Advancing the representation of critical minerals supply chains in the global economic models

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Introduction

Acknowledging the need for more ambitious climate mitigation policies, in recent years many countries have increased the stringency of their climate pledges. Earlier studies have estimated that achieving ambitious climate mitigation targets will require an unprecedented expansion in renewable infrastructure and technologies, such as wind turbines, solar panels, batteries for electric vehicles, etc., leading to the growing demand for critical minerals and materials, such as nickel, platinum group metals, zinc, rare earths, etc., which are essential inputs for the development of renewable energy systems. 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., ERL, 2022). Other sectors such as medicine, electronics, aerospace and defense are also expected to increase their use of these important inputs. Nevertheless, the mining of critical minerals is projected to remain orders of magnitude smaller than the mining of fossil fuels. For example, the IEA projects that the total amount of critical minerals needed will be under 30 million tons, whereas coal demand is expected to be still 5 billion by 2030. Apart from pure supply and logistical constraints, the rising demand for critical minerals and materials is also associated with national security aspects and is prone to generate geopolitical frictions (Vakulchuk et al., RSER, 2022), as mining and processing/refining of many important minerals are concentrated in a limited number of countries. Trade policy interventions are frequent, in particular in the form of export restrictions.

It is important to have the analytical capacity for the assessment of future energy transition scenarios, as well as trade and domestic policies, with an explicit representation of the critical minerals supply chains. The evolution of the latter is impacted by various drivers, including costs of technologies, future changes in incomes and population, the spatial distribution of the minerals' mining and refining capacities, bilateral trade patterns, etc. At the same time, such a level of detail is missing in most global databases and integrated assessment models. In this study, we address this gap by enhancing the Global Trade Analysis Project Database with detailed representations of critical minerals and metals supply chains, including both upstream and downstream activities.

Methodological Framework

We start from a refined version of the GTAP 11 circular economy (GTAP-CE) Data Base with the 2017 reference year, which disaggregates the mining and refining of iron, bauxite, copper and other non-ferrous metals ores from a single extraction sector, tracing production and bilateral trade across 160 countries and regions, as well as 99 sectors. In particular, we use a new version 11 of the GTAP-CE Data Base, which introduced updates to the trade and production data and will be publicly released later this year.

We further disaggregate around 20 additional ores and metals, including lithium, cobalt, rare earth elements, nickel, graphite, manganese, platinum group metals, gallium, silver, phosphorus, chromium, titanium and magnesium, among others. The implemented splits include mining, processing/refining and use stages (downstream sectors, such as magnets, batteries, solar panels, wind turbines, electric vehicles, etc.). Figure 1 provides an overview of the illustrative steps for identifying supply-chain transformations of minerals within the harmonized system (HS) commodity classification. While codes listed in Figure 1 correspond to the HS6 digit notations, for selected minerals we also utilize a more detailed trade data classification at the HS8 level.

		Extraction	Processing		End use
Rare earths	HS code	253090	2846, 280530	850511, 850519	850231, 870240
	description	Mineral substances; n.e.c. in chapter 25	Compounds, inorganic or organic, of rare-earth metals; …. Earth-metals, rare; scandium and yttrium, whether or not intermixed or interalloyed	Magnets; permanent magnets and articles intended to become permanent magnets after magnetisation, of metal. Magnets; permanent magnets and articles intended to become permanent magnets after magnetisation, other than of metal	Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines). Vehicles; public transport type (carries 10 or more persons, including driver), with only electric motor for propulsion, new or used
Cobalt	HS code	260500	282200	850760	870240
	description	Cobalt ores and concentrates	Cobalt oxides and hydroxides; commercial cobalt oxide	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)	Vehicles; public transport type (carries 10 or more persons, including driver), with only electric motor for propulsion, new or used
	HS code		810520		
	description		Cobalt mattes and other intermediate products of cobalt metallurgy; unwrought cobalt; cobalt powders		
Lithium	HS code	253090	283691, 282520	850760	870240
	description	Ores and concentrates n.e.c. in chapter 26	Carbonates; lithium carbonate. Lithium oxide and hydroxide	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)	Vehicles; public transport type (carries 10 or more persons, including driver), with only electric motor for propulsion, new or used
Graphite	HS code	2504		850760	870240
	description	Graphite, natural		Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)	Vehicles; public transport type (carries 10 or more persons, including driver), with only electric motor for propulsion, new or used
Manganese	HS code	2602	282010	850760	870240
	description	Manganese ores and concentrates…	Manganese dioxide	Electric accumulators; lithium-ion, including separators, whether or not rectangular (including square)	Vehicles; public transport type (carries 10 or more persons, including driver), with only electric motor for propulsion, new or used
	HS code		720211, 720219		850231
	description		Ferro-alloys; ferro-manganese, containing by weight more than 2% of carbon. Ferro-alloys; ferro-manganese, containing by weight 2% or less of carbon		Electric generating sets; wind-powered, (excluding those with spark-ignition or compression-ignition internal combustion piston engines)

Figure 1. Identification of the minerals' supply-chain transformation steps within the trade data classification system

Overall, our data development approach consists of several steps. First, for each mineral, the supply-demand relation is created for the extraction stage. Next, based on the results for extraction, the same supply-demand relation is created for the refining process. As a result, we are able to observe the following elements: the country where the mineral is extracted, the country where it is processed, how the price changes between raw materials and processed products and the user countries of the processed products. The final stage includes the distribution of the use across final users such as the production of batteries, wind turbines, magnets, electric vehicles, etc. For mining data, we use the United States Geological Service (USGS), while for trade data we primarily rely on the CEPII-BACI database. Selected other data sources are used to complement and cross-check these data.

Parametrization of supply and use stages is implemented using both quantity and value flows. The latter are derived using quantities and prices. To implement the disaggregation of selected sectors in the GTAP Data Base, we rely on the cost structures sourced from the input-output tables for selected countries and techno-economic analyses for selected commodities/production processes published in the literature.

Discussion and next steps

We showcase the application of the newly developed GTAP MRIO Data Base by providing a detailed analysis of the global value chains, tracing the geographical and supply-chain (i.e. across different activities) distribution of the critical minerals, as well as identifying the value-added creation stages in this process. 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.

The database developed in this study is part of the broader set of research activities on developing a comprehensive modeling framework featuring the GTAP-based global recursive-dynamic computable general equilibrium model ENVISAGE (Figure 2).

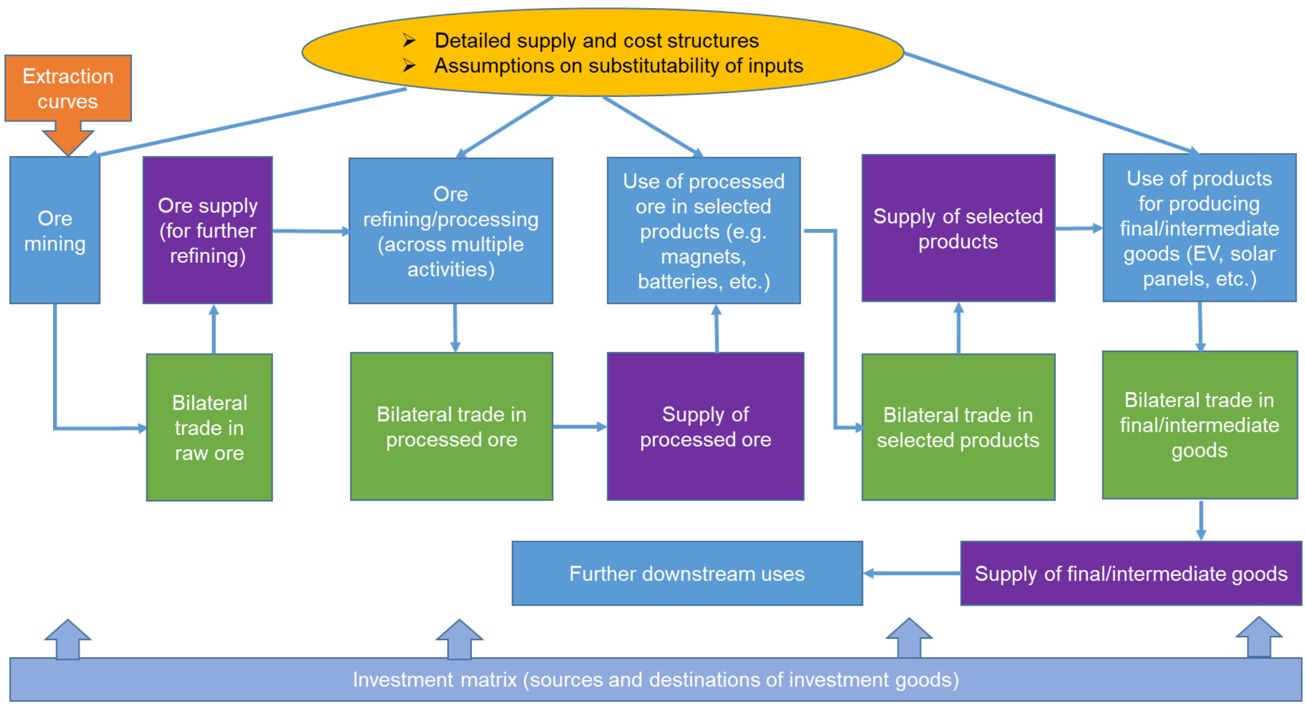

Figure 2. Overall framework under development for representing critical minerals supply chains in the global economic models

The next steps of this project will include modeling the wide range of climate mitigation scenarios in countries around the world combining them with alternative domestic policies (e.g. domestic content requirements, import tariffs, subsidies to domestic mining/refining, etc.) and analyzing the evolution of critical minerals value chains across the set of forward-looking scenarios. The results presented 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.