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Letter to the editor

Response to ‘Assessing the energy requirements and global warming potential of the production of rare earth elements’

A B S T R A C T

In this letter, we respond to the article in this journal by Weng et al. (2016) which performs a cradle to gate scale life cycle impact assessment for 26 operating and potential rare earth element (REE) mining projects. The work focuses on gross energy requirement and the global warming impacts of the primary REE production stage. The results suggest that the declining ore grades of REE significantly increase the environmental impact of REE production. We agree that a life cycle impact approach can be useful in comparing proposed REE production routes in the various different deposits currently under exploration, and were pleased to see a range of deposit types included in this work. However, we would like to make five points to clarify some of the results, which if taken at ‘face value’ from the graphs presented by Weng et al. (2016) may be misleading.
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The paper by Weng et al. (2016) is a positive attempt to compare the energy requirements and global warming impacts of a number of rare earth element (REE) projects with a range of mineralogy, processing technology and material outputs. The work is moving the subject area forward, encouraging broader comparative life cycle assessments (LCA) of a number of complex REE production routes. However, there are areas that need clarification or reconsideration to allow for a fair and representative evaluation of these production routes. Life cycle inventory data that is used by Weng et al. (2016) to calculate global warming potential (GWP) and gross energy requirements (GER) is not available in the paper or supplementary information and therefore cannot be used. Instead a comparison between the environmental impacts included in the supplementary information was used.

The first point is that these results should not refer to increasing ‘environmental impacts’ because rather than a comprehensive environmental impact they represent a subset of the full data set in that they consider only gross energy requirements and global warming impacts. These are the only criteria discussed in the comparison. Additional environmental impact data were made available in the supplementary information but not included in the results presented in the main manuscript.

The second point, and one that we would like to emphasize particularly, is that the LCA ‘gate’ for the various different projects is at varying stages in the production process so the graphs of LCIA results such as Figs. 2, 3, 4, 7 in Weng et al. (2016) are not comparing like with like. It was noted in the study that there are challenges associated with comparing different end product(s) and a method was used to divide the refining stages into two categories, although three categories were then used in the results as follows:

- fully refined: where the defined end products are individual or mixed REO (rare earth oxide),
- semi-refined: where the end products are other REE products, such as mixed REO concentrates, REE carbonates and REE hydroxides
- not refined: where the end products are flotation or other concentrates containing REO

This ‘not refined’ division, labelled as mining and beneficiation (M + B) on Fig. 3, is an important difference in that these projects, at Thor Lake, Strange Lake and Tanbreez, propose to produce and ship mineral concentrates and therefore do not dissolve the REE-bearing minerals. In contrast, the other projects all carry out this chemical-intensive dissolution stage onsite and the embodied energy and GWP in these chemicals, as well as the direct energy requirements, makes a large difference to the outcomes. A plot of refining stage versus ‘environmental impact’ (*not* the term as used by Weng et al., 2016 but a new figure calculated from the supplementary data to include all of the impacts not just global warming potential and gross energy requirement) identifies the relationship between the environmental performance and the level of refining for each project, highlighting that those with a

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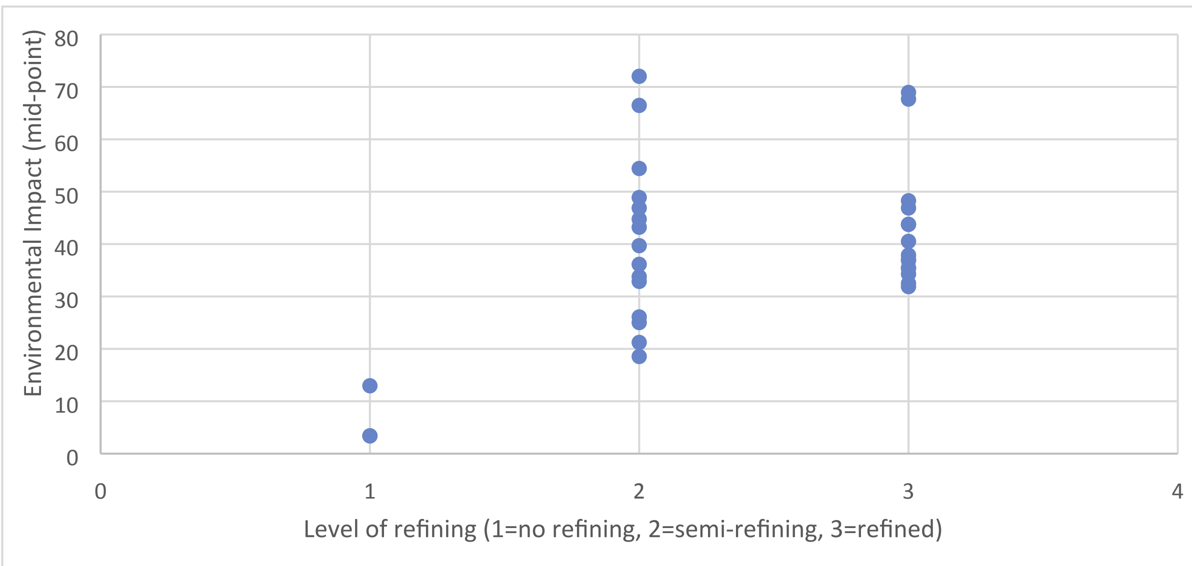
greater level of refining are more like to have a higher environmental impact, and those projects with less refining have lower environmental impacts (Fig. 1). Those projects that complete less processing on-site will require less energy and will have the lowest global warming impacts, but this only represents a small part of the production life cycle for REE and does not imply that these *deposits* are more environmentally-friendly than other projects or deposit types. The conclusion of Weng et al. (2016) that grade is the key factor in controlling environmental performance is not supported by a robust enough methodology or sufficient data. Using different gate stages does not permit this conclusion.

Fig. 1. There is a correlation between the gate, i.e. the end point of production used in the life cycle analysis and the measure of environmental impact given; recalculated here using the supplementary data for all environmental impacts given in Weng et al. (2016) rather than just global warming potential and gross energy requirement. 1 = end product(s) from beneficiation only, mineral concentrate with no further refining), 2 = end product(s) is from semi-refining, such as production of intermediate mixed REE products and 3 = end product(s) is from refining to produce separated REE products. The three Level 1 projects are Thor Lake, Strange Lake and Tanbreez (Thor Lake and Strange Lake have the same environmental impact and so placed one on top of another).



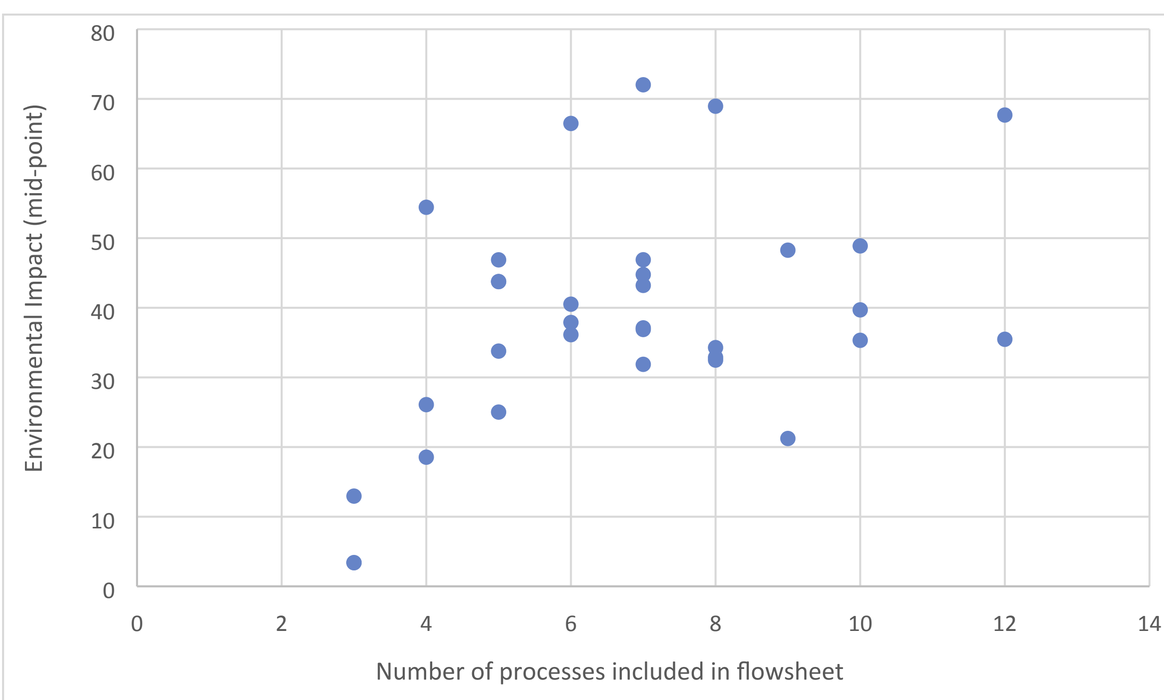


Fig. 2. There is a broad positive correlation, especially at lower number of processes, between the number of processes included in the life cycle assessment for a project (= unit black boxes in the flowsheet used in LCA) and the environmental impact.

The third point is that Weng et al. (2016) note that a large number of assumptions had to be used for many of the processing methods and highlighted that this is a limitation to the study. Flowsheets for individual projects have been included in the additional information but there is no information on the inventory analysis to clarify which chemical inputs and which outputs are included in the study. We agree that consistent data from each of the REE projects for the inventory analysis is a major challenge. Each project requires a bespoke processing flowsheet depending on a number of factors (Bongaerts et al., 2015). Weng et al. (2016) also noted this problem. It is critical that all assumptions are justified, especially when these choices are informed by data/information coming from diverse flowsheets. Assuming that two (or more) mines have the same mineral compositions and topology is geologically incorrect. For example, Bayan Obo, the World's largest REE mine, in Inner Mongolia, China, was used as the basis for calculations for synchysite and apatite production at Songwe Hill (text wrongly attributes bastnäsite as the ore mineral at Songwe Hill) (Croll et al., 2015) (Table 1, Fig. 3 in Weng et al., 2016). Results are presented for 36 scenarios at 26 locations and project specific flowsheets were used for 24 of these scenarios. The other eight are much more speculative and based on REE processing data from other operations. These eight projects rely on assumed REE processing project configurations of other deposits (Table 1) and owing to the bespoke nature of REE production routes, these assumptions are unlikely to be accurate. Deciding how much it is possible to predict the performance of any particular project using assumptions from other projects is an interesting topic and would benefit from some additional research and analysis.

The results obtained from certain deposit types don't necessarily provide an environmental standard for future projects with the same geology. Eco Ridge is the only alluvial placer used in the study, and is atypical of the minerals sands that one would normally associate with placer deposits of REE. The conglomerate/quartzite deposit is not sufficient to draw conclusions for all placer deposits. REE are only semi-refined at Eco Ridge, which fails to represent the energy intensive and environmentally demanding refining phase.

Alkaline rocks look superficially more environmentally friendly than other deposit types but three projects: Thor Lake (Nechalacho), Strange Lake and Tanbreez, have no refining on site thus have low GWP and GER in this study. Kvanefjeld nepheline syenite (mineral is streenstrupine, lujavrite given in Weng et al., 2016 is a rock name) performs around average in the LCIA, there are two inputs on the flow chart for this project and no stage for dissolution of the minerals, as well as no detail on the refining to remove U or process and separate REE. Norra Kärr is also probably in the mid-range (as best we can interpret Figs. 2, 3 and 7). This project has a more detailed processing flowsheet, but only sulphuric acid and magnesia as chemical inputs and no account of use of chemicals in solvent extraction etc.

Table 1
Projects using REE processing configuration based on other operations

Project	Assumed REE processing project configuration
Bokan-Dotson	Bear Lodge
Browns Range	Araxá
Tantalus	Southern Chinese Ion Adsorption
Foxtrot	Roundtop (which is based on Southern Chinese Ion Adsorption)
Kipawa Lake	Dubbo Zirconia
Round Top	Southern Chinese Ion Adsorption
Songwe Hill	Bayan Obo
Zandkopsdrift	Bayan Obo

A fourth and important factor in comparing REE projects is that of the functional unit used for the LCA. Weng et al. (2016) used a functional unit for their life cycle assessment of "1t of run of mine (ROM) materials from the mining site of selected REE projects, in conjunction with the project's annual production capacity and recovery rate of REO, as well as the principal by/co-products". In general, in LCA, the functional unit must be consistent and should define what quantity of the product's function is achieved to cause the environmental impact identified (ISO, 2006). The functional unit described above suggests that each project has a unique functional unit depending on the scale, recovery rate and co/products of the project. If this method has been used rather than the use of a static 1t of ROM material for each project, then the results would not be suitable for comparison.

A fifth, and final important point is that Weng et al. (2016) used an economic allocation for the life cycle assessment as indicated by equation (1). This method of economic allocation used a unit price for separated individual REE, which does not reflect the different end product(s) at each project. For example the flotation concentrates produced at Thor Lake, which include REE, do not actually have the same market value as the separated individual REO used as the unit price. Weng et al. (2016) highlights the prices of individual REO with no reference to REE concentrate prices. Mineral concentrates are cheaper than mixed REE compounds, which can be orders of magnitude cheaper than separated individual REE and REO (Roskill, 2016). Table 2 in the paper also provides U and Th (which are not REE) with a unit price but does not explain whether these have been used in the economic allocation.

$$Xi = \frac{Ei*Ri*Ci*P}{\sum_i (Ei*Ri*Ci*P)} \tag{1}$$

Xi: Environmental footprint contribution of Commodity *i* (%)
Ci: Ore grade of commodity *i* (%)
Ei: Unit values of commodity *i* ($USD/t)
Ri: Recovery rate of commodity *i* (%)
P: Annual production capacity of the project (t ROM/y)

Our conclusion is that the research is heading in the right direction, but the inconsistencies in the comparison of projects means that the LCIA are not formed with a rigorous enough methodology to draw truly meaningful conclusions. The level of refining and the number of processes in the flowsheet show a greater positive correlation than grade, mineralogy or deposit type. This highlights the importance of ensuring consistent detail in the inventory analysis, as well as a robust method of allocation.

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References

Bongaerts, J., Liu, J., Heyde, F., 2015. Valuation of a rare earths elements project using the real options model – applications of the real option model to bayan Obo mine. IMRE J. 9 (3).
Croll, R., Swinden, S., Hall, M., Brown, C., Dempers, N., de Jager, C., Wild, G., Castilloux, R., Errol Trusler, G., 2015. Mkango Resources Limited Songwe REE Project NI 43-101 Pre-feasibility Report.
ISO, 2006. 14040: Environmental Management – Life Cycle Assessment – Principles and Framework. British Standards Institution, London.

Weng, Z., Haque, N., Mudd, G., Jowitt, S., 2016. Assessing the energy requirements and global warming potential of the production of rare earth elements. J. Clean. Prod. 139, 1282–1297.
Roskill, 2016. Rare earths: Global industry, markets and outlook, 16th ed. Roskill, London, UK.

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