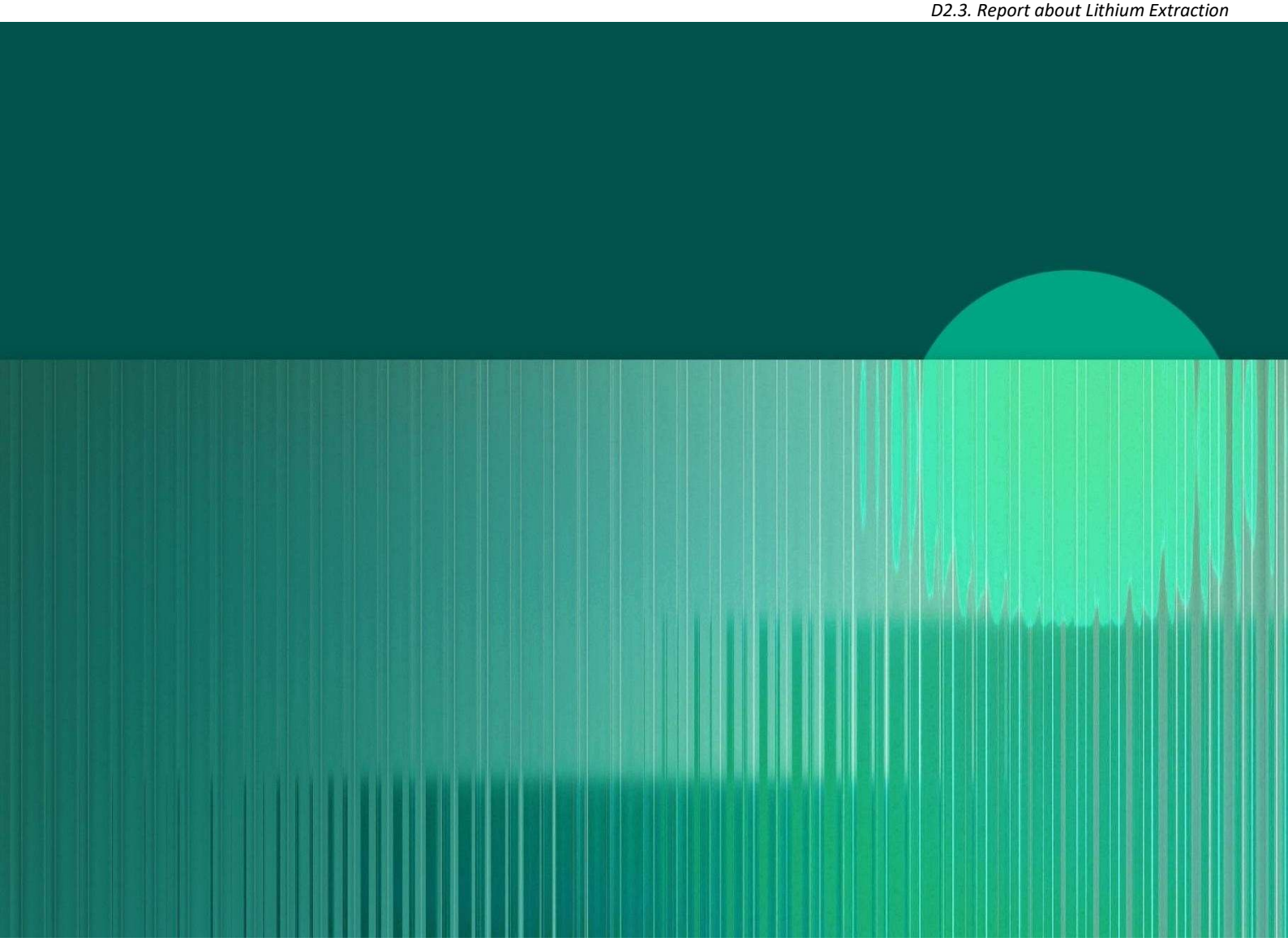

Report about Lithium Extraction (D2.3)

Research infrastructures cooperation for energy transition between European and Latin American and the Caribbean countries.

This project has received funding from the European Union's Horizon research and innovation program under grant agreement No. 101131725

Document Control Information

Settings	Value
Document Title:	Strategic Report for the Development of the Lithium Industry.
Project Title:	EULAC Energytran: Research infrastructures cooperation for energy transition between Europe and Latin American and Caribbean countries
Project Coordinator:	OEI
Deliverable leader:	CEUC (PUC)
Number and type of deliverable:	Document, report
Work Package number:	WP2
Doc. Version:	Version 1
Description:	Document explaining the elaboration of the report
Dissemination level:	Public
Date:	30/11/2025

Deliverable (webpage) Approver(s) and Reviewer(s)

All Approvers are required. Records of each approver must be maintained. All Reviewers in the list are considered required unless explicitly listed as Optional.

Name	Role	Action	Date
CEUC (PUC)	Deliverable leader	Elaboration	October 2025
General Assembly of the project	General Assembly of the project	Approve	November 2025

Deliverable (monograph) history

The Deliverable Author is authorized to make the following types of changes on the deliverable without requiring re-approval:

- Editorial, formatting, and spelling
- Clarification

To request a change, contact the Document Author or Owner.
Changes on the deliverable (inventory) are summarized in the following table in reverse chronological order (latest version first).

Revision	Date	Created by	Short Description of Changes
Draft 1	30/10/2025	CEUC (PUC)	Draft version
Version 1	10/12/2025	CEUC (PUC)	Final version included on the CEUC website: https://s3.amazonaws.com/assets.energia.uc.cl/Energytran_Strategic_Report_for_the_Development_of_the_Lithium_Industry_49a5d93887.pdf

Executive Summary

The report is specifically focused on the “Strategic Report for the Development of the Lithium Industry” and presents an analysis of the various impact factors that may define lithium production in Chile, Argentina, and Bolivia, such as technology, economics, and socio-environmental factors. This study, developed within the framework of the EnergyTrans project, evaluates the opportunities and limitations associated with emerging lithium extraction technologies, the evolution of governance and socio-environmental models in the countries that make up the Lithium Triangle, and the growing global demand for lithium as a result of the energy transition and its effects on local economies.

The document takes a multidisciplinary approach, combining a technical assessment of direct lithium extraction (DLE) technologies, a comparative analysis of public policies, and a review of the industrial strategies currently being promoted by the three countries. Its purpose is to understand how the region can increase its participation in the global battery value chain while ensuring environmental sustainability, social legitimacy, and long-term economic resilience.

For this reason, the report is organized around two main themes:

1. The potential of new extraction technologies such as adsorption, ion exchange resins, solvent extraction, and membrane systems to improve recovery rates, reduce environmental impacts, and increase competitiveness among producers in the region.
2. The institutional and regulatory conditions necessary to facilitate technology adoption, attract investment, strengthen local capacities, and ensure equitable distribution of the benefits associated with lithium development.

The content of the book can be structured into three main sections:

- The first section describes the global and regional context of the lithium market, including demand projections, technological trends, and the growing relevance of critical minerals in the energy transition.
- The second section presents the methodological framework of the study and analyzes current production systems, resource characteristics, and existing levels of technological readiness in the Lithium Triangle.
- The final section summarizes the main findings and formulates strategic recommendations to promote responsible development, strengthen sectoral governance, and advance regional cooperation.

The transition to cleaner energy systems will continue to increase the strategic importance of lithium. The future of the industry in the Lithium Triangle will depend on each country's ability to balance technological innovation, environmental protection, and social acceptance. Ultimately, a successful development model must combine economic opportunity, territorial sustainability, and inclusive governance, generating long-term value for both local communities and the region as a whole.

Process followed for the elaboration of the Strategic Report for the development of the Lithium Industry

In the analysis of the technological, economic, and regulatory evolution of the lithium industry in the Lithium Triangle region, a mixed methodological approach was adopted with the aim of understanding the dynamics, tensions, and possible trajectories that emerge around the activity of this industry. This approach combines the technical evaluation of extraction technologies, the analysis of public policies and industrial strategies, and the comparison between the institutional models of Chile, Argentina, and Bolivia.

The research, carried out between December 2024 and September 2025, was based on three main pillars:

1. Technical and environmental review of lithium extraction processes, both conventional and DLE, including adsorption, ion exchange, solvent extraction, and membrane systems technologies.
2. Institutional and regulatory analysis, focusing on governance frameworks, state participation mechanisms, industrialization strategies, and policy instruments associated with the energy transition.
3. Comparative territorial assessment, contrasting geology, water availability, environmental impacts, and models of relationship with local communities.

This approach made it possible to cover the different actors, perspectives, and technological and productive capacities present in the three countries. Unlike methodologies focused exclusively on commercial metrics or production statistics, this study prioritized the factors that determine the viability and sustainability of different technological and governance models.

Eight key areas of analysis were selected to examine the technological and strategic challenges facing the lithium industry in the region. These cases reveal differences in terms of resources, institutional capacities, and production strategies:

- Lithium extraction in Chile's salt flats (Atacama and Maricunga)
- Technological challenges of DLE in brines with high geochemical complexity (Argentina)
- State model of the lithium value chain in Bolivia
- Water use and water sustainability in lithium operations
- Energy transition associated with battery demand
- Projections for added value and local manufacturing of cathode materials
- Socio-environmental impacts and territorial governance in extraction areas
- Strategies for attracting investment and public-private partnership mechanisms

The selected cases reveal both common elements, such as the growing role of lithium in the global energy transition, and differences due to regulatory frameworks, resource characteristics, and production models adopted by each country.

The comparative approach has identified the factors that favor or hinder the adoption of new extraction technologies, as well as the conditions necessary to move toward more sustainable production models.

At the same time, the comparison between countries made it possible to define public policy recommendations aimed at:

- Strengthening sectoral governance
- Promoting technological innovation with sustainability criteria
- Improve coordination between levels of government and productive actors
- Foster the socio-environmental legitimacy of lithium projects in the region

Key aspects included in the Strategic Report for the development of the Lithium Industry

Understanding lithium development as a process involving technological, institutional, social, and environmental transformations, the study organizes its findings into an analytical framework with four central axes. These axes allow for addressing the complexity of the sector and the tensions surrounding lithium exploitation. The dimensions defined are: (a) technological axis, (b) governance axis, (c) social axis, and (d) environmental axis.

a) Technological axis: The technological axis examines the evolution, maturity, and viability of different methods of lithium extraction and processing, both in salt flats and other types of deposits. In the Lithium Triangle, geochemical and operational differences mean that the adoption of Direct Lithium Extraction (DLE) technologies is marked by opportunities, but also by significant technical limitations.

The study's analysis highlights:

- The need for a realistic Technology Readiness Level (TRL) assessment, due to the geochemical variability of brines
- The coexistence of traditional evaporation-based methods with emerging direct extraction technologies
- The importance of associated infrastructure (energy, water, transportation) in determining operational sustainability
- The strategic role of R&D in closing gaps in efficiency, recovery, and costs.

This axis shows that the lithium technology area will be diverse and will depend on incentives, local conditions, and industrial integration capacity.

b) Governance axis: Decisions on how lithium is regulated, produced, invested in, and distributed are one of the most decisive components of the sector's future. The study shows that the three countries have opposing institutional approaches, which generates differentiated opportunities and significant internal tensions.

Key aspects identified include:

- The definition of the role of the state in exploration, production, and value addition
- The conditions for attracting private investment, especially in high-risk technologies such as DLE
- The existence of clear mechanisms for capturing and distributing income to communities, regional governments, and development funds
- Coherence between industrial, regulatory, and production policies

Without robust, aligned governance that enjoys social legitimacy, the expansion of lithium risks reproducing inequalities between communities and losing opportunities for industrialization in the region.

c) Social Dimension: The social dimension addresses the impacts of lithium on communities and territories, the perceptions of different stakeholders, and tensions related to identity, well-being, and local development. Beyond the economic benefits, the relationship between lithium mining and communities is complex and heterogeneous.

The study identifies key elements for understanding these dynamics:

- The centrality of social license and its fragility in contexts of environmental uncertainty
- The coexistence of divergent imaginaries: lithium as a "historic opportunity", but also as an "ecosystem threat"
- Internal differences within the communities themselves
- The importance of considering cultural values, territorial practices, and meanings attributed to salt flats and high Andean ecosystems.

Incorporating this dimension not only allows for the interpretation of conflicts, but also for the design of more inclusive and legitimate strategies that are aligned with local expectations.

d) Environmental axis: All processes associated with lithium, whether by evaporation, DLE, or other methods, are subject to criticism regarding water use, the integrity of salt flat ecosystems, and resilience to climate change. The global energy transition creates a paradox: the need for critical minerals for decarbonization and, at the same time, pressure to minimize their local impacts.

The study's findings highlight:

- The water vulnerability of the ecosystems where the projects are developed
- The need to improve impact assessment tools, participatory monitoring, and transparency of hydrogeological data
- The tension between the global benefits of decarbonization and localized environmental costs
- Emerging debates around the concept of environmental damage, who defines it, and how it is mitigated or compensated.

The environmental axis shows that the sustainability of lithium will depend on the ability of countries to implement robust mechanisms for adaptive management and governance of ecosystems at risk.

Main conclusions and policy recommendations

One of the major challenges facing the countries of the Lithium Triangle in the coming years will be to develop this strategic resource in a manner consistent with global energy transition commitments and to make it com t with the urgency demanded by the climate crisis. As this study shows, moving toward a sustainable, competitive, and socially legitimate lithium development model requires meeting four fundamental conditions.

1. **Lithium development must be socially and territorially fair**: Distributional tensions between producing regions and urban centers, between local communities and state or private actors, between different socioeconomic groups, and even between generations are one of the main obstacles to the sustainable expansion of lithium. Any national strategy that aspires to consolidate itself must guarantee: Territorial equity in the distribution of benefits, clear mechanisms for citizen participation and consultation, and transparent processes that strengthen institutional trust.

2. **Lithium development must be environmentally sustainable**: Lithium is found in highly fragile ecosystems, where water use, hydrogeological stability, and biodiversity must be considered critical dimensions of the production process. The countries of the Lithium Triangle must ensure that their policies: minimize impacts on watersheds and salt flat systems, strengthen environmental assessment and participatory monitoring instruments, promote extraction technologies with a lower water and energy footprint, and are coordinated with conservation and adaptive management strategies.

3. **Lithium development hand in hand with economic stability and industrialization**: The energy transition based on critical minerals and renewable energies represents a historic opportunity for the countries of the Lithium Triangle. This study identifies that this opportunity will depend on: The ability to move toward greater value capture, shifting from the export of carbonate/hydroxide to the production of advanced materials; the consolidation of coherent industrial policies with clear incentives for innovation and investment; the creation of technological and productive links between the public, private, and academic sectors; and the establishment of national R&D capacities that reduce external technological dependence.

4. **Lithium development must guarantee economic and strategic security**: The current global scenario, marked by successive crises, geopolitical tensions, and fierce competition for critical minerals, has reignited concerns about security of supply and control of strategic value chains. In the case of lithium, this dimension is expressed in: the high geographical concentration of resources, dependence on a few players in critical stages of processing (refining), and growing technological rivalry between the major economic powers. Ensuring stability, predictability, and resilience in the supply chain requires stable regulatory frameworks, diversification of trading partners, long-term strategic agreements, and regional coordination to increase the bargaining power of producing countries.

Policy Recommendations

General recommendations to encourage technological innovation in the industry	General recommendations to strengthen industry governance and investment	General recommendations to improve social and environmental justice in the industry
Promote national technological development strategies that allow for the evaluation, testing, and adaptation of direct lithium extraction (DLE) technologies to the local characteristics of each salt flat.	Move toward a macro-financial regime favorable to green industrialization through tax incentives, innovation funds, and public-private co-investment schemes.	Fund scientific research to establish hydrogeological and ecosystem baselines in salt flats, especially in areas where data is insufficient or disputed.
Promote the creation of R&D ecosystems that bring together universities, technology centers, and companies to improve the efficiency, recovery, and sustainability of the process.	Consolidate stable, transparent, and coherent national regulatory frameworks to guide investment, reduce uncertainty, and strengthen the state's capacity for strategic decision-making.	Develop and implement land use planning criteria to regulate the installation of lithium projects, incorporating saturation thresholds, excluded areas, and cumulative impact assessments.
Promote regional cooperation as a guiding principle to strengthen bargaining power, share technical knowledge, and coordinate lithium industrialization agendas.	Ensure multilevel coordination mechanisms between the central government, regional governments, and communities to improve institutional coherence and the legitimacy of strategic decisions.	Guarantee independent, participatory environmental monitoring mechanisms with public access to information, strengthening the socio-environmental legitimacy of the sector.

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