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Understanding Cartel Viability: Implications for a Latin American Lithium Suppliers Agreement

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Abstract: The energy transition requires significant volumes of minerals of which the Global South holds large reserves. This context revives hopes and fears that producing countries in the Global South might hold sufficient market power to demand above market prices, technology transfers and even migration of productive processes to their countries. Our research question is what determines the effectiveness of states' collusion on natural resource exploitation and how does that affect the probability of Latin American collusion regarding lithium. The study utilizes Social Science methods for developing frameworks of analysis and comparative case studies. Following an overview of what is required for effective cartels, the study focuses on characteristics of the six primary lithium producers and potential producers in Latin America: Chile, Argentina, Bolivia, Brazil, Mexico, and Peru. Theory and empirical evidence indicate that Latin American lithium producers should be very cautious in assessing their bargaining power vis a vis the market. More focus should be put on how best to utilize market determined profits to support sustainable national development. The conclusion highlights limitations of Latin American countries' capacities and suggests future lines of research regarding potential commodity cartels for resources essential to the energy transition.

Keywords: lithium; cartels; Latin America; EV; Australia; China

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1. Introduction

Electric vehicles (EV) have become a focus in the global struggle to mitigate climate change. Governments around the globe have committed to addressing climate change and a chief step is a transition to a greener energy paradigm, which demands decarbonizing transportation and the power grid. Transportation alternatives, including EVs, were already being explored in response to pollution, industrial policy for the auto sector, and energy security concerns [1]. Hence, focus on EVs was a readily available, high impact strategy to jumpstart the struggle to mitigate climate change.

Intermittent renewable energy, chiefly wind and solar, requires storing energy generated or accessed at one time for use at another. Batteries, ranging in size from household to industrial, are increasingly playing a prime role in energy storage. With the current state of technology, rechargeable lithium-ion (Li-ion) batteries constitute the dominant energy storage systems for transportation and increasingly for the power grid and on-site generation. Consequently, the expected pace of a desired and successful energy transition generates expectations about a booming lithium market. How this market evolves and is governed will make the uptake of EVs and the response to climate change easier or more difficult.

Just over half of the current commercially viable lithium reserves are located in Latin America [2]. The potential market for lithium produces wild speculation about Latin America's role in that market. The transition to a greener energy paradigm could be smoother if lithium production in Latin America expands significantly. In the process, these nations could promote broader based and sustainable economic and political development with these new revenues.

Unfortunately, much of the speculation about the lithium market confuses the characteristics of lithium with those of crude oil, leading to incorrect analogies about the “New Oil” [3], or labeling countries the “Saudi Arabia of Lithium” (e.g., Bolivia [4,5], Chile [6] and even Afghanistan [7]). Such speculation produces poor policy if governments of producing countries respond as if they have significant market power. Argentine government officials called for an Organization of Lithium Producing Countries in 2014 and again in 2022, [8,9] and Mexico’s President announced that a state company would be created because lithium impacted the country’s sovereignty [10]. In extreme cases, governments envision complete dominance over the production chain by fabricating EVs themselves—all in the belief that they are embarking upon a strategy for sustainable development and insertion into the higher value added rungs of the lithium global value chain. These views echo the unrealistic dreams of commodity producing nations of the past, that creating commodity cartels is the “best hope for gaining control over their natural resources, influencing world commodity prices, and negotiating a restructuring of the international economic system” [11].

Lithium, however, is not only recyclable and not scarce, but it may have more in common with guano and rubber, the markets for which were initially dominated by Latin American countries, than with oil or gold. Unfortunately, the characteristics of guano and rubber, their markets, and technological innovations produced short-lived booms, then busts, leaving Latin American producers with debt and unsustainable national development strategies.

At the height of the guano boom (1850–1875) Peru initially benefitted greatly because its guano resources on the Chincha Islands were abundant and of superior quality. However, in just over two decades the country’s main reserves declined in the face of exploding demand, habitat damage at the main site, and the inability of the seabirds to produce enough new guano. Need and technology led first to direct extraction of nitrogen and phosphates from the fish themselves (fishmeal) and subsequently to the discovery of significant deposits of nitrates and phosphates on land [12,13].

In the case of rubber, the innovations of the Industrial Revolution generated significant demand, especially when bicycles, automobiles and military uses expanded in the late 19th–early 20th centuries. The Amazon basin initially had a natural monopoly because of the extent of its superior quality wild rubber trees. From 1860 to 1910, 60% of world supply came from Brazil, Bolivia and Peru, despite the high cost of production and transportation in the Amazon. However, high prices were countered by British entrepreneurs planting Amazonian rubber trees in Asian plantations; after 1910 abundant supply from Asia, synthetic rubber, and other substitutes for rubber produced a crash in prices [10]. Unfortunately for Latin American producers, there were few forward and backward linkages from rubber to contribute to national development, as the skills, technology, and infrastructure utilized were specific to the rubber trade [14,15].

Despite these, and other similar historical experiences, Bolivia, at the beginning of the lithium era in the first decade of the 21st century, attempted to pursue a unilateral and nationalist policy regarding its lithium potential, requiring total government control over the industry, technology transfers, domestic content requirements, and a move up the global value chain from simply producer of the raw material to producer of a final product, batteries [16]. That policy failed to attract foreign investors who were sourcing their lithium elsewhere and after more than a decade of failing to produce commercially viable lithium, the government recognized the country’s unilateral approach as a failure [17]. The lesson drawn by some scholars, think tanks, governments and even multilateral banks, nevertheless, is that Latin American lithium producers could accomplish those nationalist goals if they negotiated access to their reserves in a collaborative form with foreign investors [18].

Collaboration among countries to set the terms for access to a natural resource and not just to exchange information and ideas implies creating a producer’s cartel. Producer cartels come in different forms along a continuum from a “gentlemen’s agreement” to a formal charter. They are distinguished from actors simply colluding in a tacit manner by their engagement in explicit communications and agreements to control production and price [19]. Though an advisor to a country producing a natural resource may begin simply suggesting "cooperation" among producers to get a better deal from investors/purchasers, the goals sought quickly morph into restricting access to alter the terms of the deals.

The issue of commodity cartels has not been of major concern to academics and policymakers beyond the periodic booms of the oil cartel, OPEC. However, climate change and the energy transition's focus on energy storage for both transportation and renewable power has drawn the attention of academics, think tanks, policymakers and even multilateral development banks (Inter-American Development Bank [IDB] and Development Bank of Latin America [CAF]) to the potential for collaboration among Latin American countries holding significant reserves of lithium.

This article identifies the challenges that creating a coherent, stable, and enduring cartel of Latin American lithium producers faces and discusses what a cartel would need to do to address those challenges. As the energy transition requires significant volumes of minerals of which the Global South holds large reserves, the discussion in this paper is relevant beyond lithium. It thus represents a pioneering study designed to stimulate further research into the political economy of the global energy transition.

The methodology utilized incorporates standard social science methods for qualitative research: the construction of a framework for analyzing behavior based on a critical reading of the existing literature, which is subsequently examined through a structured, focused comparison of relevant cases [20,21]. Case selection among Latin American countries is determined by whether they hold major reserves and resources of lithium, leading to the selection of Argentina, Bolivia, Chile, Mexico, Peru and Brazil. Data are accumulated from articles, reports and news sources generated by academics, governments, think tanks, and industry sources.

Section 2 begins the analysis with a review of the literature on commodity cartels, and presents the consensus regarding the market, technological, political and institutional requirements for developing a stable commodity cartel. I find the literature lacks analysis of how environmental, social and governance (ESG) issues have become critical in the mining sector, and I incorporate them into my general framework of cartel creation and behavior. A series of hypotheses are generated, and their relationship to each other is postulated. In Section 3 the general framework is then contextualized to reflect lithium's relevant characteristics, within the context of an international market whose structure has undergone substantial change in the past decade and is experiencing significant stimuli for innovation, both in sourcing of lithium as well as in battery technology that will affect both supply of and demand of lithium in the medium term. Section 4 discusses current and potential production in Latin America and the obstacles to increased production from the region. It highlights how diversified production potential is in Latin America and how this diversity complicates the ability of a Latin American cartel to impact the market and the stream of benefits that members would want to accrue to the region. The conclusion addresses the main findings and future research paths to pursue.

2. International Collusion in Natural Resources

Economists and political economists have not been able to reach a consensus on a theoretical model for explaining when cartels form and what determines their durability [22,23], or even their goals. Revenue maximization [22] (206) or value maximization [24] are the usual goals assumed by economists, but other social scientists and historians are intrigued by the fact that governments in the Global South and their advisors have sought to promote their vision of national development by moving up the value chain [25,26].

There is, nevertheless, a consensus that the market, technology, producer goals and the institutional characteristics of the agreement to collaborate matter. Though cartel scholarship has not incorporated ESG issues associated with mining, they are increasingly important factors influencing demand, supply, technology, and government policy. In this paper a general framework of cartel creation and stability is developed to guide analysis based on the reasoning behind the selection of these variables. While this is not a theory of cartels, making explicit the expected relationships among causal factors facilitates building a framework for the study of cartels that can be useful in speculating about the lithium market and the viability of a lithium cartel.

2.1. Why Is Collaboration Difficult

Cartels face three common challenges in their endeavor to utilize access to their resource to gain bargaining leverage with investors and consumers: (1) producers outside the cartel need to be restrained lest their production significantly weaken the cartel's efforts to limit supply in the market, (2) members need to agree on production limits, their allocation and the distribution of the resulting wealth generated, and (3) the cartel must be able to detect and punish cheating on the agreements by members [19,22,27,28].

Collaboration among cartel members is easiest when the organization has the backing of government power, as in the Texas Railroad Commission in the United States, but that structure is rare in the international sphere. A cartel may be lucky enough to have a "swing producer" whose decisions to increase or decrease production can stabilize the market, as Saudi Arabia did at times for OPEC, but again, that cartel structure is rare [27]. Most commonly, collaboration within commodity cartels is heavily dependent upon members having the financial, economic and political resources necessary for a long-term commitment since commodities generally experience market instability. These resources include hard currency reserves, diversification of exports, and political support to ride out the low points in the market. Additionally, of course, that long-term commitment has to appear reasonable to members in the face of demand, supply and technological factors that are contributing to market instability.

These challenges cannot be resolved simply through good will among members or a common vision that commodity producers in the Global South have been exploited by the Global North and their multinational corporations. The literature on cartels as well as that on the political economy of development point to a variety of reasons why members of the cartel may find it difficult to agree on a common policy or attractive to cheat on the common policy.

- Differing assumptions regarding the size of global reserves, the level of future demand, and the potential and timing of substitutes for their product result in disagreements regarding appropriate levels of production and distribution of the benefits and costs of collusion [29] (18–20).
- Members will likely differ significantly in their cost functions and discount rates, in particular when state-owned enterprises (SOE) are involved since governments generally prioritize political over economic returns [30].
- Since international commodity markets tend to be complex, expertise in understanding them is important [31,32], but political ideologies can marginalize such expertise [33].
- In addition, production occurs within the sovereign domain of governments and their willingness to provide credible information or abide by multilateral decisions precisely when a government finds it in its interest to violate multilateral decisions. Compliance can therefore not be assumed.

2.2. When Might Cartels Form?

Understanding the market characteristics of a commodity is the starting point for considering whether producers have the *potential* to collaborate on production and pricing [22,34]. Although technology and policy impact markets, they do so within a particular market situation. Consequently, analysts of commodity cartels begin by analyzing the necessary preconditions in terms of market characteristics, specifically demand and supply, then production and marketing structure.

- Demand characteristics—The demand curve should be highly inelastic, indicating that large monopoly profits might be had if a cartel can be developed.

- Supply characteristics [34]—Reserves of the commodity should be concentrated among few countries, while resources that might be brought to respond to higher demand and prices should continue to face cost and technological obstacles to becoming incorporated into reserves. Substitutes for the final product or specific commodity input should not be readily available to consumers.
- Production and Market Structure—The range between high- and low-cost producers should narrow enough not to tempt low-cost producers to cheat on the cartel. A cartel needs to have market power [27]. In the absence of a "swing producer" sufficient market share should be concentrated among a group of members small enough to facilitate cooperation in the face of price instability.

2.3. Impact of Technology

Analysts often make the simplifying assumption that resource owners "carefully consider the substitute's prospect" [35] but as the guano and rubber examples demonstrate, countries may not adjust to a decrease in demand for their resource. We should, therefore, assume that technological innovations that stimulate substitutes (either by creating them, lowering their costs so they can compete, or modifying other elements that make them more attractive to consumers of the commodity in question {e.g., lower environmental or social costs}) will have an impact but leave open the question of whether cartel members are cognizant of the extent of that impact.

Technological innovation can impact demand for and supply of a commodity, as well as the productive structure of the market, with implications for a cartel. Demand for the cartel's commodity could fall if technology stimulates competitive substitutes or it could rise if technology generates new uses for the commodity. Technology can increase the supply of a commodity by lowering its costs of production in new areas or decrease the supply by revealing negative externalities associated with its production. Since technology can be proprietary, its patent can alter the competitive relationship among producers, turning yesterday's high-cost producer into a low-cost producer, and vice versa.

The process of innovation is dynamic and generates spin-offs that can create feed-back loops to keep the process moving even as market stimuli around the original innovation diminish. As prices rise for the commodity of interest, more investment will flow to alternatives, increasing their likely success and speeding up their timeframe. In the case of a commodity whose rising price and scarcity is perceived to impact national development and security in consuming countries, government may complement private investment in research and development [35].

2.4. ESG Issues

Environmental and social challenges to mining, as well as inefficient or problematic governance structures, can limit access to those resources or if appropriately addressed, open up new areas for production.

Mining raises significant environmental and health challenges for societies and their governments. However, the relationships among environment, health, and government policy are not obvious: societies and governments have to make trade-offs and establish priorities among multiple goals, and the contribution of science to conceptualizing and providing good information regarding causation and valuing the trade-offs is often murky or incomplete. In addition, not all environmental and health issues are related to production of a particular commodity; non-trivial exogenous factors include climate change, other mining activities, agriculture, tourism and demographic changes. However, local histories are usually incomplete when it comes to the information necessary to answer with great confidence many questions about the impact of the mining of a particular commodity.

Applying the social science concept of "governance" [36,37] to mining means thinking about a process in which actors beyond the government have a direct impact on the forms and rules guiding the development and commercialization of a commodity. Governance includes the public and private sectors, as well as civil society. It is operationalized through rules and institutions that are created by the interaction (often biased in favor of one actor) among these actors. The concept is designed to conceptualize a rule-making and rule-implementing context in which government does not impose its choice, but in which the relevant actors formally and informally negotiate the terms of the choice. The choices made in these resource governance structures are not just about "managing" a specific project. Instead, they set the context in which projects are developed according to what members of the governance structure agree is the purpose of resource development and how the benefits and costs of that development will be distributed among the members [38].

There are currently two basic models of governance in the mining sector. One privileges the providers of capital and technology and governments that provide access to the natural resources [39–46]. The other model for governance brings NGOs and civil society in as equal partners, recognizing that people are not just consumers of products but care about the impacts of production on the environment and society [47]. These alternative governance models do not reject company and government-based models but attempt to incorporate and subordinate them into broader based normative and democratic governance models. They emphasize not just extractive company and government best practices, but global value chains and transparency along the chain.

Designing an appropriate governance structure does not solve problems, rather it provides a structure for addressing them. Implementation of a sustainable and cooperative agreement is not easy even with a governance structure built around transparency and accountability. National ownership of the resource can further complicate matters, especially without a legitimate process of eminent domain. Participants may cheat, differ on priorities or the distribution of resulting costs and benefits. Communities, however, may lack the knowledge and professional support to effectively bring their needs to the attention of the relevant authorities. Since some NGOs and university scholars are ideologically opposed to any mining or to capitalism, this evaluator capability question cannot simply be solved by linking communities to analysts who favor them. We need scientific review of the relevant studies to arrive at the best possible understanding of metrics, thresholds, and cause and effect. Unresolved ESG issues can make it difficult for governments and companies to credibly commit to strategies and investments to increase supply because stakeholders can either block approval of mining projects or raise their costs beyond commercial viability [48].

2.5. Politics and Policy

Governments operate in the short term because the individuals constituting the government cannot be sure that they will remain in office beyond the time when those short-term benefits operate, also known as the ruler's time horizons are generally short [49]. In the short term, politics can trump economics or delay technological innovations. Though costly, governments might be able to distribute those costs to national groups in the political opposition or to foreign investors and consumers. Though in the medium term those costs may be so great that even a government's partisans are affected, the specific party/politician who pursued these policies may be out of office because of term limits, an electoral loss, or even a *coup d'etat*, and thus not likely to be saddled with responsibility for those costs.

Economists expect that the possibility that rising R&D expenditure could hasten the arrival of substitutes should, *ceteris paribus*, lead to reductions in government take and higher levels of extraction, especially for countries with significant dependence on revenue from the commodity, vulnerability to stranded assets associated with that commodity, or significant reserves. However, the "ceteris paribus" clause obscures the political costs that a government could face in the short term if it adopts the policy that is rational in the long term from an economic perspective. Government revenue may be heavily dependent on exports of a particular commodity but a government might want to increase rents precisely because price is declining. Gotchberg and Menaldo 2021 make the point that quasi-rents (distinguished from Ricardian and Market Power rents) are a choice and governments have appropriated them to the point of destroying an industry or depleting a natural resource. These choices could be the result of having a fiscal strategy based on quasi-rents from existing commodity exports in the short term, having lower reserves of the commodity, or ideological paradigms highlighting Global North exploitation of the Global South. Members making these choices will complicate cartel adjustment to market instability or an adverse shift in global demand because their specific incentives would be to maximize their short term returns from the commodity.

2.6. Cartel Institutionalization

If a cartel has been created and is initially stable, it means that the economic prerequisites for cartel formation (see above) have been met. However, once the market fluctuates because of economic, political, or social factors, the key challenge that a cartel faces is how to ensure that one or more of its members do not undercut the cartel price in order to expand their own production and earn higher revenues [24].

Virtually every study on cartels includes influencing the probability of detection and cost of punishment as a vital task for a cartel. Stable cartels must, therefore, be endowed with the *ability* to detect and punish transgressors. Based on empirical observations of member countries' refusal to accept constraints on production or policy suggested by analysts in the cartel, I argue that another task for a cartel to be stable appears fundamental, though understudied: develop its capacity to generate scientifically valid market studies that are credible to its members.

To pursue the necessary tasks a cartel must be institutionalized, meaning having capacity and autonomy and a bureaucracy that is free and able to undertake sophisticated analyses of the market and member resources and needs. Decision-making is performed by the representatives of the member countries, but to have a chance of influencing market instability (i.e., restricting supply, promoting supply) and bargaining over contract terms between state sellers, purchasers, service companies, and the range of actors in national governance structures when asked, the cartel needs to provide credible information, even at the expense of disagreeing with what member states might want to hear. In short, the internal structure and operating mechanisms of the cartel are as important as what is happening in the market for a cartel to be viable and effective.

2.7. A Framework for Studying Cartel Viability

This analysis of the literature in Sections 2.1–2.6 suggests five determinants of cartel viability: market characteristics, technology, ESG, government policy, and institutionalization of the cartel. The proposed framework for studying cartel viability is built around seven hypotheses concerning the impact of these five determinants.

Our first hypothesis comes directly from the discussion regarding market characteristics in Section 2.2.

Hypothesis 1. *Market characteristics do not determine whether producers will attempt to create a cartel, but they do determine whether a cartel may be initially successful.*

A second hypothesis is based on the discussion regarding technology's impact on supply and demand of a commodity but brings the discussion regarding politics and policy in Section 2.5 to bear.

Hypothesis 2. *Technological innovation which influences demand or supply will complicate collaboration among cartel members because its impact on members varies and domestic economics and politics will determine how a member responds to the impact of technology.*

ESG factors contribute two Hypotheses 3 and 4, one directly from the discussion in Section 2.4 and a subhypothesis which draws on the discussion concerning politics and policy in Section 2.5.

Hypothesis 3. *ESG factors will influence cost and production levels for individual members of the cartel.*

Hypothesis 4. *The impact of ESG factors will be greater if government and policy occur within a democratic context and less in an authoritarian context.*

The impact of politics and policy merits its own hypothesis, drawn directly from the discussion in Section 2.5.

Hypothesis 5. *Governments with significant levels of hard currency reserves, diversification of exports, and political support generated by ideological affinity rather than patronage will be more likely to collaborate in the cartel when market forces turn against it.*

Our last two Hypotheses 6 and 7 are based on the discussion in Section 2.6. Hypothesis 5 draws directly from that discussion while Hypothesis 6 integrates the discussions in Sections 2.2–2.5. The payoff to Hypothesis 6 is that it postulates that even institutionalized cartels find themselves significantly challenged by what occurs in the market, with technology and in the context of ESG and policy politics.

Hypothesis 6. *Institutionalized cartels will be able to deal with market fluctuations better than cartels based on common goals but with minimal institutional ability to evaluate, publicize and punish members who violate the cartel's decisions.*

Hypothesis 7. *The institutionalization of a cartel can only mitigate internal tensions over cartel policy, not eliminate them. Significant shifts in market, technology and governments will either destroy the cartel or convert it into an information center until the economic prerequisites that produced its rise return.*

3. Contextualizing the Model for Lithium

3.1. Market

3.1.1. Demand

Lithium has many uses beyond batteries, including ceramics, glass, lubricants and pharmaceuticals. As EV batteries now account for 47% of lithium demand [49], the EV market has a fundamental impact on lithium demand and prices. Lithium chemicals are priced by their quality and purity. Currently battery manufacturers utilize three grades of lithium for batteries, based on quality of the product and of the producer. Tier 1 includes lithium carbonate purity of 99.9% for premium batteries for the global EV market, Tier 2 a purity of 99.5% for batteries sold largely in the Chinese EV market and Tier 3 a purity of 99.3% for producers who have either not yet produced or are small battery cell producers [50,51].

Forecasting EV demand is all about climate change policy scenarios. One of the set of scenarios most widely used in academic work is that of the International Energy Agency (IEA), which issues an annual report, covers more than 150 countries and utilizes four scenarios, representing increasingly more ambitious policy requirements. Two major caveats must be kept in mind: these are "scenarios" not predictions, and the differences in assumptions for each scenario are significant. The Stated Policies Scenario (STEPS) is the most conservative, based on what governments as well as "industry stakeholders" are actually doing at the moment: it examines a broad range of policies put in place or under development and assesses the likelihood that a country will implement them. The Announced Pledges Scenario (APS) is based on major national announcements regarding policy ambitions and targets for 2030 or 2050, therefore indicating what governments would like to achieve. The Sustainable Development Scenario reveals what the contributors to the IEA's analysis consider to be "a plausible path to concurrently achieve universal energy access, set a path towards meeting the objectives of the Paris Agreement on climate change and significantly reduce air pollution." Finally, the New Zero Emissions by 2050 Scenario considers what the world needs to accomplish "and by when, for the world to achieve net zero energy related and industrial process CO_2 emissions by 2050 while meeting other energy-related sustainable development goals" [49,52], (96).

The economic and political investments for creating a successful cartel are costly and justified by cartel members and their supporters in terms of medium to long term benefits (e.g., maximizing value of reserves, creating forward and backward linkages to promote national development, etc.) so the STEP scenario is particularly appropriate because its projections are more likely than those of the other three scenarios. These figures, nevertheless, need to be carefully evaluated and one must refrain from assuming a certainty to future demand.

In the IEA STEP Scenario, lithium demand is expected to increase fourfold in 2030 over 2021, to 330,000 tons, and sixfold to 500,000 tons in the more ambitious APS Scenario. EV batteries account for all the increased lithium demand from 2021 to 2030 in both scenarios [49] (176), [53], indicating the fundamental importance of the EV market for demand projection to 2030. Of course, these demand figures also demonstrate the wild variations in estimates of future lithium supply, since Benchmark Minerals, a leading source of information, estimated in 2020 that by 2030 lithium demand would reach 2.2 million tons [54] and the IDB noted in 2020 that "By 2050, global demand for lithium is expected to increase by more than 950%..." [55].

At a first glance, the future demand from EV seems unmistakably bright, even as its maximum parameters are debatable. In 2021, after a 40% increase in EV car sales over 2020, there were 16.5 million electric cars on the road (excluding 2/3 wheelers). The 2022 IEA study suggests that, under the STEPS Scenario, by 2030 there will be 200 million Evs, or 10% of total road vehicle stock [49] (98). Li-ion batteries are expected to be the battery of choice at least until 2030; technological advances in non-lithium chemistry could significantly decrease demand, but only in the unspecified "longer term [49] (183).

The EV data for 2021 is really a China and European Union (EU) story since they represented 85% of EV sales that year, with the U.S. following at 10%. The projections for 2030, however, assume that over 150 countries follow through on existing policies across the world. The IEA also notes that the key drivers to the expansion of the EV fleet are government subsidies, government regulation and a major private-public partnership to dramatically expand the power grid as well as charging station infrastructure. The IEA clarifies that it is not *predicting* an outcome, just illustrating what could happen if governments and industry stakeholders follow through, and includes a caveat that "the unpredictability of how the geopolitical situation and its implications for energy markets will evolve raises the level of uncertainty in this edition . . . " [49] (96–98). Nevertheless, advocates of a Latin American lithium cartel take these and similar demand scenarios as clear guidance of future demand.

Thinking about governments and industry stakeholders, the recent experience with a pandemic, a Russian military invasion in Europe, the global rise of conservative political movements intending to decrease government expenditure and regulations, and the fudging of many Global South countries that their Nationally Determined Contributions for fighting climate change depend on Global North countries and multilateral institutions financing such policies [56,57], might suggest caution regarding ideal visions of a green future rather than making major decisions based on them.

Gross EV figures do not provide an accurate picture regarding lithium demand since battery sizes vary, but more importantly because they include both battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV), whose batteries are significantly smaller. While the Chinese and the U.S. markets heavily favor BEVs (80% and 65%, respectively, of EV stock), the EU is fairly evenly split with 55% of EV stock. PHEV have been particularly attractive to consumers seeking more range and heavier vehicles (SUV) [49] (18, 20).

Consumer resistance to the cost of the energy transition certainly should not be minimized and the above-identified drivers of EV demand suggest we should be cautious about the pace of EV market share. Consumers not only purchase vehicles, they elect governments in democracies and are catered to in many authoritarian governments (e.g., China). If consumers think the price of the energy transition is too high, they will support politicians who may deny human responsibility for climate change, downplay the need to subsidize the transition or make significant changes in lifestyle, and favor carbon capture, utilization and storage (CCUS) solutions in the future (e.g., presidents Donald Trump in the U.S and Andrés Manuel López Obrador (AMLO) in Mexico; the U.S. congressional reduction of President Joseph Biden's ambitions for a national EV charging station infrastructure). These politicians will formulate policies that will reduce subsidies to EV purchases and slow the pace of charging infrastructure.

The lithium market has been erratic because of uncertainty over the pace of the energy transition and the exuberant expansion of lithium supply early in the EV development. Speculation about demand for lithium produced a booming market as subsidies and mandates in both China and Europe stimulated the EV market [58] (12); between January 2015 and January 2018 lithium carbonate reference prices increased by more than 400% [59] (85). However, increases in production and resources, a decrease in Chinese subsidies for Evs, then the COVID pandemic, depressed demand and prices fell significantly through 2020. A recovery in 2021 still left February prices 62% below the 2018 peak [60,61]. In many cases, prices between mid-2018 and end of 2020 were below the costs of production [62]. Prices recovered at the end of 2021 and accelerated to new highs in the first quarter of 2022 [63], though prices fell between April and July 2022 by 5.5% [64]. However, even at its recent peak in March 2022 some analysts expected prices to fall in five years as new production comes online [65].

3.1.2. Supply

Many claims to the contrary, lithium is not scarce. Lithium is the lightest metal on earth, found in continental brines and pegmatites (the chief sources today) but also in geothermal brines, oilfield brines, other minerals and clays, and even seawater [66]. While lithium is physically abundant, it is geochemically scarce since it is found in low concentrations (averaging less than 0.01% by weight in the Earth's crust), always in compounds, and thus requires separation. The separation processes in compounds other than those found in continental brines and pegmatites are, with current technology, difficult and costly [67]. The supply of lithium is thus fundamentally a question of the commercial viability of bringing it from a source to market.

The characteristics of supply in the market have changed considerably in the past decade. In 2008, of the 25,400 tons produced, Chile was the number one producer in the world (10,600 tons), with Australia in second place (6280 tons) [68] (93). However, in 2021 an estimated 100,000 tons were produced and Australia far outdistanced other producers with 55,000 tons, followed by Chile (26,000 tons), China (14,000 tons) and Argentina (6200 tons) [69] (101) (Supplementary Materials provides lithium production by country from 2010–2021).

The US Geological Survey distinguishes between "reserves" and "resources" [69] (195), with the former essentially the supply that is currently (or soon to be) commercially viable and the latter "resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence" but not commercially viable under current market and technology conditions. We can thus consider "reserves" to constitute the expected supply in the short to medium term. Demonstrating the dynamic nature of reserves, expectations about the potential EV market and a price boom in 2016–2017 stimulated exploration activity. The known resource base (which will contribute to future reserves) increased substantially from 11 million tons in 2008 [70] to 53 million tons in 2017 and to 89 million tons in 2021. There may be further significant adjustments upward as investors and governments seek to take advantage of growing world demand after the global recession provoked by the COVID-19 pandemic.

World resources (89.1 million tons) are currently four times that of reserves (22 million tons). Of the current lithium reserves, two Latin American countries (Chile and Argentina) hold 51.8% (11.4 m tons of 22 m tons total, Table 1). Turning to global resources, six of the top 20 countries are in Latin America, and they account for 59.3% (52,850 m tons) of known resources (89.1 m tons, Table 2). The so-called "Lithium Triangle" in South America

(Argentina, Bolivia and Chile) currently accounts for 55.9% of known resources (Table 2). Latin America, and in particular the Lithium Triangle, currently dominate both reserves and resources.

Table 1. Lithium Reserves (2021 (22 million tons, rounded)).

Chile	9,200,000
Australia	5,700,000
Argentina	2,200,000
China	1,500,000
United States	750,000
Zimbabwe	220,000
Brazil	95,000
Portugal	60,000
Others	2,700,000

Source: U.S. Geological Survey, *Mineral Commodity Summaries 2022*, January 2022. https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf (accessed on 12 June 2022).

Table 2. Lithium Resources (2021 (tons)) (Total Resources 89.1 million tons).

Country	Reserves	Country	Reserves
Bolivia	21 million	Czechia	1.3 million
Argentina	19 million	Serbia	1.2 million
Chile	9.8 million	Russia	1 million
United States	9.1 million	**Peru**	880,000
Australia	7.3 million	Mali	700,000
China	5.1 million	Zimbabwe	500,000
Congo (Kinshasa)	3 million	**Brazil**	470,000
Canada	2.9 million	Spain	300,000
Germany	2.7 million	Portugal	270,000
Mexico	1.7 million	Ghana	130,000
		Others	210,000

Source: U.S. Geological Survey, *Mineral Commodity Summaries 2022*, January 2022 https://pubs.usgs.gov/periodicals/mcs2022/mcs2022.pdf (accessed on 12 June 2022).

However, a few notes of caution about the dynamism of supply are worth considering. First, the host material in which lithium is found varies in terms of its characteristics—e.g., salt flats have different permeabilities, their brines vary in impurities, and their composition changes over time as the brine is pumped out and its underground reservoir is replenished by residues redeposited and natural water flows [71,72]. These differences impact their ability to be commercialized, affecting costs of production and processing. Consequently, having a significant lithium deposit does not automatically translate into being a major player in lithium markets. Second, comparing USGS commodity summaries over the past fifteen years, that domination has significantly decreased over time—in 2006, Chile alone constituted 73.2% of known reserves, while Chile and Bolivia accounted for 76.3% of known reserves [73]. Third, Australia is currently the largest lithium producer, second largest reserve holder, and fifth largest source of resources.

3.1.3. Production and Marketing Structure

Lithium for batteries is in either carbonate or hydroxide compounds, depending on the chemistries utilized in the battery (see discussion below). Carbonate is processed from lithium chloride, which is extracted from brine. Lithium hydroxide is produced directly from rock (spodumene) and can then be processed into carbonate. If hydroxide is desired, carbonate can be processed to produce it.

Since Chile produces lithium carbonates from brine and Australia lithium hydroxide from spodumene, the dramatic rise and displacement of Chile by Australia indicates that the market is moving from lithium carbonate to lithium hydroxide. Initially, brine processed into lithium carbonate held a cost advantage over pegmatite processed into lithium hydroxide and then into lithium carbonate. However, technological advances in batteries to reduce the use of cobalt, a costly input whose supply is judged insecure, made lithium hydroxide rather than lithium carbonate the preferred input in the new chemistry. The cost advantage of lithium carbonate over lithium hydroxide is consequently eliminated, producing shifts in lithium sourcing [74]. However, the battery market is dynamic, and with the growing interest in lithium-iron phosphate (LFP) batteries (see below) the advantage may shift again to carbonate.

The major companies invest in both types of lithium, demonstrating that they source globally; most Latin American state-owned enterprises (SOE) do not have this advantage, being required to focus on national resource development. Orocobre, the leading lithium carbonate producer in Argentina is adjusting to market changes by partnering with a Japanese company to build a lithium hydroxide plant in Japan [75]. To diversify its supply, the leading lithium producer in Chile, SQM, developed a joint venture in an Australian spodumene operation as well as a joint venture in Argentina to develop a brine operation [76,77]. Chile's other leading lithium producer, Albemarle, announced plans to build lithium hydroxide plants in Australia [78].

Expansion of production in Latin America is problematic, mainly for ESG issues discussed below. Argentina has largely avoided ESG conflicts to date and has the most projects in the pipeline, but its macroeconomic situation, export tax, currency and profit repatriation regulations may dissuade investors [79] at least until the next presidential election in 2024.

Processing and marketing are dominated by four Chinese companies, Ganfeng, General Lithium, Tianqi, and Sichuan Yahua Industrial Group. Competitors from Europe and the US are attempting to make inroads into that dominance, but at this point cost advantages and regulatory laxness by China suggests that it will be difficult to displace them [68]. Five Asian firms from China, South Korea and Japan dominate battery production accounting for 80% in 2021, with two Chinese companies, Contemporary Amperex Technology Co. (CATL) and BYD responsible for 40% [53] (14–15) [65] (8).

The current production and marketing characteristics of the global lithium value chain raise serious challenges for the viability of a producers' cartel.

3.2. Technology

3.2.1. Demand

There are important variations among battery chemistry that impact the lithium market [80]. The search for increased mileage means increasing energy density and has been met by incorporating high-nickel cathodes into the battery [81]. Ref. [18] discusses various lithium based chemistries (p. 12), but does not address the question of whether technology will significantly cut into demand for lithium. In these configurations, lithium hydroxide performs better than lithium carbonate, and some forecasts see the market for the latter fading quickly [82].

Technological advances in battery chemistry may reduce lithium demand per battery. While lithium is currently the preferred chemical for rechargeable batteries, because it is flammable and unstable as well as perhaps having supply constraints, there is great interest in alternative chemical processes, including dual-carbon, sodium-ion, zinc-ion, and Vanadium redox flow batteries [83]. With current technology lithium has a price advantage, but as lithium prices increase and technology progresses, that advantage will certainly decrease.

Ultracapacitors (also known as supercapacitors) could increase the efficiency of "microhybrid" vehicles (gas-powered with small electric motors) by 40% when driven in the city, thereby extending the life of the internal combustion engine (ICE), especially as the cost of the energy transition begins to worry citizens. In addition, ultracapacitors could be paired with existing lithium-ion batteries for further efficiency gains, thereby reducing total demand for the size and number of these batteries [84,85].

Hydrogen fuel cell electric vehicles (FCEV) may impact the lithium market by competing with BEV in the light duty vehicle sector because they are more energy dense (hence longer range) and do not need recharging (because they generate electricity in the fuel cells). FCEV is already making inroads with heavy transport vehicles but does not yet compete with BEV in the light vehicle sector because of the cost of hydrogen fuel and lack of refilling stations [86,87]. Though hydrogen fuel cells have their own challenges, including developing commercially viable supplies of green hydrogen [88,89], significant technological progress in addressing these challenges is occurring [90].

Lithium batteries are also utilized for large scale energy storage in variable renewable energy (VRE) sections of the power grid. Although at present lithium-ion technologies are the low-cost leaders, as the grid increases its share of renewables the demand for longer term storage (from 36 h to seasonal storage) becomes critical for enhancing grid operational flexibility. Geologic hydrogen storage, flexible power generators utilizing natural gas with carbon capture and storage (CCS) and heavy-duty vehicle proton exchange membrane (HDV-PEM) fuel cells in stationary service are currently "the least-cost low-carbon technologies for both current and future capital costs" [91].

3.2.2. Supply

Currently, commercially viable brines are characterized by evaporation ponds with lithium concentrations of 1000 ppm and extraction rates of 30–50%. However, the world abounds in brines with significantly lower grades down to 300 ppm [92]. Technological advances have made both exploration and extraction more efficient, reducing costs and making new areas commercially viable. Speculation regarding lithium shortages in the medium term stimulates technological innovation in production, processing and battery chemistry that could make separating lithium from other minerals and clays commercially viable, as well as making recycling profitable, thus increasing supply.

The most promising technological innovation for increasing lithium supply are proprietary processes and technologies grouped under the rubric of Direct Lithium Extraction (DLE). The U.S. Department of Energy and Lawrence Berkeley National Laboratory are researching at least three alternative means of separating lithium from brine: solvents to collect lithium ions, membranes that only permit lithium ions to filter through, and charged electrodes that attract lithium ions [93]. Livent has been utilizing DLE in their Hombre Muerto operation in Argentina [92] (6) and other companies are pursuing it in pilot projects. Currently, over 60 variations of DLE are being used or investigated [93]. Recovery rates of lithium can improve from 50–70% in evaporation processes to 90% in DLE [94], which could significantly increase supply without any increase in exploration and the opening of new sites.

DLE can dramatically reduce both the time and capital needed to bring new sources of lithium into production, as well as reduce the evaporation of water in production from salt lake brines, further undermining speculations about lithium shortages in the medium term. DLE technologies have the potential to unlock resources across North America, providing companies with an opportunity to tap lithium deposits previously believed to be inaccessible or not economically feasible using traditional lithium extraction methods. This technological advance makes California's Salton Sea in the U.S. a potentially significant new source of lithium from geothermal brine sources, supplying up to 40% of global demand, according to the California Energy Commission [95]. Other potential major thermal brine sources of lithium are located in Arkansas in the U.S. [96,97], the Rhine Valley in Germany [98] and Cornwall, England [93,99]. DLE processes are also used in oil and gas brines in Alberta, Canada [100]. The switch from salt flat brines to geothermal and oil and gas brines will have a major impact on where lithium is produced unless the world is truly facing restricted supplies.

Further complicating demand projections, unlike fuel, lithium does not get consumed over the life of the battery. In 2019 just over 50% of spent lithium batteries were recycled [101,102]. This does not mean that 50% of lithium from batteries was actually recycled, just that the batteries have components that are being recycled in some form [103]. However, technological innovation in EV batteries in laboratory research for li-ion battery recycling is moving fast [104]. Rising demand in the battery market has economic impacts that attract capital, including public investment, to innovative processes and foster a faster move from lab to commercial production. In addition, rising prices for lithium will make recycling more cost-effective. Economies of scale will bring down the cost of recycling and avoiding the environmental pollution of spent batteries will promote legislation demanding it. Ultimately, recycling will be driven by the interaction of policy, technology, and market.

Significant steps are already being taken. In February 2019 the U.S. Department of Energy, in collaboration with industry and universities opened an R&D Center for battery recycling and announced USD 5.5 million in prize money for "innovative solutions to collecting, storing, and transporting discarded lithium-ion batteries for eventual recycling." [105–107]. Volkswagen opened a pilot battery recycling plant in January 2021 in Germany to recycle not only lithium but also cobalt, manganese and nickel [108]. Governments are promoting and even mandating battery recycling around the globe—China, Japan, South Korea, United Kingdom, France, Belgium, Switzerland, Germany, Canada, United States, Australia and Mexico.

How much that recycling will impact lithium demand, however, is uncertain. Even if the li-ion battery is not replaced by storage systems using other chemicals, manufacturers are removing or decreasing valuable elements to make lithium-ion batteries as cheap as possible. However, reducing the value of the elements of a battery also reduces the value of recycling them [93,109,110]. This is particularly challenging for lithium iron phosphate (LFP) batteries—the batteries cost less because they have no cobalt or nickel, use less lithium, last longer and are safer [49] (137). LFP chemistry may not utilize enough valuable components to make recycling profitable, short of a dramatic increase in lithium prices. However, although it powers Tesla's Model 3 (no other LDV uses it, although it is used in medium and heavy duty vehicles [49]) (1138) its lower energy density means that it cannot adequately power large car models (SUV's account for half of all EV models in the world's major markets) [49] (20).

Renewable Natural Gas (RNG) vehicles cut into the electric bus and truck market, competing with fuel cells and battery-electric. Since vehicles using conventional natural gas can burn RNG this fuel source is already proving itself on the road, accounting for more than 50% of the fuel used in such vehicles in 2020 [111]. When sourced from animal manure or food waste, RNG is actually "net-carbon-negative" [112]. As with EVs, government subsidies are helping the development of this fuel source and it faces similar challenges such as refueling stations. RNG is also being used to generate on board recharging of batteries, thereby reducing the need for greater energy density, and thus lithium [113,114].

Carbon capture, utilization, and storage (CCUS) technology, if commercial, can allow the continued use of fossil fuels, thereby decreasing the growth of demand for lithium in a variety of ways. The development of low carbon hydrogen and biofuels and natural gas as fuel for buses and trucks could then compete with electrification. CCUS would also allow at least natural gas, if not coal, to feed the power grid thereby reducing demand for grid storage [115,116]. In short, by freeing up lithium for the EV market and combining with other mitigations in lithium demand, CCUS can contribute to reducing future demand for lithium.

3.3. ESG Issues

Lithium production, whether through mineral ore or brine processes, raises significant environmental, social, and governance challenges for societies and their governments. Institutional flaws in governance and a lack of systematic scientific and social science research to link externalities of lithium production to the outcomes constitute the main causes for controversy. Refs. [53,117,118] An extensive analysis of bibliographic materials in 2018 concluded that research on lithium focused on technology, markets and cleaner sources of energy, excluding the local impact of lithium mining. Those authors argued for "filling the current gaps in addressing the local socio-environmental impacts due to lithium mining in terms of: (i) focused research topics/themes, (ii) methodologies and (iii) broader system perspectives" [119].

Latin American lithium producers are all democratic nations, but elections, laws and regulations are not sufficient to address social, health and environmental issues in lithium producing areas. Indigenous communities have lived in the Andean region of Chile, Bolivia and Argentina for millennia. The three South American countries are signatories to both the United Nations Declaration on the Rights of Indigenous Peoples and the convention concerning Indigenous and Tribal Peoples issued by the International Labor Organization (ILO), specifically Article 6 which requires consultation with communities when legislative or administrative policies affect them directly. With the help of NGOs, communities are increasingly empowered by such legislation and can demand that their basic human rights and access to communal land and water be respected. Even when favorable policy is adopted, however, communities may lack the knowledge and professional support to bring their needs to the attention of the relevant authorities. In Chile, for example, agreements between some mining companies and local communities create community monitoring systems to confirm whether companies are complying with environmental regulations using only authorized volumes of water. Unfortunately, some communities do not have trained personnel to monitor the agreement or interpret volumes of technical data [119].

The lack of systematic scientific and social science research to link what communities and NGOs see as externalities of lithium production to the outcomes being contested obstructs a clear understanding of the relationships. Companies and governments often do not want to collect the information, and even scholars and think tank analysts have lagged in conducting the necessary research [54,117,119]. Interdependencies are crucial and have both positive and negative impacts. In some cases, those negatives may outweigh the positives, but one cannot assume that will be the case everywhere. In addition, those positive and negative impacts will be differently distributed, even within a local community, and need to be considered [120].

3.3.1. Environment

The most visible issue regarding the impact of lithium production on the environment and health of local communities concerns water, its scarcity and contamination. Lithium reserves are located in arid salt flats, thermal zones, and mining regions where local communities, flora and fauna depend on the same limited water used in the lithium operations.

Lithium extraction methods from arid salt flats can exacerbate local environmental challenges. The traditional process extracts brine into holding pools and subjects the brine to up to two years of open-air evaporation. However, the groundwater which is pumped out with the brine winds up evaporating and thus depleting an already limited water supply. Hard rock mining for lithium also uses significant amounts of water. Contamination of water is another issue. Processing lithium from brines or hard rock requires toxic chemicals, which can leach beyond processing sites or spill out of holding pools, contaminating surrounding areas [121–124]. Water scarcity even affects competition among lithium producers since regulators control extraction based on water supplies and if one company gains extra water (legally or illegally) it affects production possibilities for other companies [125].

Air quality may be particularly relevant in brine operations. The evaporation process releases minerals (not just lithium) into the air, where the wind and storms carry it into local communities, thereby exposing humans and animals to an increased level of whatever toxicity existed prior to lithium production and processing [118].

Hard rock mining has additional issues. Lithium mines are open pit and the minerals are extracted by heating the rocks using fossil fuels. The process scars the landscape, uses significant amounts of water and energy, leaves behind mine tailings with mineral residue that can escape holding pools and releases 15 tons of CO_2 for every ton of lithium extracted [95,117,126] (40).

Given all these current issues, how much can lithium production methods improve to mitigate damage to the environment and still be commercially competitive? Utilizing DLE in salt flat brines such as those in South America holds promise, especially since it does not use fresh water, but it may exacerbate other issues, including the disposal of spent brine and the introduction of chemicals to quickly promote the extraction process [72]. Companies and investment advisers can analyze the economic costs of the DLE components, and markets can respond to those costs, but the industry is clearly lagging in studying the environmental and health costs of the DLE processes in specific locales.

3.3.2. Social

There can also be demographic impacts as local people migrate involuntarily from their ancestral settlements as a result of increased water scarcity. At the same time, labor attracted by mining operations migrates in or commutes daily from nearby towns. A full accounting of the health impacts of lithium should consider those remaining (generally older residents) and those migrating, especially if they migrate to locales with lower standards of living (e.g., unemployed in shanty towns). In addition, the mental and physical health costs of an influx of large numbers of single men to work in the expanded lithium areas needs to be considered [127].

DLE processes in salt flats are not the only alternative for improving the environment and health costs associated with lithium extraction and processing [128,129]. Direct extraction from geothermal brines (as found in Canada, the U.S., Mexico and England) has very low carbon emissions as well as very limited use of land and water per ton of lithium [93]. However, unless demand significantly exceeded supply (and we have demonstrated why in a free market context that is not likely to be the case in the medium term), mitigating environment and social costs in this manner would negatively affect production in Argentina, Bolivia, Chile and Peru. Recycling, by decreasing demand for new lithium, would also favorably affect ES issues at the local level, but at the cost of revenue for producing countries and governments.

3.3.3. Governance

Natural resource policy and management in Latin America tends to be quite centralized, with a relatively insulated federal government (except in Argentina where provincial governments own the natural resources in non-federal lands) imposing policy on the sector. However, as resource markets become more competitive and civil society more engaged in protesting the environmental and social costs of natural resource extraction, this governance model has trouble developing public policy for sustainable resource exploitation.

Sustainable lithium production in Latin America (as well as elsewhere [53]) needs a governance regime to create ethical and responsible production chains that will help ensure local benefits and get closer to a policy that appropriately balances in a sustainable fashion national development, community welfare, and corporate profit. A variety of possibilities for governance structures have been proposed, including ones that internationalize governance [67,120,130,131]. Whatever the structure, the governance regime also needs to be flexible enough to adapt to opportunities and challenges as the industry evolves, without undermining its effectiveness.

Four of the Latin American lithium producers are currently engaged in reforms of their lithium governance structures in ways that enhance government authority over private investment, activate social engagement and increase uncertainty. Chile restricted entrance of new firms since it declared lithium a "strategic" resource in the 1970s and ESG issues have derailed efforts by the two existing firms to expand production [53]. Chileans will vote on a new constitution in September 2022 which focuses on environment and indigenous rights and increases the autonomy and authority of provincial and local jurisdictions. While it does not nationalize lithium or mining, its impact on the sector is uncertain, depending on whether the constitution is approved and subsequently how it is implemented [64,132]. Mexico nationalized its lithium reserves in April 2022, reserving all production, processing and marketing of the mineral to a yet-to-be-created SOE. Ganfeng's existing contract to exploit the Sonora lithium clays will be reviewed by the government and if found acceptable, it would be permitted to move ahead with its open pit mine which is scheduled to become commercial in the first quarter of 2024. However, when the SOE will be producing significant commercial quantities of lithium or whether Ganfeng will move ahead with its planned second phase is highly uncertain [133,134]. Though the Falchoni lithium mine in Peru had been expected to begin construction at the end of 2024 uncertainties surrounding the future of the mining sector abound. Peru's Congress is discussing legislation to regulate lithium production, the President favored nationalization during his 2021 electoral campaign and the mining sector has experienced significant mine closures in 2022 over ESG issues [135–137]. Under Evo Morales, Bolivia created a governance structure ostensibly based on state leadership, environmental defense, indigenous empowerment and industrialization of lithium. The failure of that governance structure, along with low quality brines and a significant lack of infrastructure, has led a new government on the left to slowly open opportunities for companies with DLE technology to partner with its SOE in production [138].

3.4. Politics and Policy

In Latin America subsoil resources are owned by the nation and government policy regarding natural resources is expected to promote national development. Lithium has become a topic of great national interest in Latin America and thus becomes discussed, and policy made, in the context of a politics of nationalism and "strategic resource" A number of states have used their ownership of a natural resource to effectively promote national development (e.g., Chile with copper, Botswana with diamonds, Norway with oil), but many others have governments which enrich themselves and their partisans by controlling access to the resource (also known as, predatory rent-seeking behavior [139]). Development success or failure, therefore, is not attributable to a nationalist perspective but rather to the manner in which that perspective has been translated into public policy and the conditions under which it has been implemented.

A government's promotion of national wealth and national development built upon the nation's ownership of these lithium resources will depend on the government's ability to stimulate sustainable development of the sector. In addition, public policy must appropriate a level of wealth consistent with sustainable development of the sector and utilize the proceeds for public goods. However, government appropriation of wealth from the nation's natural resources does not automatically translate into using it for national development rather than private or partisan benefits, as the vast literature on the "resource curse" makes clear [140,141]. For the purposes of this article, suffice it to say that if resource wealth is not used for sustainable and national development politics will continually be divided over how to gain from the nation's "strategic" resources.

4. Discussion: Challenges for a Latin American Lithium Suppliers Agreement (LALSA)

Whatever the specificities of the cartel, and I will not propose any, it would need to address the challenges outlined in Sections 2 and 3. In this section, I briefly summarize those and then move on to the specifics of the six Latin American current and potential lithium producers to illustrate why it would be extremely difficult for a LALSA to address those challenges and effectively collude.

Tables 3 and 4 provide details on the important characteristics that will be relevant for considering national responses to cartel proposals for adjusting to adverse moves in the market. The tables clearly demonstrate the diversity among potential members which would therefore introduce intra-cartel tension.

Table 3. Potential Member Lithium Characteristics (2022 unless otherwise noted).

Country	Current Production As Share of Global (%) [a]	Source of Lithium	Relative Cost of Production [b]	Reserves (million tons)	Resources (million tons)
Argentina	6.2	Salt lake brines Hard rock	low	2.2	19.0
Bolivia	0	Salt lake brines	high	[c]	21.0
Chile	26.0	Salt lake brines	low	9.2	9.8
Mexico	0	Lithium clay geothermal brines	Unknown (Needs to include costs related to drug trafficking gangs in region)	[c]	1.7
Peru	0	Hard rock	Unknown	[c]	0.88
Brazil	0	Hard rock	Unknown	0.95	0.47

Sources: [a] [142] p. 101. [b] [143] (18) Slide 18 indicates that Argentina has the lowest cost among brine producers, followed by Chile; Bolivian brines have significant impurities, evaporation is interrupted by more rain than in Argentina and Chile, and infrastructure is lacking [144]. Websites of the two companies close to commercial production in Mexico and Peru claim low costs but the information is not credible until their products are actually in the market. [c] [142] (fn. 8) lists 9 countries having a total of 2.7 million tons, but only provides tonnage for Austria (0.06) and Finland (0.05) among them. Mexico is listed among the 9, so it must have less than 0.05 tons of reserves; Bolivia and Peru were not listed by the USGS as having any reserves.

Table 4. Potential Member National Characteristics (2022).

Country	ESG Vulnerabilities in the Mining Sector [a]	Macroeconomic Stability Issues [b]
Argentina	moderate	recurrent
Bolivia	high	few
Brazil	moderate	moderate
Chile	high	few
Mexico	moderate	moderate
Peru	high	few

Sources: [a] [53,65,144]; [b] author's summary for the period 2000–2022 (Bolivia since 2007).

The current production weight of the group depends heavily on Chile, but its downward trajectory in relative production is clear (Chile's official technical agency for minerals expects its share of world production to fall to 17% by 2030 [141] (17)). An increase in production in Argentina is expected but it's not clear whether and by how much that would raise the country's share of global production. Since the other four countries have not yet had commercial production their market participation is still an unknown. The table also indicates that the sources of lithium among potential members varies, with Argentina diversified into salt lake brines and some hard rock, Peru and Brazil set to produce from hard rock, Chile and Bolivia from salt lake brines, and Mexico from both lithium clay and geothermal brines. The costs of production also vary and for half the potential members we do not even have credible cost figures yet; in addition, the security situation in Mexico's key area (Sonora) will certainly add to costs there. Finally, there is a significant difference in the reserves/resources panorama, with half the group having significant stock and the other half only a fraction of the first.

Table 4 indicates that ESG issues are major challenges for the mining industry in half of the lithium countries in Latin America. That includes the country with the highest current production (Chile) and with the most resources (Bolivia). In none of these Latin American countries are ESG issues of minor concern. Macroeconomic stability matters because instability can dissuade investment and also drive governments to extract greater resources from export commodities such as lithium. Though Latin America has a history of severe economic crises Chile, Peru, and Bolivia have performed well through external shocks over the past 15 years, while Mexico has done so adequately. Brazil experienced a severe economic crisis tied to the collapse of the commodity boom a decade ago and spectacular corruption scandals but is progressively working its way out of it. Unfortunately, Argentina (potentially the largest Latin American lithium producer by 2030 and holder of its second largest resources) has a long history of recurrent severe economic crises which it has been unable to conquer.

A cartel needs to have market power, either through a swing producer or a small group of members, and it must convince non-members who are major producers to refrain from undermining cartel policy. Having reserves does not automatically translate into production and it is clear that production, reserves and resources are proliferating outside the region. Hence, a major challenge for a LALSA is to promote production among its members. Lack of production from member states can be due to a variety of causes—e.g., not wanting to be "exploited" by investors and consumers; governments making unreasonable demands in a market where investors and consumers have options; and governments unable to follow through on contracts because of ESG issues. Table 3 makes it clear that bringing production online would have to be one of the cartel's first priorities. Argentina, Bolivia and Chile are prime potential candidates for increased production and if speculations about the other three countries resources are correct, they are as well. However, the task of the cartel would have to be to keep costs competitive in these countries in the face of ESG pressures (particularly acute in Bolivia, Chile and Peru), and in the case of Argentina, a temptation to raid the lithium sector to finance macroeconomic instability.

Since the productive process for the four different sources of lithium in Table 3 is distinct and the path of their lithium into battery grade lithium also differs, cartel efforts to ensure member costs stay competitive would be quite complex, demanding expertise in financial and business analyses and interference with members' domestic policies and structures that influence such costs. Diversity in sourcing and costs also means that demands regarding price, technology transfer and domestic content would need to be coordinated for members to derive some agreed upon share of the benefits from cartel policies. Of course, the level of detailed knowledge necessary to determine proposals opens opportunities for member states to provide limited or incorrect data. LALSA would thus need a professional and skilled bureaucracy with sufficient autonomy to carry out its tasks credibly and to be supported in these efforts by the very governments they are investigating.

There are many sources of tensions among member interests to be considered and solved if the cartel is to prosper. We cannot address them all in this paper, but an additional two stand out given the diversity of member characteristics. One, governments with large resources but minimal if any production (Bolivia stands out, but this may also apply to Mexico and Peru) may seek cartel leverage to maximize potential revenue while those countries that are already significant producers (Chile and Argentina) and whose governments already benefit from a revenue stream may fear that pursuing maximum revenue in the future will endanger an important revenue source in the present. Additionally, two, the credibility of the cartel to increase supply if non-price demands are met is questionable if members with large resources and minimal if any production have national policies that discourage investment (e.g., Bolivia and now maybe Mexico).

Creating a cartel institution in Latin America will also be influenced by the general issue that has plagued all regional Latin American institutions—governments prioritize "sovereignty" over cooperation and government instability in the region means that national commitments to abide by agreements always lack credibility. For example, democracy clauses and human rights commitments were prioritized and highlighted in the 1990s and 2000s in regional agreements (Union of South American States, Southern Common Market [Mercosur], the Organization of American States' [OAS'] Inter-American Democratic Charter and Inter-American Charter on Human Rights) that were initially accepted by everyone. However, once governments began to diverge on ideology debates arose over the definition of the concepts of democracy and human rights and then the norms were abandoned in the name of the sovereign right of each government to decide how it wanted to behave [145,146]. Under these conditions, persuasion was tried but with no evaluation of behavior change nor sanctions for clear violations. These failures presage an inability for a LALSA to have institutional capacity and autonomy to detect cheating and for the members to punish transgressions.

Expanding the LALSA at least with Associate members from outside the region could increase its weight in the market and render the need to pressure Latin American producers to adjust domestic policies less pressing. Australia would be a clear candidate: the country has the geological capacity to increase production and is an attractive place for mining investment. There is, however, no reason to expect Australia to break with a long pro-mining tradition that has generated its economic development [53] (13–14). Its own history in the bauxite and copper cartels of which it was a member, demonstrates its unwillingness to restrict production for the sake of the cartel [22].

Another serious problem for a LALSA arises from the processing and battery production side where China dominates. China produces lithium but it imports far more lithium to sustain its dominant position in lithium processing and EV battery production. LALSA would benefit in the medium-long term from US and European competition with China across the lithium value chain, but the economic and regulatory advantages favoring processing and battery production in China render such competition unlikely in the short-medium term [53] (16). Any successes by a LALSA in keeping prices high or efforts to force the transfer of processing and battery making to its membership would make it more difficult for US and European companies to compete with China and encourage those companies and their governments to promote lithium production outside of Latin America.

Chinese companies, with encouragement and support from the government, have been investing in lithium production in Latin America and Australia to secure the supply chain [53] (14–15) [79] (13–15). China will not favor actions that raise prices of its raw materials nor those that force lithium production companies with Chinese investment to preferentially sell their product to competitors. Though Ganfeng have been willing to discuss investing in EV battery recycling in Mexico [3], whose automobile sector is an integral part of the U.S. auto sector, there is no indication that they would be willing to offshore premium EV battery production itself to Latin America.

5. Conclusions

The study of cartels may be coming back into academic fashion since the energy transition will make increased demands on the supply of minerals heavily sourced from the Global South. In the meantime, the literature on international cartels which developed in the 1970s–1990s remains extremely useful for understanding opportunities and challenges for cartels. In this article I argued that an important update would be the incorporation of ESG issues for understanding the evolution of cartel stability and demonstrated its utility through the prospects for collusion among Latin American lithium producers. It thus represents a pioneering study designed to stimulate further research into the political economy of the global energy transition.

The article also contributes to the growing literature that is skeptical about the comparison of oil and lithium. It is the first study to undertake a comprehensive analysis of the political economy of lithium, grounding that analysis in the experiences and future expectations of producers in Latin America, currently the region of the world that dominates lithium reserves and resources.

This article identifies the challenges that a cartel of Latin American lithium producers would need to address to effectively increase its appropriation of commodity rents and force its way further up the global lithium value chain. A general framework for the study of a commodity cartel was postulated and contextualized for lithium, thereby facilitating consideration of the challenges facing advocates of collusion by Latin American lithium producers. The study reminds us that commodity markets in general are inherently unstable and that lithium itself went through a boom-and-bust period in the past decade. Our key findings regarding collusion among Latin American lithium producers are twofold. First, there is sufficient information about the prospects for technology, new producers, recycling, and alternatives to lithium-based BEV to impact the market in the medium term in ways that will likely weaken the presence of Latin American producers and doom an attempted cartel. Second, even if Latin American lithium producers were to manage to collude in the short term the interests and market power of Australia and China are sufficient to derail a producers' cartel.

Grand undertakings, such as creating a cartel, are inherently risky and should be formulated prudently. Although we do not yet have clear answers about how technology for the energy transition will stabilize on a series of storage solutions, how to resolve ESG issues, or how to make governments more responsible to their citizens for failed policies, we need to seek credible answers and make decisions based on them, rather than simply postulate a world short of lithium, governments able to control production, and, societies which benefit from such control. Pursuing a strategy based on the idea of having market power to set terms for access to the region's lithium reserves appears most likely to ensure that Latin America will miss out on the demand for lithium in the short-medium term.

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