

Multi-Regional Input-Output analysis to improve Resource Efficiency in traction battery value chains

Julius Ott^{1*}

¹ *University of Graz, Merangasse 18, 8010 Graz, Austria*

**Corresponding author. julius.ott@uni-graz.at*

ABSTRACT

Battery Electric Vehicles (BEVs) are seen as important contributors to the decarbonization of human mobility and therefore undoubtedly provide significant value. However, BEVs are also highly resource intensive throughout their life cycle, with various options for improvement, from material extraction to End of Life (EoL). This is especially true for the battery, where much of the resource use is obscured within its complex value chain. Providing the same value to humanity with fewer resources would be highly beneficial on a global scale. The idea of Resource Efficiency (RE) is to generate the most monetary benefit (e.g., GDP, value added) from the utilization of a unit of resource. This concept appears in various policy areas related to the circular economy, bioeconomy, and the United Nations Sustainable Development Goals (SDGs). To answer the research question, 'What are the potentials to increase the RE in traction batteries?', the research consists of several distinct steps: The final demand for electric equipment is isolated from other demands, represented in the Multi-Regional Input-Output (MRIO) tables of Exiobase 3 and its impacts on resource consumption are analysed. After that, the status quo RE is presented. Finally, the RE is tested on its sensitivity to modifications of the driver of its denominator as identified by Pothen (2017) by setting up an alternative scenario. Due to the sectoral resolution, the research doesn't differentiate between different chemical elements, however the results offer valuable guidance on the drivers of resource consumption in the traction battery value chain and the potentials for achieving higher RE. More specifically, this research provides insights such as preferred manufacturing locations and "material hotspots" for policymakers and industry stakeholders aiming to improve the RE of BEVs in general and batteries in particular.

1. INTRODUCTION

To reduce traffic-related emissions, electric vehicles powered by traction batteries are a promising alternative to conventional vehicles with combustion engines. This leads to an expected increase in demand for Lithium-Ion Batteries (LIBs). Depending on the scenario, even a tenfold increase of LIB demand until 2030 seems realistic (Usai et al., 2022). It is also possible that future material demand for LIBs in electric vehicles will exceed raw material production (Maisel et al., 2023). These challenges, including the scarcity of raw materials and the generation of waste, necessitate effective resource efficiency (RE) improvement strategies throughout the entire life cycle of batteries.

The emergence of potential sustainability trade-offs underlines the challenges in traction battery value chains. Sustainability trade-offs refer to the complex and often interrelated decisions that are made in the pursuit of sustainable outcomes, where improvements in one area may come at the expense of another (Morrison-Saunders & Pope, 2013). New Europe-centred recycling processes can improve the RE in certain countries (e.g., through resource efficient machinery). However, this could also lead to negative effects in other countries or inefficiencies in the global economy. The use of MRIO analysis can be a promising approach to analysing sustainability trade-offs and the associated impacts (Zimek et al, 2022). Recent literature that applied environmentally extended and socially extended MRIO analysis can be complemented using RE focused MRIO as in this research.

2. RESOURCE CONSUMPTION FOCUSED MRIO ANALYSIS

MRIO tables represent economic relationships both within and between different regions or countries. MRIO analysis can be used to assess various aspects such as outsourcing, environmental impacts, and value generation in global trade systems (Miller and Blair, 2009). Generally, the tables consist of monetary values dependent on country (or region) and economic sector (e.g., agricultural activities, mining, manufacturing etc.) (ibid.). Further intermediate and final demand is distinguished (ibid.). Examples for final demand are expenditure by households or the government (ibid.). Their demand in the different sectors causes also intermediate demand (and therefore impact) in other regions and sectors (ibid.). This enables the tracing of impacts throughout (complex) value chains (ibid.). Since all MRIO data is in monetary units,

material consumption is also expressed in monetary units, not in mass units (ibid.). For this research, the MRIO tables from the Exiobase 3 database (Stadler et al., 2025), with the most recent year 2022, are used. In addition to major economies and several European countries, the database provides data for five aggregated world regions, as shown in Figure 1 below.

region	EU	Advanced/Emerging	region group	region name
WA	FALSE	Emerging	Non-EU Emerging	RoW Asia and Pacific
WL	FALSE	Emerging	Non-EU Emerging	RoW America
WE	FALSE	Emerging	Non-EU Emerging	RoW Europe
WF	FALSE	Emerging	Non-EU Emerging	RoW Africa
WM	FALSE	Emerging	Non-EU Emerging	RoW Middle East

Figure 1: Exiobase world regions and abbreviations (according to Stadler et al., 2025)

A final advantage of using MRIO tables for resource efficiency is the inclusion of integrated value-added data. This means that no third-party source is needed to obtain value-added data. Value added can be obtained by simply subtracting the aggregated intermediate demand from the aggregated total output (Aslam et al. 2017). Detailed knowledge about batteries is not essential for this research due to the macro scale of the database and the method used.

The application of the research method consists of several distinct steps starting with goal and scope definition, followed by impact calculation, resource efficiency evaluation and scenario analysis for further interpretation (see Figure 2 below):



Figure 2: Research design (own illustration)

For the goal and scope definition (see figure 2), the sector and region are selected, in which the final demand for batteries occurs. In this case WE for RoW Europe was selected (meaning smaller European countries that are not

explicitly mentioned otherwise in the MRIO database, see figure 1). Then, the final demand in this sector was kept but the final demand for all other sectors and regions was set to zero. This enables the tracing of impacts caused solely by the final demand for electric equipment in smaller European countries without interference of other value chains.

Second, the impact of this selected final demand is calculated. Since this research focused on resource efficiency the following impact categories, inspired by Pothen (2017), are selected and graphically presented:

- Figure 3: Material consumption by region
- Figure 4: Material consumption by type of material (sectors)
- Appendix: Value added by region
- Figure 5: Imports and exports relative to its overall material consumption (only for one type of material)

The resource efficiency is then calculated through dividing the material consumption by region by the value added by region. This results in an overview of more and less efficient regions.

Lastly a scenario with final demand consumption in China instead of WE was set up and the changes are presented in figure 7.

3. RESULTS

In the case of the status quo, all demands are set to zero except the demand for electrical equipment from the region WE. It is therefore no surprise that the region WE has the highest material consumption, in figure 3 below. Much of the demanded materials can be fulfilled by WE itself. However, through intermediate demand, material is also consumed in China, Russia and to a lesser extent, in many other countries.

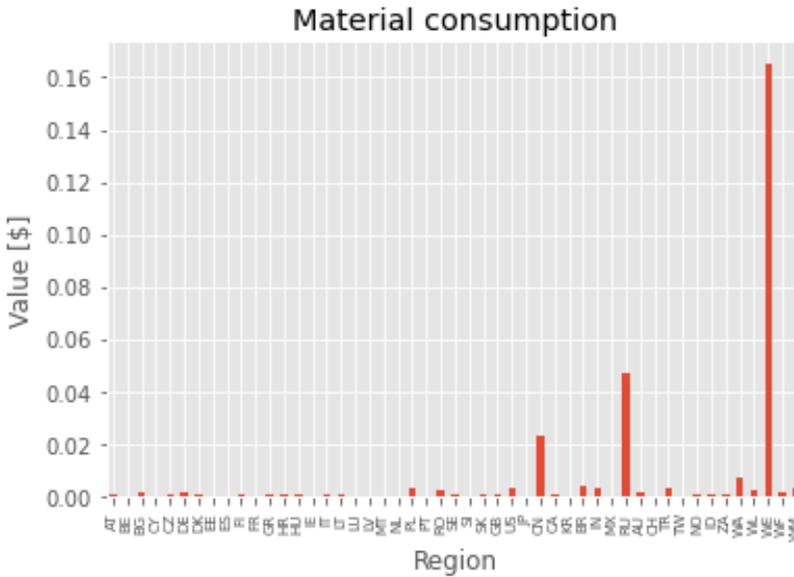


Figure 3: Regional material consumption caused by status quo final demand

Next, the same analysis is conducted for material type instead of regional level. This is comparable to the structure effect described in Pothen et al. (2017). The results are shown in figure 4 below. For improved clarity of the figure, only the 10 material types with the highest values were selected. It can be observed that “Non-Metallic Minerals - Sand gravel and crushed rock for construction” is the sector that contributes most material to the battery production (or rather electric equipment as the general sector). This is followed by natural gas for energy and various other minerals and energy carriers.

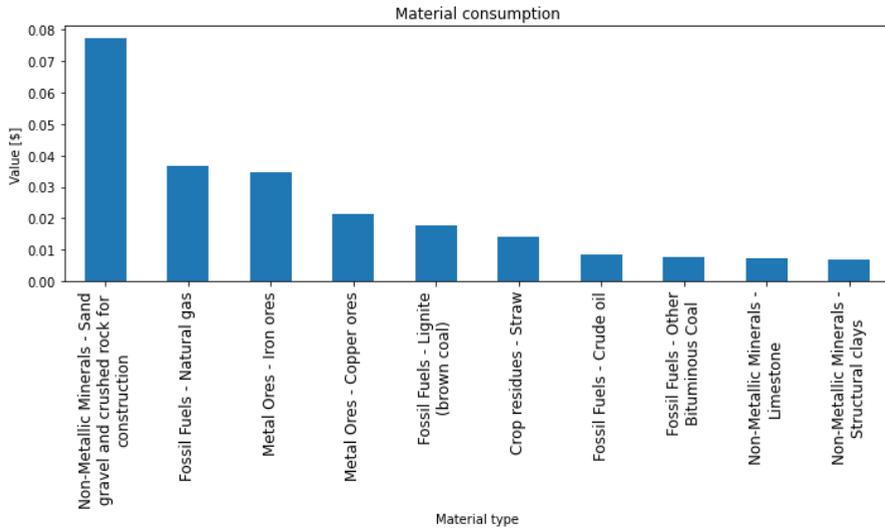


Figure 4: Sectoral material consumption caused by status quo final demand

The analysis for imports and exports is only done (exemplary) for the most used material, “non-metallic minerals”. The results in figure 5 show that the footprint in red consists of imports from China, and (to a lesser extent) of several other countries. However more than half of the material consumed comes from WE itself. Overall, the impacts of the status quo are not very high in absolute numbers. This confirms the findings of figure 3 and provides more detailed insights for this specific material. Since the units of this figure are in kilotons (kt) rather than monetary units, one can gain an understanding of the material intensity of these processes.

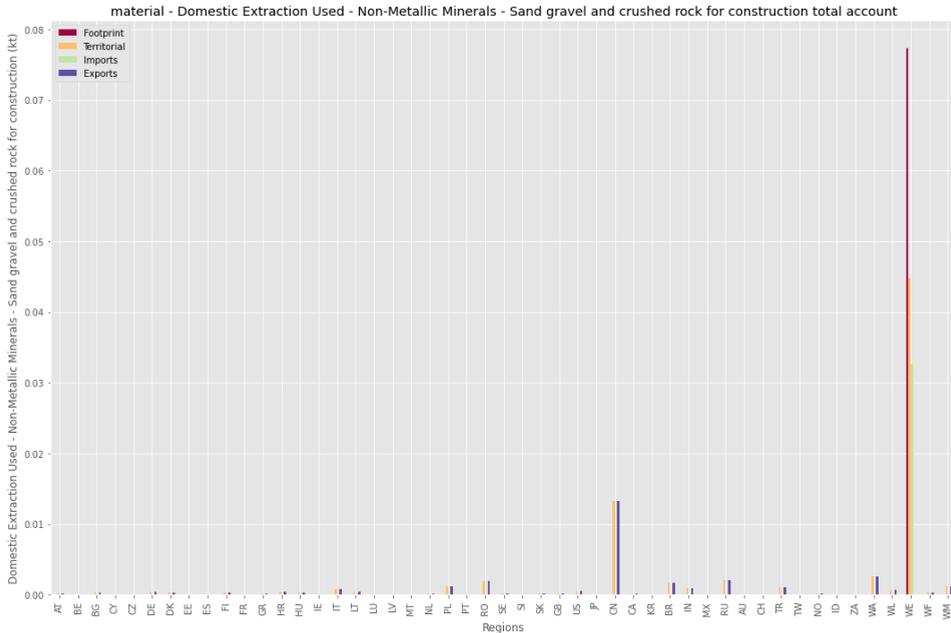


Figure 5: Non-metallic minerals import export balance

Apart from material consumption, the second important “ingredient” for calculating the resource efficiency is the value added. To conserve space, the figure depicting the value added by region is located in the appendix. Figure 6, shown below, directly presents the final result of resource efficiency. Here, Japan stands out as the most resource efficient country. It is worth noting that Japan does not have exceptionally high value added or extremely low resource consumption but beats all other regions with the combination of both factors. The resource efficiency in Japan is more than twice as high as that of the runner-up, South Korea.

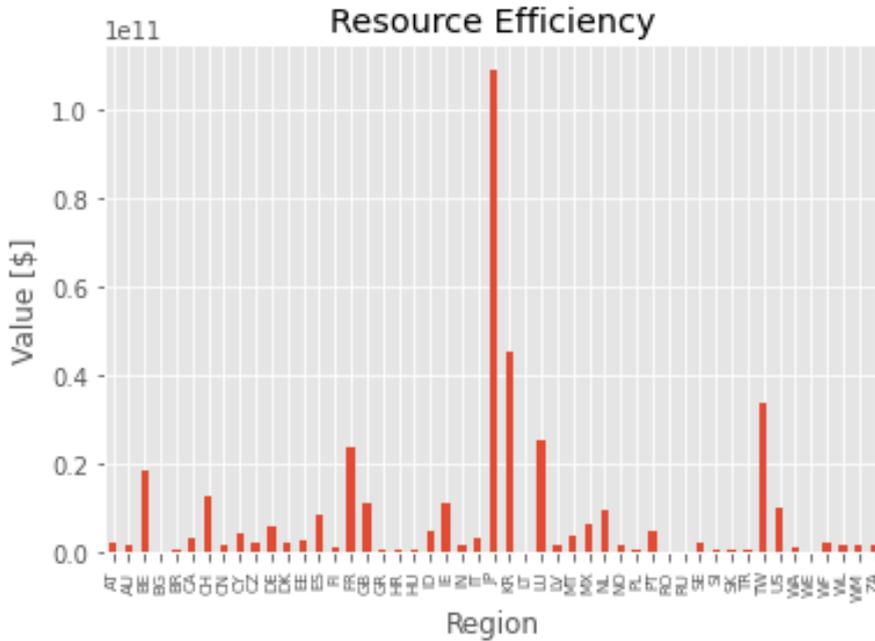


Figure 6: Resource efficiency by region (own illustration)

As a last step, the scenario of switching the sourcing from Europe to China led to various changes (see figure 7) with Taiwan emerging as the main beneficiary in terms of RE improvement, while Japan lost its lead in RE from the baseline scenario.

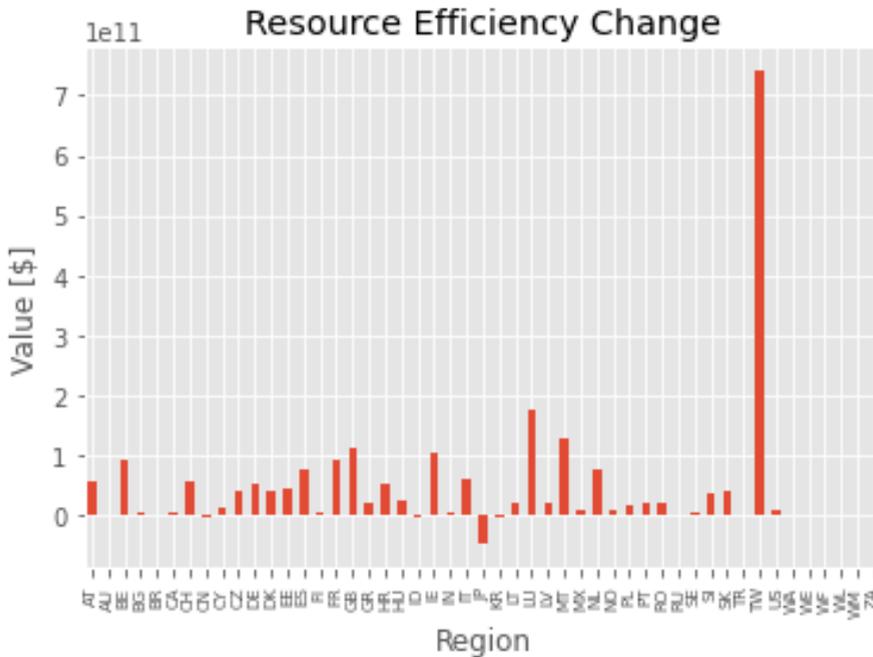


Figure 7: Change of resource efficiency when switching final demand from Europe to China

4. DISCUSSION AND CONCLUSION

The results of this research provide a valuable overview on the drivers of resource consumption and potentials for achieving higher RE in the traction battery value chain. For this, various economic sectors and regions that are involved in the battery value chain are identified and assessed using the consumption-based MRIO method. For example, depending on whether demand for batteries is fulfilled by European countries or China, different quantities of “ingredients” are needed for the battery production. This can be metals, but also services like the manufacturing and assembly of the different parts as well as transportation.

The findings offer insights into the countries and sectors that are important for the traction battery value chain production. These countries and sectors have the greatest leverage in increasing RE through targeted measures. The scenario analysis suggests that neighbouring countries of the demand-

originating country are more involved in the value chain, while China is always involved.

Regarding RE, the results suggest that high-income countries may achieve more material-efficient production despite higher production costs. The way RE is defined here, this approach effectively enhances resource efficiency. Conversely, relocating production to low-income countries tends to reduce resource efficiency. Regarding practical implementations: Policymakers and industry stakeholders aiming to improve the RE of BEV's in general and batteries in particular can benefit from the insights.

Typical limitations of MRIO analysis also apply to this research. The sectors have a limited level of detail and don't allow for assessments on (battery) component level. This research doesn't differentiate between different chemical elements, and the sector "electrical equipment" is not used for batteries exclusively.

Further research could examine trends over multiple years instead of focusing on a single year. Additionally, if e.g., metal treatment is observed as material-consuming, further research could target the identification of which exact part of the process is causing the material consumption, and which measures can help. Different methods might have to be applied for this. Further research could also explore methods to adjust or control for differences in income levels in order to ensure that comparisons are equitable. This research explicitly includes income levels by how resource efficiency is defined here. This research does not examine circular economy strategies, such as the R-strategies, and their impact on resource efficiency. Future studies could investigate the connections between these topics.

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REFERENCES

- Aslam, A., Novta, N., & Rodrigues Bastos, F. R. (2017). Calculating Trade in Value Added. IMF Working Papers, 2017(178), A001. Retrieved Jun 6, 2025, from <https://doi.org/10.5089/9781484311493.001.A001>
- Maisel, F., Neef, C., Marscheider-Weidemann, F. & Nissen, N.F. (2023). A forecast on future raw material demand and recycling potential of lithium-ion batteries in electric vehicles. *Resources, Conservation and Recycling*, 192, 106920.
- Miller, R.E. & Blair, P.D. (2009). *Input-output analysis: Foundations and Extensions*, Second ed., Cambridge Univ. Press, Cambridge.
- Morrison-Saunders, A. & Pope, J. (2013). Conceptualising and managing trade-offs in sustainability assessment. *Environmental Impact Assessment Review*, 38, pp. 54-63
- Pothen, F. (2017). A structural decomposition of global raw material consumption. *Ecological Economics*, 141, 154-165. <https://doi.org/10.1016/j.ecolecon.2017.05.032>
- Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., Giljum, S., Lutter, S., Merciai, S., Schmidt, J. H., Theurl, M. C., Plutzar, C., Kastner, T., Eisenmenger, N., Erb, K.-H., ... Tukker, A. (2025). EXIOBASE 3 (3.9.5) [Data set]. Zenodo. <https://doi.org/10.5281/zenodo.14869924>
- Usai, L. et al 2022 *Environ. Res.: Infrastruct. Sustain.* 2 011002. doi : <https://doi.org/10.1088/2634-4505/ac49a0>
- Zimek, M., Asada, R., Baumgartner, R.J., Brenner-Fliesser, M., Kaltenegger, I., & Hadler, M. (2022). Sustainability trade-offs in the steel industry – A MRIO-based social impact assessment of bio-economy innovations in a belgian steel mill. *Cleaner Production Letters*, 3, 100011.