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Development of a Vehicle Technology Choice Model Considering Critical Minerals

Atsuo Komatsubara [1)] **Tomoki Nishi** [2)]

1) Toyota Central R&D Labs. Inc.,
41-1 Yokomichi, Nagakute, Aichi, 480-1192, Japan (E-mail: komatsubara@mosk.tytlabs.co.jp)

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To mitigate climate change, battery electric vehicles (BEVs) are among the most promising technologies for reducing CO_2 emissions from road transport. Although BEVs reduce CO_2 emissions during the use phase, they require more diverse and larger quantities of critical minerals than conventional technologies, especially for lithium-ion batteries (LIBs). This increase in critical mineral demand could create supply and price risks that hinder the transition to BEVs. However, few studies on vehicle technology choice explicitly consider critical mineral constraints, and the impact of critical minerals has not been sufficiently discussed.

Previously, we developed a vehicle technology choice model that iteratively updates mineral prices, LIB costs, and BEV costs, based on passenger-car technology choices and the resulting demand for critical minerals. This model has three key features: (i) it endogenizes mineral prices as a function of demand and captures the resulting changes in LIB and BEV costs; (ii) it is soft-linked to an integrated assessment model to assess BEV adoption pathways consistent with climate targets; and (iii) it employs a logit-based discrete choice formulation to represent consumer heterogeneity and the gradual diffusion of technologies. In this paper, we expand the scope to the entire four-wheeled vehicle fleet by adding trucks and buses, and incorporate battery energy storage systems (BESS) into critical mineral demand, enabling a more comprehensive assessment. We assessed the impacts of mineral recycling, second-life use of end-of-life (EoL) LIBs in BESS, and the shift in LIB cathode chemistries on BEV and plug-in hybrid electric vehicle (PHEV) diffusion. The quantitative results are scenario-dependent and should therefore be interpreted mainly in terms of relative differences across cases.

Fig. 1 compares the constant mineral price case (C1; left columns) with the demand-driven variable price case (C2; right columns). In C2, demand-driven mineral price increases raised LIB material costs, keeping LIB costs high and constrained further BEV diffusion. The impact was smaller for trucks and buses because LIB costs account for a smaller share of their total costs. PHEVs maintained a similar sales share despite higher mineral prices because of their small LIB capacity, indicating their robustness to critical mineral price risks.

Mineral recycling from EoL LIBs reduced net mineral demand and contributed to an increase in the BEV sales share. On the other hand, second-life use had only a limited impact on the BEV sales share, because it reduced new BESS demand while decreasing near-term recycling supply, which increased net critical mineral demand in the short term. Among the measures examined, the shift toward low-cobalt cathode chemistries yielded the largest increase in the BEV sales share.

This study has several limitations. Mineral prices are driven only by short-term demand and do not reflect supply-side factors (e.g., mine development lead times and declining ore grades) or potential geopolitical and environmental risks. Recycling and second-life use are also simplified and do not capture regional and supply-chain constraints. Nevertheless, this study provides a useful foundation for assessing the feasibility of decarbonization pathways and impacts of measures affecting critical mineral demand, in a context where critical mineral demand could increase severalfold and drive significant increases in critical mineral prices.

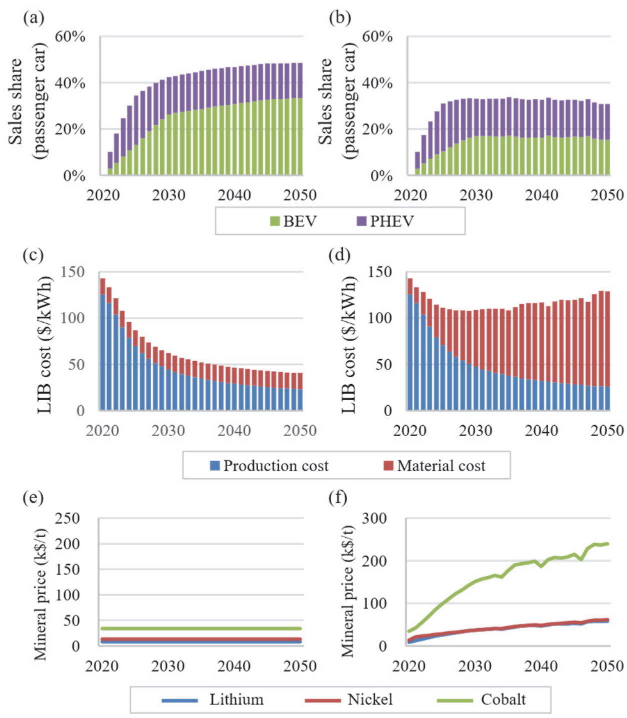

Fig.1 Impacts of critical mineral price variability: C1 (left column, constant prices) vs. C2 (right column, varying prices). (a,b) Passenger car sales shares (BEV and PHEV), (c,d) LIB costs, and (e,f) mineral prices.