GLOBAL DYNAMICS OF CRITICAL RAW MATERIAL MARKETS AND EUROPE'S 2030 HYDROGEN TARGET: A GAME THEORETIC MODEL

Sebastian ZWICKL-BERNHARD*[1], Marzia SESINI[2], Max MÜNCHMEYER[2], Benjamin F. HOBBS[3]

Motivation and background

In Europe and globally, energy systems are being transformed towards full decarbonization and green technologies. This transformation involves not only integrating renewable energy sources (RES) into power systems but also a fundamental shift from fossil fuels to RES in the provision of energy services in the heating, transport, industrial, and other sectors. As we gain a better understanding of how the decarbonization of energy systems could look in concrete terms (e.g., electrification through heat pumps in the heating sector or green hydrogen use in the industrial sector), it is also becoming clear that the demand for critical raw materials will increase tremendously.

The importance of how and where critical raw materials are sourced has already been recognized in Europe. The European Commission recently published the *Critical Raw Materials Act* (CRMA) [1]. Essentially, the report is one of the first comprehensive reports to shed light on how Europe can meet its critical raw material needs as it decarbonizes its energy system. In particular, the report highlights the fact that for selected critical raw materials, such as cobalt, Europe is and is likely to remain highly dependent on a few exporting countries that hold significant shares (some almost 100%) of the global reserves of these materials. Consequently, the report suggests, among others, two measures to reduce import dependency and to ensure the security of supply for Europe:

- Diversification of exporters, with the aim of no single exporter accounting for more than 65% of annual European demand
- Strategic stockpiling to make the demand curve more flexible and strengthen its position on the global market (even as a major consumer without significant domestic supply)

Dealing with Europe's ability to secure an adequate supply of critical raw materials (in terms of both supply quantities and prices) is of paramount importance, especially with regard to the foundation they provide for the necessary deployment of RES to achieve decarbonized energy systems. The issue takes on added importance due to security of supply concerns and significant tensions within European energy markets today, largely due to heavy import dependence on fossil fuels from individual exporters [2].

Core objective

The aim is to take the next obvious step in building on the CRMA and to study the global dynamics of the critical raw material markets. In particular, this conference paper presents a newly developed mathematical model that allows to consider the market equilibrium of critical raw materials under the strategic behavior of different market participants. In addition, the measures of the CRMA (such as diversification of exporters and strategic stockpiling) are taken into account for the equilibrium of the European market. We take a comprehensive look at the markets for platinum, iridium and scandium. Each of the three materials is characterized by a key role in Europe's 2030 hydrogen target (production of 10 million tons and import of 10 million tons by 2030). By applying our model to these three markets, we provide a mathematical tool to describe the interactions between global markets for critical raw materials and defined decarbonization targets. More specifically, our analyses provide insights into the

[1] Energy Economics Group (EEG), Technische Universität Wien, Gußhausstraße 25-29/E370-3, 1040 Wien, Austria
[2] Robert Schuman Centre for Advanced Studies, European University Institute, Via dei Roccettini 9, I-50014 San Domenico di Fiesole, Italy
[3] Department of Environmental Health & Engineering, The Johns Hopkins University, Ames Hall 313, 3400 North Charles Street, Baltimore, MD 21218, USA

vulnerability of the European and global market to the exercise of market power, and how market power can be mitigated through means such as limiting market share, creating strategic reserves, and developing substitutes and alternative supply chains.

Methodology

A deterministic bi-level optimization problem is proposed to answer the research questions. The lower-level problem considers the behavior of competitive fringe supply, in which a fixed demand is met by minimizing supply cost by the fringe suppliers, given the upper-level decisions by the major exporter. The leader maximizes its profit and can exercise market power. The main links between the lower-level problem and the upper-level problem are the export price and quantity offered by the major exporter to the market clearing and, in the other direction, the cleared quantity and price (i.e., decision variables from the lower-level, whose dependence on the upper-level variables is recognized by the leader).

Lower-level problem: market clearing at minimized total cost

$$\min_{x} GenerationCostExporter + MaintenanceCostFringeExporter + StockpilingCostEurope$$

$$x = [ExportQuantity, ExportCapacity, MarketArbitrage, StockEurope, \dots]$$

$GenerationCostExporter \dots Minimize\ the\ total\ cost\ satisfying\ the\ demand\ of\ the\ European\ and\ global\ market$

$MaintenanceCostFringeExporter \dots Maintenance\ cost\ of\ the\ fringe\ exporters\ for\ available\ export\ capacity$

$StockpilingCostEurope \dots Stockpiling\ cost\ for\ the\ European\ market$

$MarketArbitrage \dots Arbitrage\ between\ the\ European\ and\ the\ global\ market\ (i.e., no\ price\ discrimination)$

$StockEurope \dots Quantity\ of\ stockpiling\ for\ the\ European\ market$

Upper-level problem: profit maximization of the major exporter

$$\max_{y} Export\widetilde{Quantity} * \ MarketClearingPrice$$

$$y = [Marginal\widetilde{Export}Cost, Export\widetilde{Quantity}]$$

$Export\widetilde{Quantity} \dots Export\ (or\ supply)\ quantity\ of\ the\ major\ exporter\ for\ the\ European\ and\ global\ market$

$MarketClearingPrice \dots Market\ Clearing\ price\ (result\ of\ the\ optimal\ descision\ of the\ lower-level\ problem)$

$Marginal\widetilde{Export}Cost \dots Marginal\ export\ (or\ supply)\ cost\ of\ the\ major\ exporter$

References

[1] European Commission, “Critical Raw Materials: ensuring secure and sustainable supply chains for EU's green and digital future.”, 2023, online available under: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661.

[2] M. Hafner, and S. Tagliapietra, “The Geopolitics of the Global Energy Transition.”, Springer Nature, 2020, doi: 10.1007/978-3-030-39066-2.