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Curb your enthusiasm. Challenges to the development of lithium-based linkages in Argentina

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ABSTRACT:

This paper contributes to the literature on resource-based development by analysing the opportunities and obstacles faced by linkage-development initiatives adopted in Argentina around lithium. A case study research has been designed that analyses two dimensions of the lithium-ion battery (LIB) global production network (GPN). Firstly, the dynamics of the lithium-ion battery GPN within which lithium is produced and consumed. Secondly, the multi-level governance scheme, shaped by a system of norms put in place by the federal and provincial governments, that regulates the access, exploitation and use of lithium in Argentina. The article finds that the development of forward linkages faces significant hurdles. The obstacles mainly arise from the lack of capabilities to produce LIBs in a competitive manner, since both the technology and markets are dominated by firms operating in a few Asian countries. Moreover, the normative frame in Argentina is not conductive for firms to localize lithium-processing activities in the country. The development of production backward linkages, although not unproblematic, is benefitted by pressures to raise the productivity levels of lithium exploitations and to improve the quality of lithium products; by the availability of location-specific capabilities; and by social and environmental domestic concerns which may create incentives for some technological solutions to be developed locally. The paper concludes that the effective development of resource based linkages would highly benefit from an aligned strategic vision among the relevant stakeholders of the system, including the federal and provincial governments, local and foreign firms, and the scientific community.

1. Introduction

In the last decade, lithium has become a critical resource, a new “white gold” that has gained the attention of firms, governments and researchers. Although this metal has had several industrial uses over many years, since the 1990s, its demand has soared with the growing use of lithium-ion batteries (LIB). Originally, LIBs were used in electronic devices and, more recently, in the electro mobility industry (Kavanagh et al., 2018). For some time, lithium supply could not keep pace with the steady rise in demand and, therefore, prices surged. From an average price of USD 5000 per ton in 2016 (Azevedo et al., 2018) the spot price of battery grade lithium carbonate in China spiked to around USD 21,000 in 2018 (Jaskula 2019).[1] Then, the drop in demand caused by the decision of the Chinese government to cut subsidies to electric vehicles production (Kalantzakos 2020) and the launch of new operations in Australia (Jaskula 2020) induced a fall in prices, which stabilised around USD 7300 per ton in 2020.

Against this new background, lithium assumed a strategic nature in the South American countries of the so-called lithium triangle –i.e. Argentina, Bolivia and Chile. This region accounts for around 58% of world lithium resources (Jaskula 2020). However, this strategic nature was neither related to its importance for the nuclear industry (as it had been the case of Chile, in 1979) nor to the (sole) purpose of increasing mining rents. Rather, the strategic status given to lithium in the last decade arose from its potential for promoting production linkages and creating technological capabilities in local actors (Montenegro Bravo 2018; Nacif 2018; Barandiarán 2019; López et al., 2019). In particular, the three countries attached a great importance to fostering

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[1] For a longer-term analysis and price prospects see Sterba et al. (2019).

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manufacturing activities related to the LIB industry. This orientation reflects that lithium has become "the subject of a sociotechnical imaginary that reimagines how mining can serve development goals" (Barandiarán 2019, p. 382).

The case of lithium can be examined in the light of the commodity boom, a period of high prices which extended between 2000 and 2015 (de la Torre et al., 2016). Against the pessimistic "resource curse" thesis (Sachs and Warner 1995; Gylfason 2001; Auty 2002), in these years several resource-rich countries attempted to use natural resources as a platform for diversifying their economic structure by building production linkages with other areas of the economic structure (Dietsche 2014). This has motivated a rich body of empirical investigations on recent resource-based development strategies in low and middle-income countries (see, for instance, Iizuka and Katz 2010; Morris et al., 2012; Marín et al., 2015; Katz 2017; López 2017; Andersen et al., 2018). Linkage-development strategies in the lithium industry are more recent and, therefore, the literature examining their effects is still limited. Some descriptive accounts can be found in Nacif (2012), Montenegro Bravo (2018) and Obaya (2019) for the case of Bolivia; in Fornillo, 2015a and López et al. (2019) for the case of Argentina; and Lagos (2018) and Maxwell and Mora (2019) for the case of Chile.

This article seeks to characterise the strategies adopted by domestic actors to generate backward and forward linkages around lithium in Argentina and aims to understand the opportunities and challenges faced by these strategies. Backward linkages are those leading to new investment in input-supplying facilities (Hirschman, 1981). In lithium producing countries, backward linkages develop in the upstream segment of the LIB supply chain. This includes the production of inputs and capital goods, and the provision of services for the elaboration of the lithium compounds. Forward linkages regard investment in output-using facilities (Hirschman, 1981) which comprise midstream and downstream manufacturing activities using lithium compounds as an input to produce cathodes, battery cells, and packs.

The analysis of the linkage-development strategy builds upon the global production network (GPN) heuristic framework (Coe et al., 2008; Coe and Yeung 2015). We focus, in particular, on the interaction between two dimensions of analysis. First, the dynamics of the lithium-ion battery GPN within which the metal is produced and consumed. Here, we also analyse the capabilities of local actors to take part of such competitive networks. Second, the multi-level governance scheme, shaped by norms put in place by the federal and provincial governments, that regulates the access, exploitation and use of lithium in Argentina. At the sub-national level, we focus on the case of Jujuy. This province has been the only district with lithium-rich brines in Argentina that aimed at creating linkages along the LIB value chain (López et al., 2019).

The GPN framework allows us to overcome the limitations of the so-called "good governance" approach. This normative proposition gained force as a "blueprint" for resource-rich nations to overcome the "resource curse" (Bridge 2008, Bourgouin et al., 2013). "Good governance" recommendations have the virtue of incorporating elements that reinforce the regulatory capacity of states. But, they do not take into consideration the industrial and technological dimensions and, accordingly, the development of linkages as a policy aim.

The case of Argentina offers a rich laboratory for exploring this matter. It is one of the leading players in the world lithium scenario, accounting for 24% of the resources and 14% of the reserves, concentrated in three provinces: Catamarca, Jujuy and Salta (Jaskula 2019). In 2018, it ranked fourth among lithium manufacturers, explaining 7% of global production. Differently from Bolivia and Chile, where the investment regulations are very restrictive, the lithium regulatory framework in Argentina is very open to private investment (Obaya et al., 2020). As a result, the number of projects led by private companies in Argentina is much higher than in other lithium-rich nations (Cochilco, 2018; Secretaría de Política Minera and Trabajo 2019).

However, despite the enthusiasm lithium generates in many parts of the world, it is worth highlighting that the global lithium market is relatively small compared to other mining activities.[2] Even if the optimistic government forecasts are met (Secretaría de Política Minera and Trabajo 2019), lithium exports would hardly account for over 2% of total Argentinian exports by 2022 (in 2018, this share reached 0.4%). This limitation reinforces the relevance of promoting local linkages around lithium. The creation of new capabilities could foster inter-sectoral spillovers, thus allowing for the emergence of activities. Ultimately, the reproduction of this type of resource-based dynamics may contribute to diversify the productive structure of Argentina and, in particular, of the backward provinces where lithium-rich brines are located.

The conclusions of our analysis suggest that the initiatives aimed at expanding backward linkages have more potential than those oriented towards forward linkages. The productive and technological dynamics operating within the lithium-ion battery GPN generate conditions favouring the creation of capabilities and the localisation of linkages around the resource exploration and exploitation stages. For instance, there are pressures to raise the productivity of lithium exploitations and to improve the quality of lithium products. Moreover, the location-specific challenges that characterise the exploitation of natural resources put local actors with knowledge in the field in a favourable position to take part of tailor-made innovations in upstream activities.

On the contrary, we see significant hurdles for advancing towards downstream activities. The ability to achieve competitive costs in the production of battery cells highly depends on the scale of operations. Currently, the LIB market is dominated by a few firms in a small number of Asian countries, which raises an entry barrier to newcomers. Furthermore, the current low volume of demand of LIBs from South America –in particular from the automotive sector (International Energy Agency 2020)– limits the incentives of large firms to set up operations in the region. At a policy level, we found that the federal and liberal nature of the lithium normative frame constrains policy makers' ability to formulate a comprehensive and articulated linkage development strategy. As a result, the fact of being endowed with large lithium resources does not provide specific advantages for developing forward linkages in Argentina.

The article is organized in five sections that follow this introduction. First, we review the principal arguments elaborated by the literature on natural resources and development. Second, the research design, including the stages of analysis and the information sources, is presented. Third, we describe the main initiatives oriented to promote linkages and innovation activities around lithium in Argentina. Fourth, we analyse the initiatives in the light of the GPN dimensions of analysis. Finally, we draw some conclusions on the opportunities and challenges faced by these initiatives and give insights for resource-development policy making.

2. Resource-based industries and economic development

The relationship between natural resources and economic development is far from being deterministic and has stimulated a rich academic literature (Gunton 2003). The main arguments can be organized around two divergent perspectives.[3] On the one hand, "pessimistic" views consider that the dependence on natural resources hinders economic growth and deteriorates development outcomes (Frankel 2010; van der Ploeg 2011, Auty 2017). The roots of this negative perspective can be traced back to the works of Singer (1950), Prebisch (1950) and the

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[2] For instance, the global gold market was 58 times larger than the lithium market in 2016, whereas the size of the world copper market was 50 times that of lithium (MINEM, 2017).

[3] Among these two extreme positions, there are a myriad of studies presenting more nuanced views. For instance, Fleming et al. (2015) propose a more focused analysis, in which the impact of resource exploitation on employment and growth is not analysed at a country level, but within different regions.

structuralist framework developed by the Economic Commission for Latin America and the Caribbean (ECLAC) –for a revision, see Sánchez et al. (2019)– in the post-World War II years.

However, it was in the 1980s when the resource "curse" thesis took shape and gained force (Corden and Neary 1982; Auty 1990; Sachs and Warner 1995; Gylfason et al., 1999). This strand of literature proposes a variety of institutional and macroeconomic mechanisms that link the relative abundance in natural resources to a poor economic performance. The identified mechanisms include the volatility of commodity prices, the mismanagement of the resource revenues, the emergence of rent-seeking behaviour in domestic elites, and the negative effects on institutional quality (a survey of the literature can be found in Badeeb et al., 2017).

On the other hand, the "optimistic" arguments seek to respond to resource curse arguments by focusing on institutional and technological factors. The institutionalist approach is epitomized in the concept of "good governance", advanced by Bretton Woods Institutions and NGOs like the Natural Resource Charter (Bourgouin et al., 2013; Singh et al., 2013). To avoid the negative consequences derived from resource mismanagement, corruption and rent-seeking behaviour, this approach proposes a set of relatively straightforward guidelines to escape the curse (Bourgouin et al., 2013). The good governance approach is more concerned with the appropriation and use of resource rents, rather than with fostering economic diversification based on the exploitation of natural resources. Hence, the proposed initiatives focus on improving the efficiency in revenues management, transparency, and accountability –see, for instance, the Natural Resource Charter (Natural Resources Governance Institute, 2014).

The factors that promote value creation and technological learning in resource-based industries have been analysed by others streams of the economics literature. The roots of this view can be found in the staple theory of export-led development (Watkins 1963). These studies shed light on how resource-intensive exports have created linkages, as put it by Hirschman, 1981, with other industries thus promoting the diversification of many resource-rich economies. This approach finds strong empirical support in the experience of high-income economies, such as the United States, Australia, Canada and the Scandinavian countries (Platt and di Tella 1985; David and Wright 1997; Freudenburg and Gramling 1998; Smith 2007; Ville and Wicken 2012; Nuur et al., 2018).

The key in successful experiences of resource-based development has been the ability to involve a large number of actors in creating, adopting and diffusing new knowledge across the economic structure, based on resource-related innovation activities (Wright and Czelusta 2004; Morris et al., 2012; Halland et al., 2015; Venables 2016; López 2017; Katz and Pietrobelli 2018). The literature also highlights the importance of institutions favouring the diffusion of such knowledge by promoting collaboration among firms, universities and research institutes around innovation and capacity-building activities (Ville and Wicken 2012). The policy toolbox included publicly funded R&D projects, training programs for domestic suppliers, local content provisions, and rules allowing local firms to compete on an equal footing in mining firms' tenders (Sasson and Blomgren, 2011; Urzúa 2012; Ville and Wicken 2012; Tordo and Anouti 2013; Hunter 2014; Halland et al., 2015; CEPAL 2016).

During the last commodity boom, developing countries rich in natural resources attached a great strategic importance to the promotion of linkages (Dietsche 2014). The recent expansion and consolidation of GPNs was conducive to this strategy as large firms exploiting the resources showed a growing preference for outsourcing a wide range of activities (Katz and Pietrobelli 2018).

The linkage-development policy strategies have varied widely among countries. African nations, for instance, have shown a marked preference for the adoption of local content rules (Adewuyi and Ademola Oyejide 2012; Teka 2012; Ovadia 2014; Ablo 2015; Ayentimi Desmond 2016). Sometimes, these provisions were combined with other measures, like the establishment of technological development centres for local suppliers (see the case of Ghana in Ablo 2015); government's production sharing agreements with international oil companies; and large capacity building initiatives like pipe mills, dockyards, or subsea equipment (see the cases of Angola and Nigeria in Ovadia 2014). Another mechanism used to promote local linkages has been the creation of state-owned companies. This has been, for instance, the case of Brazil (Dantas and Bell 2009, 2011), or Algeria (Djeflat and Lundvall 2016). In Bolivia, a state-owned company was created to manage the development of the lithium value chain (Montenegro Bravo 2018).

Chile offers an interesting case, since it sought to promote backward linkages through a more market-friendly approach. Born in 2008 as a private initiative led by BHP Billiton, the so-called World Class Suppliers Programme was later adopted as a public policy and extended to other firms. The primary purpose of the programme was to foster technological collaboration between mining firms and their suppliers by reducing information asymmetries, and coordination and transaction costs. In a nutshell, the programme created a platform where mining firms announced some of the technological challenges they faced. Local suppliers were invited to submit innovative solutions to tackle those challenges, which should be applicable, scaled up and entail the creation of new local capabilities. Once the proposals were selected, the parties had to negotiate and sign bilateral contracts defining the timeline of the project, the committed investments, the hours of work, the goals, etc. (Navarro 2018).

In practice, the outcomes of these policy strategies felt short of expectations. The creation of linkages was limited and most domestic firms proved unable to get involved in technologically complex tasks, where they faced the competition of well-established international suppliers (Teka 2012; Tordo and Anouti 2013; Halland et al., 2015; Venables 2016). In the case of Chile, for instance, some selected projects were successful in addressing the technological challenges. But, they failed in scaling up the innovations, replicating them in other environments and fostering export diversification (Bravo-Ortega and Muñoz 2018; Navarro 2018). Furthermore, the most knowledge-intensive activities remained located in large high-income urban centres. Linkages in remote mining areas chiefly limited to low tech goods and services, often encouraged by community development policies or corporate social responsibility programs (CEPAL 2016; López 2017; Atienza et al., 2018).

It is therefore clear that, although GPN have created opportunities for developing countries, relevant obstacles remain (Bridge 2008). The efficient operation of large-scale production sites involves large investments and the master of complex technologies, which generate high entry barriers. Furthermore, the extractive global value chains are dominated by large corporations that impose hierarchical modes of governance. Asymmetric relations within the chain limit the diffusion of knowledge thus hindering technological learning and upgrading opportunities for suppliers in most backward economies (Pietrobelli et al., 2018). As a result, the opportunities to develop local linkages or to incorporate domestic innovations into production processes weaken as we get closer to the core business activities of the mining companies (Morris et al., 2012).

3. Research design

This study seeks to characterise the strategies to generate backward and forward linkages around lithium in Argentina, and to understand the opportunities and challenges faced by them. First, we conducted field research to identify projects aimed at developing lithium-based linkages in Argentina. We focused only on publicly funded initiatives, which account for the bulk of capability-creating initiatives, since the role of the private sector has been mainly focused on traditional exploring and manufacturing activities in the upstream segment of the value chain. Several projects involve the collaboration of federal and provincial organisations, which reflects the multi-level nature of resource-based development in a federal country like Argentina. Many of the initiatives are carried out in Jujuy which, as said above, has been

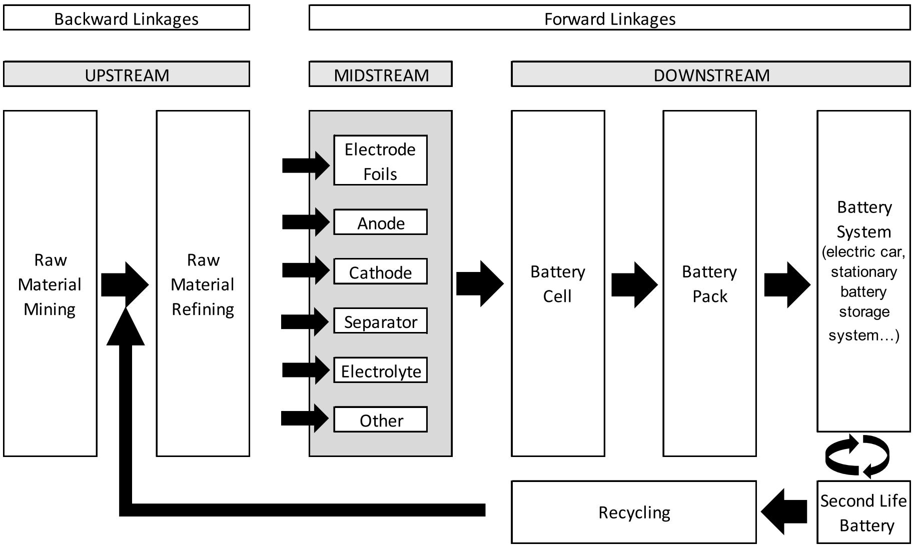

Fig. 1. Lithium-based linkages in the lithium-ion battery production process.
Source: own elaboration.

the most active province in seeking to promote linkages. This province hosts the Centre for Research and Development in Advanced Materials and Energy Storage of Jujuy (CIDMEJU). This is a research institute with a tripartite management organisation composed of the National Scientific and Technical Research Council (CONICET), the National University of Jujuy (UNJU), and the Secretary of Science and Technology of the Ministry of Education of the province of Jujuy.

In a second stage, we classified the initiatives according to two different criteria. The first one regards the policy goals of the project: i) the creation of production capacity; or ii) the development of technological capabilities. The former refers to "resources used to produce goods at given levels of efficiency and given input combinations" (e.g. capital-embodied technology and operating know-how experience); whereas the latter refers to "additional and distinct resources needed to generate and manage technical change" (e.g. skills, knowledge and experience) (Bell and Pavitt 1993, p. 260–261). Although the outcomes of the capability-creation projects do not crystallise immediately in new linkages, they improve the ability of local actors to manage the generation of linkages.

The second classification criteria distinguishes between projects promoting backward and forward linkages (Hirschman, 1981). We focused on the LIB value chain (Fig. 1), which is expected to be the principal source of lithium demand in the next few years (Bernhart 2019).

Backward linkages develop in "upstream" activities, i.e. those related to the production of inputs and capital goods and the provision of services for the elaboration of the lithium compounds used in the production of batteries. Differently from hard rock lithium mining, the boundaries between raw material production and intermediate processing are blurred in brine exploitations (Weimer et al., 2019). For this reason, the entire process is generally carried out by the same firms within a confined geographical area. In some cases, however, the upgrading of industrial grade lithium carbonate to a battery grade level[4] is carried out in other locations, closer to the production of cathode active material.

The traditional production process to get lithium carbonate from brines is commonly known as "evaporitic technology". The brine is pumped into large ponds and lithium is concentrated by solar evaporation and wind.[5] The complete cycle takes between 12 and 24 months, depending on climatic conditions. The obtained solution, with a concentration level of lithium of around 6000 parts per million, is then processed in a recovery plant. The remaining chemical species are removed by chemical treatment to obtain lithium carbonate or lithium hydroxide (Flexer et al., 2018).

Forward linkages develop in "downstream" sectors, i.e. manufacturing activities that use lithium compounds as an input for the production of cathodes, battery cells and packs (Weimer et al., 2019). The share of lithium in the battery varies in accordance to the cathode technology (Eftekhari 2019). For instance, in a battery using a lithium nickel manganese cobalt oxide cathode (NMC), the cost of lithium only represents around 5% of the cost of the battery (Puchta 2019).

Finally, we examined the opportunities and obstacles faced by the linkage-development initiatives through the lenses of the GPN literature (Coe et al., 2008) –and, in particular, its application to the study of natural resource-based networks (Bridge 2008). We analysed the interaction between the dynamics of the LIB production network and the capabilities of local actors to take part of such networks; and the multi-level normative system regulating the access and exploitation of lithium in Argentina.

We used a combination of methods to collect information, including interviews[6] and companies and public organisation reports. Among the latter, the Ministry of Energy and Mining of the Argentine Republic (MINEM 2017; MINEM 2018, Secretaría de Política Minera and Trabajo 2019), the Chilean Copper Commission (Cochilco, 2018) and the Jaskula (2019).

4. Linkage-development projects around lithium in Argentina

4.1. Backward linkage-development initiatives

The selected initiatives deal with four issues: geological studies; extraction and processing technologies; lithium products; and local suppliers (see Table 1). Most of them correspond to R&D projects carried out in federal and provincial public research centres, the only exception

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[4] To be considered as "battery-grade", the purity of lithium carbonate must be at least of 99.5%.

[5] For a more detailed description of the process, see Tran et al. (2015).

[6] Between February and August 2018, we conducted 28 interviews to officials, researchers, and managers who carry out activities related to the lithium industry (Annex I).

Table 1
Main backward linkage-development initiatives in the LIB production network (2018).

Theme	Type	Code	Name of the initiative	Stage	Type of deposit	Objectives	Key actors
Geological studies	Technological capability-building	B1	Resources and hydrogeology of salt flats	Extraction	Brines	To improve the quantification of resources. To improve the knowledge on: i) the composition of the salt flats; ii) the hydrogeology of the salt flats; iii) the modes and times of recharge of the brine; iv) the origin of the salt flats.	Federal level: COFEMIN, SEGEMAR, UNJU Sub-national level: provincial mining authorities International: Chinese and United States geological services
Extraction and processing technologies	Technological capability-building	B2	Development of processes to improve the efficiency of evaporitic methods	Extraction and refining	Brines	To recover water for irrigation activities. To reduce the dependence on climatic conditions. To produce biogas from sewage generated in mining camps, thus improving the environmental management of camps, and replacing inputs acquired from external providers in distant locations. To develop production processes allowing for a profitable exploitation of other resources contained in the salt flat (e.g. magnesium hydroxide, magnesium sulphate, calcium sulphate).	Federal level: UNSa/ INTI (Palpalá)/ SEGEMAR/UNJU Federal and sub-national levels: CIDMEJU Private sector: Sales de Jujuy
	Technological capability-building	B3	Development of non-evaporitic methods	Extraction and processing	Brines	To shorten the time to recover lithium chloride. To reduce water consumption during the lithium recovery process.	Federal level: INQUIMAE Federal and sub-national levels: CIDMEJU
	Technological capability-building	B4	Development processes for the exploitation of pegmatite deposits	Refining	Pegmatite	To develop an environmentally friendly (i.e. energy consumption and use of inputs) process to recover lithium and other elements from pegmatites.	Federal level: UNCUYO/CONICET Private sector: Latin Resources
Lithium products	Technological capability-building	B5	Development of processes to produce lithium hydroxide	Extraction and refining	Brines	To develop a process to produce lithium hydroxide from lithium chloride.	Federal level: CIDMEJU/INTI (Palpalá)/INQUIMAE
	Technological capability-building	B6	Development of processes for the production of metallic lithium	Extraction and refining	Brines	To develop a process to produce metallic lithium.	Federal and sub-national levels: CIDMEJU Private sector: Clorar Ingeniería
Local suppliers	Production capacity building	B7	Training programmes for the provision of services to lithium firms	Extraction and refining	Brines	To improve the capabilities of local firms to offer services to companies operating in salt flats (e.g. transportation and logistics, plant and infrastructure maintenance, catering, laundry and cleaning, etc.).	Federal level: INTI (Palpalá) Federal and sub-national levels: CIDMEJU Private sector: Sales de Jujuy/Minera Exar

Note (acronyms and abbreviations).
CIDMEJU: Centre for Research and Development in Advanced Materials and Energy Storage of Jujuy.
COFEMIN: Federal Mining Council.
CONICET: National Scientific and Technical Research Council.
INQUIMAE: Institute of Physical Chemistry of Materials, Environment and Energy.
INTI: National Institute of Industrial Technology.
SEGEMAR: Argentine Mining Geological Service.
UBA: University of Buenos Aires.
UNCUYO: National University of Cuyo.
UNJU: National University of Jujuy.
UNSa: National University of Salta.
Source: own elaboration based on our fieldwork.

being the training programmes organized by the INTI and lithium firms in Jujuy. The main purpose of these initiatives is to develop new capabilities in local actors and institutions, not only as an outcome of the research process but also by involving doctoral students in the projects.

One matter addressed by these initiatives is the geological study of the salt flats in the Puna region (north-western area of Argentina) (project code B1 in Table 1). These projects seek to improve the assessment of lithium resources and to provide new knowledge allowing for a more efficient and sustainable exploitation of the salt flats. The SEGEMAR and geologists from the UNJU have independently conducted studies on the origin, hydrogeology, and recharge sources of lithium-rich salt flats. Besides, the SEGEMAR elaborated a lithium map of the region in collaboration with the geological services of China, and conducted a hydrogeological study of the Puna basins jointly with the United States Geological Survey.

A second group of initiatives deals with extraction and processing technologies for both brines and pegmatite deposits.[7] In the case of brines, the R&D projects (B2) seek to tackle some of the fundamental challenges faced by the prevailing evaporitic technology, such as extended harvesting times, and difficulties for separating lithium from

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[7] Currently, lithium-rich pegmatite resources are not exploited in Argentina, since the activity is not authorized by the provincial governments.

other elements (in particular, magnesium) and for exploiting other resources contained in the brine profitably (e.g. magnesium hydroxide) (Flexer et al., 2018).

There is also an initiative to develop a non-evaporitic method (B3). In a nutshell, this consists of an electrochemical technique that uses battery type electrodes to extract selectively lithium from brines. The most significant advantages of this technology are the time reduction for obtaining lithium (from months to hours), the low consumption of energy because of the use of solar panels, and the high selectivity of lithium over impurities in the brine. This latter issue is one of the main challenges faced by the current evaporitic technology, as battery manufacturers are adopting increasingly strict standards regarding the purity of lithium carbonate (Weimer et al., 2019). Although a few non-evaporitic technologies have already been developed at the global level –e.g. absorption, solvent extraction, or ion exchange–, all of them are at pre-commercial stages. The big hurdle of this electrochemical method –which is at the laboratory level stage– is technology scaling (Calvo 2019).

Within this group of initiatives, there is a project conducted by the UNCUYO to develop a new environmentally friendly hydrometallurgical process to refine lithium recovered from pegmatite deposits (Rosales et al. 2016, 2019) (B4). The new technology was patented and licensed to the Australian firm Latin Resources, which partially funded the pilot plan. This company has exploration permits in the province of San Luis, in Argentina, and in its home country.[8]

A third group of initiatives corresponds to the development of new processes to manufacture lithium hydroxide and metallic lithium. The motivation behind these projects is based on the growing importance of these two inputs in the fabrication of LIB. In the case of lithium hydroxide, its demand has increased for two reasons: it decomposes at lower temperatures –which leads to improved material use–; and it is obligatory in the nickel-rich cathode technology that is replacing high cobalt content materials (Weimer et al., 2019). In brine operations, lithium hydroxide can only be obtained from lithium carbonate. This is a handicap in relation to hard rock exploitations where it is recovered directly from spodumene concentrate. One of the research projects seeks to produce lithium hydroxide from brines through electrodialysis technologies. In the case of metallic lithium, the interest stems from its potential use in the anodes of some battery technologies currently under development –e.g. lithium-sulphur batteries– (Bernhart 2019).

Finally, there is an initiative oriented to offer training to members of local indigenous communities living close to the brines in the province of Jujuy. The objective is to make those communities able to provide low-tech services to mining firms, including, for instance, equipment maintenance, catering, transport, etc. The actions developed within this project are co-developed by the INTI and lithium operators, within the frame of their corporate social responsibility programs.

4.2. Forward linkage-development initiatives

Forward linkage-development initiatives, especially those related to the production of batteries, have been of great interest to the government of Jujuy (Table 2). The principal argument behind this position is that "processing" the lithium carbonate within the province would bring more benefits than exporting it as a commodity. With this purpose, the government actively searched for potential partners who could provide the technology to manufacture LIB in Jujuy. This strategy has received significant support from the scientific community and has involved research groups from CONICET and the CIDMEJU.

The main project is led by the state-owned company JEMSE (Project Code F1). The company has a shareholding of 8.5% in Sales de Jujuy (the only lithium firm that operates in the province). This partnership gives JEMSE the right to select the buyer of a 5% quota of total lithium production in the venture and sell it at a market price. In December 2017, JEMSE used this right to negotiate the creation of the joint-venture Jujuy Litio with the Italian business group SERI, a newcomer in the fabrication of LIB. In exchange for securing long-term access to the lithium quota owned by JEMSE, the group SERI would collaborate in the establishment and operation of LIB manufacturing facilities in Jujuy.

The ultimate goal of Jujuy Litio, where JEMSE has a shareholding of 60%, is to set up a modular industrial complex in Jujuy that covers all the stages of the LIB value chain: the production of cathode active material, battery cells and packs. The launch of the initiative, however, has been postponed several times and dramatically downsized. Although the original plan was to set a plant with a production capacity of 200 MWh, the operation would be initially constrained to a very low capacity of 5 MWh to assemble imported battery cells. The investment would amount to EUR 750,000 and the firm would have a staff of 15/20 people –only 5/6 would take part of assembly operations (Oehler 2019).

In parallel to this project, there are capability-building initiatives related to LIB technologies. One project is co-developed by Lithops –an Italian technological company that makes part of the SERI group– and the Argentine company Y-TEC (a joint venture between CONICET and the Argentine oil company YPF). The two firms are working on a process –currently at a pilot stage– for the production of lithium iron phosphate cathode active material, in collaboration with the *Politecnico di Milano* (F2). Eventually, the product would an input by Jujuy Litio.

Additionally, there is a wide variety of research and development projects –including the training of doctoral students– related to battery production and recycling activities (F3). The issues addressed by these projects include, for instance, the optimization of LIB technologies; the computer design of cell assembly in batteries and cooling systems; and the study of post-lithium-ion battery technologies. These activities are mainly carried out by CONICET research institutes –notably, the INIFTA and the LAES–, often in collaboration with research organisations overseas. Regarding LIB recycling, a research group from CONICET and UNCUYO developed and patented an environmentally-friendly technology for this purpose. A pilot plan was set up in collaboration with the local government of Godoy Cruz (province of Mendoza), with a capacity of recycle 600 batteries per month.

5. Mind the gap: from capability-building to linkage-creation

The progressive transition towards electro mobility and renewable energies has led the expansion of the LIB industry. This has created opportunities in a great variety of fields, ranging from the production of raw materials to that of battery components. Also, the intensification of this trend poses significant challenges that demand new capabilities for developing more environmentally-friendly and efficient resource exploitation processes; producing cheaper and more efficient batteries; and improving battery recycling technologies, among other things.

The projects adopted in Argentina aim to develop capabilities to tackle many of these challenges. However, the possibility of creating production linkages based on the acquired capabilities depends on factors that go beyond the outcomes of the projects. In the following sections we analyse the capability-building potential of the projects presented in Section 4 by examining the GPN structure and the competition dynamics in LIB midstream and downstream segments, and also the capacity of local actors to take part of such networks (Section 5.1). Then, in Section 5.2, we analyse the limited ability of the government to build a comprehensive strategic vision and to adopt policies to facilitate the interaction and cooperation between relevant stakeholders.

5.1. Opportunities and obstacles arising from the LIB production network

In this section we examine dynamics in the battery GPN that open opportunities but, at the same time, raise significant challenges for the

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[8] Australia is the largest world producer of lithium. According to estimates by Jaskula (2020), in 2019 it accounted for over 54% of word production.

Table 2

Main forward linkage-development initiatives in the LIB production network (2018).

Type	Code	Name of the initiative	Stage	Objectives	Key actors
Production capacity building	F1	Assembly and manufacture of battery cells and packs	Battery cells and packs	To produce batteries, cells and active material in Jujuy.	Sub-national levels: JEMSE/Jujuy Litio Private sector: SERI Group (FIB-FAAM, Lithops)
Technological capability-building	F2	Research and development on LIB and their components	Electrodes and battery cells	To develop capabilities that provide support to the local production of LIB and their components. To develop innovations in the LIB industry (e.g. new materials).	Federal level: LAES (UNC)/INIFTA/UNCA/INQUIMAE Federal and sub-national levels: CIDMEJU Firms: Lithops/Y-TEC
Technological capability-building	F3	Development of processes for lithium-ion battery recycling	Recycling	To develop environmentally friendly processes to recycle LIB.	Federal level: UNCUYO Sub-national level: government of the department of Godoy Cruz (Mendoza)

Note (acronyms and abbreviations).

INIFTA: Institute of Theoretical and Applied Physical-Chemical Research (National University of La Plata).

JEMSE: Jujuy Energy and Mining State Society.

LAES: Laboratory of Sustainable Energies (National University of Córdoba).

UNCA: National University of Catamarca.

Source: own elaboration based on our fieldwork.

development of linkages in Argentina. We explore, in particular, the pressures on lithium resources created by the race of electric vehicles producing countries for securing access to the resources. Then, we analyse the significant obstacles for Argentina to advance into the creation of forward linkages in LIB downstream activities.

5.1.1. *The race for securing access to a critical resource: backward linkages opportunities*

Electric vehicle manufacturing countries have given increasing importance to securing the provision of critical raw materials for the production of LIBs. The United States and the European Union, for instance, have included lithium among a list of critical resources considered vital for security or economic reasons (Federal Register 2018; European Commission 2020). The primary concern is not about the availability of the resource but about the risks that a high geographical concentration of the reserves generates on its uninterrupted provision (Kalantzakos 2020).

China, the largest lithium consumer, has taken the lead by pursuing an aggressive dual strategy combining the exploitation of lithium deposits overseas (mainly in Australia) with that of local brines (Hao et al., 2017). In parallel, the country adopted a R&D agenda focused on the development of more efficient processes for the exploitation of its low-quality lithium deposits. Also, it invested much effort in improving battery recycling technologies (Hao et al., 2017), and it is the global leader in patent applications in this field (Moreno-Brieva and Marín 2019).

Europe and the United States took longer to recognise the critical role of raw materials for the future of their electro mobility industry (Calabrese 2016) and to take actions to secure its provision. In 2017, the European Union launched the European Battery Alliance, which seeks to “develop an innovative, sustainable and competitive battery ‘ecosystem’ in Europe” (European Commission 2019). The strategy involves securing access to raw material for primary and secondary (i.e. recycling) battery applications. Recently, it has been claimed that 10 mining locations had been identified for the potential exploitation of lithium in the continent (Hall and Milne 2019). The European Commission has designed actions to advance the development of capabilities to exploit them (European Commission 2020).

In the United States, the Department of Energy created the Critical Materials Institute that conducts research and promotes industrial collaboration aiming at eliminating and reducing reliance of critical material such as lithium. In particular, efforts are focused on source diversification, materials substitution, and improved stewardship of existing resources (Ames Laboratory, 2020). There are states in the United States aspiring to concentrate lithium from different type of deposits (Grant, 2020).

The position of Argentina will be challenged by the growing competition from newcomers. However, it is unlikely that non-producing regions will develop efficient methods of production for deposits with lower concentrations of lithium in the short term (European Commission 2020). Accordingly, the availability of high-quality brines Argentina will continue attracting mining operators as they allow for lower production costs. The liberal mining regulations of Argentina in comparison with its neighbours in the lithium triangle reinforces its attractiveness (Obaya et al., 2020).

Against this backdrop, it is expected an increasing competition and a growing pressure on local lithium resources that raise significant sustainability challenges. This situation highlights the importance of the capability-development initiatives in upstream segments described in Section 4.1. Lithium-processing technologies have several shortcomings related, for instance, to waste management, low rates of recovery of the lithium contained in brines, and water demanding industrial processes (Flexer et al., 2018).

Moreover, there is a need for developing more efficient processing technologies that allow for a reduction of production and (mainly) capital costs, as well as exploration and lead times of lithium brines. These factors are among the major disadvantages of brines exploitation compared to pegmatite deposits. As seen before, there are initiatives in this field (involving both improved evaporitic processes and non-evaporitic processes) in Argentina (Projects B2 and B3).

The fact that resources are embedded in unique geological and ecological environments requires creating location-specific knowledge –what Andersen et al. (2018) refer to as “natural resource knowledge idiosyncrasy”. Hence, the development of these technologies depends on a sound understanding of local conditions, including the hydrogeological characteristics and composition of the brines, the local environment and climate, and the communities who live in the area. This strengthens the position of local actors with capabilities to take advantage of upstream linkage development opportunities (Andersen 2012; Morris et al. 2012; Marín et al. 2015; Stubrin 2017; Katz and Pietrobelli 2018).

The expansion of the lithium industry at a global level could also generate opportunities for exporting locally developed innovations. For instance, non-evaporitic technologies (Project B3) could be adapted for the exploitation of geothermal and oilfield brines overseas (Flexer et al., 2018). Also, the improvements of the evaporitic method could be used within the lithium triangle region.

As stressed by interviewees, one significant obstacle that hinders the

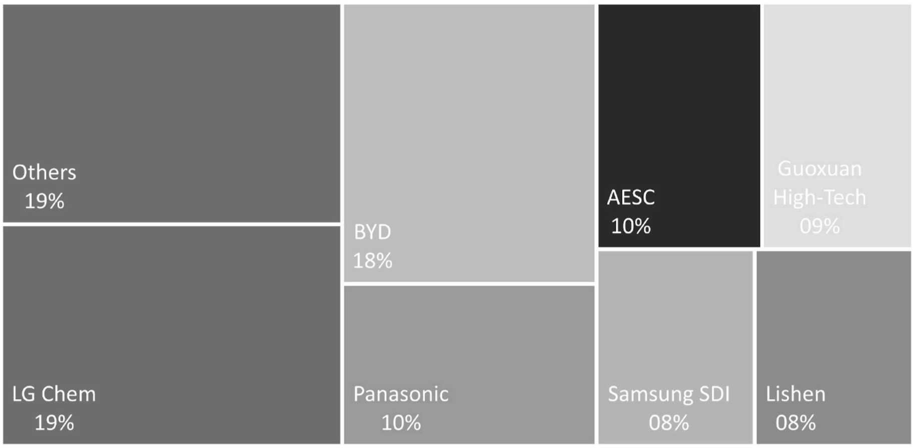

Fig. 2. Production capacity of main LIB companies (2017).
Source: Fact.MR.

development of backward-linkage development initiatives is the reluctance of the transnational mining firms operating in lithium-rich brines in Argentina to cooperate with local researchers –especially, in strategic knowledge-intensive areas. This obstacle is not exclusive to Argentina but common in developing countries. As shown by the international business literature, multinational companies have a marked preference to develop this type of innovations in-house or in collaboration with their global strategic partners (Pietrobelli et al., 2018). A high level of collaboration between these two actors is crucial for the transition from the experimental to the production stage, i.e. from capability-building to linkage development.

Notably, the position of private companies contrasts with that of foreign governments. Both the United States and the Chinese geological surveys collaborated with the Argentinian government in improving the knowledge of local salt flats (Project B1). As discussed above, this can be explained by the growing concern of these countries for securing access to critical raw materials (Kalantzakos 2020).

5.1.2. *Market concentration and technological race in LIB midstream and downstream segments*

The expansion of the electro mobility industry is leading to a rapid increase in the demand of LIB cells. While in 2018 the market reached a level of 160 GWh, some forecasts suggest that it will rise to around 1200 GWh in 2030 (Pillot 2019). Although this expansion opens new business opportunities, the structure and dynamics of the lithium-ion battery GPN pose significant entry barriers for newcomers. This is bad news for resource-rich countries aiming to embark in a forward linkage-development strategy.

One of the chief obstacles lies in the centrality of the scale of production to achieve competitive costs in the production of cell batteries. According to Bernhart (2019), companies with a market share below 8–10% of the global market will face cost disadvantages compared to larger producers. As seen in Fig. 2, the battery cell market is very concentrated: the seven largest players accounted for 81% of the production capacity in 2017 (the remaining production is nearly exclusively in the hands of Chinese companies). The market for cathodes –the component of the battery containing lithium– is less concentrated at the level of players. The top-five market leaders account for nearly 55% of the global market.[9] Still, the concentration in terms of the geographical concentration of manufacturing activities in Asian countries is very high (Bernhart 2019).

It is worth stressing that a high-income region like Europe, with a large and well-established automotive industry, does not host major lithium-ion battery manufacturing facilities. To overcome what policymakers and companies considered as a risk for European carmakers, the European Battery Alliance has included among its action plan the provision of financial support to large European cell manufacturers[10].

The intensity of the technological race within the lithium-ion battery GPN poses another challenge to newcomers. Compared to upstream activities, price competition in midstream and downstream sectors is more intense, which puts great pressure to lower production costs. One of the primary goals pursued by incumbent companies and researchers is the reduction of battery costs. Innovation efforts are mainly concentrated on the development of cathodes with higher volumetric energy density and a change in the composition of materials. Companies also point to lowering manufacturing costs by improving, for instance, the coating and the assembly process (Bernhart 2019). As a result, profit margins in the segment of cell manufacturing are, in average, lower than in the production of raw materials.

It is forecast that battery pack prices will decrease from a current average of USD 176/kWh to around USD 94/kWh in 2025[11] (Goldie-Scot 2019). Hence, to keep market competitiveness, it will be necessary to engage in an intense technology race demanding a high volume of resources for R&D activities. Currently, these efforts are concentrated in a few countries. Moreno-Brieva and Marín (2019) show that, between 1900 and 2014, 90.5% of patent applications related to lithium are accounted by South Korea, Japan, the United States, China, and Germany. In what specifically regards lithium-ion secondary batteries, the participation of these countries raises to 95.7%.

In this context, the development of forward linkages faces significant challenges for small newcomers like Argentina. The demand for LIB in the country –and even within the South America region– is negligible, which prevents the possibility that the regional market can be a driver for the potential establishment of a local battery industry. This is particularly the case of vehicle batteries, as carmakers located in the region have not started the transition towards electric mobility (International Energy Agency 2020).[12] From a supply chain perspective, the assembly of battery packs commonly takes place close to the vehicle assembly location, since the transport cost of battery packs is much higher than that of cells (Coffin and Horowitz 2018).

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[9] Source: Fact.MR Consulting.

[10] The establishment of the Northvolt battery plant, in North Sweden, with a projected capacity of 32 GWh, has been funded by European financial institutions (European Commission 2019).

[11] In 2010, the cost was of around USD 1160/kWh.

[12] The Strategic Plan 2030 presented in 2019 by the national carmakers association (ADEFA) focused on the production of internal combustion engines vehicles. The demand for electric vehicles would be supplied from abroad.

Moreover, the share of lithium in total battery costs is around only 5% (Puchta 2019). This entails that the economic advantage of being endowed with lithium reserves is very limited for the development of a LIB industry. This would even be the case if the resource can be accessed at a preferential price, which is not the case of Argentina. Besides, it is important to distinguish scientific from manufacturing capabilities, although they are interrelated. The local scientific community has accumulated the former type of capabilities (Project F2), but the scope for creating linkages with the domestic industrial structure is limited.

These obstacles have been acknowledged by the authorities of JEMSE, who oriented Jujuy Litio's project to the commercialisation of locally assembled batteries for energy storage in off-grid renewable energy (Oehler 2019). Although the expected growth rate of this market segment is forecast to be lower than that of vehicle batteries (Pillot 2019), it offers a niche that presents some advantages. The governance of the value chain is less hierarchical, which provides more autonomy to manufacturers. Besides, Argentina has embarked on a plan to expand the production of renewables energies, which offers a potential source of demand for that batteries (Roger 2018).

Nevertheless, the potential of the Jujuy Litio project to generate local linkages seems to be limited, at least at the beginning. As stated above, the initial plan involves an assembly capacity of imported battery cells of 5 MWh, and less than 20 people would be employed by the firm. For comparison it can be mentioned that, in 2015, the average production capacity of small battery producers in Europe was 146 MWh (Lebedeva et al., 2016). The sustainability of the project, and its capacity to further local technological capabilities, depends on a dramatic expansion of the production capacity and the localisation of more knowledge-intensive activities. Moreover, according to the terms of the agreement signed with the SERI Group, the responsibility for commercialising the batteries is under the responsibility of the Argentinian partner (López et al., 2019). The limited marketing capabilities of the province of Jujuy constrain the possibility of a demand-pull production growth, unless a provincial or a nation-wide procurement program is put in force.

It is worth noting that the evolution of the technical preferences and requirements by GPN flagships in downstream segments also generate innovation pressures and opportunities for actors operating in upstream nodes. For instance, in face of a growing preference for lithium hydroxide by battery manufacturers, the initiative to develop electro dialysis techniques to obtain this product from lithium chloride (Project B6) has potential for future applications. Likewise, electrode producers have become more demanding in relation to the removal of impurities traces in lithium carbonate that affect the performance of the battery. Some interviewees argued that the level of detail and specificity of these requirements put lithium carbonate closer to a differentiated product rather than to a commodity. This requires improved refining processes that might differ according to the chemical composition of the brines. We did not identify capability-building initiatives on this matter in Argentina.

Table 3
The federal mining regulatory framework.

Principle	Norm	Year	Description
Fiscal stability and tax incentives	Mining Investment Law	1993	Mining companies are granted fiscal stability for 30 years since the presentation of the feasibility study of the project. The legislation allows for the deduction of investment expenses in prospection, exploration, and feasibility studies from corporate income tax. It grants additional tax benefits. The top limit for royalties charged by provinces is fixed at 3%.
Federalism	National Constitution (Article 124)	1994	The provinces have the original domain of the natural resources in their territory. Provinces have competences to establish their own rules to regulate extractive activity.
Private exploitation of mining resources	Mining Code	1997 (reform)	By virtue of its original ownership over the mines, provinces have the power to grant exploration and exploitation rights. Individuals and private firms can carry out exploration and exploitation activities with the authorization of the provincial government provided they pay a canon and invest a minimum capital. State-owned companies and other public entities are entitled to prospecting and creating special areas for resource exploration and exploitation.

Source: own elaboration based on Slipak (2015).

5.2. Lithium governance: the lack of a coordinated and comprehensive strategy

The normative governance of lithium in Argentina is fundamentally based on three pieces of legislation: the National Constitution, the Mining Investment Law, and the Mining Code (Slipak 2015). This entails a significant difference from Bolivia and Chile, where lithium is regulated by a specific body of rules because of its strategic nature (Obaya et al., 2020). In essence, the norms are shaped by three principles: fiscal stability and tax incentives for mining operators; federalism, which delegates the management of resources to provinces, and private exploitation (Table 3).

The sections below analyse the limitations of this normative framework to deploy a linkage development strategy to cope with the opportunities and challenges emerged from the LIB industry. Its liberal nature provides little room for conditioning the grant of mining licenses to linkage development initiatives and promoting knowledge-based university-industry cooperation. Besides, the federal nature of the system hinders the adoption of a national strategy involving different government levels. The current scheme lacks mechanisms to build a shared strategic vision among the relevant stakeholders of the local lithium industry.

5.2.1. A liberal mining regulatory framework: all carrots and no sticks

The mining regulatory scheme in Argentina has a marked liberal orientation, shaped in the 1990s, under the influence of the so-called Washington Consensus (Haslam et al., 2016). This normative frame has been marked by the adoption a governance "blueprint", labelled as "Latin America Mining Law Model" (Bastida et al., 2005). The transmission belt for adopting the regulations were the Bretton Woods institutions and, in particular, the World Bank.

Overall, it privileges the goal of attracting private investment by establishing an internationally open and stable legal framework. Mining taxes and royalties are low and no provisions on local content or technology transfer are included (Bridge 2008, Haslam et al., 2016). In this view, the potential social benefits of lithium extraction mainly result from the maximization of investment and, hence, from the expansion of the production volume. This would cause higher employment levels and tax collection that might lead to "fiscal" and/or "consumption" linkages (Hirschman, 1981).

This regulatory framework leaves little room for governments –either at federal or provincial levels– to condition the grant of mining

Table 4
Uncoordinated strategies for the development of the lithium industry.

Type of initiative		Type of linkage	
		Backward-linkages	Forward-linkages
Production-capacity initiatives	Prevailing vision	Liberal approach	Local production of LIB
	Policy tools	Fiscal stability, tax benefits, license grants to private operators Training to local suppliers	Right of the state-owned firm JEMSE to determine sale conditions for a 5% quota of total lithium production Joint venture with small European battery producer
	Relevant actors	Mining government areas at federal and provincial levels Private mining firms	Province of Jujuy: production, science, and innovation areas Firms: JEMSE, Jujuy Litio, SERI Group
Capability-building initiatives	Prevailing vision	Training of doctoral students on lithium related matters	
		Knowledge and technology development to improve the efficiency and sustainability of lithium exploiting processes	Knowledge and technology development related to LIB
	Policy tools	Creation of a research institute specialised in lithium-related issues (CIDMEJU)	
		Funding R&D projects and doctoral scholarships on lithium-related issues (CONICET)	
	Relevant actors	CIDMEJU, CONICET, UNCUYO	
		INQUIMAE, SEGEMAR, UNSa	INIFTA, LAES, Y-TEC, Lithops

Source: own elaboration.

licenses to rules oriented to foster the development of production linkages. Accordingly, the country has made no use of some typical measures applied by resource-rich countries to ignite a linkage-development process: e.g. local content policy in mining operations, regulation of tenders, preferential lithium prices for firms localizing manufacturing processes, requirements of technology transfer from international operators to local firms, procurement policies. In this scenario, the promotion of linkages remains limited to the provision of public goods that contribute to lower the operational costs, such as energy and logistics infrastructure, or training of the labour force (e.g. Project B7). Along the same vein, governments have limited tools to foster knowledge-based university-industry cooperation. For instance, university geologists have had limited access to salt flats to carry out their research projects, whereas firms have also been reluctant to provide access to brines to study its composition and to develop experimental production techniques.

Under the current norms, mining operators can commercialise their production of lithium carbonate with no restraints. This limits the possibility of fostering forward linkages, by offering special conditions for firms to process lithium in the country. The only exemption is the right of the state-owned firm JEMSE to select the buyer for a 5% quota of total lithium production in Sales de Jujuy, in exchange of establishing manufacturing facilities in the province. But, the ability of the government of Jujuy to attract battery producers with proven capabilities has been very limited. Economic incentives are very low as the lithium quota is very small and should be commercialised at a market price.

The Chilean case regarding the lithium quota offers a contrast. Whereas JEMSE can offer around 600 tons of lithium carbonate per year at a market price, CORFO, the Chilean development agency, can tender a lithium quota of 11,250 tons at a preferential price. This results from the renegotiation of the contracts with the two companies operating in the Atacama salt flat –i.e. SQM and Albemarle. Under the new terms, the firms have to sell up to 25% of their production at a preferential price to selected producers that carry out manufacturing activities using lithium as input in the country (Maxwell and Mora 2019). In a context in which the scale of production has become an increasingly important factor in determining firms competitiveness in the lithium industry (Bernhart 2019), the size of the quota is a crucial factor for a policy aspiring to develop sustainable forward linkages. However, the Chilean experience shows that this is not a sufficient condition in a context of declining lithium prices. In July 2019, CORFO announced that the three companies selected to allocate the lithium quota had withdrawn from the international tender (Poveda 2019).

The current Argentinian lithium governance scheme offers a "big carrot" to attract mining investors but has no "stick" to promote the creation of production linkages. Production linkages would, therefore, be an outcome of autonomous decisions made by mining companies in response to strategic decisions to "intrinsic" drivers –such as the intention to cut down logistic costs or to set up lean production systems (Morris et al., 2012)– or to the need to access local knowledge familiarised with the specificities of the brines (Andersen et al., 2018; Katz and Pietrobelli 2018; Pietrobelli et al., 2018). But, as shown by the experience of latecomers in the LIB industry, the development of manufacturing and technological capabilities beyond the provision of basic services and goods requires strong and well-funded public intervention (see for instance, European Commission 2019).

5.2.2. The lack of coordination mechanisms to formulate a comprehensive and articulated national strategy

The linkage-development policy agenda in Argentina has been very fragmented. To a large extent, as summarised in Table 4, this fragmentation reflects the different visions about the potential contribution of lithium to economic development, and the lack of mechanisms to articulate them into a coordinated strategy. The divergence is more notorious regarding production-capacity initiatives. The vision of government departments with competences on mining issues, both at federal and provincial level, have advocated a liberal approach. They privilege guaranteeing stable and favourable conditions for lithium operators. By contrast, government areas related to science, technology, and innovation have been more inclined to foster local linkages. At the provincial level, in the resource-rich provinces of Salta and Catamarca it also prevailed liberal view, whereas the province of Jujuy assumed a strategy more oriented to the development of production linkages.

Regarding capability-building initiatives, the divergence of vision among relevant actors is less significant, as depicted in Table 4. The interests are largely explained by the disciplinary fields of specialization. The interventions are based on shared policy tools, including doctoral grants, research funding and infrastructure.

The federal governance scheme, in which the management of natural resources is in the control of provinces, further stresses the difficulties to design a comprehensive and articulated linkage-development policy. In principle, it creates conditions for the lithium-rich provinces to compete to attract investments and raise risks of a regulatory race to the bottom by lowering investment and operation costs. Consequently, provincial governments find it difficult to adopt performance provisions and high environmental standards individually without losing ground vis-à-vis competing provinces. So far the Federal Mining Council (COFEMIN), a government organisation responsible for the articulation of mining policies among provinces, has been effective in constraining them to advance into this harmful competition.

An additional problem is that lithium-rich provinces in Argentina are too small and have limited resources and capabilities to design, implement and enforce linkage-development measures. It is the federal government the political entity with more resources and a greater variety of policy tools. However, it has no competence on regulating lithium resources.

Coordination problems, however, have not only prevailed between government levels and departments but also among state actors, private firms and the scientific community. Many of the capability-building initiatives carried out by scientific institutions (Tables 1 and 2) tackle issues that are not defined as technological problems by mining companies. Sometimes this is because of the characteristics the current operating and environmental standards. For instance, companies have no significant incentives to reduce the use of water or waste disposal, or to alter their brine pumping practices, provided they comply with the current standards put in place by provincial government authorities. The lack of incentives in this field is stressed by the poor public knowledge about the hydrogeological dynamics and the water balance of the salt flats and aquifers surrounding them. Companies rarely release their technical balances, and datasets are incomplete (Flexer et al., 2018).

The sustainable exploitation of natural resources requires, compared to manufacturing activities, a better understanding of the environment (Iizuka and Katz 2010; Katz 2020). This issue has been acknowledged by the National Lithium Commission in Chile, which recommended conducting studies to improve the understanding on this matter (Comisión Nacional del Litio, 2015). In Argentina, the principal claims for stricter environmental regulations mostly come from indigenous communities and environmental organisations (Argento and Puente 2019). Nevertheless, this did not result in significant changes at a normative level.

In the same vein, the R&D projects oriented to improve the recovery of other elements contained in brines –e.g. magnesium, potassium, caesium or rubidium– do not gain priority from mining companies goal. This is explained by the current low market prices of some of these products (e.g. potassium), but also by the strategic focus of firms on lithium as the main value proposition of their business models. Governments have not shown great interest on this issue either. Although it has been highlighted that an integral exploitation of the salt flats would contribute to reduce the waste generated by evaporitic processes, the topic has not been considered a priority for provincial authorities. Here, again, the position of Argentine authorities contrasts with the recommendations by the National Lithium Commission in Chile, which advocated to improve the knowledge on the composition and reserves of other elements in the brines and to adopt measures for advancing a more integral exploitation of the salt flats (Comisión Nacional del Litio, 2015).

Another example of misalignment between linkage-development initiatives and governance rules regards the research projects on production techniques for lithium-rich pegmatite deposits. Here, the provinces with pegmatitic districts –notably San Luis and Córdoba– are reluctant to allow the exploitation of lithium within their territories. Consequently, it is highly likely that the patented technology developed by the UNCUYO, licensed to the Australian firm Latin Resources, will be used in lithium exploitation overseas.

The ability of science and technology government institutions to play a role as coordinating agents to plan technological missions, bringing together relevant stakeholder, is very limited. The organisation of the research system in Argentina gives researchers and doctoral students a great freedom to set their own agenda. The Ministry of Science, Technology and Innovation can exert influence by setting research grants terms and conditions. However, the budget for research and development activities is very limited and distributed among many projects without a clear strategic focus.

6. Conclusions

This study aims to contribute to the resource-based development literature by analysing initiatives adopted by Argentina to promote lithium-based linkages. Building upon the GPN heuristic frame, we attempt to understand the opportunities and challenges faced by these initiatives (Coe and Yeung 2015). The GPN framework provides tools to study the development implications of resource-based activities, thus overcoming the limitations of the “good governance” frame, which is focused on domestic normative issues such as revenues management, transparency, and accountability best practices. The GPN frame examines the potential to expand domestic value- and knowledge-creating activities by exploring the position of local operations in GPN structures, and how actors in the territory relate to GPN leaders. It also studies how norms, operating in different governance levels, affect the capacity of governments to promote development dynamics.

The expansion of the electro mobility industry generates pressures and creates conditions for investment and innovation in a wide range of activities along the LIB production network. However, we showed that policies directed to expand lithium-based backward linkages in the country have more potential than forward-linkage initiatives. This results from the combination of three factors: intrinsic determinants related to the pressures to set up a competitive exploitation process (Morris et al., 2012); pressures originated in the lithium-ion battery GPN to improve the productivity and sustainability of local exploitations as well as the quality of the raw materials; and the availability of local capabilities to address the location-specific features that characterise the exploitation of natural resources (Andersen 2012).

We also showed, however, that the potential of backward linkages is discouraged by the characteristics of the multi-level lithium governance frame. In particular, we point to the lack of a federally driven national lithium strategy, capable of creating an articulated strategic vision among relevant stakeholders operating in the country. There is a wide range of ambitious but weakly coordinated and poorly funded initiatives, ranging from extraction methods to battery recycling. Against the backdrop of severe budget constraints, linkage-development initiatives would highly benefit from the elaboration of a comprehensive and coherent policy agenda. This should be coordinated by the federal government and must be focused on the strategic issues with more potential to create linkages. This agenda should result from a collaborative process aimed to align the visions and interests of relevant stakeholders, including the federal and provincial governments, local and foreign firms operating in the country, and the scientific community.

The government has different options on the table. In 2014, some political actors elaborated a legislative project to declare lithium a national strategic resource (Fornillo, 2015b; Nacif 2015). Under this proposal, the provincial governments would lose control over lithium deposits and the granting of exploitation theconcessions would become the responsibility of a National Commission coordinated by the federal government. This project also envisaged the creation of a state-owned firm, which would have priority to buy the lithium produced in the country. In addition, it contemplated the creation of a national fund, endowed by lithium producing companies, to promote research and the localisation of downstream production activities in the country. The proposal entailed a major reform and failed to advance in Congress. It affected vested interests and faced opposition from a wide number of sectors, including provincial governments and private firms (Nacif 2015).

We believe that, in the short term, the federal and provincial governments have some tools that might face less resistance and would contribute to lay the foundations for a wide pro-lithium industrialization consensus. As shown by the case of JEMSE, there is some scope for provinces to impose conditions on lithium operators, based on their competence to grant licenses –i.e. they have some “sticks”. Likewise, stricter standards can be set based on environmental impact studies. These conditions could be oriented to promote industrial-university collaboration so that accumulated technological capabilities can be employed to develop production linkages.

The evidence presented in this article indicates that the fabrication of LIBs and their components should not be the main strategic goal for lithium producing countries. This approach, which is very popular among policy makers and within some sectors of the academic community in developing countries, is largely based on a conceptual frame that conceives the export of unprocessed raw materials as a barrier to economic development (Barandiarán 2019). However, there are several technological and market factors that put severe constraints on the ability of countries like Argentina to adopt an economically sustainable battery production strategy. The technological spillovers and commercial perspectives of the current project led by Jujuy Litio, the joint venture between the state-owned firm JEMSE and the SERI Group, seem to be limited. Furthermore, the liberal governance scheme in force in Argentina is detrimental for the development of forward linkages, where active policy intervention is a necessary condition –although not sufficient as discussed by Obaya et al. (2020). Whereas these restrictions are clear in the case of automotive LIB, it is possible that they are less stringent in other battery markets (for instance, stationary LIB). However, the forecast growth rate of these segment is much less attractive than that of vehicles (Pillot 2019). Also, there might be more opportunities in the production of lithium products for other industries[13] with less hierarchical GPN governance structures and less exposed to price-based competition.

The development of a strategic vision for lithium should focus on involving a large number of actors in resource-related innovation activities (Wright and Czelusta 2004; Morris et al., 2012; Halland et al., 2015; Venables 2016; López 2017; Katz and Pietrobelli 2018). This does not necessarily involve advancing towards downstream segments of the LIB value chain. Rather, it requires productive development policies and a strong innovation system (Lundvall 1992, Edquist 2005) capable of creating, adopting and diffusing knowledge-intensive links within the domestic economic structure.

Author statement

Martín Obaya: conceptualization, methodology, Investigation, Writing.

Andrés López: conceptualization, methodology, Investigation, writing, funding acquisition.

Paulo Pascuini: Investigation, Writing (review and editing), visualization.

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ANNEX I. Interviews conducted during fieldwork

Institution	Position
CIDMEJU	Organizing Director
	President
	Researcher
Clorar	Director
CONICET-FAMAF – UNC	Researcher
CONICET-INQUIMAE- UBA	Researcher
CONICET-UNCUYO	Researcher
Exar Mining Company	President
FIB-FAAM	President
INIFTA	Researcher
INTI - Jujuy	Coordinator
	Director
JEMSE	President
Jujuy Litio	Director
Secretariat of Mining and Hydrocarbons of Jujuy	Secretary
Secretariat of Science and Technology of Jujuy	Secretary
National Regulator of Electricity (ENRE)	Head of Regulatory Standards
Norlab	Director
SEGEMAR	Adviser
	Executive Secretary
	President
Institute of Geology and Mineral Resources of SEGEMAR	Director
Mining Technological Institute of SEGEMAR	National Director
SQM	Innovation Manager
UNJU	Professor
	Professor/Researcher
Institute of Geology and Mining - UNJU	Professor/Researcher
Y-TEC	General Manager

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[13] An analysis of different lithium uses can be found in Baran (2017).

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