# Incorporating Critical Minerals into the GTAP Circular Economy Data Base

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**Abstract**

Climate mitigation is widely recognized as one of the key transformational challenges faced by humanity. Acknowledging the need for more ambitious policies, in recent years many countries have increased the stringency of their mitigation pledges. 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., 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. In this paper, we focus on enhancing the GTAP version 11 Data Base with additional sectoral details representing the critical minerals and selected downstream sectors. 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). Sectoral splits also include disaggregation of electric vehicles (EVs), differentiated by type (residential and commercial), out of the motor vehicles sector. The current study represents the first step in the broader set of activities, related to the assessment of the role of critical minerals in future climate policy efforts.

## Introduction

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 (Höhne 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). Achieving such ambitious mitigation targets would require a departure from the historically observed developmental trajectory, implying drastic transformations for the energy system (Azevedo et al., 2021; Rogelj et al., 2015), changes in behavioral patterns, such as dietary shifts toward less meat-oriented food systems (Clark et al., 2020), as well as major infrastructural upgrades in many cases requiring an early retirement of the existing fossil fuel and energy-intensive capital assets and their substitution with alternative renewable energy technologies (Tong et al., 2019).

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 1.5$^{o}$C, 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 one of the Global Trade Analysis Project (GTAP) Data Base (Aguiar et al., 2023) that 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. Böhringer et al., 2021; Chepeliev et al., 2021).

## Data and methods

In this paper, we will 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. Table 1 provides an overview of the top 10 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.

**Table 1. Overview of the global supply and uses of the key critical minerals**

| Critical mineral | Top producers | Main uses | Output value, bn USD |
|---|---|---|---|
| Nickel | Indonesia, the Philippines, New Caledonia, Russia and Australia | Lithium and other rechargeable batteries | 50.44 |
| Platinum Group Metals | South Africa, Russia | Treating automobile exhaust; production of hydrogen as fuel from water | 45.40 |
| Zinc | China, Peru, Australia | Batteries designed to store renewable energy | 38.08 |
| Rare Earth Element | China (90% of world production) | Nickel-metal hydride batteries (rechargeable), hybrid/electric vehicles, and advanced electronics | 8.79 |
| Cobalt | DRC (top producer), Norway supplies much of the EU and US demand | Rechargeable batteries, as well as alloys used in many manufacturing sectors | 8.43 |
| Graphite | China (80% of global supply), Brazil, Mozambique | As an electrode in many lithium batteries and fuel cells. Various electronic applications due to its thermal conductive properties. | 4.05 |
| Manganese | Australia, Gabon, and South Africa | Used for improving battery performance, durability, and capacity | 2.79 |
| Vanadium | China, Russia and South Africa | Is key for the production of grid-scale batteries | 1.89 |
| Niobium | Brazil and Canada | Production of improved steels and alloys used in solar PV as well as Li-ion batteries. Superconductive magnets for nuclear power generation. | 1.75 |
| Lithium | The largest producers are Australia, Chile and China | Critical in producing rechargeable batteries and an additive to the cooling water in nuclear power plants | 1.35 |

*Source:* developed by authors based on USGS (2023), UN COMTRADE (2023), London Metal Exchange (2023).

Based on the implemented review of the key critical minerals and their downstream uses, we will identify the most important commodities that will be disaggregated in the GTAP Data Base. We will 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). We will also disaggregate electric vehicles (EVs), potentially differentiated by type (residential and commercial) out of the motor vehicles sector. Corresponding sectoral splits will be 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 will 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).

**Conclusion and next steps**

The enhanced global GTAP-based data framework developed in this study would be of particular interest to modelers and policy-makers who are involved in the analysis of future climate mitigation policies in general and supply chains of the critical minerals, in particular. The current study represents the first step in the broader set of activities, related to the assessment of the role of critical minerals in future climate policy efforts. The next steps of this project will include modeling of the wide range of ambitious climate mitigation scenarios in countries around the world and analysis of the evolution of critical minerals value chains within such a transition.

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