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Reply to: Concerns about global phosphorus demand for lithium-iron-phosphate batteries in the light electric vehicle sector

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In our original study, we quantify future material demand for electric vehicle (EV) batteries, considering EV fleet and battery chemistry development scenarios[1]. Spears et al.[2] point to an important gap in our study[1], which is that we did not include an assessment of global future phosphorus demand associated with our lithium-iron-phosphate (LFP) scenario, and neither did we reflect on potential supply resilience and sustainability issues.

In order to close this gap, we have slightly extended our model to include phosphorous. All calculations are based on our previous model[1] for quantifying the global material demand for EV batteries (https://doi.org/10.6084/m9.figshare.13042001.v4), while all additional data is provided here: https://doi.org/10.6084/m9.figshare.16669759.v4. Figure 1 presents the results for phosphorus. We can confirm the calculation of Spears et al.[2]: in the sustainable development (SD) scenario, which assumes a faster EV fleet growth than the stated policies (STEP) scenario, up to 3 Mt of phosphorus will be required for the production of LFP batteries in 2050 (Fig. 1a). The cumulative phosphorus demand for light-duty EV batteries from 2020 to 2050 is in the range of 28–35 Mt in the SD scenario (Fig. 1c). However, there are considerable uncertainties related to this phosphorus demand. The uncertainties relate to, amongst others, EV fleet development (even in our SD scenario EV market penetration is only about 50% in 2050), LFP battery market share (we assume a constant 60% market penetration after 2030), and battery capacity per vehicle (see Fig. 1c for a sensitivity analysis). In the STEP scenario, the estimated demand is roughly half as high. Closed-loop EV battery recycling could lower the demand for primary phosphorous, however, recycling technologies are still in their very beginnings. By 2050, EV batteries containing about 1 Mt of phosphorus could reach their end-of-life (Fig. 1b). The potential cumulative demand reduction as a function of phosphorous recycling rate is shown in Fig. 1d. If one assumes that direct battery recycling technologies will become available at commercial scale over the next decade, and will achieve 90% recycling efficiencies, about 20% of the cumulative phosphorous demand until 2050 could be supplied by closed-loop recycling. In this case, about 0.9 Mt of phosphorous, roughly one third of the demand, could be supplied by closed-loop recycling in 2050 (Fig. 1b).

Demand for phosphorus for battery-grade precursor production could increase by as much as a factor of 40 from 2020 to 2050 according to our model. As a result of the potentially fast growing LFP industry, light-duty EVs alone could consume as much phosphorus as is currently produced for industrial purposes globally in as little as 20–25 years from now (Fig. 1a). This does not yet include the potential demand for phosphorus from other uses of LFP batteries, e.g., heavy-duty vehicles[3] and stationary energy storage applications. We agree with Spears et al.[2] that, if not managed properly, this could result in short term supply chain challenges and competition for phosphorous between food and non-food applications with potentially negative consequences for the battery industry. This could also lead to price spikes, although the effect of higher phosphorus prices on LFP battery prices would be rather limited (see cost break-down in https://doi.org/10.6084/m9.figshare.16669759.v4). Given further the geographically concentrated nature of phosphorus supply, which is one of the reasons that the EU classifies phosphorus as a critical raw material, this calls for additional analyses of the use of LFP batteries for all applications from a sustainability perspective (economic, environmental, and social), which was not part of our model.

Such analyses should, as Spears et al.[2] already point out, include other LFP battery applications and potential opportunities for cross-sector phosphorus recycling such as the recycling of phosphorus from wastewater, which could not only increase circularity, but also reduce certain environmental impacts. This requires also further investigation of the technical and economic feasibility of phosphorus recycling to battery-grade raw materials for LFP production or of a recycling of phosphorus from batteries for agricultural purposes. To conclude, we do not believe that phosphorus is as critical a raw material from a known reserves perspective as other battery elements, such as lithium, cobalt, nickel or graphite[1]. Yet, we agree with Spears et al.[2] that there are potential resilience and sustainability issues related to the future supply of phosphorus that should be further investigated in a cross-sector circularity context to prevent unintended side-effects of large-scale LFP battery deployment.

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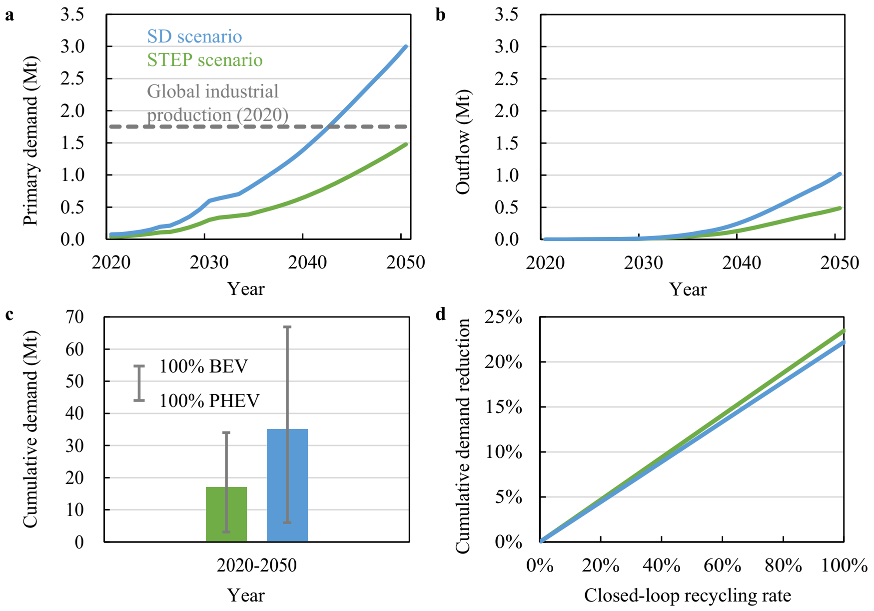

Fig. 1 Battery phosphorus flows in the LFP battery scenario. a Primary demand. Gray dashed horizontal line represents estimated current global phosphorus production for industrial use in 2020, which is based on phosphate rock production amount in 2020[4] (assuming medium-grade ore of 20% P_2O_5[5]) of which 9% for industrial use[6]. **b** Outflow in end-of-life batteries. **c** Cumulative demand in 2020–2050 without recycling. Gray error bars represent a sensitivity analysis for battery capacity considering two extreme cases, i.e., if all EVs were plug-in hybrid EVs (PHEVs) with small 10 kWh batteries or if all EVs were large battery EVs (BEVs) with 110 kWh batteries, e.g., Tesla's Model S Long Range Plus[7]. **d** Impact of closed-loop recycling rate on cumulative demand reduction in 2020–2050. Note that pyrometallurgical and hydrometallurgical recycling methods for LFP may not be economical to recover phosphorus at industrial scale. Direct recycling, i.e., recovering LFP cathode directly, could be economical, but is still at early-stage development[8]. Here we assume 90% recycling rate of LFP cathode by direct recycling to explore the potential impact of closed-loop recycling on primary phosphorus demand. STEP scenario the Stated Policies scenario, SD scenario Sustainable Development scenario, Mt million tons.

Data availability

The data for Fig. 1 are available from https://doi.org/10.6084/m9.figshare.16669759.v4.

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References

1. Xu, C. et al. Future material demand for automotive lithium-based batteries. *Commun. Mater.* **1**, 99 (2020).
2. Spears, B. M., Brownlie, W., Cordell, D., Hermann, L. & Mogollon, J. Concerns about global phosphorus demand for Lithium-Iron-Phosphate batteries in the light electric vehicle sector. *Commun. Mater.* https://doi.org/10.1038/s43246-022-00236-4 (2022).
3. Hao, H. et al. Impact of transport electrification on critical metal sustainability with a focus on the heavy-duty segment. *Nat. Commun.* **10**, 5398 (2019).
4. *Mineral Commodity Summaries 2021*. https://pubs.usgs.gov/periodicals/mcs2021/mcs2021-phosphate.pdf (USGS, 2021).
5. Haldar, S. K. in *Mineral Exploration* 2nd edn (ed Haldar, S. K.) 259–290 (Elsevier, 2018).
6. Achary, V. M. M. et al. Phosphite: a novel P fertilizer for weed management and pathogen control. *Plant Biotechnol. J.* **15**, 1493–1508 (2017).
7. *Tesla is working on new ~110 kWh battery pack for more than 400 miles of range* https://electrek.co/2020/02/19/tesla-110-kwh-battery-pack-400-miles-range/ (Electrek, 2020).
8. Xu, P. et al. Efficient direct recycling of lithium-ion battery cathodes by targeted healing. *Joule* **4**, 2609–2626 (2020).

Author contributions

C.X. conducted the results and draft with input from B.S., Q.D., L.G., M.H., and A.T. B.S. and C.X. wrote the reply together with input of the other authors.

Competing interests

The authors declare no competing interests.

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