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Making the case for Africa and the democratic republic of the Congo as the global rare earth element supply leaders

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The initiative to electrify and decarbonize economies over the next two decades, particularly in the energy and transportation sectors, is going to cause a significant increase in demand for critical rare earth elements , Rare earth elements have already proved themselves highly useful, contributing to many everyday items including batteries, electric vehicles, computer components, photovoltaic panels, and turbines to name a few examples. The number of countries outside of the United States that currently source and provide these critical elements is limited, posing implications for the security and continuity of the global and national supply chain and specifically to the national security of the US. This article is a mini review of the existing literature with recommendations for partnerships. It discusses potential stress points in the current supply chain of REEs and explores the feasibility of expanded American partnerships with Africa and the Democratic Republic of the Congo specifically to address opportunities to strengthen the security and transparency of the global supply chain of REEs. In Africa, REEs are concentrated in countries like South Africa, Madagascar, Malawi, Kenya, Namibia, the DRC, Mozambique, Tanzania, Zambia, and Burundi. These countries have significant quantities of neodymium, praseodymium, and dysprosium among other REEs that are required in the numerous technological items (including green technologies) that are manufactured today. The framework for extracting the elements from those countries requires specific attention to ensure the preservation of natural assets that are key to global health.

KEYWORDS

rare earth elements (REE), democratic republic of Congo (DRC), mining and mineral processing, climate resilience and sustainability, supply chain management, Geology, Blockchain, Material Science and Earth Science

The case for rare earth elements

Today, we face an environmental urgency to reduce the detrimental impact of carbon energy and fossil fuels on the environment. Landfills are overflowing, petroleum-based products are polluting the ocean, and emissions are accelerating global warming. Through review of the literature, this paper summarizes the potential stress points in the current supply chain. Rare earth elements are used in high-tech and green technology devices, notably batteries, computer memories, permanent magnets, EVs, solar panels, and wind turbines among others (Hurst, 2010). As global citizens become more conscious of the negative effects of carbon energy and fossil fuels, there has been a global shift toward electrification and de-carbonization in line with the Net-Zero Policy for 2050 and the Paris

Atomic Number	Element	Symbol
21	Scandium**	Sc
39	Yttrium	Y
57	Lanthanum	La
58	Cerium	Ce
59	Praseodymium	Pr
60	Neodymium	Nd
61	Promethium*	Pm
62	Samarium	Sm
63	Europium	Eu
64	Gadolinium	Gd
65	Terbium	Tb
66	Dysprosium	Dy
67	Holmium	Ho
68	Erbium	Er
69	Thulium	Tm
70	Ytterbium	Yb
71	Lutetium	Lu

FIGURE 1
Seventeen essential rare earth elements.

Accord. This shift requires the existence of a secure and efficient supply chain of REEs. Government policy in the United States, through legislation like the Inflation Reduction Act, is supercharging the American industry for both energy independence and climate and sustainability. As key material inputs for the manufacture of green technology, REEs are crucial in the move toward greener energy.

While REEs are not rare in quantity, their presence as deposits in host rocks is not very common (Kasay et al., 2022). They are often enriched in carbonatites, peralkaline igneous rocks, mineralized pegmatites, and alkaline. Other sources include hydrothermal bauxites, veins, and ion adsorption clays. They are mineralized pegmatites, derived laterites, and their respective placers. Figure 1 depicts the seventeen REEs with atomic numbers.

A government study (Bauer et al., 2011) reviewed the role of REEs in clean energy and supply risk. The study identified clean energy technologies that use materials at risk of supply chain disruptions, including wind turbines, EVs, PV thin films, and fluorescent lighting. The uncertain supply chain of seven REEs was identified as potentially affecting the future deployment of clean energy [Neodymium (Nd), uranium ore (U), terbium (Tb), dysprosium (Dy), europium (Eu), and yttrium (Y)]. The study's findings highlighted the importance of securing the supply chain and America's access to the materials needed in the manufacturing of clean energy technology (Castor and Hendricks, 2006).

Countries worldwide are attempting to strike a balance between meeting energy supply demand and environmental requirements. Several projects globally are in retooling, planning, or development stages to address the impending supply shortages of REEs. Since the start of the new millennium, companies in Japan, Brazil, India, and Greenland began reopening REE processing operations (Ives, 2013). In the mid-1900s, China dominated the market with cheap mineral production, which caused most of the US producers to end production—Molycorp Mineral is an example of a company that abandoned its Death Valley business in 2002 after retooling its operation to meet environmental concerns over contaminated groundwater (Ives, 2013). According to the New York Times, several companies in Greenland are preparing to mine and process its abundant REE reserves, which are becoming more accessible as Greenland's ice sheet continues to melt (Ewing, 2021). A 2011 *Forbes* article argues that in Brazil the mining company Vale labored over whether to process REEs at a copper mine in the Amazon (Trevis Team and Great Speculations, 2011). The Manohar Parrikar Institute for Defense Studies and Analysis stipulates that India has exported REEs to Japan to challenge China's rare earth monopoly, and Reuters highlights that a Toyota subsidiary is preparing to mine REEs in Vietnam (Kubota, 2010; Lele, 2012).

The domestic United States economy, like a significant proportion of the global economy, has followed the positive trend toward greener energy, becoming more dependent on solar, wind, and other processes to provide electric energy. Permanent magnets are the most efficient way to convert mechanical motion into electricity or the reverse. Large quantities of REEs are required to manufacture permanent magnets, adding substantially to demand for the elements through the clean energy economy transition. Additionally, EVs are continuing to increase market share in the transportation sector. Ali and Grewal (2018) argue EVs require four times as many REE inputs as traditional vehicles. It is projected that these and other complimentary domestic economy trends will increase the demand for REEs by 6–800 percent.

This projected growth in demand highlights the need for the US to proactively form partnerships with African countries, where the supply of REEs is abundant, to secure the necessary supply chain for a green energy revolution in America.

The importance of partnerships

There are a number of stakeholders in the supply chain of sourcing REEs, from the miners and workers to surrounding communities, local and international regulators, investors, and end users. Each of these stakeholders is essential to a stable and efficient supply chain, and each stakeholder has a valid and significant vested interest in the system.

Partnerships are essential to ensure that the various interests of each stakeholder can be acknowledged and reasonably addressed so that there is a proper incentive to support and participate in the supply chain system. For example, investors' concerns for profitability must be balanced with concerns for workers' safety, requiring partnerships between investors and regulators; communities' concerns for environmental security must be measured with the regulators' resources to monitor and enforce policies. Mediating the supply chain system, therefore, involves intersecting considerations. The complex balance of interests involved in mining REEs requires public-private partnerships ("PPPs") that are both formal and informal to successfully address all issues comprehensively (Lograsso, 2022).

The United States's domestic approach to REEs for the past three decades has been to close drilling sites and mines and focus on wastewater treatment, carbon sequestration, and coal ash processing; however, a diverse supply chain is necessary to support global resilience. While this policy appeases the activist environmentalist and the conservative advocates, it will not even provide a full percentage of the REEs we need to electrify the United States or address global demand (Qu and Wängnerud. 2018).

The challenges that can impact the supply chain were demonstrated during the COVID-19 pandemic. Sovereign nations prioritized their own national demands during a disruption in international logistics. Material inputs for numerous products in the US were back-ordered, including the necessary material inputs for green energy technology. A disproportionate amount of REEs is currently sourced and refined outside of the US, requiring careful management of international relationships to ensure the security of the economic supply chain for energy (Weng et al., 2013).

The benefits of a US-DRC partnership

Partnerships and investments to diversify mineral suppliers are important for United States energy and national security. The DRC has a history of mineral partnerships with the United States and is recognized as the supplier of uranium ore to the US and its allies during World War II (Bele, 2021); however, the DRC has faced historical governance, social, and labor issues that have raised international concerns related to material sourcing and supply chains (Hammer, 2021). While progress has been made to address these concerns (Lee, 2022), incentives and transparency from well-designed partnerships present an opportunity to benefit both the DRC and partner countries and companies. Partnership and investment by the US on environmental protections, mineral providence and mining safety could prove mutually beneficial for domestic security and energy independences.

The DRC is a mineral-rich country with vast deposits of minerals needed for low-carbon technologies. Currently, the DRC provides the vast majority of mined cobalt and has significant untapped reserves of copper, tin, and gold (International Trade Administration U.S. Department of Commerce, 2022). Additionally, the DRC is endowed with other rare earth mineral resources, and occurrences of REEs have been reportedly found in carbonatite complexes around Bingo, Lueshe, and Kirumba, as well as in other regions in the DRC including Numbi, Manono-Kitotolo, Kampene, Kobokobo and North Lugulu, which cover most of the major cities and regions in the country (Kasay et al., 2022).

Coltan, the mineral found in tech items ranging from cell phones to weapons, is one of the world's most essential and demanded minerals; at least 60 percent of coltan reserves are found in the DRC increasing digitalization, and the advancement of 5G technology will intensify the demand for Congolese coltan (Ojewale, 2021). The US Ambassador to the DRC, Michael Hammer, was documented as saying, "With its abundance of natural resources, the DRC is at the heart of the critical minerals discussion and will play a central role in the future of green energy" (Links, 2022).

The DRC also has plans to produce ten million tons of green hydrogen per year. This is the equivalent of twenty-seven European countries combined. To meet the Intergovernmental Panel on Climate Change (IPCC) and Paris Agreement goals of a 2-degree reduction in CO_2 by 2035, 100 tons of green hydrogen must be produced per year (Lee, 2022). The DRC has the capacity to provide more than 10 percent of the global goal, not including oxygen production, which can be counted on from its 500 million acres of rainforest. Investing in the education and stability of the DRC is thus an investment in the stability of the world (Hammer 2021).

The true value of the DRC mineral deposit is unknown due to a lack of resource investigation, rainforest protection legislation, and the cost of processing. The main issue with REEs (as outlined by the IEA and other organizations) is not simply finding new resources, but with the chemical- and energy-intensive processing required for REE production. According to Jowitt (2022), the REE mining sector is too small with too many issues to make good economic sense. "This is especially true when considering the acid or alkali and energy intensity of REE processing and refining and the low-level radioactive waste generated by these processes given that REE mineralization is often enriched in elements such as U and Th" (Weng et al., 2013). Jowitt as well as many other scholars and other organizations hone in on the enrichment and extraction issues while pointing out that the demand increases require a tipping point solution. Because the DRC deposit value is not actually known, the accepted total REE industry value of $4.338 billion as compared to other mining industries like iron ore (USD$162 billion), copper (USD$123 billion), gold (USD$182.1 billion), and even platinum group element (USD$51.234 billion) cannot be taken as fact. Also, the push for innovation in mining extraction technology within the DRC and the US toward environment sustainability must also be considered as well as the willing low-cost workforce (Jowitt, 2022).

Partnership and investment by the US in mining and sourcing projects in the DRC, with a focus on supply chains that have transparency and monitoring for environmental impact and workforce safety, have been successfully implemented in the Great Lakes region of the DRC by the Public-Private Alliance for Responsible Mineral Trade (International Trade Administration U.S. Department of Commerce, 2022). Significant human and capital resources need to be allocated to REE projects to ensure environmental security. The US is able to bring the expertise and the capital to a partnership with the DRC to ensure rare earth minerals are responsibly mined from the country's plentiful resources. There are multiple real-world examples of unregulated and underfunded mining projects that require extensive investment for remediation, as Mike Ives highlighted:

Under-regulated rare earths projects can produce wastewater and tailings ponds that leak acids, heavy metals, and radioactive elements into groundwater, and market pressures for cheap and reliable rare earths pressure project managers to skimp on environmental protections. In Malaysia, Mitsubishi Chemical is now engaged in a $100 million cleanup of its Bukit Merah rare earths processing site, which it closed in 1992 amid opposition from local residents and Japanese politicians and environmentalists. It is one of Asia's largest radioactive waste cleanup sites, and local physicians said the thorium contamination from the plant has led to an increase in leukemia and other ailments. (Ives, 2013).

Visibility and data collection are essential for the success of a DRC/US partnership, bringing together many stakeholders, including those of the government and the private sector. Partnership and investment by the US in mining and sourcing projects in the DRC, with a focus on supply chains that have transparency and monitoring for environmental impact and workforce safety, have been successfully implemented in the Great Lakes region of the DRC by the Public-Private Alliance for Responsible Mineral Trade, as one example (Trade Administration United States. Department of Commerce 2022.) According to the

Brookings Institute (Eleftherios and White, 2022), "the White House announced in March its Freight Logistics Optimization Works (FLOW) initiative, a pilot program for a voluntary and secure national exchange for key intermodal freight data available to all participants who share data." And, according to the authors, visibility requires developing and maintaining high digital standards. Jones (2023); Gholz (2014) stated that China's dominance in the REE industry weakens the security and resilience of US supply chains. "Chinese firms accounted for 97 percent of rare earth oxide production and a large fraction of the processing business that turns these into rare earth metals, alloys, and products like magnets" (Research and Markets, 2015). The DRC's forest, for example, is critical in combating climate change through CO_2 sequestration and green hydrogen production, and unregulated extraction of REEs could lead to deforestation and cause substantial long-term damage to environmental ecosystems. A United States partnership with the DRC has the unknown potential to reduce the monopolistic and poorly regulated nature of REE extraction to date (Ali and Grewal, 2018).

Discussion

Through this review the DRC's potential as a partner for future REE supplies for the US was explored. Given the number of stakeholders in the supply chain of sourcing REEs—from the miners and workers to surrounding communities, local and international regulators, investors, and end users—diverse partnerships for REE projects are essential. Each of the stakeholders is key to a stable and efficient supply chain, and each stakeholder has a valid and significant vested interest in the system. Research and development of safe, viable, and environmentally responsible options are critical for the implementation of projects.

A Path to Success.

a. Refinement: The processing and extraction of REEs require partnerships up and down the supply chain. "Trash to treasure" is an important step—with geologic ore, mine tailing, water recapturing, and fertilizer production innovation, as a few strategies—to increase efficiency and protect the planet. The research and development of managing waste are only as strong as the Department of Energy's partnership and off-ramping to private entrepreneurial firms.
b. Increasing commercialization opportunities in the refinement of plant building and technology transfer with regulations around greenhouse gas processing and reduction.To progress energy security the United States Department of Commerce and Department of Energy can direct infrastructure and climate funding to American entrepreneurship interested in doing business with Africa within the areas of facility building and greenhouse gas reduction technologies. University and Government lab technology transfer programs will also play a role in commercialization.
c. Logistics and providence technology are critical in increasing access. The DRC has taken major strides to create safety and security. The DRC must learn from South Africa experience with mining diamonds and invest in providence technology. Blockchain technology offers some significant solutions. Technology can allow us to shorten the supply chain, not just by taking out members but by making sure those who mine, produce, and deliver REEs receive the payments in a way that is direct and timely.

This is a costly but prosperous industry that future generations could thrive in. Future generations who increasingly thrive on technology have an opportunity for an economic future in clean energy through REEs. The growing sensitivity to human rights and climate change could be the perfect combination for fair processing and cross-cultural partnerships.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2023.1167778/full#supplementary-material

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