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Original research article

What do frontline communities want to know about lithium extraction? Identifying research areas to support environmental justice in Lithium Valley, California☆

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ABSTRACT

Clean energy technologies provide global benefits through climate mitigation and many local environmental benefits for consumers. However, the supply chains that produce them inevitably impose some environmental burden on the communities where they operate. To align with the principles of environmental justice, the burdens and benefits of clean energy supply chains should be distributed equitably, with decision-making processes that empower local communities to participate. Academic research can play a key role as a source of transparent information that addresses the concerns of frontline communities; however, this requires deliberate effort during the initial stages of research to understand what those concerns are and seek data that will respond to them. As a case study, this article analyzes public meetings about a developing lithium industry in Imperial, California, and reviews relevant literature to build a research agenda that is guided by the priorities of local stakeholders. We find that water consumption, public health impacts, local employment, and opportunities to participate are high-priority topics for community members. We also compare the content of discussions across groups, finding that participants in community-focused meetings mainly asked about the local impacts of the process, whereas state-led discussions focused on the sustainability of direct lithium extraction compared to conventional production methods. To address the priorities of frontline communities, we recommend evaluating water consumption in the context of regional availability, including local air emissions and waste streams in sustainability analyses, and monitoring the impact on local employment over time to ensure the promises made during development accrue to communities.

1. Introduction

The fundamental approach of most climate change mitigation strategies is to generate electricity using renewable energy sources and decarbonize transportation with electric vehicles (EVs) powered by lithium-ion batteries (LIBs) [1–3]. While these strategies reduce dependence on fossil fuels, they rely on a different suite of minerals [4]. In particular, the central role of LIBs will significantly increase demand for lithium, cobalt, nickel, and graphite [4,5]. The mining and refining processes for these minerals present environmental burdens distinct from those associated with fossil fuels; therefore, attention to the life cycle of LIBs is necessary to predict and control supply chain impacts as they develop.

In this article, we focus on lithium, which is the only non-substitutable element in EV batteries. To supply the clean energy technologies needed to keep global warming under 2^{o} C, the World Bank estimates that lithium production will need to increase to nearly 500 % of current production levels by 2050 [5]. Projected lithium demand is

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reduced under transportation scenarios that favor public transit, active mobility, smaller vehicles, and high recycling rates [6]. However, even under the most optimistic assumptions regarding collection and material recovery rates, the projected volume of retired batteries only represents 38–60 % of the estimated total demand for lithium in 2040 [6,7]. As such, new lithium extraction sites and technologies will inevitably be needed to supply demand for zero-emissions transportation.

Commercial lithium extraction has historically occurred via mining hardrock minerals, such as spodumene or lepidolite, or by concentrating continental brines through evaporation [8,9]. Evaporation has a lower energy consumption than ore-based lithium production [10–12], however, it requires a significant amount of land, and by design must take place in water-scarce areas so rainfall will not slow down the evaporation process [13]. Although the brine is not suitable for agricultural or domestic use, the amount of water lost to the atmosphere over time can have substantial hydrological impacts on the salar systems from which brines are extracted [10,14]. The environmental impacts of lithium extraction, particularly water consumption, have led to increasing anti-mining activism in Chile, the largest producer of brine-based lithium [15], and have motivated research into alternative production methods with a lower environmental footprint [13,16].

One promising alternative is direct lithium extraction (DLE), a method of separating lithium from brine through chemical processing rather than relying on the slower process of natural evaporation [17]. DLE enables lithium recovery from lower-concentration sources of brine, including mineral-rich geothermal fluids that are already brought to the surface for energy production [18]. DLE has a smaller physical and water footprint than status quo production methods and can use energy from onsite geothermal power plants, resulting in lower carbon emissions [18,19]. However, DLE is an emerging technology, and most information about the process and its impact comes from the industry rather than peer-reviewed literature or other independent sources.

The development of new technology and resources presents an opportunity to avoid historically inequitable practices associated with the mining industry and support supply chains that are more consistent with the principles of environmental justice [20]. While there are numerous definitions of environmental justice theory, this article is based on a "trivalent" understanding of environmental justice encompassing distributive, recognition, and procedural justice [21,22]. Distributive justice questions how environmental burdens and benefits are distributed in a society, recognition justice asks whether all individuals and cultures are acknowledged and valued, and procedural justice considers who is able to meaningfully participate in decision-making processes [21,23–25]. The three are interrelated; for example, procedurally just public participation processes enable local communities to advocate for themselves, which may lead to a more distributively just allocation of burdens and benefits [21]. On the other hand, distributive injustice creates barriers that make it difficult for disadvantaged communities to participate in decision-making processes; for example, people from lower-income households may find it more challenging to attend public hearings because they are unable to take time off work, travel to the location, or find childcare.

Another related barrier to equal participation is knowledge asymmetry among stakeholders that influences the ability of different groups to participate in decision-making processes [26]. Upholding trivalent justice, therefore, requires providing accessible information about the anticipated impacts of a proposed development [27–29]. However, providing this type of information is constrained by knowledge gaps, such as incomplete data on public health and other local impacts across industrial processes, including lithium extraction [26,30]. In the field of science and technology studies, this is referred to as "undone science" and is primarily attributed to historical patterns of funding that reflect institutional priorities (for example, of government or private industry) rather than those of local communities [30]. Thus, it is not only a question of disclosing information that already exists, but of generating that information by studying the impacts of concern for local communities and learning from their lived experience.

Researchers analyzing environmental justice and the clean energy minerals supply chain have identified a need to expand the scope of analyses beyond greenhouse gas (GHG) emissions and cost/benefit analyses. Instead, these studies recommend a more holistic approach that evaluates the local socioeconomic and environmental impacts of supply chains [20,26,31–34]. In this article, we develop a research agenda about local impacts that will support environmental justice in the proposed development of a Lithium resource in Imperial County, California ("Lithium Valley"). To do so, we identify stakeholders' key concerns and priorities in a proposed Lithium extraction development using participant observation of community meetings and content analysis of public meeting transcripts. This analysis is complemented by a literature review of industry reports and peer-reviewed articles about the impacts of lithium extraction. The following questions guide our approach:

- What are the potential benefits and burdens of developing a lithium industry in Imperial County?
- What information exists about these impacts, and how are they represented in research about other lithium developments?
- How can these impacts be studied and communicated to empower all stakeholders to participate in decision-making processes and facilitate a just distribution of impacts?

On a practical level, we expect this analysis to support environmental justice in this specific development. However, this work is also intended to provide an example of how researchers can utilize public meeting records– a relatively unintrusive source of data– to connect their research with the perspectives of stakeholders who are underrepresented in academic literature. Furthermore, it may encourage standardized documentation of decision-making processes (i.e., recording and transcribing meetings) to aid future analysis. While we focus on lithium and DLE, balancing global and local impacts will be relevant to many other essential clean energy technologies, including wind, solar, and hydropower.

1.1. Lithium Valley

1.1.1. Background on the Salton Sea region

The Salton Sea is a saltwater lake in Southern California, approximately 40 miles North of the US/Mexico border in Mexicali. The Salton Sea Basin has filled and evaporated throughout history as the Colorado River naturally changed course [35]. The modern Salton Sea was formed in 1905 when the Colorado River breached a canal built by engineers [36]. Following this event, the water levels were largely maintained through agricultural runoff from irrigation in the surrounding valley. However, the lake level has been dropping in recent years due to evaporation and decreasing inflows, creating public health and ecological crises such as high incidence of respiratory disease and loss of bird and fish habitat [37]. The region has an extreme climate, with average high temperatures over 100F/38C for four months of the year [38]. Without mitigation, these crises will be exacerbated as the region gets even hotter due to climate change [39].

The Salton Sea is located between Riverside County on the North end and Imperial County to the South. There are approximately 180,000 residents in Imperial County, the vast majority (85 %) of whom are Hispanic or Latino, with 77 % speaking a language other than English at home [40]. However, this may be an underestimate, as Hispanic populations have historically been undercounted by the United States Census [41]. On the Northern end of the Sea, Mecca is the closest census-designated place, where 99 % of households speak a language other than English at home, and 39 % of the population is estimated to live in poverty [42]. Agriculture and education are the largest sources of employment in the region [43]. Since so many people work outdoors, air quality and extreme heat are of paramount concern. Unemployment rates are over 10 % higher in the region than elsewhere in California

[44].

Indigenous tribes have also occupied the region for millennia, with evidence of extended settlement, an extensive trail system, and exchange networks dating back to at least 1000 BCE [45]. Today, several tribes are culturally affiliated with the Salton Sea region, including the Quechan Indian Nation, the Torres Martinez Desert Cahuilla Indians, the Cocopah Indian Tribe, and the Kumeyaay Nation. The proposed developments are not located within Indigenous reservation territory, but the Salton Sea and surrounding environment have significance for the people who historically occupied the land. For example, there is a sacred site close to the geothermal facilities called Obsidian Butte, where Indigenous people sourced obsidian to make tools and use in religious ceremonies [45]. As such, the affiliated tribes expect to be meaningfully consulted on proposed lithium and geothermal developments.

1.1.2. Lithium and geothermal resources

The lithium resources are not in the lake itself but in the Salton Sea geothermal field, a deposit of high-temperature, mineral-rich brine thousands of feet below the surface near the Southern end of the lake in Imperial County. Currently, 11 geothermal power plants operate in the area, with a combined output of 340 MW (MW) [46]. Based on the brine's mineral composition, these facilities are estimated to have an annual throughput of 127,750 metric tons (MT) of lithium carbonate equivalent (LCE), which represents nearly eight times the quantity of US lithium consumption in 2019 [8,47]. Three companies plan to pursue lithium extraction as an addition to existing geothermal plants or by building a new geothermal and lithium extraction facility [48].

The deposit is considered one of the most promising sources of lithium brine in the United States (US) [18,47,49]. As the US and other regions look to maximize domestic production of critical materials such as lithium, there has been strong support for DLE from geothermal brine in the Salton Sea at a State and Federal level [50–52]. Major automakers have also announced their support for the development and engaged in contractual agreements to offtake lithium supplied by geothermal DLE [53]. However, the technology is still in the early stages, and the upcoming planned developments will be at the pilot scale.

In September 2020, the California Governor signed AB 1657, which convened a Blue-Ribbon Commission of 14 appointees charged with "reviewing, investigating, and analyzing certain issues and potential incentives ... regarding lithium extraction and use in California" [54]. The Commission, known colloquially as the 'Lithium Valley Commission' (LVC), comprises representatives from various state agencies and levels of government, the geothermal industry, community advocacy organizations, an environmental organization, and the tribal councils of two Indigenous communities [55]. The Commission's final report was released in November 2022.

2. Methods

We used content analysis of public LVC meeting transcripts and townhall style community meetings to identify the most relevant impacts to stakeholders in this development. Content analysis refers to the systematic coding and analysis of documented communication. It has been used extensively across disciplines for diverse purposes, including understanding the focus of a group or institution, and identifying themes and trends [56–58]. Environmental researchers have deployed content analysis of public meeting minutes to understand stakeholder engagement and perspectives [59–61].

Next, we reviewed the available information published by the industry via sustainability reports [62], environmental impact reviews [63], and patents [64] to establish a baseline of information about the potential impacts. Finally, we performed a literature review of peer-reviewed articles about lithium extraction to identify gaps and best practices that can inform future research.

2.1.1. Data sources for content analysis

2.1.1.1. Lithium Valley Commission. Publicly available transcripts from nine Lithium Valley Commission meetings (February through October 2021) were downloaded from the California Energy Commission website [65]. The meetings were held monthly from 1:30–5:00 pm. Due to the COVID-19 pandemic, all meetings took place virtually using a webinar format, with an option to hear simultaneous interpretation in Spanish. Beginning in May 2022, the meetings were hybrid, with four locations offering the option to attend an in-person livestream. Typically, the meetings consisted of discussion and updates from the commissioners, followed by presentations on pre-defined topics by invited speakers, with opportunities for public comment following each agenda item. Public comment is limited to three minutes per speaker. The meetings were recorded, transcribed, and posted to the LVC's webpage [54].

2.1.1.2. Community meetings. To further understand the concerns and priorities of residents who live near the development, a researcher attended seven community meetings. Three were organized by the Leadership Counsel for Justice and Accountability, a community-based environmental justice organization that works with communities in the Eastern Coachella Valley [66]. As the meetings were not recorded, the researcher and organizers both took detailed notes to record the questions asked by participants. In addition, questions were tabulated from four community forums held by the LVC, one in November 2021 and three in October 2022 after the Commission's draft report had been released. Details about the purpose, format, attendance, and questions asked during each meeting are included in the supplementary materials.

2.1.2. Thematic coding

A list of themes related to specific environmental and socioeconomic impacts and community engagement was developed based on literature about environmental justice and social responsibility in mineral extraction (Table 1). Frequent points of discussion during LVC meetings and questions from community meetings were then categorized within the themes identified where applicable or into new themes if they had not emerged in the literature review. After developing the final list of themes, we selected associated keywords and coded the LVC transcripts using the text search function of Atlas.ti (Table 1). The text was coded

Table 1
Thematic codes and associated keywords from transcripts of the Lithium Valley Commission and community meetings.

Topic	Keywords	Source
Air quality	Air, dust, particulate matter, PM, NOx, SOx, ozone	[67]
Waste stream	Waste, byproduct	[13]
Climate	Climate, carbon, greenhouse gas, GHG, CO2, global warming	LVC
Local ecology	Ecosystem, habitat, conservation, playa, restoration, species	[31]
Water	Water, acre feet, gallon	[14,68,69]
Seismicity	Seismicity, seismic, tectonic, earthquake, San Andreas	Community meetings
Emergency plan	Emergency, worst case scenario, disaster	Community meetings
Public health	Health, healthcare, illness, disease	[70]
Infrastructure	infrastructure, broadband, rail, road	[71,72]
Employment	Employ, employment, jobs, workforce, training, skilled, unemployment, union	[71]
Housing affordability	Housing, cost of living, affordability, property value	[71], Community meetings
Community engagement	Participation, community engagement, outreach, procedural justice	LVC, Community meetings

using the "or" operator, including the inflected forms for each keyword. For example, the code "air quality" was applied to all lines containing "air" or "pollution" or "local emissions" or "dust" or "particulate matter" or "criteria pollutant." Finally, the corresponding coded text and questions were explored and an additional subcode was applied based on the context in which they were mentioned. The full codebook including logic for assigning contextual subcodes and results for each subcode is provided in the supplementary material.

2.1.3. Literature review

To understand how these topics are addressed in peer-reviewed articles about lithium extraction, we performed a keyword, abstract, and title search on Scopus, using the search protocol:

- ("lithium" AND "extraction" OR "lithium" AND "production) AND ("life cycle assessment" OR "environmental impact")
- ("lithium" AND "extraction" OR "lithium" AND "production) AND ("social impact" OR "social LCA")

The initial search yielded 285 results for environmental impacts and 28 for social impacts, which were screened based on the title. We excluded articles about reuse and recycling, the technical performance of different materials or production pathways, and non-lithium LIB materials (e.g., articles about graphite production). As there was a high degree of overlap in articles between the two searches, we combined the resulting list. These were reviewed by abstract and introduction to exclude articles about LIBs that did not include the impact of material extraction. Additional articles were identified following in-text citations, yielding 104 articles in total, which were categorized based on the type of analysis (e.g., social impact, LCA) and product of focus (e.g., lithium, electric vehicle, cathode, etc.). Of these articles, 21 analyzed or discussed the impact of lithium extraction separately. We assessed how, if at all, these articles addressed the impacts of interest to stakeholders in Lithium Valley to identify examples that could be emulated in this development, as well as gaps.

Our literature review is consistent with others that have found that most studies assessing the environmental impact of LIBs focus on the global impacts, such as GHG emissions and benefits, rather than the local impacts of mining [26,73]. Furthermore, while there is a rapidly growing body of literature assessing the sustainability of LIBs and LIB-powered products such as EVs, research on the impact of specific minerals is much more limited.

3. Results

In this section, we present high-priority topics that emerged from the content analysis: water, public health, employment, and infrastructure. We first describe how stakeholders discussed them in different contexts and explore what information is available from industry-reported data. Next, we analyze how these issues are addressed in articles about lithium based on our literature review.

3.1. High-priority topics

The local community's highest priorities were water ($n = 16$), public health (n = 16), and employment (n = 16), as indicated by the number of questions asked. Meanwhile, the LVC's most frequently discussed topics were water ($n = 295$), employment ($n = 260$), and infrastructure ($n = 95$), as indicated by the word count analysis (Fig. 1).

3.1.1. Water

For both groups, water was the most frequently mentioned environmental topic. However, the two groups discussed water in different contexts (Fig. 2). Community members mainly asked about the source of water that would support DLE ($n = 5$), the quantity of water consumed by the process ($n = 4$), and whether DLE would impact local water quality ($n = 2$). By contrast, the LVC mainly discussed water in the context of regional policy and management, such as water rights allocation and required permits ($n = 124$). Where the LVC discussed consumption, it was primarily to highlight the sustainability of DLE ($n = 62$) more so than to explain its expected water consumption ($n = 30$).

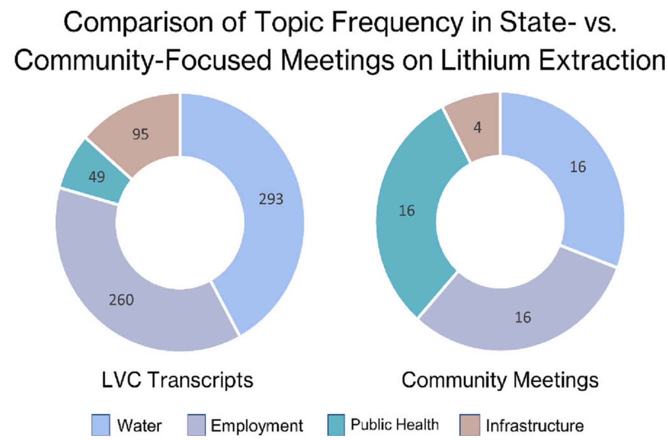

Fig. 1. Comparison of topic frequency in state-led vs. community-focused meetings. The numbers refer to associated keyword mentions for LVC transcripts and related questions for community meetings.

According to the Draft Environmental Impact Report (DEIR) for one of the proposed lithium extraction sites, the expected consumption for the facility is approximately 340 cubic meters (m^3) per hour for cooling and processing during operation, or slightly over 4 million m^3 per year [63]. To put this in perspective, alfalfa for cattle feed is one of the region's primary commodities, and the industry consumes approximately 1.1 billion m^3 of water per year (alfalfa consumes six acre-feet per acre, with over 150,000 acres harvested annually [74,75]. The facility's expected annual production is 20,000 MT LiOH, indicating a consumption rate of approximately 238 m^3/MT LCE. Another company has proposed a goal of 190 m^3/MT LCE [76]. Representatives from each company indicated during the LVC meetings that they would recycle water during their process, but as the technology for both DLE and water recycling is still under development, it is difficult to estimate the reductions that could be achieved through recycling.

DLE will not use groundwater or water from the Salton Sea. The source of brine is from geothermal reservoirs several thousand feet below ground, and process water will be purchased from the local utility's supply of surface water from the Colorado River [63,77]. Groundwater in the region is not suitable for human consumption or irrigation due to its high salinity [75].

In peer-reviewed literature, the water consumption of producing lithium through evaporation has been studied through the lens of life cycle assessment (LCA) [10,78] and local impact analysis [14,15,79,80]. Kelly et al. [10] evaluate consumptive use of freshwater resources using company data for a commercial operation in Chile. Consumptive use refers to water that is used during production and not returned to the freshwater system because it is evaporated or contained in the final product. They do not include brine, as it cannot be used for human activity, and they do not include process water that is recycled. Meanwhile, Schenker et al. [78] calculate a water scarcity footprint using the available water remaining (AWARE) method, a weighting system in LCA that uses regional characterization factors to represent the potential to deprive another user of water [81]. Liu and Agusdinata [14] take a different approach, modeling the stress resulting from changes in groundwater depth for agents who live near lithium extraction sites in Salar de Atacama, the largest site for production of lithium in Chile. In particular, they focus on the stress from water drawdown and vegetation drying depth. These studies all represent lithium production using pumped groundwater, rather than surface water from a river. The fact

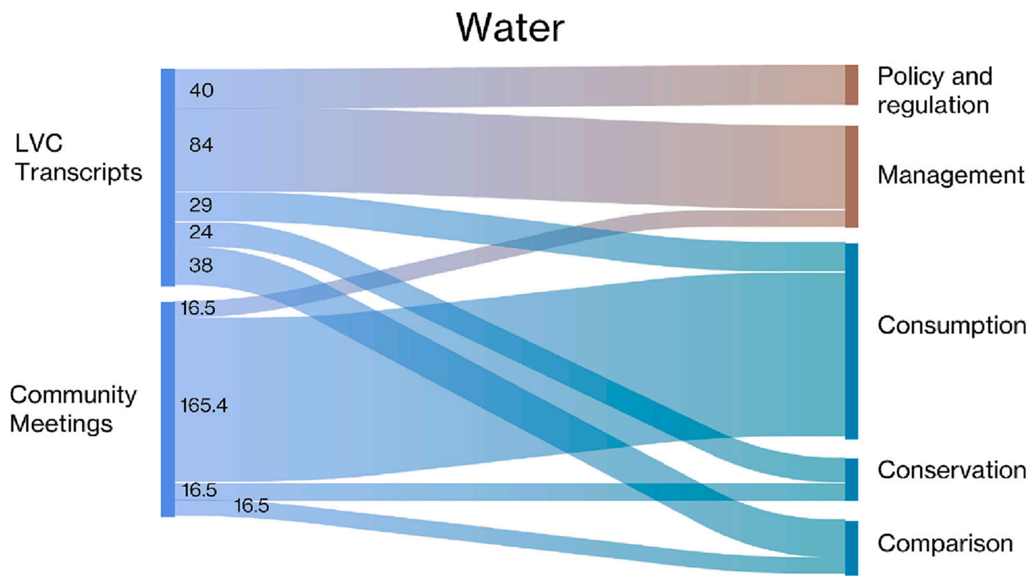

Fig. 2. Breakdown of how water was discussed in community-focused and LVC meetings, normalized by the total number of coded quotations in each document group.

that DLE in Lithium Valley would use surface water may avoid issues related to groundwater availability and the local watershed; however, it means the industry and surrounding communities may be vulnerable to water scarcity due to drought that reduces flows from upstream states.

3.1.2. Health

Participants in community forums asked about the impact of lithium and geothermal energy production on respiratory health, the byproducts generated by the process, whether the properties of lithium impact public health, and how health impacts would be monitored. In four meetings, participants commented that public health was non-negotiable and not an acceptable trade for money or employment; as a public commenter stated during the LVC's community forum, "jobs don't fix the health issue" [82]. Meanwhile, mentions of health-related keywords were lower in the LVC compared to topics like infrastructure or employment. Discussions of health mainly related to the existing regional public health situation ($n = 14$), mechanisms that protect public health such as permits and regulatory oversight (n = 14), and the potential to help address the public health crisis (Fig. 3). For example, tax revenue could fund improved public health infrastructure, or new facilities could mitigate dust by paving over exposed lakebed.

There is no available information about the potential health implications of DLE in the region, as the environmental impacts are still being quantified and have yet to be translated into human health impacts. As a starting point to build on for future analysis, we investigate two relevant environmental impacts in the DEIR: air quality and hazardous materials.

- Waste stream/hazardous materials: Participants in both community meetings ($n = 2$) and the LVC ($n = 21$) asked questions about the waste stream from DLE and management of byproducts. While DLE enables most byproducts to be reinjected into the brine reservoir, the impurity removal process precipitates silica, iron, and "lesser concentrations of arsenic, barium, and lead" [64]. Other minerals such as zinc and manganese may also be recovered from the brine if it is

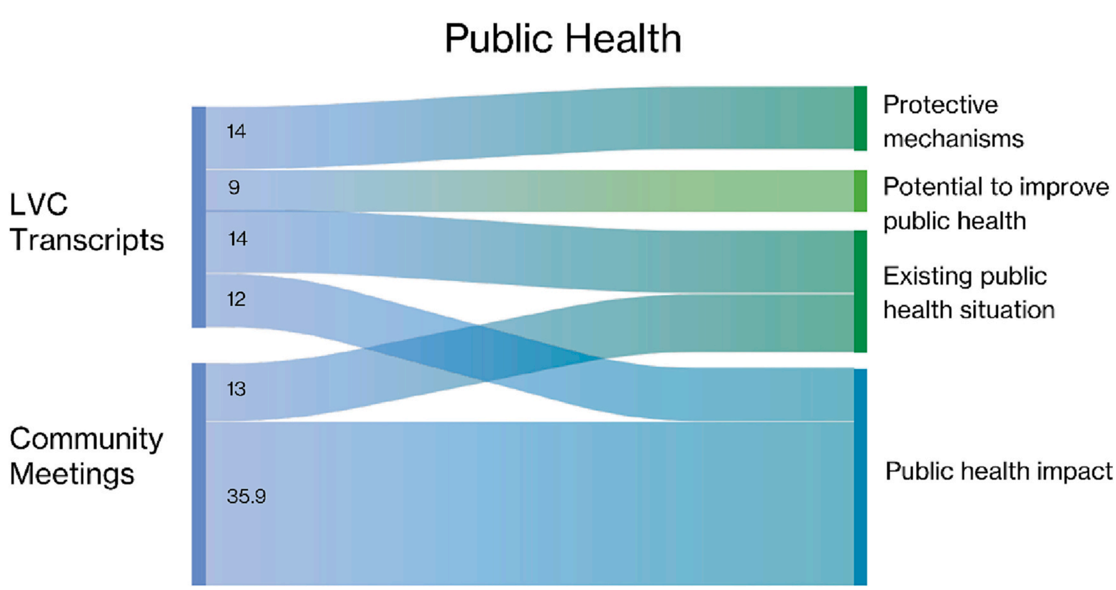

Fig. 3. Breakdown of how public health was discussed in community-focused and LVC meetings, normalized by the total number of coded quotations in each document group.

economically feasible, and Salton Sea geothermal operators have made attempts to do so in the past [83]. According to the available DEIR, approximately 136,200 MT of iron-silicate material will be processed annually for a facility producing 20,000 MT LiOH. This material will be tested and disposed of at one of several facilities depending on whether it exceeds California's hazardous waste thresholds; the DEIR estimates that up to 10 % of trucks carrying waste from the process would be delivered to a waste treatment facility in Arizona. There are also requirements and plans in the DEIR for onsite storage of byproducts and waste. Assuming the waste is handled in accordance with local guidelines, this implies that the main local environmental impact in terms of waste would be due to traffic, rather than leakage of hazardous materials.

- Air quality: The DEIR estimates criteria pollutant emissions during construction and operation for the pilot facility, which are under the local air district's significance thresholds. The main sources of air emissions are operational vehicles, stationary equipment, and trucks that will travel in and out of the project area on a daily basis. The Salton Sea Air Basin is currently in nonattainment of criteria pollutant levels for Ozone and PM_{10} according to the California Air Resources Board [84]. The air quality issues are primarily attributed to toxic dust that is exposed as the Salton Sea recedes, emissions from agricultural burning, and traffic at the US-Mexico border crossing in the city of Calexico [85,86]. Regularly monitoring air quality near new developments starting prior to construction is recommended to ensure that DLE is not creating an additional burden, and to so that air quality issues from other sources are not incorrectly attributed to lithium extraction.

Of the articles returned by our search protocol, six mentioned public health in the abstract [78,87–90]. All were LCAs or high-level sustainability assessments, with all but one focusing on LIBs or LIB materials rather than lithium specifically. Public health is modeled in LCA by including human toxicity potential, particulate matter formation, and SOx/Nox emissions as impact categories. For instance, Arvidsson et al. [87] quantify the health impacts of a LIB cell in terms of disability-adjusted life years to identify hot spots and measures to avoid or mitigate the use of problematic materials. However, their focus– and indeed that of most articles that include the health impacts of LIBs– is on cobalt, a material used in some cathodes that is associated with serious toxicity and human rights abuses. Our search did not return any articles that focused specifically on the local health impacts of producing lithium.

Additionally, while our search returned articles about the waste stream of end-of-life LIBs, the management of waste generated during the mineral extraction phase was not generally included. One exception is Kosai et al. [91], who include mine tailings in in their analysis of land disturbances from mining activities; though again, their focus is on non-lithium battery materials with greater land disturbance footprints, such as copper. Schenker et al. [78] present methodology to calculate waste output stoichiometrically based on the brine composition; however, they do not include waste production in their LCA because it would mainly consist of discarded salts that are not expected to have significant environmental impact for the possible impact categories. The lack of attention to local waste streams points to difficulty in capturing certain local concerns in high-level analyses like LCA.

3.1.3. Employment

Employment represents an area of alignment between the two groups (Fig. 4), although it was a relatively higher priority in the LVC than in community meetings. The focus for community members was whether the industry would hire locally and what resources and training programs would be available to ensure residents were qualified (n = 10). Additional questions were about the safety and quality of jobs (n = 3), how many jobs would be created (n = 3), and whether undocumented residents would be eligible for employment and professional development opportunities (n = 1). The LVC primarily discussed the workforce needs of the lithium and geothermal industry (n = 74), as well as the training and development of local capacity (n = 88). Commissioners pointed to training programs through the local community college and labor union apprenticeship programs as potential avenues for workforce development. The Commission also discussed job creation (n = 66), including ancillary jobs in supporting industries such as food services, logistics, battery cathode production, and restoration. A related topic was job quality (n = 44) and whether the industry would create temporary or permanent jobs, union jobs, safe working conditions, and benefits.

Both groups also brought up the local community's experience with previous industries. In community meetings, residents commented that previous industries had promised employment opportunities that had not been realized (n = 2), a sentiment echoed in the LVC (n = 19. The commissioner representing a local EJ organization explained that the promised job creation had primarily consisted of temporary

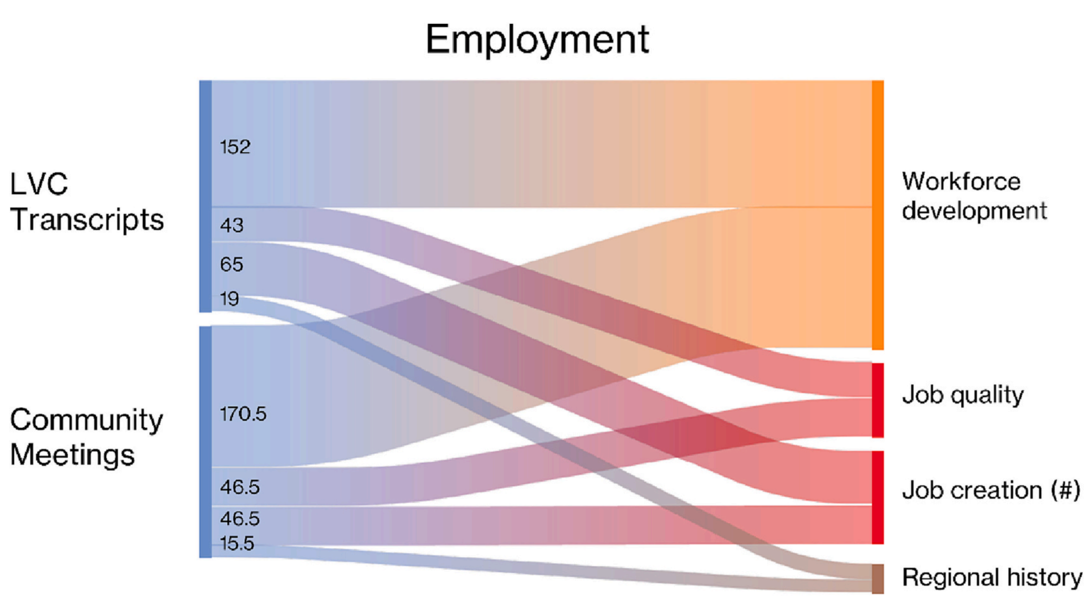

Fig. 4. Breakdown of how employment was discussed in community-focused and LVC meetings, normalized by the total number of coded quotations in each document group. The figure illustrates an alignment in how both groups discussed employment-related topics.

construction and/or lower-paying jobs and thus did not meaningfully benefit the community as advertised. In the case of solar energy, the developments used public incentives and displaced agricultural land, effectively displacing a more reliable source of employment.

Our literature review returned several studies that include employment and socioeconomic impacts. Liu et al. [15] used company reports and census and internal migration data to examine the complex employment impacts of the lithium industry in San Pedro de Atacama, Chile. They analyze whether jobs are created for the local population vs. an imported workforce. This would be a valuable research direction for the Salton Sea given that supporting a local workforce is a high priority. Another method to include socioeconomic considerations is through social life cycle assessment (S-LCA), which evaluates the impact of a product or system across different stakeholder and impact categories [92]. In research about LIBs, S-LCA has been deployed to identify hotspots with the greatest risk for social harm, for example, due to child labor or occupational hazards (e.g., [93]). However, it can also be used to address the operations of a specific company or component material such as lithium carbonate. S-LCA could address stakeholder priorities in this development by analyzing the facility-level production of geothermal energy and lithium hydroxide, including the following impact categories (Table 2).

A potential benefit of implementing this type of analysis is that it would enable structured comparison between different production pathways. This could facilitate more accountability in global lithium supply chain practices and incentivize companies to adopt behaviors that may have higher costs, but create more benefits for the surrounding community, e.g., paying their employees a living wage.

3.1.4. Infrastructure

In community meetings, participants asked what infrastructure would be built due to lithium production ($n = 2$) and what would happen if the area was reclassified as an industrial zone ($n = 1$). They also mentioned the need to improve roads in the region (n = 1). The LVC discussed the infrastructure needs of the lithium industry ($n = 57$) and the community ($n = 27$), noting areas that could be mutually beneficial. For instance, the industry will require improved roads, which could improve mobility in the region. Industry representatives highlighted a need for improved internet access, which was previously identified as a local issue, particularly during the COVID-19 pandemic when students faced disproportionate challenges accessing online learning [94]. The LVC also discussed the potential for Lithium Valley to become a supply hub for LIBs by co-locating value chain production infrastructure, which would offer environmental and strategic benefits.

Co-locating production enables a lower environmental footprint for the resulting product through reduced transportation, which represents an estimated 10 % of the energy and GHG burden of LIB production [10], and the ability to maintain precursor chemicals in liquid form instead of heating to dehydrate for shipment, then rehydrating. However, the benefits of co-locating production have not been quantified explicitly. Domestic LIB cathode production would also be beneficial from a circular economy perspective, as materials recovered through recycling could be domestically refined and reused in battery production instead of being exported internationally [7]. On the other hand, residents expressed concern about the impact of the area being designated as an industrial zone, which could create an influx of traffic and pollution from production and warehouse infrastructure.

Table 2
Recommended categories for a social LCA about lithium and geothermal production in the Salton Sea region.

Stakeholder category	Relevant impact subcategories
Worker	● Freedom of association and collective bargaining ● Fair salary ● Health and safety ● Social benefits
Local community	● Access to material resources ● Delocalization and migration ● Safe and healthy living conditions ● Respect of indigenous rights ● Community engagement ● Local employment ● Secure living conditions

3.1.5. Other themes

Several other prevalent topics were discussed in one or both settings:

- Geography of Lithium Valley: A frequent topic of discussion in later meetings was the need to define "Lithium Valley," and specify which communities would be eligible for benefits such as workforce development programs and tax revenue ($n = 9$). Multiple people made the point that the benefits should be concentrated in areas that will experience the greatest environmental burden. This suggests a need to analyze environmental impacts with attention to their spatial distribution and identify measures to make the benefits accessible to the communities that will be most impacted.
- Local ecology: The community asked about the impact of lithium extraction on the soil ($n = 1$), and how lithium extraction could support the restoration of the Salton Sea (n = 1). The LVC primarily discussed ongoing restoration efforts in the region ($n = 48$), including the importance of the geothermal and lithium industry complementing those efforts ($n = 30$).
- GHG emissions: The LVC discussed the strategic role of lithium and geothermal in meeting California's climate goals.
- Seismicity: The community asked about the impact of lithium extraction on the San Andreas fault ($n = 2$).
- Finally, participants at community meetings asked about the impact a new industry could have on the cost of living ($n = 1$), and what the "worst-case scenario" for an accident at an extraction facility might be (n = 2).

3.2. Community engagement and tribal consultation

There were 27 questions or comments in community meetings regarding community engagement; specifically, how the community could be involved and what voice they had in the process ($n = 15$), and requests for accessible information and third-party research (i.e., studies that are not conducted by industry) ($n = 12$). These comments included requests that community engagement events be more conversational and devote more time to listening to community members, rather than following the standard LVC meeting format of presentations followed by limited opportunity for public comment. Participants in multiple forums expressed a need for more information about the environmental impacts of DLE. They suggested several approaches to make the information more accessible, such as using graphics and analogies and sharing information in a shorter format via different social media platforms.

As a public body, the LVC was subject to transparency laws requiring the meetings to be publicly noticed. All documents presented or discussed during LVC meetings were posted to a publicly available docket, and the meetings and documents were translated into Spanish beginning in May 2021. The LVC also held several in-person community forums during the evening to enable broader participation. Local community advocacy organizations (Comite Civico del Valle, Alianza Coachella Valley, and Leadership Counsel) participated in the LVC-related events and helped distribute information to residents. There will be additional opportunities to participate during the environmental permitting process, which includes a public review and comment period. This is an example of state-led participation among various established methods for pursuing just outcomes in planning processes. One identified strength of this approach is ensuring that the community's voice is heard, while potential challenges include loss of trust if the process is perceived to be unjust or unresponsive to community concerns [98].

A relevant research direction is evaluating to what extent laws intended to facilitate public participation, tribal consultation, benefits-sharing, and environmental protection uphold the principles of procedural justice. Our literature review returned one instructive example; in an article about lithium extraction in Argentina, Marchegiani et al. [95] assess whether relevant laws "effectively support indigenous communities in taking part in decisions on extractive industry development on their territories, as opposed to merely allowing them to participate in a process already limited to a predetermined set of development options". The authors provide an overview of the legal landscape governing extractive industries in Indigenous territory in Argentina, particularly ILO Convention 169, and discuss two case studies about its implementation that are informed by interviews with Indigenous community members. The community members they interviewed expressed several barriers to free, prior, and informed consent. For instance, the information provided was highly technical and presented in dense, inaccessible formats such as lengthy reports. Furthermore, the information was provided by the industry, using language that emphasized benefits and minimized burdens. The authors reflect that extractive industries define which communities they consult with and the terms of engagement, giving them disproportionate power to shape community-industry relationships. Similar studies would be a valuable pursuit in Lithium Valley to support ongoing procedural justice.

4. Discussion

In terms of distributive justice, DLE has the potential to benefit the local community by generating employment and providing a source of revenue that could help address existing challenges in the region, including public health and the restoration of the Salton Sea. The industry would also require transportation and telecommunications infrastructure upgrades that are needed in the area and could improve internet and mobility access. Meanwhile, the potential burdens related to environmental impacts are mainly associated with increased traffic from trucks delivering supplies and transporting outgoing shipments of products and waste. Another critical environmental issue is water consumption. While the process is not expected to interact with groundwater, it represents a new source of demand for Colorado River water, which could create tension with competing uses if current water scarcity issues continue.

A baseline of information exists to address many stakeholder questions because of the permitting process required under the California Environmental Quality Act (CEQA). Any company operating in the area must prepare a publicly available environmental impact report that estimates impacts on air quality, biological and cultural resources, energy, soils, hydrology and water quality, greenhouse gas emissions, and hazardous materials [96]. There are additional requirements for specific environmental impacts. For example, any hazardous materials must be contained in protected spaces and disposed of at a licensed facility; plans for this are outlined in the DEIR [63].

The fact that some information is available from EIRs demonstrates the benefit of sourcing materials from regions with strict environmental regulations. At the same time, this information is only available from industry-sponsored studies. Requiring industry-reported data is consistent with the principle of evidential equity, an aspect of procedural justice specifying that the burden of proof about the safety of facility siting rests with the developer [27,97,98]. However, the data may not be transparent or trusted by community stakeholders. As third-party sources of information, researchers at academic institutions and national labs can play a valuable role by validating the findings of such reports and monitoring ongoing impacts (Table 3). Meanwhile, research about employment, education, and housing affordability could transparently validate positive impact, identify improvement opportunities if benefits fall short of what was promised, or proactively mitigate potential issues as they arise.

Table 3
Research recommendations to support environmental justice in the lithium supply chain.

Topic	Research recommendations	Examples
Water	Use AWARE weighting to incorporate regional scarcity in LCA	[78]
	Estimate and communicate impact on regional water availability	[14]
Health	Monitor and communicate air emissions and waste management	
	Translate environmental impacts to human health impacts as data becomes available	
	Include human toxicity impacts in LCA about lithium and LIBs	[87]
Employment	Validate local hiring practices by comparing company reports with census data about migration and employment	[15]
	Conduct social LCA of lithium production that includes impact categories related to living wage, worker safety, local employment, safe and healthy living conditions, and respect for indigenous rights	[92]
Community engagement	Use case studies to identify and overcome challenges in the implementation of laws intended to protect indigenous communities and facilitate public participation	[95]
Other	Include the local impact of delivery trucks in environmental analysis. This information is required for EIRs but rarely included in peer-reviewed impact assessments.	
	Delineate the spatial concentration of environmental impacts so the communities that will experience the greatest impact can be prioritized in benefits-sharing agreements	

Most peer-reviewed articles focus on the GHG implications of LIBs or end-use technologies, such as EVs or stationary energy storage, rather than on the local impacts of specific battery minerals. Where local impacts such as health are analyzed, it is mainly to identify hotspots and avoid problematic materials on a global scale. These are valuable areas of study to support the urgent goals of reducing GHG emissions from the transportation sector and minimizing burdens from the supply chain. However, the lack of focus on the local impacts of lithium makes it challenging to respond to stakeholders' questions and indicates that the perspective of local stakeholders is not well represented in high-level discussions about decarbonization pathways. We recommend the following research areas to incorporate the priorities of the local community:

It is important to note that EIRs and peer-reviewed articles alike are typically difficult for members of the public to access; the DEIR source used in this article is a technical report that is over 1000 pages long and was prepared mainly with local agencies and policymakers as the intended audience. Enabling meaningful participation requires sharing information generated by such studies in accessible formats, with ongoing opportunities for multilateral communication between the State, industry, tribal governments, community members, and community and environmental advocacy organizations.

5. Conclusion

We analyzed public meetings about lithium extraction to elevate the perspective of local stakeholders and identified research that would respond to their questions, intending to advance environmental justice in the development of Lithium Valley. We find that water, public health, employment, and infrastructure are the highest priority impacts for stakeholders involved in the development of DLE in the Salton Sea Region, and stakeholders in both the LVC and community meetings vocalized the importance of community engagement and transparency.

The two groups were aligned regarding the importance of hiring locally and developing the capacity of the local workforce. However, there was a greater emphasis on public health in community meetings compared to the LVC. While both groups frequently mentioned water, community members asked how much lithium extraction would consume and where the water would come from. In contrast, the LVC mainly discussed water availability and the sustainability of DLE compared to alternative production methods.

The existing challenges in the region inform the promise LVC participants see for lithium to uplift the community, while also contributing to increased concern and skepticism on behalf of some community members. For example, unemployment rates are significantly higher in the region than elsewhere in California, which informs the LVC's emphasis on employment and workforce development [44]. At the same time, the experience of the local community with previous industries informs their skepticism regarding the promise of employment. Meanwhile, public health in the Salton Sea region is characterized by severe respiratory issues, which motivates significant concern regarding any impacts on air quality. As a result, careful consideration and communication of public health implications are vital for any new development in the region. These findings illustrate the importance of situating potential impacts within the local social, political, and environmental context.

To align with the principles of environmental justice, the community's questions regarding the public health impacts, water consumption, and waste stream would need to be answered transparently prior to development, which is challenging given the nascency of DLE technology and the desire by businesses to retain proprietary secrets about their technology. A baseline of information is available from industry reports because of California's environmental protection laws. However, further research is needed to generate third-party information about the air emissions, waste streams, and water consumption of DLE, and evaluate the impact on local employment and housing affordability. Additionally, EIRs do not evaluate public health impacts. Another valuable area of study would be analyzing the State-led community engagement and tribal consultation process in greater detail to identify barriers to participation and evaluate the ability of communities and Indigenous groups to shape the outcome of a proposed development, including whether all parties agree that free, prior, and informed consent is upheld during the planning and development process.

The priorities and recommendations identified by this paper are based on content analysis of public state-led meetings and community-focused meetings. The advantages of using content analysis in this capacity are twofold; first, compared to surveys or interviews, it does not place an additional burden of time or effort on stakeholders who are already voicing their opinions in other forums. Second, it may be more easily utilized by scientists in traditionally quantitative disciplines who seek to connect their research with marginalized communities. One limitation is that relevant, publicly accessible meetings may not be available in other developments. Another limitation is that the views expressed in community-focused meetings may represent the most outspoken residents, rather than the community as a whole.

The key contribution of this method is systematically codifying and publishing the perspectives of stakeholders who may not otherwise be formally represented in academic literature and have therefore been excluded from the scientific process by not being citable. This facilitates future analysis that will address the most important issues for frontline communities rather than relying on questions previously identified by academic research or policymakers. While we focus on lithium and DLE, the importance of balancing global and local impacts will be relevant to many other essential clean energy technologies, including wind, solar, and hydropower.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: MS and MLW participated in meetings whose transcripts were analyzed. Their participation did not have a material influence on the results.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2023.103043.

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