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The electric vehicle revolution

Economic and policy implications for natural resource exporters in developing countries

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Abstract: The emergence of a mass market for electric vehicles (EVs) offers considerable development opportunities for resource exporters, given their intensive raw material requirements, including for cobalt, nickel, lithium, copper, aluminium, and manganese. To exploit the benefits of new demand, empirical evidence on the 'resource curse' increasingly points to the benefits of strengthening institutions for effective policy management and to mitigate the risk of poorly directed, often excessively procyclical, investment. With many developing countries staking major claims for expanding domestic electric vehicle raw material industries, these issues appear highly pertinent, not least given their complexity, opacity, and volatility. This paper analyses both the outlook for electric vehicle demand and associated raw material usage, as well as the key drivers and sensitivities required to track future market transformation. It subsequently assesses key fiscal, regulatory, and institutional reform priorities and market barriers bearing on successful domestic resource mobilization in these resource chains.

Key words: electric vehicles, raw materials, resource curse, policy, resource mobilization

JEL classification: Q31, Q33, Q38, Q55

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1 Introduction

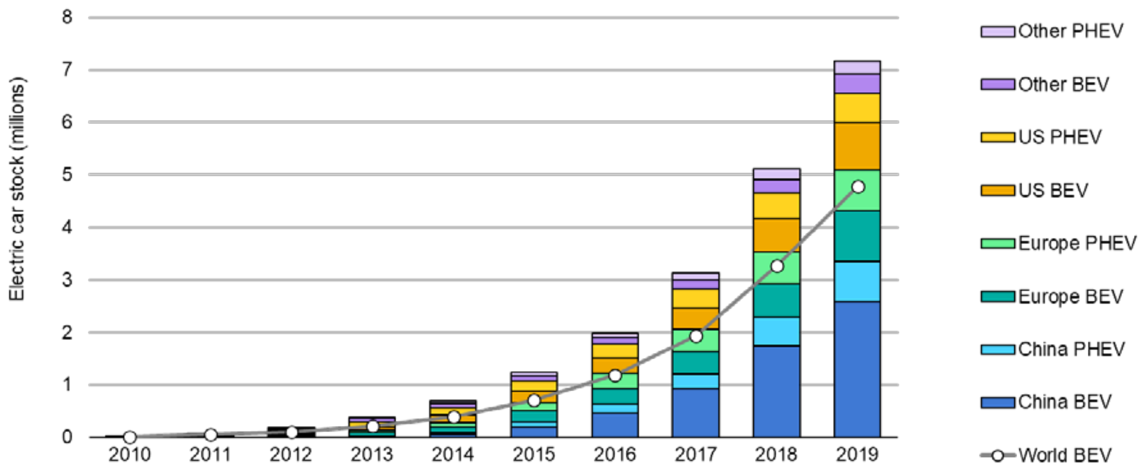
1.2 Beyond abatement in the power sector…

The Paris Agreement has raised the issue of climate change to the fore of international politics, hailing massive structural changes in the energy sector. Passenger and road freight, which are overwhelmingly fuelled by oil products, account for around 6 giga-tonnes of CO_2 annually (IEA 2019). The automotive sector is thus facing fundamental regulatory challenges to deliver a step change in emissions intensity, requiring huge investments to support the development of a mass market for electric vehicles (EVs) (in conjunction with rapid decarbonization of the power industry).

The long-term potential for structural change is enormous: the IEA (2019), for example, projects that global EV sales could reach 27 million by 2030 under their EV30@30 (a rapid transformation) scenario. Jones et al. (2020) project annual global EV sales of 15.7 million in 2030 under the base case. Under most analyses, China is expected to account for a dominant share of total EV sales, perhaps in the order of one-half of the global total (Jones et al. 2020).

However, the rate and of depth of this transformation are subject to deep uncertainty and the associated challenges should not be underestimated. EV markets remain nascent, with sales of battery and plug-in hybrid EVs currently accounting for around 2.1 million vehicles annually in 2019 (see Figure 1) (equivalent to less than 3 per cent of the global passenger vehicles market). Moreover, their future growth prospects remain highly dependent on a complex mix of factors including the extent of public policy support, the willingness and ability of industry to invest wholesale in this emergent power train, and the appetite of consumers to adopt new purchasing and driving habits.

Figure 1: Global EV stock, 2010–19



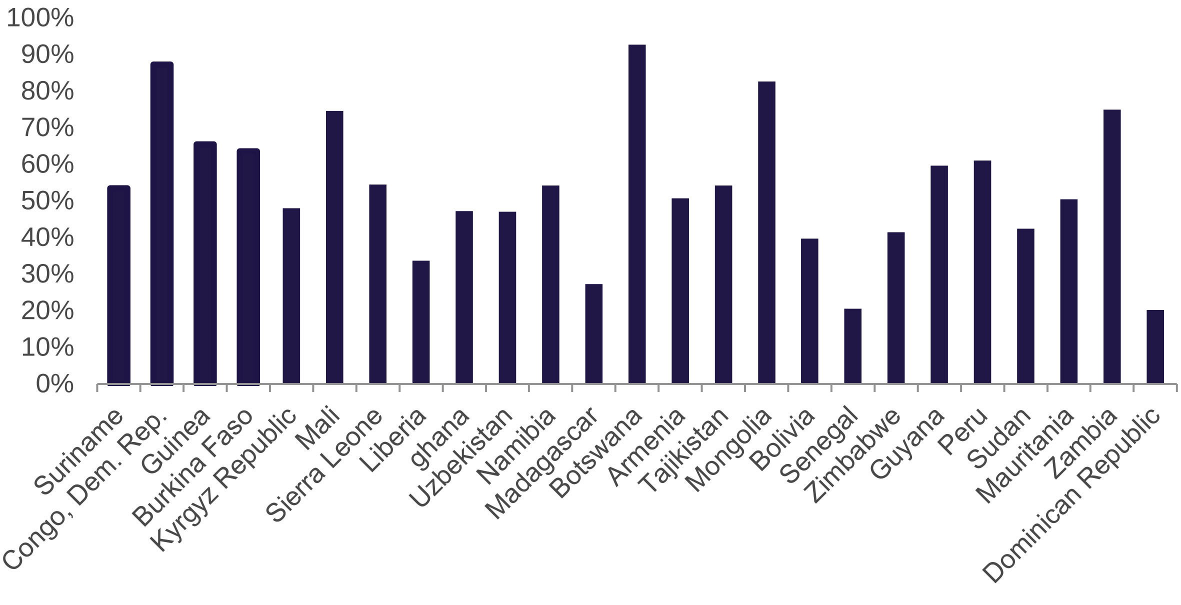
Source: IEA (2020).

Most analyses to date have typically focussed on potential barriers to consumers, including high capital costs, limited driving ranges, extended charging times, concerns regarding battery durability, and the lack of charging infrastructure (Hagman et al. 2016; Lévay et al. 2017). However, supply-side challenges should also not be discounted. The scale of investment required by the automotive industry is massive: Volkswagen alone, for example, has committed to spending over €133 billion in developing electrified powertrains between 2019 and 2023. This is challenging, particularly in current market conditions: global vehicle sales have actually declined for three successive years since 2018 (OICA n.d.). Furthermore, a range of technical and investment challenges also apply at different stages of the supply chain. The complexity and cost of battery recycling (particularly in compliance with high environmental standards) and the absence of technical recycling capacity are good cases in point (Harper et al. 2019).

1.3 Why does this matter for developing countries?

Raw material production and exports are a critical source for the economies of many developing countries. In the Democratic Republic of Congo (DRC), for example, the minerals industry accounted for 87 per cent of exports (see Figure 2) and 33 per cent of gross domestic product (GDP) respectively in 2018 (ICMM 2018). Across the border in Zambia, these statistics were 75 per cent and 21 per cent. More broadly, the mining industry accounted for over one-third of total national export revenues in 22 of the top 25 most mineral-dependent (all developing) economies in 2018 (ICMM 2018).

Figure 2: Mining contribution to total export revenues by country, 2018



Source: author's calculations based on ICMM (2018).

The global automotive industries are an important driver of demand for these economically critical sectors: in South Africa, for example, the mining sector supplies a range of manufacturing inputs including manganese for alloying steel body sheet and precious metals such as platinum for use in auto catalysts. These industries are likely to be materially impacted by the prospect of mass electrification of the global vehicle fleet. Understanding these effects is an important issue for policy makers in resource-exporting countries and the principal focus of this paper.

At its core, electric mobility implies a critical change in the locus of value creation in this multi-trillion dollar a year market. Instead of competing based on the quality and price of the engine and transmission systems, the key differentiator for an EV lies in its battery, which determines vehicle safety, durability, charging times, and, critically, driving range (shown to be a key determinant of consumer purchasing decisions). This will depend, to a significant degree, on the quality of their inputs (extremely high-quality feedstocks are required to achieve high energy density, avoid short circuits, and ensure strong deep cycle charging performance, etc).

Electric mobility is already decisively shaping the mineral industries across many countries. According to the United States Geological Survey (USGS), for example, lithium production in Argentina and Chile increased by around 290 and 240 per cent (to 6,400 and 18,000 tonnes respectively) between 2009 and 2019. In the form of lithium carbonate, valued at say US$8,000 per tonne, this represents exports of around US$195 million per year (USGS 2010a, 2020a). Over the same period, production of cobalt in the DRC increased by 400 per cent to 100,000 tonnes annually (and is now that country's second most valuable export after copper (OECD n.d.; USGS 2010b, 2020b)).

1.4 What are the policy implications for resource exporters?

Effective management of the natural resources sector poses many challenges, particularly for developing countries. Positive macroeconomic and broader developmental outcomes from natural resource endowments are far from assured. This is reflected in the long-standing debate on the existence and determinants of the 'resource curse'. An empirical review of these issues is outside the scope of this paper (see van der Ploeg 2011 for a discussion).[1] However, two points are particularly salient in this context.

First, available evidence increasingly points to the importance of strong institutions in mitigating the 'resource curse' (Mehlum et al. 2006a, 2006b; Sarmidi et al. 2013). This has broad reform implications, including with regards to enhancing systems of democratic governance and the effective rule of law. Efforts to promote transparency surrounding the scale and nature of the opportunities and risks in the mining industry arising from major structural shifts in the global economy, and to build capacity among policy makers to adapt to these changes, are likely to be a valuable component of overall institutional strengthening.[2]

Second, and relatedly, the volatility of natural resource prices (see Figure 3) has been shown to harm output and growth, including by fostering boom–bust cycles, debt overhang, and credit constraints (impacting and interacting with the financial sector development and credit market conditions) (see, for example, Aghion et al. 2009; Mansano and Rigobon 2001). Tools to rigorously assess the underlying structural drivers of demand growth, and to distinguish these from short cyclical patterns, are thus likely to be valuable in designing policy to support long-term value creation and avoid some of the pitfalls associated with myopic and irrational behaviour.

These issues are acutely relevant to EV-related raw materials, at least in part because many of the mineral inputs are (currently at least) 'niche' markets (which makes them potentially more volatile). This means that demand growth can easily be overwhelmed by supply responses (an issue which is exacerbated by the opacity of many of these markets). Expectations of future demand growth,

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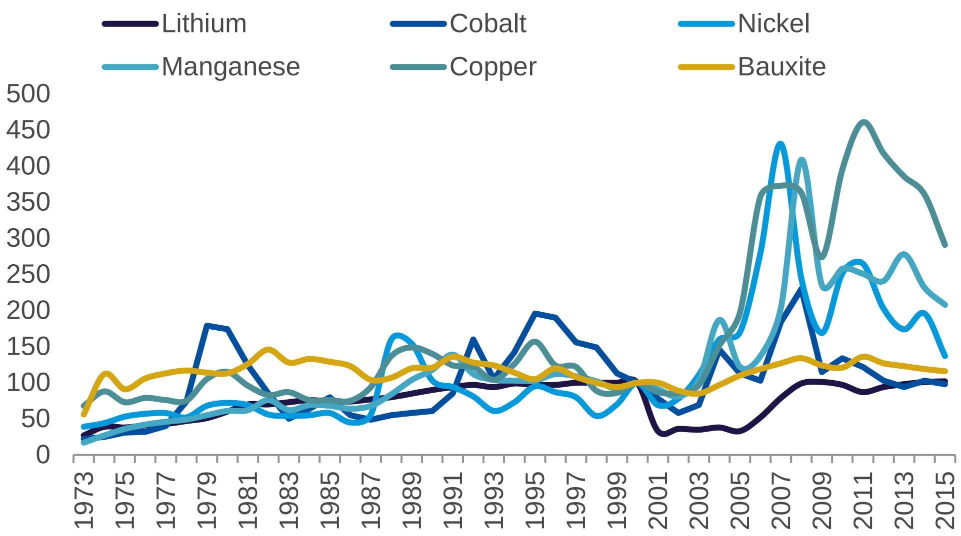
[1] At the core of this debate is whether extraction of exhaustible natural resources impedes development by placing upward pressures on exchange rates, restricting innovation in the broader economy, encouraging political and social instability (including corruption and conflict), or by fostering inefficient and volatile spending and borrowing (resulting in periodic credit market dislocation).

[2] Limiting the 'appropriability' of natural resource rents through both technical and institutional channels has been identified as a key mechanism for mitigating economic risks from natural resource extraction (Boschini et al. 2007).

for example, fuelled a significant spike in the prices of commodities such as lithium, cobalt, and manganese, particularly in the period from 2016 to 2018. This was followed by a major downswing in prices in the subsequent years as forecasts moderated and supply adjustments took place.

Figure 3: Overview of raw material prices 1973–2015 (2000 prices=100), selected EV raw material inputs



Source: author's calculations based on USGS data (USGS n.d.).

It is perhaps not surprising, given the widespread optimism for growth in EV sales, that some developing country exporters have staked major claims on battery-related resource mobilization. However, these plans and associated (often publicly supported) investment plans have often taken insufficient account of the potential risks and challenges associated with market entry. The Bolivian government, for example, has reportedly earmarked up to US$1 billion of public investment for the development of the domestic lithium industry (Mariette 2020). However, implementation has been substantially impeded by a range of practical barriers, including in relation to prevailing legislative, technical, and enabling conditions.

Thus, while the emergence of a mass market for EVs represents a promising development opportunity for mineral-abundant countries (as well as investors), it will be important to understand the risks and opportunities (and drivers thereof) in more detail. In this context, it is critical to note that the scale and timing of the market transformation in electric mobility, and the implications for future raw material demand, remains highly uncertain (not least given the variability in mineral utilization patterns across EV technologies and types of lithium-ion batteries (LiBs) which are predominantly used in their manufacture).

Fundamentally, sector planning and investment will need to be based not only on longer-term views of market transformation but also on the potential for successfully achieving domestic market share. This will likely depend on a wide variety of factors, including the nature of the natural resource endowment, as well as the quality of the policy and enabling environment. These are undoubtedly perennial issues but require careful interpretation in this context, taking account of the specific characteristics of the value chains and production process and the broader market context in which this transformation takes place (including shifting policy and consumer preferences in purchasing countries towards raw materials which meet high environmental social and governance (ESG) standards).

1.5 The road ahead…

Understanding and tracking trends in electric mobility is critical for both industry and policy makers alike. In particular, the ability to anticipate structural change in the face of noisy, cyclically influenced data will be critical for designing and implementing regulatory, fiscal, and institutional reforms to support long-term value creation and avoid some of the pitfalls associated with myopic and irrational behaviour. This includes measures designed to: capture a share of the resulting mineral wealth and associated export and fiscal revenues; promote value-added processing and manufacturing in a way which takes appropriate account of domestic comparative advantages; and mitigate adverse environmental and social consequences from mineral extraction and processing (as well as economic risks associated with shifting customer and investor preferences).

Section 2 of this paper provides an overview of the available evidence on future electrification trends and their impacts on raw material demand, with a particular focus on those required for the production of EV powertrains and supporting charging infrastructure (such as lithium, cobalt, nickel, manganese, aluminium, and copper). To help policy makers understand and track the size and structure of the resulting resource market opportunities in the face of deep structural uncertainties, this section also analyses the key drivers of future market transformation. Section 3 discusses the implications for governments in developing countries, including for macroeconomic, fiscal, and sector management policies. Section 4 concludes that:

- The potential development opportunities from growth in EV raw materials are substantial, particularly for developing countries with well-aligned resource endowments, strong institutions, and sound enabling conditions;

- Sector planning and economic (as well as revenue) forecasting should take due account of the key risks to enhanced resource mobilization, including the potential for extreme volatility as well as competition from alternative supply sources;

- Revenue administration may become more challenging due to the widespread lack of raw material price data, the fundamental complexity of the value chains, and current trends towards vertical integration, warranting institutional reforms and technical investments to better mitigate fiscal risks;

- Improving often weak information regarding the existence and nature of geological deposits, including an emphasis on geological research in ore bodies that may host battery raw materials, is a priority;

- EV raw material producers are potentially exposed to buyer power and lack international market knowledge, potentially warranting institutional and informational reforms to mitigate terms-of-trade risks;

- Value is heavily concentrated in mid and downstream segments in a number of key material chains, but expanding domestic processing and refining is likely to be challenging for many developing countries, particularly in Africa and Latin America, where local demand, technological knowhow, and other factors of production (including low-cost power) are lacking; and

- There are significant environmental and social externalities associated with EV raw material production and processing, requiring effective implementation of mitigatory fiscal and regulatory reforms (which may also become increasingly critical for market access, given changing customer preferences with respect to production standards). These need to be considered alongside the potential revenue streams, as they imply a future fiscal burden for governments unless internalized by companies.

2 EVs and future raw material demand

2.1 The EV story so far…

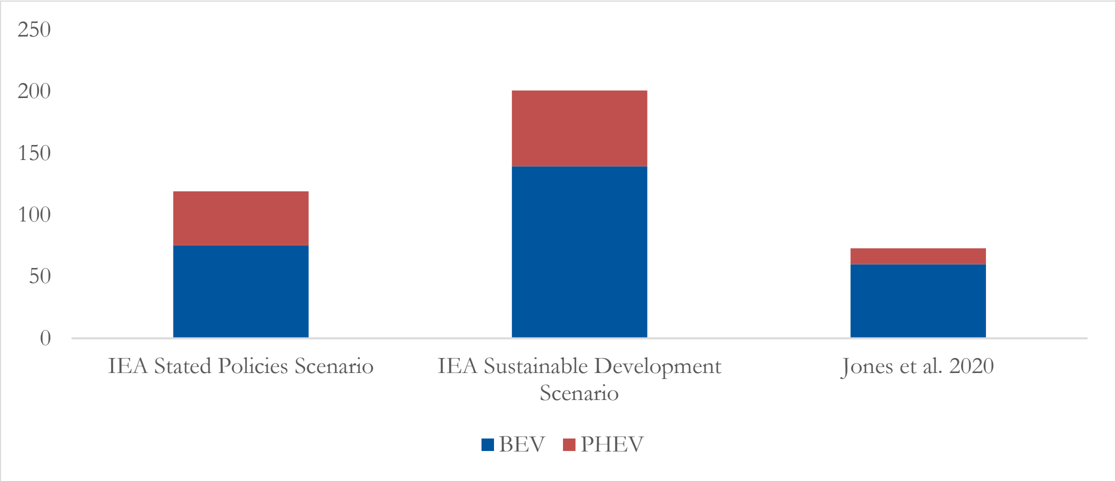
Despite rapid growth in recent years, EV sales continue to account for a small share of the market: according to the IEA (2020); for example, global sales of electrified light duty passenger vehicles amounted to around 2.1 million in 2019 (a five-fold increase since 2014), representing only around 2 per cent of the total market. China accounts for roughly 50 per cent of global sales, as it seeks to both disrupt the hegemony of EU, US, and Japanese auto manufacturers and help improve local air quality, particularly in urban areas.

Most recently, the entire automotive sector has been hit by a demand rapid contraction following the COVID-19 outbreak and resulting lockdowns (exacerbating the traditional volatility of consumer durable markets during a macroeconomic slowdown). As such (as of August 2020), automotive sales have declined by the order of 20–40 per cent across most major regions on an annualized basis, with European markets being particularly adversely impacted (ACEA n.d.; VDA n.d.).

The implications of COVID-19 for EV market penetration remain somewhat unclear at the time of writing. Following a collapse in EV sales during the early months of the crisis, it appears that these are recovering relatively well: according to the IEA (2020), for example, EVs are expected to fare better than the overall passenger car market, with overall sales expected to remain broadly flat compared to 2019 (by contrast, total global passenger car sales this year are set to decline by 15 per cent) (IEA 2020).

Looking to EV sales in the longer term, many forecasters are bullish (see, for example, Figure 4). The IEA, for example, projects cumulative global sales of plug-in and full battery EVs of around 120 million by 2030 under the 'Stated Policies Scenario'. However, this rises to around 200 million by the same period in the 'Sustainable Development Scenario' (IEA 2020). Jones et al. (2020) project EV sales of around 15.3 million in their base case by 2030 (and 63 million cumulatively over the period from 2015 to 2030).

Figure 4: Cumulative EV sales by 2030 by scenario/study



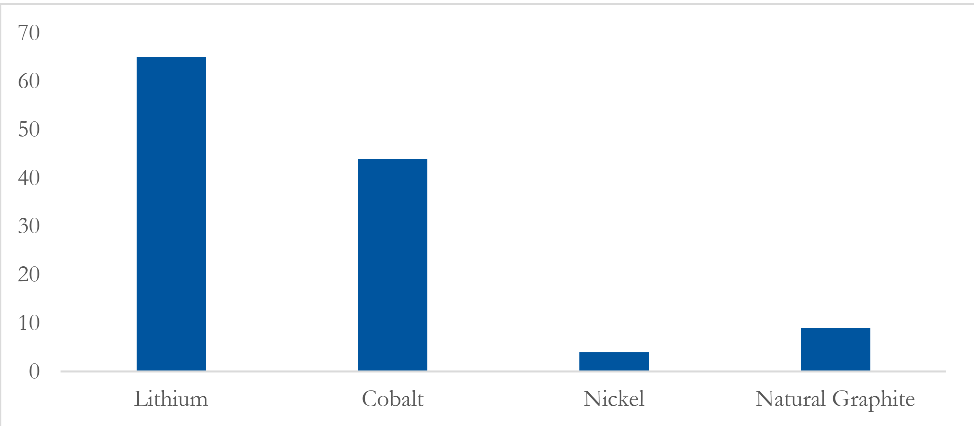
Source: author's calculations based on IEA (2020) and Jones et al. (2020).

2.2 An emergent source of raw material demand

Raw material demand is traditionally linked to structural changes in the economy, including population growth, urbanization, and industrialization. Thus, as the world prepares to transition to a new, low carbon energy system, it is perhaps unsurprising that this will have a key bearing on the size and composition of its future raw material needs. The World Bank (2017), for example, concludes that 'the technologies assumed to populate the clean energy shift—wind, solar, hydrogen, and electricity systems—are in fact significantly more material intensive in their composition than current traditional fossil-fuel-based energy supply'.

Already, growth in EV sales (as well as in grid storage to support deeper penetration of renewable power) is starting to transform a number of mineral markets, particularly those which are small in scale and highly exposed to these end uses (Jones et al. 2020). In the case of lithium and cobalt, for example, batteries for EVs account for approximately 40–65 per cent of overall market demand (see Figure 5). For other markets, such as nickel or manganese, which have more diversified applications (being predominantly used for production of steel alloys), the current share is considerable smaller (often below 5 per cent). But the growth outlook is buoyant, meaning that these end uses are set to become increasingly important demand drivers in the future.

Figure 5: Share of selected mineral demand in batteries



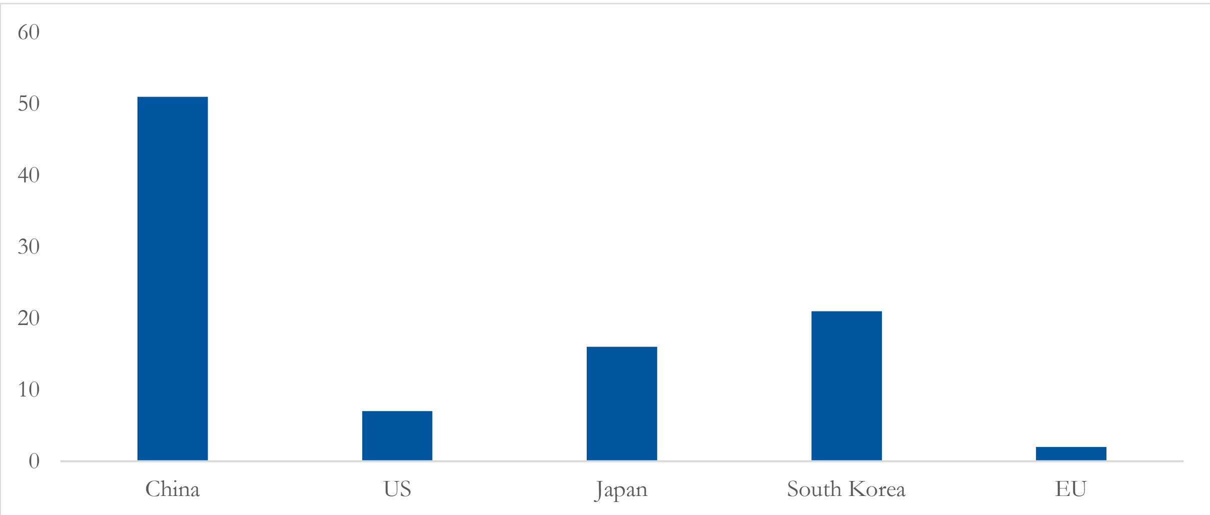
Source: author's calculations based on Jones et al. (2020), EU Commission (2018), and USGS (2020a, 2020c).

The World Bank (2020), for example, finds that under a 2-degree scenario, production of graphite, lithium, and cobalt will need to be ramped up by more than 450 per cent by 2050—from 2018 levels—to meet demand from energy storage technologies (particularly for EVs).[3] Analysis by Jones et al. (2020) suggests that demand in 2030 for cobalt, lithium, manganese, and nickel used in EVs is projected to increase by 39.6, 19.6, 5.2, and 4.7 times consumption levels in 2015, respectively. IEA (2020) finds that annual demand for cobalt and lithium rises to around 375,000 and 365,000 tonnes respectively in 2030 under the Sustainable Development Scenario (global production in 2019 was approximately 140,000 and 77,000 tonnes (USGS 2020a, 2020b). Neither are these impacts restricted to 'minor' materials markets. Jones et al. (2020) project, for example, that EVs and associated charging infrastructure build-out will account for around a quarter and one-sixth of total demand growth in aluminium and copper, and a nearly five-fold increase in nickel utilization in EVs by 2030, equivalent to around 20–25 per cent of current consumption. EV diffusion thus has the potential to be a key driver of investment across a broad spectrum of both major and minor commodities.

2.3 A transformation in the trade and supply chain policies for EV materials is underway

These demand trends are also set to have a major bearing on raw material trade flows and concomitant supply chain risks. This is largely due to the geographic mismatch between EV production (centred in Asia, Europe, and, to a lesser extent, the USA) and the locus of raw materials extraction (dominated by Australia, the Americas, and Africa). Jones et al. (2020) find that, for example, China's share of demand for global lithium and cobalt for transport (increasingly the dominant end use) is likely to rise to about 68 per cent in 2030.

Figure 6: Percentage share of global LiB manufacturing capacity by region, 2014



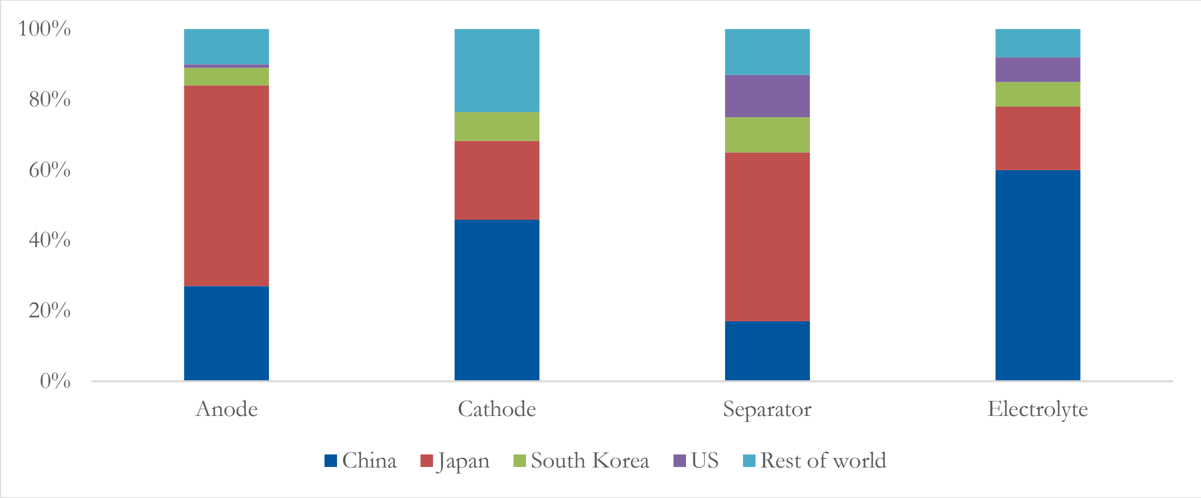
Source: author's calculations based on Lebedeva et al. (2017).

In addition to a heavy concentration of EV demand in China, it is noteworthy from Figures 6 and 7 that Asian producers also dominate downstream cell and component manufacturing. In 2016, four countries—specifically, China, the USA, Japan, and South Korea—were host to 97 per cent of the total LiB manufacturing capacity (Mayyas et al. 2019). Japan and China combined, for example, accounted for two-thirds of total cell manufacturing capacity and between two-thirds

[3] These projections do not include the associated infrastructure needed to support the deployment of these technologies (for example, transmission lines) or the physical parts (like the chassis of newly built electric vehicles).

and four-fifths of the major component markets, including cathode, anode, separator, and electrolyte (Lebedeva et al. 2017). Further upstream, China accounts for 47 per cent of lithium carbonate and cobalt refinery capacity, for example (although there has been some rebalancing of processing capacity towards raw material exporters such as Australia in recent years) (Igogo et al. 2019). A similar level of dominance is also observed in other key intermediates markets such as manganese and nickel sulphate. In the case of recent strategic investment in rare earth production in the USA, for example, mined ores continue to be shipped to China for processing, due to a lack of domestic capacity.

Figure 7: LiB component manufacturing capacity by region, 2015



Source: author's calculations based on Lebedeva et al. (2017).

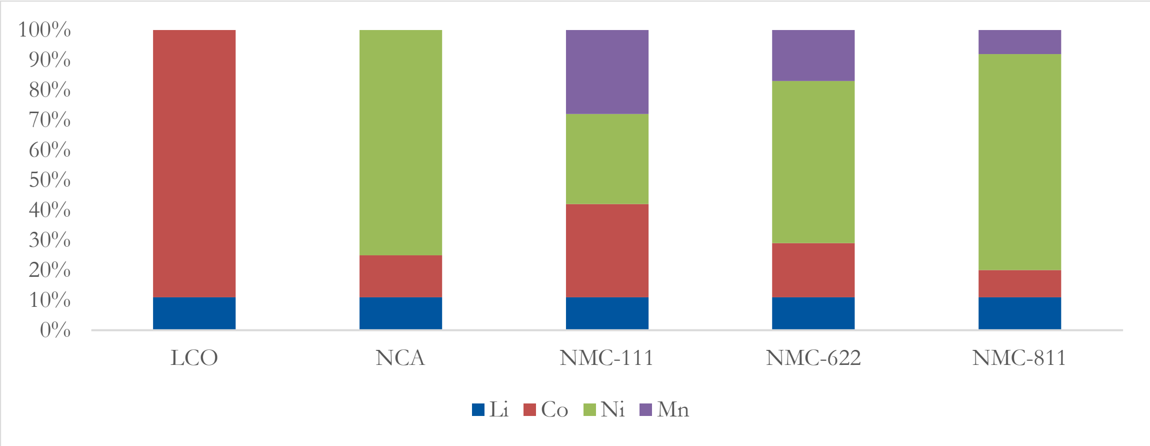
This is prompting a number of advanced countries, in particular, to promote domestic battery manufacturing capacity (supply chain risks have risen up the political agenda, particularly following the Covid-19 crisis and deteriorating Sino–US relations). In 2019, for example, the European Commission warned 'the EU's high dependency on battery cell imports could expose industry to high costs and risks in the supply chain and undermine the automotive industry's ability to compete with foreign competitors' (EU Commission 2019). The European Investment Bank, for example, is allocating €1 billion (US$1.1 billion) for battery-related projects 2020 (European Investment Bank 2020). The US government has also begun to intervene, including by funding domestic production of rare earth elements (which are a key input to EVs, wind turbines, and the defence industry) in an effort to limit import dependency on China.

2.4 Evaluating and tracking demand drivers is key

Uncertainty regarding the scale and timing of energy sector transformations is commonplace, given the complexity of the systemic changes and their dependency on future public policies. This commonly leads to large error bounds in medium- and long-term forecasts of EV adoption: for example, in the case of renewables deployment forecasts, the IEA's 2017 estimate for capacity growth to 2022 was one-third higher than its 2016 estimate (IEA 2017).

These issues are still more material in the context of forecasting associated metals demand. This is, at least in part, because the intensity with which metals are used in low carbon technologies is more variable than is the case with energy inputs. Indeed, the volume and mix of mineral inputs differ even within technologies (for example, according to the different vintages of LiB) (see Figure 8 for an illustration of mineral inputs to the different LiB cathode technologies).[4]

Figure 8: Overview of raw material by LiB cathode chemistry



Source: author's calculations based on Olivetti et al. 2017.

Under IEA analysis, for example, demand for lithium and cobalt is approximately 170,000–190,000 tonnes higher in 2030 in their '2-Degree Scenario' relative to their 'Stated Policies Scenario' (IEA 2019). However, these ranges become still broader—potentially nearly doubling in scale—when uncertainty regarding the future mix of LiB technologies is factored in (IEA 2020). To put a rough sense of scale on these uncertainty bounds, the differences between the future scenarios, even leaving aside those associated with heterogenous mineral utilization within LiB technologies, are significantly greater than the entire global market for these commodities today.

Such deep structural uncertainty, while to a certain degree unavoidable, nevertheless creates substantial problems for both investors and policy makers alike: in the case of governments, for example, it complicates revenue forecasting and increases the risk of inefficient and mistimed investment (particularly given potential political incentives to organize around optimistic predictions). Effective strategic policy planning is likely to require a robust and regularly updated view on mineral demand from EV demand growth, which takes account of new information regarding different drivers of market outcomes.

2.5 Assessing demand drivers: a comparative static approach

To this end, this section seeks to characterize some of the key factors shaping future raw materials demand from EV adoption. It employs a model developed by Jones et al. (2020) which simulates such demand in a way that is transparent, consistent, and inclusive of the various structural drivers, including cost, macro, infrastructure, and technology related factors. This 'COMIT' model provides a robust framework for evaluating the scale and timing of the market transformation, the relevant drivers, and their associated impact on metals demand (and is transparent and simple to update when new data becomes available). A simple schematic of the key sets of model inputs is set out in Figure 9.

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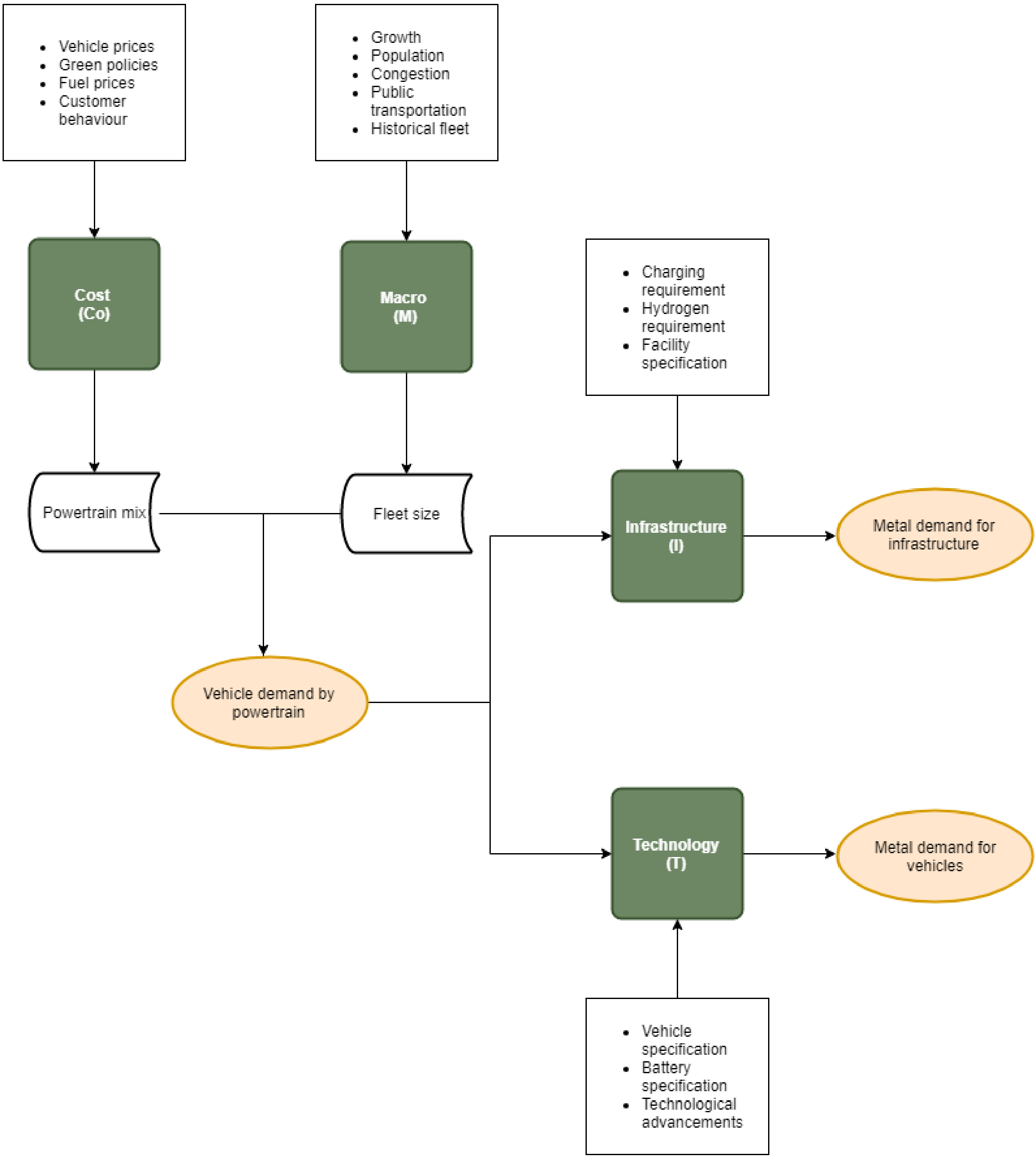
[4] These include lithium-nickel-manganese-cobalt oxide (or NMC), which are widely used in EV models such as the Chevrolet Bolt, the BMW i3, and the VW e-Golf (of which there are a number of different sub-types featuring different ratios of nickel and cobalt). In addition, lithium-nickel-cobalt-aluminum oxide (or NCA) is used in a number of the best-selling EVs in the USA (such as the Tesla Model S).

Figure 9: Overview of EV and raw material demand drivers



Source: Jones et al. (2020), under the Creative Commons license CC BY 4.0.

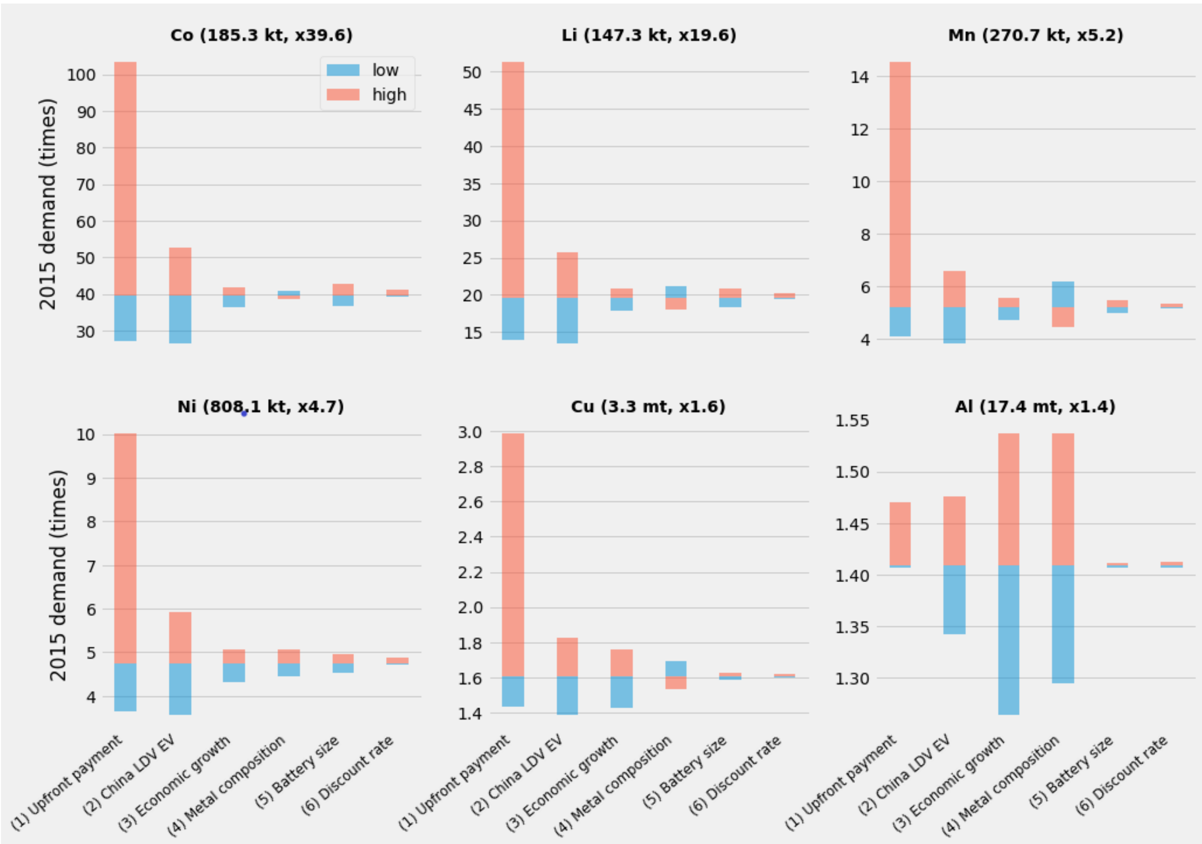
Let us examine the sensitivity of demand for key mined commodities to four general factors, namely, the rates of global economic performance and technological advancement in the battery sector, key changes in policy support (with a focus on China), and drivers of consumer behaviour (in particular EV prices and the discount rate over which future operating costs are amortized). These drivers, together with a brief summary of the specific simulations undertaken, are outlined in Table 1, while the quantitative impacts are summarized in Figure 10 and discussed in more detail below.

Table 1: Overview of EV-related mineral demand drivers and comparative static analyses

Driver	Key variables	Simulation notes
Consumer choice	EV price deflation Fuel costs	50 per cent increase and decrease in the rate of change EV/battery capital costs
Policy support	EV subsidies Fleet standards Tail pipe standards	50 per cent increase/decrease in EV penetration in China due to policy adjustments
Macroeconomics	Real GDP growth	50 per cent increase and decrease in the baseline rates of economic growth
Technology	Battery size Battery mineral intensity Vehicle weight Recycling	50 per cent increase and decrease in the rate of change in metal loadings associated with LIBs and aluminium utilization in EVs 50 per cent increase and decrease in battery size/driving range
Finance	Interest rate	50 per cent increase and decrease in discount rate
Recycling	Volume of recovered secondary materials	Not simulated

Source: author's elaboration.

Figure 10: Summary of change in mineral demand in 2030, by demand driver



Source: author's calculations.

Consumer choice

The potential role of upfront capital and financing costs in the metal demand outlook is explored by simulating the resulting impacts on a vehicle's (relative) total cost of ownership (TCO) and subsequently on consumer behaviour.[5] Capital costs associated with EV purchase are currently higher relative to an internal combustion engine (ICE). A key component of these costs relates to battery production. At market prices of around US$150 per kiloWatt hour (kWh), a 50 kWh EV battery, currently capable of propelling a family car around 200 miles on a single charge, would be valued at around US$7,500. However, these costs—as with many other green technologies—have fallen rapidly with learning-by-doing and scale economies in production: IEA, for example, estimates that capital costs associated with LiB manufacture fell by around 80 per cent between 2009 and 2019 (IEA 2020). Thus, tracking the evolution of cell manufacturing—and broader EV manufacturing or sale costs—is likely to be critically important for estimating the speed and depth of the structural shift in the future powertrain: for example, a doubling of the decline rate in EV capital costs results in an explosion in the demand for materials such as cobalt and lithium whose demand is simulated to be ~285,000 and ~225,000 tonnes higher in 2030 compared to the base case. Interestingly, these effects are highly asymmetric, with much lower downside risks, in part due to the offsetting effects of policy.

Policy support

Several governments around the world have employed a range of policy support measures, including capital subsidies, regulatory mandates on producers and consumers, and public investments in charging infrastructure, to encourage the mass adoption of EVs.[6] However, federal and provincial measures in China are most critical to track, given the roughly 50 per cent market share of the global EV market. The range of policy support measures enacted in this country are too numerous to fully document here, but a short synopsis may be helpful for policy makers seeking to understand these key external drivers.[7] In an effort to explore the quantitative importance of Chinese EV policies, we simulate high and low EV penetration rates of 12.1 per cent and 36.3 per cent respectively in 2030 (representing a 50 per cent departure from the base case projection of 24.2 per cent in the same period). In the case of the high EV scenario, for example, more rapid adoption in China places the global supply of cobalt and lithium under significant additional pressure, with incremental demand in the order of 70,000 and 45,000 tonnes higher in 2030 (the impacts are broadly symmetrical in the downside case). These scenarios have a more moderate, but not trivial, impact on demand for more diversified commodities such as copper and nickel, implying a change in consumption of around 500,000 and 300,000 tonnes annually in 2030.

[5] The TCO methodology evaluates the cost competitiveness of different powertrains, assuming that consumers account for all monetary (including both capital and operating) costs incurred over the life cycle of the product (see also, Al-Alawi and Bradley 2013; Hutchinson et al. 2014).

[6] It is also noteworthy that EV policy support has been intensified as part of countercyclical policy responses to the COVID-19 crisis in many countries, including increased public investment in charging infrastructure (e.g., China, EU), changes in the rules on taxable corporate benefits relating to EVs (e.g., UK and Germany), and schemes to encourage early retirement of ICEs (e.g. China).

[7] China's 'New Energy Vehicles' policy was first developed in 2010 and has significantly boosted EV sales in recent years through subsidy schemes for producers and other financial and non-financial incentives offered to consumers and producers. More recently, China has been in the process of phasing out financial incentives for producers and retargeting these at vehicles containing large and high-energy density battery technologies). Instead, producers are regulated by the dual credit system, which imposes targets on automotive companies to both increase the share of EVs and reduce corporate average fuel consumption.

Macroeconomics

Economic growth is a key driver of vehicle sales and associated metal demand due to its impact on vehicle affordability. To understand this sensitivity further, optimistic (pessimistic) scenarios in which global economic growth is 50 per cent higher (lower) than the baseline assumptions are simulated for the period 2020 to 2030. The results suggest a relatively modest degree of demand sensitivity for cobalt, lithium, manganese, and nickel; even in the low case, demand for these minerals is still likely to grow rapidly, increasing by ~37, 18, 5, 4 times respectively compared to 2015 demand levels. By contrast, demand for copper, for example, which is used in supporting infrastructure, is relatively more sensitive to such economic factors given the capital intensity of such investments (and associated affordability issues).

Technological progress

There are many potential facets of technological progress which have a bearing on mineral demand. Material substitution is a perennial issue in mineral demand analysis, but is particularly pertinent in minor metals markets where demand is concentrated in a limited number of end uses and where there are strategic incentives for suppliers to diversify (for example due to a concentration of production in politically sensitive jurisdictions).[8] A key consideration in this regard relates to the future evolution of LiB cathode technologies. This reflects both the uncertainty around, and the potential importance of, new, less cobalt-rich chemistries: for example, the volume of cobalt used in an lithium-nickel-manganese-cobalt oxide (or NCM) '811' cathode is less than one-third that which is used in earlier ('111') vintages of this battery technology (but uses nickel more intensively).[9] A second factor relates to the outlook for replacing steel with lighter-weight materials. This is particularly relevant for aluminium whose utilization in the automotive industry has risen over several decades in response to more stringent fuel efficiency standards.[10] Thus an increase and decrease in the anticipated annual rate of change in metal loadings of 50 per cent compared to the baseline is simulated from 2020 to 2030. This has some notable impact on the cobalt, nickel, and aluminium markets. For example, in the high technological progress simulation, aluminium demand in 2030 is roughly 1,750,000 tonnes higher compared to the baseline, equivalent to around 2.75 per cent of current global demand (and represents a higher degree of sensitivity compared to economic factors in the case of these minerals). Nickel demand rises by around 50,000 tonnes in 2030 (or around 2 per cent of current global annual market) while cobalt demand falls fairly modestly by roughly 10,000 tonnes (equivalent to around 7 per cent of current global demand), in part reflecting the underlying trend towards reduced cobalt intensity in the baseline.

Finance

By contrast, consumer decisions are found to be rather less impacted by the choice of discount rates. A high discount rate more heavily weights costs that occur in the present and therefore encourages consumers to select powertrains that are cheaper now (such as an ICE) instead of

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[8] Past experience with rare earth elements is an interesting case in point. Following a temporary ban by China on exports to Japan in 2010, automotive manufacturers such as Toyota and Honda substantially reduced their use of terbium and dysprosium, for example (while adaptations in rare earth usage were also observed in applications such as oil refining and glass making) (Hsu 2019).

[9] In the longer term, alternatives to the use of lithium as the binding agent in the cathode may also be feasible but are not simulated here.

[10] Changes in battery size to enable different driving ranges would also impact the demand for metals, particularly for lithium and cobalt (and to a lesser extent nickel).

those like an EV which have the potential to save costs later. However, these intertemporal preferences are found to have a modest effect in slowing down the electrification of global fleets: demand for cobalt, for example, falls by around 10,000 tonnes in 2030 compared to the base case.[11]

Recycling

A further set of considerations, not explicitly modelled above, relates to the potential to recover key battery mineral inputs from spent batteries or to mitigate wider demand pressures through the re-use of EV batteries for other purposes in which their performance is less critical (such as in home power walls).[12] This potential is widely debated among chemical engineers and supply chain specialists. However, a realistic assessment of the potential for recycled materials to displace primary production must consider the impacts of a number of key barriers including a lack of standardization among cells (rendering sorting of secondary materials difficult prior to processing), declining cobalt content (the most valuable recovered material), a lack of economic scale in the market (since EV sales remain low and vehicle retirement typically lags sales by 5–10 years), and limited plant investment (which is in part related to the strict environmental controls associated with battery leaching and other toxic recycling processes). As such, while recycling is likely to be widely mandated on auto-producers, it is perhaps unlikely to have a major impact on metal demand for a decade, perhaps longer (Gardiner 2017; Mayyas et al. 2019). However, in the longer term, the potential for recycling to mitigate demand growth is substantial: for example, the introduction of recycling into demand simulations undertaken by the World Bank (2020) resulted in a roughly 35 per cent reduction in cobalt demand in 2050 compared to the results of analysis in a previous 2017 report which excluded such secondary market considerations (World Bank 2017).

3 Implications for raw material exporters

3.1 Towards enhanced domestic resource mobilization

The prospects of rapid growth in demand for EV raw materials has fostered attention by consumers, producers, and policy makers. Anticipating elevated risks of supply chain bottlenecks or price spikes, importing regions such as the USA and EU are increasingly defining battery materials as strategically critical.[13] This is spurring a range of policy responses, including directing trade finance towards mining and mineral processing investments, increased provision of information to industrials on supply risks, and some early-stage policy discussions around the importance of a more 'circular economy'.

Reflecting these risks, as well as some of the commercial benefits of stable raw material supplies (for example, through the ability to co-optimize downstream plants' capacity to specific input specifications), some major industrial buyers have sought to negotiate long-term contracts with producers: in February 2020, for example, Samsung signed a five-year deal for the supply of cobalt

[11] Structural shifts in fuel prices are also found to have a modest impact on consumer behaviour (see Jones et al. 2020). This is in part due to the dampening effects of capital costs, discounting, and the assumption of rising technical efficiencies (which reduces the volume of fuel required).

[12] Martinez-Laserna et al. (2018), for example, detail a number of recent commercial projects by original equipment manufacturers to prove the technical feasibility of this kind of battery second life.

[13] The EU established a critical raw material list in 2014 (EU Commission 2014). In 2020, this list was revised to include lithium. In 2018, the USA established a similar list of 25 minerals which includes many EV inputs including cobalt, lithium, manganese, and bauxite.

hydroxide with Glencore. Others have actively pursued vertical integration opportunities: for example, a branch of Toyota acquired a 15 per cent stake in Australian-based miner Orocobre to secure rights and help fund expansion of a lithium brine project in Argentina in 2019.

Resource-exporting governments in both developing and advanced countries are also adapting policies in order to try and take fuller advantage of the potential opportunities. In 2019, for example, Western Australia established a 'Future Battery Industry Strategy' designed to promote more domestic downstream integration in these value chains (the state has been host to a substantial growth in lithium refining capacity in recent years) (Government of Western Australia 2019). This is a notable departure from the previous focus of the region's mining industry based on shipping of lightly processed ores.

At the other end of the spectrum, the DRC classified cobalt as a strategic mineral, subjecting it to a 6.5 per cent additional royalty charge. This reform process was somewhat chaotic in nature and may have elevated investor concerns regarding the stability of the fiscal regime and broader governance of the sector. However, the underlying economic case for an oligopolist such as the DRC pursuing a significantly higher-value share is worthy of fuller analysis (considering both the long-term price elasticity of demand for cobalt as well as the likely investor responses to reduced sector profitability).[14]

On the face of it, Latin America appears well placed given its large deposits of copper and lithium and recent advancements in the deployment of renewable energies in its mining industries. A number of countries in South East Asia and Oceania, including those with nickel deposits such as Indonesia, Malaysia, New Caledonia, and the Philippines, could also benefit. Naturally, Africa is also a highly mineral-rich region: for example, South Africa and Ghana produce manganese, Zimbabwe has lithium deposits, Madagascar is a major nickel producer, and the DRC and Zambia have significant copper and cobalt deposits. The economic significance of these trends will depend on the size of the industry uplift relative to the overall economy: in the case of small and highly undiversified economies such as New Caledonia or Madagascar, the implications could be highly material.

However, the existence of known deposits is no guarantee of future domestic resource mobilization. As such, which countries will benefit most from these opportunities will likely depend on a wide variety of factors, including the nature of the natural resource endowment and the quality of the policy and wider enabling environment. In particular, the market for investment in natural resources is highly competitive, and foreign direct investment flows are highly sensitive to both domestic policy conditions as well as, interrelatedly, the quality, cost, and risk associated with the specific resource development project under consideration. Thus, the growing economic and strategic priority placed on raw materials for EVs and other low carbon technologies increases the need to understand and debottleneck relevant constraints to sector development.

In many cases, this is likely to sharpen the pre-existing case for policy reforms including enhancing infrastructure provision as well as fiscal and regulatory measures, including those aimed at

[14] Cobalt can be substituted for nickel in EV cathodes. These substitution effects currently appear to be moderate and, perhaps, declining (although this trend is partly influenced by shifting relative metal prices). However, demand responses could be non-linear, in particular if new, chemically stable cobalt-free battery cathodes are successfully developed. Supply and investment responses are themselves dependent on the cost competitiveness of domestic assets (higher taxation is passed through to mineral prices where reforms bear on marginal suppliers, and, where margin reductions occur, these are typically less consequential for lower-cost producers), the availability of alternative investable deposits internationally, as well as prevailing and expected market conditions (including for co-produced nickel and copper).

controlling pollution and wider adverse social impacts from mining and mineral processing (Addison 2018). However, these reform priorities may require specific interpretation and tailoring to the particular market and industrial context of these value chains. This section discusses a number of the key issues in more detail.

3.2 Exploration and geoinformation policy

A lack of basic information regarding the existence and nature of geological deposits is a perennial barrier to domestic resource mobilization, particularly (but by no means exclusively) on the continent of Africa. Many governments, supported by international agencies and national geological services, have been investing in improving the quality and accessibility of geological survey information (including the introduction of electronic cadastres and data hubs), developing and reforming legislation on sub soil use, and private sector investment promotion. Growth in EV raw material demand generally reinforces the case for such investments but may warrant increased prioritization of geological research and early-stage prospecting into new ore bodies that may host battery materials. There may also be implications for reviewing the results of previous geological survey data and sampling; many potentially lithium bearing deposits, for example, remain undiscovered due to the fact that public or private prospectors who previously explored for tantalum, tin, caesium, potash, or other potentially co-located minerals did not test for the presence of lithium (given the then absence of conducive market conditions). As such, there may be a case for public intervention in such processes, perhaps in conjunction with the university sector or public geological services, to encourage resampling of the results (or 'signatures') of historical pegmatite and other exploratory drill samples in order to better ascertain the existence of potentially newly commercially viable deposits.[15]

3.3 Revenue and economic forecasting

A number of developing country exporters are staking major claims on the development opportunities from expanding EV raw material production. In 2017, for example, the then President of Bolivia Evo Morales told a German news agency that: 'We will develop a huge Lithium industry, over $800 million have already been made available' Mazumdaru (2017). This included planned leadership by the Bolivian state-owned company Yacimientos de Litio Bolivianos in the development of 14 plants at the Salar de Uyuni project by the mid-2020s (targeting production of 50,000 tonnes of output within five years). Three years later, after disbanding a joint venture agreement (with German company ACI Systems), in the face of numerous technical, economic, and legislative barriers, this plan has been effectively abandoned.

This is not to discount the economic potential from such industrial expansions. However, at the outset, it is important to stress the currently small-scale nature of markets like lithium and cobalt (as well as others such as graphite and rare earths) compared to more traditional mining industries including copper, iron, gold, and coal, or end uses such as the manufacture of steel alloys for the construction sector as a driver of zinc, manganese, nickel, or chrome demand. However, the growth potential could be substantial, particularly for countries and territories with relevant endowments which feature one or more large assets (especially where their values are high relative to the scale of the overall economy) which could be materially expanded or newly commercialized. Importantly, any economic or fiscal projections related to EV raw material industries should take

[15] There are numerous examples of such activities by private companies, for example in Australia and Canada. However, these successes are fuelled by vibrant junior mining industries (which are commonly lacking in many developing countries, particularly those with nascent mining industries), which benefit from improved prospecting opportunities due to the availability of richer and more accessible geoinformation data and platforms.

realistic account of the outlook for market growth, domestic industry penetration in international markets, and the associated potential value and profitability (see Jones (2020) for a discussion of revenue forecasting issues in the minerals sectors). This requires a data driven and analytical approach which is grounded in the commercial realities shaping industry development.

In this context, it is well known that cost competitiveness is a key driver of foreign direct investment in the extractive industries (other important factors include the quality of the geological deposit, the enabling environment, and the attractiveness and stability of the prevailing fiscal regimes). Long-term supply and competitor analysis (particularly in fast-growing markets where new investments will be needed to satisfy demand) should generally be grounded in assessments of the (relative) full economic cost (including capital amortization) of future domestic and competing international projects or asset expansions. In the case of lithium production, for example, this would typically point to the likelihood of sustained market share by the brine-based producers in Latin America who, despite higher upfront costs, are likely to be cost competitive given substantial operating cost advantages.

However, the structure (rather than simply the level) of these costs is also likely to matter, particularly in the short and medium terms. For example, recent lithium industry growth has been disproportionately concentrated in hard rock mining in Australia and China, which have lower initial capital costs and shorter project lead times relative to brine-based deposits (found in Chile, China, Argentina, and Bolivia). Thus, host countries of hard rock lithium deposits in countries such as Zimbabwe, DRC, Brazil, and elsewhere must carefully evaluate the trade-offs between capital and operating costs and the implications for competitiveness (as well as the associated economic and fiscal impacts) over different term horizons.

In addition to domestic and international production costs, understanding commodity price mechanisms is also valuable for the formation of economic and fiscal projections (including the valuation of exports and estimating domestic industry profitability). This typically warrants a particular focus on the locus and production costs of international 'swing producers' in any market (usually the highest cost sources of production whose commercial viability is most acutely exposed to price fluctuations).[16] At time of writing, these are likely to include Chinese lithium producers, (artisanal) cobalt miners in the DRC, and smaller-scale South African miners of manganese.

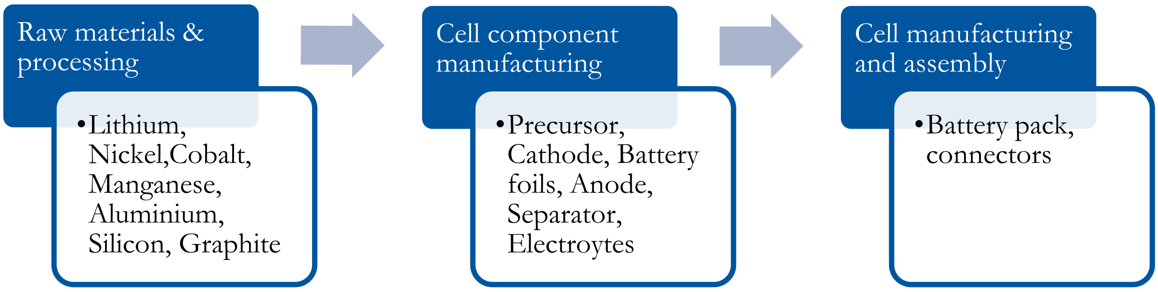
3.4 Strengthening tax administration

The EV revolution, while offering some revenue upside opportunities for many developing countries, also potentially increases the challenges of effective tax administration in resource-rich countries. This is due to a range of factors, including the lack of widely available market prices for many battery minerals and associated beneficiated products, the fundamental complexity of the value chains (see Figure 11 for a high-level schematic),[17] and the trend towards more vertically integrated industries (and thus the associated increase in the frequency and value of internal transactions).

[16] In some cases, however, 'swing' production does not always come from the highest cost producers. Notably in manganese, for example, swing production is increasingly concentrated in small-scale—often third-quartile—producers rather than larger-scale and more expensive fourth-quartile producers, due to the greater prevalence of longer-term 'take or pay' contract structures with Asian buyers.

[17] Individual minerals may be subject to numerous processing steps before being manufactured into a battery component. Nickel sulphate, the key nickel bearing chemical used in precursor manufacture, can be produced in more than a dozen different ways, each subject to different economics and technical valuations.

Figure 11: Overview of LiB supply chain and raw material inputs



Source: author's elaboration.

This is evident from recent disagreements regarding tax payments between a number of governments and major lithium producers. In 2018, for example, Chile's government announced the creation of a committee to supervise lithium contracts, following allegations about US-based Albemarle charging below-market prices for its sales to foreign affiliates. The absence of clear market price for many of these minerals (and their chemical derivatives) has thus been a barrier to governments seeking to evaluate taxable values and associated revenue shortfalls. Such issues are exacerbated by the pattern of vertical integration in many industries, which increases the prevalence of, and fiscal risks associated with, transactions between related parties. In lithium for example, Ningbo Shanshan, Toyota, and Great Wall Motors are among a series of downstream producers who have taken stakes in upstream mineral assets in recent years in an effort to secure supplies and take advantage of the commercial opportunities which arise from optimizing plants based on stable feedstocks. These issues are not limited to lithium, however.

In Ghana, for example, the Ministry of Lands and Natural Resources instructed a detailed technical and financial audit of the plans and financial practices of a major manganese producer following its acquisition by a Chinese company. This reflected concerns regarding excessive scaling-up of mine production plans (putting pressure on local infrastructure) and the associated tax revenues: the unit price of reported manganese ore exports from Ghana over the 2016–18 period remained flat, for example, while global benchmark prices over the same period almost doubled. In August 2019, the government stopped all operations with immediate effect after several infractions were found upon the completion of these preliminary technical and financial audits.

Looking to the future, mitigating the potential fiscal risks in these and other relevant examples is likely to require investment in robust and implementable transfer pricing rules. One potentially desirable option is to establish an 'arms-length' pricing formula that estimates the value of a given raw material as a function of market conditions and the technical characteristics of the ore or beneficiated product in question (considering grades, impurity levels, etc.). However, implementing such pricing rules may be technically challenging given the opacity and complexity of some battery raw material chains. One particular issue, for example, concerns the enormous differences in value and scale which can exist across product segments. The manganese example cited earlier is a good case in point. While the majority of ore extracted is almost certainly used for ferro manganese and other steel alloying purposes, battery cathode manufacturers have created a small but growing demand for highly valuable metal and chemical derivates. Addressing these issues requires an understanding of the off-taking patterns as well as the scale (since these can be readily saturated) and value of these new niche segments for the purposes of ore valuation.

The fiscal and investment risks associated with mis-specified pricing formula are potentially significant. At the same time, however, the requisite skills and data for the proper evaluation of primary and processed raw material values are rarely found in the public sector, requiring specific technical inputs by experts in raw material markets and pricing. Thus, effective institutional capacity development is likely to require closer cooperation between policy makers, international financing agencies, and industry practitioners and data providers in the provision of relevant technical support services.

3.5 Negotiation and marketing support

China, Japan, and, to a lesser extent, South Korea currently dominate battery cell, components, and intermediates manufacturing. This concentration risks weakening the terms of trade for developing country exporters, particularly where producers are small in scale and lack understanding and awareness of the broader international markets. In the DRC, for example, ASM miners sell the majority of their cobalt to (largely Chinese) traders and are commonly required to accept large discounts (perhaps even as high as 75 per cent) compared to market prices. These trends are not limited to battery-related end uses and customers; in the case of manganese, for example, the emergence of 'super smelters', largely in Indonesia and China, has gradually weakened the negotiating power of suppliers, particularly smaller-scale South African producers.

Collectivization has traditionally been a central response to such circumstances and may have some merits, for example, by creating the necessary scale to support investment in early-stage processing technologies (payables on higher-grade cobalt ores, for example, increase disproportionately on a contained basis compared to lower grades). These opportunities may also extend to marketing; individual cobalt miners in DRC, for example, commonly pool their product prior to sale to traders. Now the government is planning to go further. In January 2020, it created the *Entreprise Generale du Cobalt* as a subsidiary of state mining company Gecamines to purchase and market all cobalt that is not mined industrially in an effort to exert greater influence over prices.

At the time of writing, this company is due to become operational imminently. As such, the outcomes remain unclear. However, international experiences with such national mineral marketing agencies have often been mixed, sometimes succumbing to executive pressures for its operations to help support wider foreign policy objectives or domestic political goals, including as a mechanism for delivering patronage through appointments to executive positions (or as an opportunity for corrupt practices such as through the sale of materials at below-market prices). As such, any state marketing company will require independent market advice and strong governance arrangements to enable it to create value and avoid these common pitfalls.

3.6 Beneficiation and strategies for value creation

A key strategic question for all major natural resource exporters concerns where in the value chain to target production and investment. In this context, developing country governments commonly prioritize the development of beneficiation capacity. This largely reflects the belief that such investments are a pathway to more rapid economic development, greater and higher skilled employment, and stronger industrial and technical spillovers.

In practice, however, the appropriate response to this question warrants careful consideration on an industry and country specific basis, taking account of the locus of value within any mineral production and processing chain and the existence of (or potential for fostering) sufficient comparative advantage to sustain profitability and market share in any given downstream segment. This later point can be a function of a wide variety of factors including resource and factor endowments, enabling conditions (such as port and logistics facilities and sufficiently abundant low-cost power), as well as access to downstream markets and customers.

Importantly, the distribution of value added differs across commodity chains. In the case of some traditional markets, particularly those in which fundamental resource scarcity or quality-related rents exist, economic value added tends to be concentrated in upstream value segments. This is the case for copper, for example, where mining costs are commonly in the range of US$2,000 to US$5,000 per tonne of contained metal, compared to prices which generally range from US$5,000 to US$7,000 per tonne. These levels of 'structural' profitability are in stark contrast to the narrow treatment and recovery charges earned by downstream smelters and refiners.

By contrast, value is likely to be more heavily distributed in the mid and downstream segments in battery raw materials. In lithium, for example, spodumene (a lightly processed ore typically containing 5–8 per cent mineral by weight) has a sale value typically in the region of US$500 to US$800 per tonne. However, lithium carbonate and lithium hydroxide—substantially purer chemical derivatives—are valued anywhere in the region of US$8,000 to US$15,000 per tonne. These marked value increments have fuelled a lively debate among policy makers in many exporting countries around the world regarding the case for stimulating investment in downstream processing of lithium and other battery raw materials.

A variety of policy strategies have been employed. In the case of Western Australia, for example, the lithium royalty regime was actively adjusted to encourage beneficiation. The mining ministries of Chile and Argentina are actively seeking to promote domestic lithium processing, including by actively seeking to promote international partnerships with firms that have the skills and technologies required for low-cost beneficiation. In other markets, governments have pursued more interventionist policies. Indonesia, for example, has sought to stimulate investment in domestic processing by actively banning the export of unprocessed ores such as nickel. Such extreme measures have actually proved rather successful in fostering expansion of domestic nickel smelting and integrated stainless-steel manufacturing capacity (and associated industrial clusters). This has in part been enabled by close proximity to Chinese steel and alloy manufacturers (and working partnerships with investors on the mainland), sufficient low-cost coal-based power, and access to (indeed, in some cases, an oligopolistic market position in) primary feedstocks.

However, downstream battery cluster development is likely to face quite different challenges on the continents of Africa and Latin America. The absence of a large, geographically proximate demand centre is a good case in point. In particular, physical access to customers is typically a more important driver of commercial success in downstream markets, in part because battery chemicals 'cake' during transit due to the absorption of water in the atmosphere (substantially complicating their subsequent downstream processing).[18] However, there are also broader questions relating to the conditions required for a strategy to successfully promote integrated downstream production.

Obtaining the technical knowhow is clearly one challenge (which has been overcome in Indonesian nickel processing, for example, largely through deep partnership with Chinese companies). Access to sufficient and low-cost power is another potentially critical barrier which has contributed to declining beneficiation industries (including in manganese, chrome, and silicon) in South Africa, for example (and hinders development and competitiveness of the mining industries more generally across the continent). Transportation infrastructure is another critical enabler. Recent

[18] Other physio-chemical properties may favour localization of end-of-life chain development: the transportation of spent batteries presents significant fire hazards due to the risk of short circuits.

expansions in manganese mining in South Africa, for example, has been integrally linked to enhancements in Transnet's rail capacity. However, too often, transportation improvements have failed to materialize, requiring producers to truck ores often long distances on poorly surfaced and maintained roads.

As such, the conditions for the development of large-scale cost-effective smelting facilities too often seem a distant reality across many developing countries. Key segments of the 'lithium triangle' in South America, including in Bolivia and remote North Western regions of Argentina, are grossly underprovisioned in terms of transportation, access to a skilled labour force, and other key factors of production. These factors undermine the potential to produce cost-effective primary materials and are likely to be critical preconditions for further chain development (and, if investments and service agreements are well designed and implemented, offer substantial development spillovers for local populations).

3.7 Environmental, social, and governance risks and opportunities

Demand for EVs is associated with broader trends towards higher ESG standards in the extractives industries. Social issues arising from the extraction of cobalt in the DRC, for example, have been a foremost concern to date given the widespread environmental damage and human rights abuses associated with unregulated artisanal mining (including child labour, lack of workplace safety, and forced relocation of villages) (Amnesty International 2016). These issues have encouraged more responsible sourcing among buyers, producers, and traders.

Since 2018, for example, the London Metal Exchange requires all cobalt traded on the exchange to be audit for compliance with OECD 'Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas', or equivalent. Major buyers of cobalt, including Apple, VW, and Tesla, are also reforming their purchasing rules to ensure that all metal procured satisfies high ethical and environmental standards. In May 2020, in perhaps a bell weather decision, Huayou Cobalt—China's biggest cobalt producer—decided to stop buying from artisanal producers due to pressure over the use of child labour in DRC's informal mining sector.

These trends present both risks and opportunities for developing countries. Clearly, higher standards of environmental and social protection have the potential to confer material benefits on many, often highly vulnerable, households and communities. However, failure to ensure compliance with emerging standards risks undermining their future market access (thereby undermining an important social security net in many rural areas within resource-rich developing countries). Tesla, for example, is attempting to divert its procurement of cobalt away from DRC towards North America in an effort to mitigate such risks. Whether this is in fact achievable is unclear and—if enough buyers follow suit—may even require the payment of a premium above the relevant price benchmark given the scarcity of ex-DRC supplies.

Policies aimed at both formalizing and verifying environmental and social standards associated with artisanal mining are a clear priority. These require improved government effectiveness, including enhanced governance and transparency frameworks. Featuring among a wide variety of policies and programmes to support these goals have been recent efforts in DRC to collectivize and organize artisanal cobalt miners around larger-scale pits with cooperatives to enforce better safety rules and access to equipment (coupled with the necessary tracing equipment to ensure these enhanced standards can be verified by international buyers).

Such issues are not restricted to cobalt. The production of lithium from brines, for example, is associated with large-scale exploitation of scarce water resources. This is a critical issue in the areas such as the Atacama desert affecting local farmers and communities: the two principal mining companies operating in the region are estimated to extract around 63 billion litres of water a year (Boddenberg and Mortensen 2020). It is already shaping the evolution of the industry: the Chilean government, for example, has restricted the production quotas of the major industry participants as a direct response. Producers are increasingly compensating local communities for these damages. However, further sustained efforts by the industry, working in conjunction with regulators and local communities, to measure and limit these damages (for example through the development and diffusion of more water-efficient extractive processes) is likely to be essential to sustain the industry's future social licence to operate in such an environmentally fragile setting.

Nickel refining is another case of a battery value chain which results in substantial environmental costs and risks. Disregarding for a moment the highly energy-intensive nature of the production process, converting low-grade nickel laterite ores into a highly purified battery grade nickel also produces large amounts of waste, which in turn requires careful storage. A number of recent nickel-refining projects, including in Indonesia and Papua New Guinea, dispose of the waste in deep sea repositories. This approach is highly controversial and there have been widespread calls for its discontinuation given the threat to local coral reefs and fish stocks from failures in tailings management (which occurred at a nickel and cobalt processing facility in Papua New Guinea in 2019, for example).

As such, growth in the production of EVs risks exacerbating environmental externalities associated with the manufacture of their raw materials. This reinforces the need for effective fiscal and regulatory policies to mitigate the environmental and social risks associated with mining and metal processing in parallel with measures to promote EV diffusion. This includes efforts to decarbonize the often highly energy-intensive mining and metals industries. Unless such issues are addressed, the growth in EV sales has the potential to increase emissions in resource-rich countries: mining-related emissions are already rising due to declining ore grades (requiring more mineral processing, for example in copper) and weakening improvements in the energy productivity of some smelting and refining processes (e.g. aluminium).

Uptake of renewable power and the associated electrification of diggers, locomotives, and other diesel-powered plant equipment are beginning to emerge: the Chilean copper industry, for example, has made recent strides towards greater adoption of solar power on mine sites (and hybrid power solutions are also beginning to penetrate some of the least electricity-smelting industries, such as zinc). But much more will need to be done to decarbonize an industry which consumes around 10 per cent of total energy in countries such as Australia (Arena 2017). Power supplies to mine sites are often reliant on inefficient diesel primary and back-up generation in many remote locations, particularly in Africa.

To this end, robust, credible economy-wide carbon pricing has the potential to further catalyse the shift toward lower carbon mining. But sector-specific measures may also be required to overcome technological and informational barriers to sector transformation: CORFO, the Chilean mining ministry and development agency, for example, has set up a special technological institute to encourage solar energy and low emission mining and advanced materials of lithium and other minerals (CORFO n.d.). Governments may also help to coordinate producers with renewable power service providers to install shared facilities in order to help overcome adoption barriers faced by short- and late-life mine operators (which may not be able to commit alone to longer-term renewable contracts, for example).

4 Concluding remarks

The prospect of large-scale demand growth for the raw materials required to support the decarbonization of road transportation (and to a lesser degree power markets) presents a promising development opportunity for mineral-abundant countries. Already, EV sales growth is starting to transform a number of these mineral markets: batteries for EVs account for approximately 40–50 per cent of overall market demand for lithium and cobalt, for example. These trends have fuelled widespread optimism among developing country exporters.

However, the existence of known deposits is no guarantee of future investment or local value retention. Which countries will benefit most from these opportunities will depend on a wide variety of factors, including the nature of the natural resource endowment and the quality of the policy and wider enabling environment. To this end, a number of countries have sought to encourage battery-related resource mobilization and adapt policies to capture a larger share of the resulting value generated: for example, Bolivia has reportedly earmarked up to US$1 billion of public investment in the development of the domestic lithium industry.

A critical issue hindering economic and sector policy development and implementation is the deep uncertainty surrounding the timing and depth of any future demand shifts. This is a particularly acute issue given wide heterogeneity in the amount of minerals used across future powertrain (comparing say hydrogen to battery based mobility) and within the same technology (in particular, different LiB batteries have very different 'chemistries'). This has resulted in uncertainty bounds regarding future demand from EV sales for some minerals which are greater than the entire global market for these commodities today.

A sound understanding of the outlook for, and drivers of, demand growth (as well as the principal indicators to monitor) is key for effectively mitigating some of the economic and policy risks associated with such extreme uncertainty. To this end, this paper provides a robust framework for evaluating these trends and drivers. In particular, it highlights the critical importance of future income growth, vehicle and battery-related capital costs, policy support (particularly in major economies such as China), and technology choices (including the size and vintage of LiB technologies employed) for future EV-related metals demand.

These trends have broad implications for policy design and implementation including (but not limited to), for example: the formation of associated economic and revenue projections; reforms in the provision of geoinformation services; the design and enabling of strategies for enhanced domestic value added; tax policy choices as well as institutional and technical enablers of effective revenue administration; and the management of risks and opportunities associated with ESG issues arising in these value chains.

More specifically, the paper finds that economic and revenue forecasts should be based on realistic and suitably 'risked' assumptions regarding future market growth and domestic market penetration and the associated economic benefits. This requires a proper understanding of production costs compared to competing international supply sources as well as the key mechanisms by which market prices are formed. Overall, these opportunities could be significant for some countries and territories with a number of large and well-placed assets which could be significantly expanded or newly commercialized because of the energy transition. However, for many countries, the economic upside may be modest in scale relative to larger mineral market and traditional end uses.

Ensuring that fiscal frameworks are stable, predictable, and limit investment distortions is desirable to encourage investment in battery value chains. However, applying these principles in practice raises a number of interesting questions. The recent royalty increase on cobalt in the DRC provides a case in point. In particular, whether this reform better reflects the optimal tax burden for an oligopolist producer facing active substitution in downstream markets (particularly in battery cathode manufacture) as well as likely tax-induced reductions in sector investment remains open to fuller analysis. Another pertinent question concerns the merits and likely effectiveness of tax policy levers—implemented or under discussion in a number of countries—designed to encourage domestic downstream processing.

The growth of demand for battery minerals potentially also increases the complexity of mineral tax administration due to the lack of widely available market prices for many such materials, the fundamental complexity of their value chains, and the trend towards more vertically integrated industries. The development of 'arms-length' pricing formulae that estimate the value of a given raw material as a function of market conditions and the technical characteristics of a particular ore or beneficiated product could help mitigate fiscal risks (but commonly require input and calibration by experts in raw material markets to implement).

Such trends may also require broader informational and institutional reforms targeting different stages of mineral development from prospecting to marketing. They generally reinforce the importance of improving information on geological deposits, including increased prioritization of research and early-stage prospecting into ore bodies that may host battery materials. At the other end of the development cycle, downstream market concentration in battery intermediate and component manufacture may also warrant increased investment in expert data and marketing expertise, and, in some cases, consolidation of mineral marketing strategies, in order to limit the resultant terms-of-trade risks for primary resource exporters.

The growth in EVs and batteries has also stimulated age-old, and often rather vexed, questions regarding the potential for greater domestic downstream processing. This is partly due to the disproportionately large share of value which is currently earned in mid and downstream industry segments (compared to say copper or iron ore). However, assessment of these opportunities (and the design of associated sector policies) requires a clear focus on the sources of comparative advantage associated with, and the potential barriers to, greater domestic vertical integration. Developing countries which are short of power infrastructure have high generating costs or weak transportation infrastructure, which may struggle to create value in these segments. In addition, certain physical properties of some battery chemicals (particularly their sensitivity to moisture in transportation and storage) may favour locating refining capacity near to major downstream markets.

Finally, rising EV sales risk exacerbating social and environmental externalities associated with their manufacture. These issues are increasingly evident across a wide range of raw materials and environmental considerations, spanning water scarcity in lithium brine extraction (or copper mining), air pollution from smelting and refining of battery chemicals (or certain forms of complex scrap), and water contamination and waste management issues associated with a range of mining, processing, or recycling activities. Mitigating these issues presents opportunities for enhancing sustainable development in resource-exporting countries. However, sector governance reforms could undermine progress and potentially limit future market access (as is evident from recent experiences in exchange traded cobalt) given broader trends towards the demand for higher product standards among customers and investors.

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