**Incorporating criticality into Life Cycle Assessment for rare earth production**

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Rare earth elements (REE) have a broad and expanding range of uses in low carbon energy technologies, from wind turbines, to batteries, catalysts and electric cars. Concerns about the future supply of individual REE, such as neodymium and dysprosium, combined with their growing economic importance has led to a number of studies identifying REEs as critical metals [1, 2]. In response to this, exploration companies have identified a number of sites globally which have the potential for rare earth extraction. These sites have distinct geological characteristics with varying individual REE contents. This means that unique processing routes are needed for each project. How do we identify which projects are most suitable for our future rare earth needs, whilst minimising the environmental impacts, ensuring sustainable development?

A life cycle assessment (LCA) allows for a quantitative assessment of the environmental performance of rare earth production, providing data including energy, water, and chemical consumption as well as global warming potential, land use changes, ocean and terrestrial acidification. A major challenge with applying the LCA methodology to rare earth production is ensuring that a consistent approach is taken. For example, previous research has been inconsistent in what is included in the environmental calculation, leading to different results from independent assessments covering the same projects [3]. This lack of consistency also means that it is not possible to justly compare projects from different studies.

Current LCA methodologies also fail to take into account the complex nature of rare earth production. For example aspects relating to geopolitics and supply constraints are overlooked. A three-dimensional criticality space which includes supply risk, vulnerability to supply risk, and environmental implications was proposed by Graedel *et al* in 2015 [4]. It is possible to modify this to include the metrics for social, regulatory and geopolitical data under the broader concept of supply risk. It also includes material importance in addition to substitutability in the concept of vulnerability to supply restriction. These metrics are used as a weighted measurement against the environmental performance of the LCA, providing results that better reflect the complex forces that drive rare earth production. It also allows a greater number of stakeholders to be represented.

**References**[1] European Union (2014) Report on Critical raw materials for the EU. Report of the Ad hoc Working Group on defining critical raw materials, May 2014, 41 pp.
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[3] Vahidi, E., Navarro, J., Zhao, F. (2016) An initial life cycle assessment of rare earth oxides production from ion-adsorption clays. *Resources, Conservation and Recycling.* **113**, 1-11
[4] Graedel, T.E., Harper, E.M., Nassar, N.T., Nuss, P., Reck, B.K. (2015) Criticality of metals and metalloids. *Proc Natl Acad Sci USA,* **112,** 14, 4257-4262