oceanic mineral deposits being considered for extraction include polymetallic nodules, cobalt-rich crusts (which occur on some sea mounts), and sea floor massive sulfides (from extinct hydrothermal vents). Much of the ISA's work is currently focused on polymetallic nodules in the Pacific Ocean.

RECOMMENDATIONS

35. The GEF should be aware of where its investments involve the use of TCEs and where its investments are, or could be, affected by the extraction of TCEs.

36. In such instances, the STAP suggests that the GEF could consider the following:

- Life cycle assessments (see annex 2) for climate mitigation, food security and e-mobility projects, and similar, to identify the effects of TCE extraction, use and disposal and to develop mitigation measures.
- Adoption of responsible mining methods for projects that involve or are affected by TCE mining to ensure that local environmental impacts and effects on local communities are properly taken into account.
- Adoption of a circular economy approach, including the future recycling of TCE stocks.


Polytmetallic oceanic nodule.
Deep Green Metals

— Assisting small island developing States with very large exclusive economic zones in balancing extraction and conservation and in preparing for licensing and regulatory regimes.

— Keeping under review the possibility of phytomining and phytoextraction becoming a viable approach to land restoration and decontamination when the approach has been field tested.

ANNEX 1. PRINCIPLES FOR FOREST-SMART ARTISANAL AND SMALL-SCALE MINING[55]

GOOD GOVERNANCE

1. Develop and implement clear policies for land use allocation and land ownership.

2. Ensure that the regulatory environment of ASM [artisanal and small-scale mining] attempts to stay ahead of the development of the sector (recognizing that this sector has commonly been neglected or overlooked to date).

3. Take special care to safeguard comparatively weaker communities/individuals and those with special rights.

4. Improve mining regulations to adopt an ASM forest-smart approach.

IMPROVED UNDERSTANDING AND APPROACHES

5. Contextualize mining deforestation by taking into account other sectors.

6. Improve the understanding of where ASM is occurring and its impacts on forest landscape degradation, human health and ecosystem services as a basis for designing appropriate realistic interventions with a higher chance of success.

7. Consider all impacts of mining when considering forest-smart interventions.

8. Obtain clear understanding of the role and responsibilities of miners and regulators.

CAPACITY-BUILDING

9. Assist and strengthen the regulators of ASM in developing countries so that they can effectively implement forest-smart mining.

10. Assist and strengthen ASM operators in developing countries so that they can effectively implement forest-smart mining practices.

WIDEN THE PARTICIPANTS IN THE PURSUIT OF FOREST-SMART MINING

11. Consider the opportunities for positive synergy between ASM and large-scale mining, and build cooperation and alliances to enable ASM to perform better on forest impact mitigation.

12. Work with the overall poverty reduction agenda and secure a critical level of political stability in priority countries.

13. Work with the environmental education agenda to disseminate facts related to the need to safeguard and protect forests.

14. Consider the role of protected areas and REDD+ in limiting the impacts of ASM on forest landscapes.

15. Take advantage of existing frameworks for supply chain management and due diligence and use market influence to raise the business case for forest-smart mining.

Uganda: Wolframite (Tungsten) mining. Alex Tyson

ANNEX 2: LIFE CYCLE ASSESSMENT

Life cycle assessment is the most widely used method for evaluating environmental sustainability. However, few life cycle assessments have been conducted on TCEs.[56] (This may be attributed to lack of knowledge and data on, for example, the human toxicity, ecotoxity and freshwater aquatic ecotoxicology of TCEs.)[57] In addition, the fate of TCEs in the environment and their impacts are generally site specific and can therefore be difficult to quantify using generic fate-transport models.[58]

Further studies on life cycle assessment and life cycle inventory are needed for a better understanding of the environmental footprint of TCEs.

ENDNOTES

1 Rare earth elements are a group of 17 elements, comprising the 15 lanthanides as well as scandium and yttrium. The platinum group elements are platinum, palladium, iridium, osmium, rhodium and ruthenium. Other TCEs include gallium, germanium, indium, tellurium, niobium, tantalum and thallium.
2 Rejeski, D., S. Leonard and C. Libre (2018). *Novel Entities and the GEF: Background Paper*. Washington, D.C.: Scientific and Technical Advisory Panel to the Global Environment Facility.
3 The Democratic Republic of the Congo is the world's fourth most important country for biodiversity and a key mining destination. Primary forest loss was 38% higher in 2018 than average forest loss from 2011 to 2017 (Carrington, Damian (2019). 'Death by a thousand cuts': vast expanse of rainforest lost in 2018. Guardian, 25 April). The Democratic Republic of the Congo accounts for 60% of worldwide cobalt, 62% of tantalum (U.S. Geological Survey, 2020, Mineral commodity summaries 2020: U.S. Geological Survey, 200 p., https://doi.org/10.3133/mcs2020) and 4% of tin production (International Tin Association (2020). Global Resources and Reserves. Security of long-term tin supply). The Democratic Republic of the Congo's economy is heavily dependent on the mining sector, which in 2018 provided 29% of the country's gross domestic product, 98% of its export revenues and 25% of employment (International Monetary Fund (IMF) (2019). Democratic Republic of the Congo. IMF Country Report No. 19/285. Washington, D.C). The artisanal and small-scale mining sector directly employs 2 million people, and 16% of the population (about 10 million people) derive their livelihoods from this type of mining (Megevand, Carole (2013). Deforestation Trends in the Congo Basin: Reconciling Economic Growth and Forest Protection. Washington, D.C.: World Bank).
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