Analyzing Critical Minerals Value Chains using the GTAP MRIO Data Base

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Climate mitigation is widely recognized as one of the key transformational challenges faced by humanity (Ripple et al. 2020). Acknowledging the need for more ambitious policies, in recent years many countries have increased the stringency of their mitigation pledges. While in their original contributions, only several countries, such as Costa Rica, Bhutan and Sweden, announced net zero greenhouse gas (GHG) emission targets (HÃ¶hne et al., 2021), as of 2023, a total of 79 countries have communicated net zero goals in either policy documents (52 countries) or laws (27 countries) (Energy & Climate Intelligence Unit, 2023).
Earlier studies have estimated that achieving ambitious climate mitigation targets will require and unprecedented expansion in renewable infrastructure and technologies, such as wind turbines, solar panels, batteries for electric vehicles, etc. (e.g. Gielen et al., 2019). While such a transition is expected to substantially reduce the demand for fossil fuels resulting in stranded fossil fuel assets (Mercure et al., 2018), it would also lead to the growing demand for critical minerals, such as nickel, platinum group metals, zinc, rare earths, etc., which are essential inputs for the development of renewable energy systems (Tokimatsu et al., 2018). It is estimated that within the pathways toward limiting global warming below 1.5oC, the demand for critical minerals could increase between 2 and 267 times by 2050 depending on the mineral (Wang et al., 2022). Apart from pure supply and logistical constraints, the rising demand for critical minerals is also associated with national security aspects and is prone to generate geopolitical frictions (Vakulchuk et al., 2022).
In this regard, it is important to have the analytical capacity for the analysis of future energy transition scenarios with an explicit representation of the critical minerals value chains. At the same time, such a level of detail is missing in most global economic databases and models, including the Global Trade Analysis Project (GTAP) Multi-Region Input-Output (MRIO) Data Base (Aguiar et al., 2023), which underlies literally all global computable general equilibrium models and is widely utilized for the assessment of the socio-economic impacts of the climate mitigation policies (e.g. BÃ¶hringer et al., 2021; Chepeliev et al., 2021).
In this paper, we focus on enhancing the GTAP Data Base with additional sectoral details representing the critical minerals and selected downstream sectors. As suggested by the literature review, the group of critical minerals is highly diverse, but their mining and process is often concentrated in selected countries. We focus on the key critical minerals produced in the world in 2021 (ranking is implemented based on the value of global output). To estimate the value of the output of each critical mineral, a combination of the U. S. Geological Survey (USGS) data for quantities of output, as well as UN COMTRADE and London Metal Exchange estimates of commodity prices were used. For the case of Platinum Group Metals and Rare Earth Elements, it was first split into six elements: Platinum, Palladium, Rhodium, Osmium, Iridium, and Ruthenium, and then each commodity was evaluated separately before combining them back into a composite group.
Based on the implemented review of the key critical minerals and their downstream uses, we identify the most important commodities that will be disaggregated in the GTAP Data Base. We consider introducing up to 12 key critical minerals in the GTAP Data Base, as well as several downstream sectors, such as solar panels, wind turbines and batteries (differentiated by type). Corresponding sectoral splits are implemented to the latest version of the GTAP 11 Data Base with the 2017 reference year (Aguiar et al., 2023) and nest the additionally introduced sectoral details with the GTAP Circular Economy (GTAP-CE Data Base) (Chepeliev et al., 2022) implementing sectoral details using the SPLITCOM utility (Horridge, 2008). In such a way we benefit from the previous efforts aimed at representing additional sectoral details relevant to climate mitigation and circular economy policies, which have already disaggregated several relevant sectors in the GTAP-Power

Data Base, including aluminum, steel, copper, plastics and cement (Chepeliev et al., 2022).
Using the extended GTAP MRIO Data Base we provide a detailed analysis of the global value chains (GVC) of the critical minerals, estimating GVC participation and concentration metrics across countries and commodities. Such estimates would allow to better understand the configuration of these complex value chains and provide important policy insights in the context of import dependency and national security dimensions as the world continues to address climate mitigation challenges.