Integrating Water, Energy, and Climate Change: Irrigation Modernization in Chile's Elqui Watershed

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Abstract

This research critically analyzes socioenvironmental dynamics surrounding the water-energy-climate change interface in Chile's Elqui River Valley, located in the semi-arid Coquimbo Region. Specifically, the project investigates processes linked to irrigation modernization, an emerging phenomenon aimed at addressing water allocation inefficiencies, rescaling operations, and incorporating renewable energy in water-dependent landscapes. Irrigated agriculture is a key driver of water and energy provision practices. However, Chile's water and electricity codes operate within separate legal frameworks, despite the increasingly codependent nature of these resources. Consequently, disparities exist between national policies and empirical outcomes in a water-scarce environment, creating tensions that are being exacerbated as climate change impacts manifest. Chile is attempting to alleviate these incongruities through adaptive and integrative water/energy decision-making, central components of emerging national legislation, specifically the Energía2050 Initiative and National Climate Change Action Plan. Still, landscapes such as the Elqui Watershed are being shaped by disparities between power concentration from the neoliberal agribusiness complex, enshrined in the current constitution, and operating at the expense of small-scale entities and natural resource conservation. Such trends are a result of inconsistencies between national policies and on-the-ground socioenvironmental patterns interrogated in this project.

The research seeks to understand such paradoxes by critically investigating how irrigation modernization reflects broader systems and ideologies surrounding water and energy resource management. Globalized agribusiness, highly developed through Chile's irrigated central corridor, has supported substantial socioeconomic growth.
However, existing market models are being disrupted by rapidly accelerating water scarcity

and energy insecurity despite initiatives promoting a transition toward democratic and sustainable resource governance. To date, little evidence supports the discourse of a comprehensive movement. In fact, Chile is still largely reliant on large, centralized power generation and water diversion to support mining and heavy industry. When analyzed through a lens of scalar interplay, *agriculture, and hydropower* represent salient examples of the interrelated dynamics of water, energy, and climate change that are at the forefront of resource policy. Irrigation practices demand significant water and energy, yet also reflect landscapes of opportunity to implement efficiency strategies and increase infrastructural resilience. However, a severe lack of empirical evidence limits understanding of how these adaptations are developing and how outcomes for stakeholders are playing out. Therefore, this research is grounded in a theoretical framework that meshes elements of scale, energy geography, and political ecology to analyze nuances that are emerging throughout a rapidly shifting watershed. This approach seeks to build on previous scholarship looking at uneven dynamics of resource provision under neoliberal economic models and dominant Chilean public policy, applying such principles to a new phenomenon.

A suite of mixed methods is employed to holistically understand the complexities underlying relationships between stakeholders including environmental organizations, governmental representatives, irrigation district managers, local agricultural entities (both large and small), regional scholars/scientists, and water user associations. Takeaways will help advance insights into the role of modernized irrigation in mitigating climate change impacts and either supporting or disrupting existing power structures within the watershed. Such discoveries can help inform the greater landscape of water and energy governance in agricultural regions across the globe as climate change impacts accelerate.

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Dedication

Thank you so much to my family and friends for their love and support during a challenging and circuitous path toward completing my degree. This project was a fulfilling experience that consistently tested my endurance and resolve. To Mattias, thank you so much for traveling to Chile to help make the fieldwork a successful and fun process. Exploring the Atacama and Andes was a highlight of my international fieldwork experience. To my best friends, you guys mean the world to me and have shown up time and again, I'm so grateful for you all. To my parents, I love you so much and am ever appreciative of your belief in me every step along this journey. To the people of the Coquimbo Region, thank you for accepting me into your land with open arms and sharing your beautiful stories, I learned more than I ever could have imagined.

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1.9 Introduction

Before I returned to the Elqui Valley of Chile's Coquimbo Region to complete fieldwork in May of 2022, Social Convergence Party candidate Gabriel Boric won the national presidential election, ushering in a progressive and leftist agenda for the first time in eight years. During his acceptance speech, Boric was quoted saying "if Chile was the cradle of neoliberalism, may it also be the grave" (Gómez-Barris, 2022). I was fascinated at how closely these words resonated with my project because neoliberalism became a central research theme as the dissertation initially took shape in 2019. As I explore the water-energy-climate change interface through irrigation modernization, such economic models loom large (Panez et al., 2020). Enacted during the military dictatorship of Augusto Pinochet in the early 1980s, Chile's water (CWC) and electricity (CEC) codes were crafted specifically to promote free market-based, anti-regulatory policies designed to stimulate economic growth and limit social welfare programs (Budds, 2018; Burgos, 2017). These political configurations were foundational in supporting a robust agricultural sector, active in the global market despite insecure and diminishing water resources (Bauer, 2009; Borzutsky & Madden, 2013). In fact, the CWC represents the world's only constitutionally enshrined doctrine designating water as a fully privatized commodity (Donoso, 2017). A particularly important corollary to these institutional structures is that irrigated agriculture comprises approximately 84% of freshwater use, and 30% of electricity demand throughout the country (Jordan et al., 2023). Although the sector continues to grow, Chile is already facing alterations to water and energy security stemming from the fact that it is the most climate change-susceptible nation in Latin America, and one of the most vulnerable in the world (Urquiza & Billi, 2018).

In recent years, limited environmental policy reforms, an aggressive approach toward renewable energy growth, and attempts to incorporate integrated watershed management have manifested (Behmel et al., 2018; Pizarro et al., 2022). Meanwhile, however, core neoliberal pillars remain intact, hindering democratized resource transitions and indicating deep institutional embeddedness (Araújo, 2014). The latest example was a rejection of a constitutional charter in September of 2022 that would have radically shifted governance models toward a progressive socioenvironmental justice-oriented agenda (Nicas, 2022). Despite three years of dialogue in response to social unrest, this legislative failure reinforces the enduring influence of Pinochet-era policies (Araújo, 2014). With water, energy, and climate change at the crux of key governance issues, Chile clearly continues to struggle to disentangle from existing political and economic structures, despite ambitious efforts to reform governance models toward human and environmental justice (Panez et al., 2020). The unique intensity of this paradox playing out in Chile is particularly relevant at a time when more regions across the globe are beginning to face stress to vital water and energy resources, a crucial issue Chile is already confronting (Londoño, 2017).

Spending time in Chile revealed complex relationships with neoliberalism. Free-market capitalism has supported economic growth and human development index criteria yet also carried socioenvironmental byproducts that are increasingly rebuked by the Chilean people (Borgias, 2018; IndexMundi, 2018). Protests erupting in 2019 expressed grievances against wealth inequality, which had grown to the highest rates in Latin America (Sehnbruch & Donoso, 2020). Grassroots movements against large-scale hydropower projects have further illustrated how public sentiment has grown intolerant of top-down capitalistic systems (Maxwell, 2017; Nelson, 2013). Thirst for change began to coalesce around the Boric administration, able to establish a coalition government, thus opening the door to draft a constitutional charter carrying the potential for Chile to shift governance models (Benedikter & Zlosilo, 2022; Harrison, 2022). The legislative process represented a unique window of opportunity to reform neoliberal structures incompatible with transformations towards a renewable and more inclusive energy/water governance landscape as climate change impacts accelerate (Urquiza et al., 2018). However, such systems have proven challenging to dismantle in the past, as core economic activities such as mining, heavy industry, and cash crop exports remain lucrative in the global capitalistic economy and are reliant on deregulated free markets (Panez et al., 2020). For example, in April of 2022, a new series of reforms to the CWC was enacted yet fail to proactively address still-increasing demand, despite diminishing water security. Such outcomes reinforce the level to which the global capitalistic economy infiltrates resource governance, despite new attempts toward democratically oriented transitions (Bridge et al., 2013: Harrison, 2022).

Water and energy governance are situated at the center of institutional reform in Chile (Valdés-Pineda et al., 2014). Because climate change impacts are growing rapidly (particularly through increasing water scarcity and energy prices), there is a critical need to transition away from fossil fuels while identifying pathways toward adopting clean energy technologies and upgraded infrastructure to support water security (Bremmer, 2019). Among the areas hardest hit by climate change is the Coquimbo Region, situated in the central-north section of Chile. The semi-arid landscape is experiencing an ongoing 13-year megadrought, impacting agricultural activities that comprise the backbone of the economy (Álvarez, 2018;

Montecinos et al., 2016; Novoa et al., 2019). The drought has impacted regional water supply at unprecedented levels, as precipitation has declined by upwards of 90%, ultimately prompting rationing measures for crop cultivators (see Figure 1.1) (Rosenberg, 2022).

Figure 1.1 Embalse Puclaro Dam in the Elqui Valley showing low water levels (Source: Author)

I chose to study this region after identifying the distinctive features of water governance, renewable energy potential, and severe vulnerability to climate change. Further, Coquimbo plays host to a rare convergence of hydropower, solar, and wind capacity, representing an uncommon concentration of each major renewable energy source (Weston, 2018). Because of these characteristics, Coquimbo represents a bellwether region for understanding the rapidly shifting water, energy, climate change interface in the 21st century (Liu, 2016).

During fieldwork around Coquimbo, conversations with local stakeholders illuminated how the population is exceedingly aware of an impending crisis unless adapted resource management is engaged. Although the region has experienced noteworthy socioeconomic growth from strong agricultural and mining sectors, the exploitation of water resources is reaching a tipping point (Pizarro et al., 2022). Alongside overallocated surface waters and increasing urban demand, unregulated and energy-intensive groundwater pumping has expanded substantially, primarily accredited to mining operations surrounding headwater ecosystems (Oyarzún et al., 2019). Mitigating such imbalances will require a fundamental shift in how water and energy are used, and this is recognized across governmental institutions, civil society, and portions of the private sector (Šteflová et al., 2021). Lacking, however, is a coherent pathway that will minimize disruptions to basic needs while supporting continued economic security (Pizarro et al., 2022). Through research focused on contrasting national legislation with on-the-ground dynamics and watershed-scale analysis, potential pathways for better practices can be identified (Nagel & Ptak, 2022). Takeaways may be applied not only to the Elqui Valley but to watersheds across the globe that are being impacted by increased water and energy insecurity, yet reliant on the agricultural sector (Novoa et al., 2019; Sovacool & Walter, 2019).

Around the Elqui Watershed, irrigated fields, produce markets, and the cultural presence of an agriculturally centered landscape are ubiquitous. Meanwhile, governmental campaigns and sociocultural symbols promoting resource conservation also permeate the landscape. The reality of a future with less water seems to be gaining acceptance, yet strategies behind adaptations, not to mention shifting dynamics of winners and losers are less apparent (Baka, 2017; Jordan et al., 2023). Through interviews with key stakeholders, environmental scientists, and government entities around the Elqui Basin, it became evident that elements of a resource transition are underway (Sareen & Haarstad, 2018). Nonetheless, narratives and perspectives on specific mechanisms for change range drastically and reveal a complex landscape where coordination is encumbered by competing actors, inconsistent governance models, and uncertainty about the magnitude to which climate change will disrupt the status quo (Stang et al., 2018). Despite efforts from academic institutions, environmental organizations, civil society, and a growing sector within governmental bodies, the landscape shows extreme inertia and embeddedness that is only just recently beginning to be addressed (Araújo, 2014).

1.2 Research Topic

Climate change presents the most critical challenge facing humanity in the 21st century. Outcomes already accelerating include disruptions to water and energy security (Sovacool, 2014). Mitigation efforts and resilience building will require creative and sustainable initiatives. At this stage, however, social science research analyzing interrelated issues across water and energy systems is underdeveloped, limiting the scope for creating efficient and sustainable solutions (Araújo, 2014). Irrigated agriculture, comprising approximately 70% of global freshwater allocation and 30% of electricity demand is situated at the center of these dynamics (Scott et al., 2014; Panez et al., 2020). Research addressing core dimensions of irrigation practices and associated processes can and must play a key role in shaping the future direction of a dynamic water-energy-climate change interface (Wiegleb & Bruns, 2018).

To advance an understanding of pressing issues linked to water, energy, and climate change, this research critically examines irrigation modernization and associated processes in the semi-arid Elqui River Valley of Chile’s Coquimbo Region (Salas et al., 2018). Chile’s National Irrigation Commission (CNR) has identified technification projects as a crucial strategy to alleviate resource security challenges in the 21st century (Errázuriz, 2019). However, most of Chile's irrigation infrastructure remains antiquated and inefficient (Vicuna et al., 2014). Overall estimated evaporation losses are about 50% despite the expansion of drip technology to replace flooding or center pivot systems (Jordan et al., 2023). Irrigation modernization seeks to mitigate climate change impacts by upgrading existing infrastructure, thereby enhancing water and energy efficiency (see Figure 1.2).

Figure 1.2 Contrast between conventional irrigation practices and core components of a modernization project (Source: FCA, 2021).

Further, these efforts seek to spatially rescale existing water and energy systems towards self-sustaining microgrids, increasing resilience at local and watershed scales (Jonas, 2006; Montedonico et al., 2018). The Elqui Basin in Chile's Coquimbo region, however, reflects an intensely managed water market and complex corresponding energy grid, functionally characterized by neoliberal economic systems increasingly common across the highly globalized agricultural sector (Novoa et al., 2019; Urquiza et al., 2018).

While market-based economic models have—under certain conditions—supported wealth creation and increased agricultural activity, growing social inequalities and environmental consequences are a common byproduct and must be considered (Panez et al., 2020). Chile represents a salient example of these structures, as the only country in the world with privatized water systems codified in the national constitution (Burgos, 2017). Through analysis of socioenvironmental dynamics and processes shaped by irrigation modernization, this research seeks to develop fresh insights into complex relationships coupling water security and energy transitions (Arnold et al., 2010; Bridge, 2017). The study also aims to holistically evaluate the capacity, and prospective effectiveness of modernization practices in mitigating the effects of climate change in a semi-arid, highly managed water and energy network (Pizarro et al., 2022).

Leading climate models project Chile will experience upwards of a 45% reduction in freshwater by 2040, representing the greatest value among Latin American countries (World Resources Institute, 2018). These desertification rates are even higher in the semi-arid or arid north, where the recent drought has caused as much as a 90% reduction in precipitation and snowpack from historic levels (Pizarro et al., 2021). Moreover, despite hosting considerable renewable energy resources, utility prices remain among the highest in the world, contributing to nationwide protests in 2019 (Bremmer, 2019). Consequently, Chile's federal government (under the new progressive administration of Sebastian Piñera) is seeking to recraft legislation aimed at addressing over-allocated surface water, groundwater, and spiraling energy prices (Urquiza et al., 2018). A central mechanism includes new policies promoting the democratization of natural resource control and access, alongside integrated watershed management (Novoa et al., 2019; Peña, 2018). However, neoliberal-based market models remain deeply embedded in the landscape, resulting in the continued growth of resource demand despite diminishing energy and water security (Budds, 2004). Meanwhile, national legislation has often been disconnected from on-the-ground dynamics that commonly take place at community or watershed scales (Borgias, 2018). Therefore, irrigation modernization presents an opportunity to help alleviate these problematic trends through a range of sociotechnical upgrades aimed at reducing inefficiencies and environmental impacts across energy grids and watersheds (FCA, 2021). Primary components of irrigation modernization projects include piping formerly open canals, installing in-conduit hydropower, enhancing aquatic species protection, and improving systemwide efficiency/resilience (Oyarzún et al., 2008). To holistically evaluate the potential effectiveness of these projects, the first research question is as follows:

2. **What examples of irrigation modernization are present in the Elqui River Watershed, how are they addressing energy and water resource security, and where are there gaps that are yet to be filled?**

Furthermore, 'modernization' is contextually sensitive, and characteristics of such processes are embedded within unique political, economic, and sociocultural organizational structures. Thus, despite an increasing presence of modernization projects, particularly in water-stressed regions such as Coquimbo, the nature of associated processes are complex and remains largely unexamined. Socioenvironmental dimensions are especially relevant because prevailing Chilean market models and neoliberalism have contributed to the marginalization of disempowered groups and the degradation of proximate ecosystems. In response to the lack of critical analysis surrounding the role of uneven power structures influencing outcomes of modernization projects, the second research question is as follows:

3. **How are the benefits and adverse outcomes of irrigation modernization projects distributed between irrigation stakeholders in the Elqui Valley?**

At the forefront of resource governance is the fact that Chile is attempting to continue administering neoliberal models, namely the CWC, CEC, and agricultural law 18.450, with initiatives aimed at improving social and environmental equity, specifically the National Action Plan for Climate Change (PANCC) and the Energía2050 Initiative. Although understanding the outcomes of each of these dynamic policies across the natural resource landscape would be unattainable, scaling down the question to see how reforms of doctrines mirroring the CWC in the United States offer a powerful lens for understanding how policy change can lead to outcomes more aligned with the new Chilean government's goals. Therefore, the third research question is as follows:

4. **How can differences between the Chilean Water Code (CWC) and the United States Clean Water Act (CWA) pertaining to the dam-irrigation nexus inform policy decisions for reforming water and energy governance?**

To assess the research questions, this project applies a convergent parallel design methodology (CPDM), a novel approach for combining qualitative and quantitative data collection and analysis (Creswell, 2013). The CPDM process began with Spanish-to-English translation and assessment of key policy documents alongside participant observation. Both methods were engaged during preliminary fieldwork in the Elqui Watershed in the summer of 2019. Next, initial data collection, specifically water rights ownership, irrigation allocation, land use change (particularly renewable energy development), and watershed governance document analysis were undertaken to inform key themes and identify stakeholders for semi-structured interviews. My established network in Chile includes several water and energy experts in the Coquimbo Region, most notably my formal affiliation with Dr. Pablo Álvarez, a distinguished Agronomist who directs the Laboratory for Analyzing, Monitoring, and Modeling Agricultural and Environmental Resources (PROMMRA) research program at the University of La Serena. Professor Álvarez serves as an external committee member for this research project. During field-based research, I was able to work in the PROMMRA lab (see Figure 1.3) which facilitated access to key stakeholders such as environmental organizations, hydroelectric dam managers, large and medium-scale irrigators, local farmers, water user association (WUA) representatives, regional government, and members of the regional academic/scientific community.

Figure 1.3 The Lab for Analyzing, Monitoring, and Modeling Agricultural and Environmental Resources (PROMMRA) at the University of La Serena (Source: Author).

I then conducted semi-structured interviews with a comprehensive range of actors, which informed a deeper understanding of socioenvironmental dynamics and processes shaped by irrigation modernization. Moreover, the interviews elucidated socioenvironmental system dynamics and the watershed's particularities within a broader water-energy-climate change nexus (Stang, 2018: Wiegleb and Bruns, 2018).

Following qualitative data collection and analysis, key discoveries informed areas to target for quantitative data collection and analysis, with a specific focus on examining climate trends and corresponding geographies of the irrigation landscape (Scott et al., 2014). A CPDM methodology facilitated data collection and analysis necessary to evaluate the successes and failures of modernization projects and their effectiveness in mitigating climate change impacts (Onwuegbuzie, 2012). The suite of mixed methods supports a broader legal-based investigation and determines where, why, and how benefits and adverse outcomes of irrigation modernization are distributed while evaluating the implications of empirical outcomes (Baka, 2017; Burke & Stephens, 2018).

Key takeaways from this research will help develop pathways for cooperation amongst often competing groups (Montedonico et al., 2018; Nanduri et al., 2013). Such research is increasingly relevant, as integrated watershed management is promoted by the Chilean government and leading researchers yet hindered by path dependencies inherent in neoliberal agribusiness models (Behmel et al., 2018; Araújo, 2014; Panez et al., 2020; Peña, 2018). As irrigation continues to be a major driver of water and energy use, this research can help respond to ongoing challenges by analyzing both biophysical and socioenvironmental landscapes and dynamics (Arnold et al., 2010; Budds, 2018). This project supports decision-making tools for addressing systemic inefficiencies and inequalities through integrated planning and collaboration between stakeholders (Urquiza et al., 2018) and is positioned to make contributions across increasingly relevant, yet understudied fields in human-environment scholarship.

1.3 Research Objectives

This project advances understanding of key issues at the forefront of human-environmental geography research, critical social science, and interdisciplinary water-energy-climate change nexus scholarship. The following objectives are pursued to gain a holistic understanding of irrigation dynamics and socioenvironmental outcomes for key stakeholders throughout the Elqui Watershed:

- To identify key examples of irrigation modernization projects throughout the Elqui Basin. This process includes a critical analysis of how climate change outcomes, particularly increased water insecurity are disruptions to existing water and energy systems and present opportunities for building more resilient and efficient infrastructure. Opportunities and barriers are identified to provide a guidebook that can be distributed to environmental organizations, individual farmers, municipalities, regional governments, or WUAs, considering irrigation modernization projects.
- To situate irrigation modernization in the Elqui Valley within the transitioning global water and energy landscape. Particular attention is paid to decision-making behind such projects and whether they disrupt or reinforce existing power structures. Particularities and to nature of modernization in the Elqui Valley are compared with other regions. Comparisons are evaluated based on technical dimensions as well as the spatial distribution of benefits and impacts.

- Conduct a legal analysis and translate the Chilean Water Code (CWC), analyze sections 401 and 404 of the United States Clean Water Act (CWA), and carry out a legal review of key case law to evaluate differences in legal mechanisms for hydropower reform, democratic resource governance, integrated watershed management, and other policies that are purported as priorities by the Chilean government. This will help determine how on-the-ground circumstances are being influenced, to what extent changes or occurring, or whether path dependencies continue to hinder transitions to policies focused on social and environmental equity.

1.4 Theoretical Context

This research is theoretically grounded in a framework synergizing elements of energy geography and political ecology, conceptual bodies that situate human-environment relationships in spatial dynamics. Elements of energy geography scholarship are relevant because they concern the production of space, and systems of resource acquisition alongside uneven development (Huber, 2015). Related, political ecology centers on political and social drivers of environmental change, such as energy or water governance (Wiegleb & Bruns, 2018). Critical analysis of decision-making processes shaping irrigation modernization is embedded within power structures that exhibit spatial and temporal dynamics (Späth & Rohracher, 2010). Consequently, fusing elements of these theories provide a congruent approach to investigating the research questions. Both theoretical approaches offer a relevant lens for critically analyzing specific ideologies which informed the four primary national policies to be evaluated in this project: the Chilean Water Code (1981); the Chilean Electricity Code (1982); Energía2050 (2015); and the National Climate Change Action Plan (PANCC) of 2017. These policies configure the political-environmental relationships that drive systems of energy production, distribution, and consumption at multiple spatial scales (national, regional, local, and watershed) across the Chilean landscape (Zimmerer, 2011). Further, they will play a key role in the reforms anticipated to be enacted in the drafting of Chile's new constitution (Yajima, 2022).

Political ecology is a theoretical framework concerning relationships coupling systems of uneven capital accumulation and social dimensions of space (Zimmerer, 2016). Commonly described as nature-society relationships, these phenomena interact throughout networks of biophysical landscapes hosting valuable resources and political power structures competing for control (Neumann, 2009). For example, the Elqui Watershed hosts finite water resources that are sought by stakeholders with a range of interests and power (Pizarro et al., 2022). Political ecologists commonly shed light on these inequalities to advocate for ecological conservation and social justice (Brenner, 2001). Energy represents a significant conduit of such flows between human and environmental landscapes because natural resources such as coal, oil, gas, wind, sun, and others create value for a society based on how energy potential can be captured and then converted for human use (Raugei et al., 2018). Commodification is configured within economic systems, leading to arrangements of energy provision that are inherently political, creating winners and losers based on embedded structures of power, agency, and influence (Baka, 2017; Robbins, 2012).

Energy (and by extension many water) systems are inherently spatial, informed by territorially bounded relationships coupling biophysical characteristics and social assemblages that influence specific values placed on resources (Baland & Robinson, 2012). Emerging energy geography literature considers social phenomena and political power through spatially uneven, contested, and constantly changing spatial outcomes (Harrison &

Popke, 2017). Critical social science research is engaging with space as a distinct and dynamic agent, driving and being driven by socioenvironmental dynamics that interact throughout systems of resource provision (Huber, 2015). For example, irrigation modernization in the Elqui Valley is shaped by: (water rights, access to electricity, representation from WUAs on the political side) and (annual streamflow, renewable energy generation, and climate change impacts on the ecological side). Understanding these dynamics necessitates critical analysis to determine how the spatial distribution of resources is balanced among these often-competitive factors (Birkenholtz, 2009). Attention to spatial relationships will reinforce the ways energy and water systems represent complex webs of power-laden interaction, rather than simple cause-and-effect relationships (Bridge, 2017).

Elements of energy geography scholarship integrate well with political ecology literature by spatializing power structures that drive nature-society interactions (Budds, 2018). Used cooperatively, these concepts can help reveal how neoliberal institutional systems have driven incongruities between economic development and environmental health (Borgias, 2018). For example, national policies promote models that use privatization as a mechanism for optimizing efficiencies of water and energy use, despite social and ecological byproducts (Budds, 2004). In Coquimbo, political ideologies that informed the CEC and CWC have influenced a complex resource distribution network, incorporating market-based models for growing pisco and wine grapes plus other commodities central to the economy of the region (Urquiza & Billi, 2018). Privatization has tradeoffs, as commercial-scale agricultural and hydropower development are prioritized, while energy/water conservation and resource democratization are suppressed (Novoa et al., 2019; Proaño, 2018). Although transitions in the region are emerging, renewable energy or integrated watershed projects struggle with path dependencies, because both the political and physical landscape has been shaped by the market model (Araújo, 2014; Behmel et al., 2018; Peña, 2018). These existing structures favor multinational investment, and continued resource extraction, rather than promoting the shift towards democratization articulated in Energía2050 and the PANCC (Lane, 2014, Urquiza et al., 2018).

Specifically, scalar dynamics within political ecology and energy geography literature are critically analyzed to shed light on the ways natural resource provision, driven by uneven power structures, incur disproportionate socioecological impacts across space (Bridge, 2017; Robbins, 2012; Walker, 2005). These frameworks have been informed and shaped by geographers, as a growing body of literature correlates nature-society relationships with outcomes resulting in unequal access to vital resources, namely water and electricity (Baka, 2017; Bridge, 2017; González-Eguino, 2015; Huber; 2017). Energy geography and political ecology align with core elements of human-environment relations because they interrogate spatial outcomes stemming from interactions between political systems and ecological impacts based on commodities of value (Lane, 2014). For example, access to energy and water are fundamental human needs, yet they are entrenched within interactive networks coupling political systems and natural resource governance (Burke & Stephens, 2018). Chile's commodification of natural resources concurrently increases and decreases access for different demographics based primarily on access to capital and socioeconomic status, rather than proximity to sites of production, or sociocultural ties to the land and its natural resources (Baka, 2017). Therefore, situating these theoretical bodies within this research can help elucidate how the politics behind decision-making both drives and is driven, by spatially sensitive nature-society connections (Huber, 2017).

The global proliferation of neoliberal economic systems represents the dominant driver of contemporary energy provision networks because access to capital, deregulation, and free markets have facilitated mass production, distribution, and access to previously isolated frontiers of energy/water resources (Budds, 2004). Traditional forms of energy such as petroleum may fit neatly within neoliberal models, as they rely on major capital investment and global transportation corridors facilitated by free markets (Bradshaw, 2010; Huber, 2015). Emerging energy and water technologies, however, particularly renewables, are respatializing resource landscapes and challenging the durability of neoliberal systems (Pasqualetti, 2011; Pasqualetti & Brown, 2014). For example, household-scale solar is localizing energy use and shifting demand curves from existing traditional facilities (Hansen & Coenan, 2015). Concurrently, however, this technology is dependent on rare earth mineral extraction, primarily from the global south, and international supply chains, which operate at the heart of neoliberal systems (Sovacool, 2014; Undurraga, 2015). Further, certain renewable energy projects are funded by multinational companies, comprised of raw materials from a globalized supply chain, and scaled to facilitate returns on significant capital investment (Barton & Fløysand, 2010; Devine-Wright, 2011). Other initiatives promote participatory structures and seek to democratize access by focusing on providing services to marginalized groups (Urquiza et al., 2018). However, these alternative projects function within the constraints of existing economic and sociopolitical systems, perhaps disrupting yet consistently confronting embedded power structures (Bridge, 2017). A critical political ecological analysis is effective at situating sociopolitical and economic patterns within specific relationship dynamics between stakeholders (Mitchell & Parker, 2017). Therefore, political ecology serves as a useful framework for understanding corresponding energy provision patterns, particularly at the watershed scale where ecological impacts such as water scarcity and aquatic species decline are most acute, yet profits are often channeled to other locations (Borzutsky & Madden, 2013).

1.5 Theorizing Scale within Political Ecology & Energy Geography

This research applies the concept of scale as an analytical tool for understanding phenomena related to the water, energy, climate change interface in the Elqui Watershed. Scale is a powerful yet contested term that has been debated and advanced by scholars, notably within the discipline of Human Geography (Marston, 2000; Neumann, 2009). Further, political ecologists and energy geographers engage with scale regularly, as it provides a lens for comprehending complex human-environment interactions based on patterns of resource usage and control (Howitt, 1993; Huber, 2015). This project critically analyzes irrigation modernization as a template for understanding the power-laden dynamics of water and energy policy in an era of unprecedented anthropogenic climate change impacts (Bridge, 2017). Therefore, scalar interplay is a key framework for looking at how different actors are either being empowered or marginalized by resource access and how dynamics may be changing as new socioenvironmental movements and adapted legislative policies manifest (Jonas, 2006; Urquiza & Billi, 2018).

Applying scale as a malleable tool, rather than a fixed territorial categorization, stems from the gradual development of this concept within Human Geography. A horizontal, rather than a vertical comprehension of scale has laid a foundation for its consideration as a socially sensitive and agentic process (Marston et al., 2005). Vertical scale considers space fixed and tied to political or physical boundaries, while horizontal scale engages with space as a socially produced phenomenon, disrupted or reinforced through uneven power dynamics

(Neumann, 2009; Smith, 1984). Some prominent human geographers have rejected the coexistence of vertical and horizontal scales (Springer 2014; Woodward et al., 2012). Other scholars have sought to link vertical hierarchies with horizontal networks (Brenner, 1998; Jonas, 2006; Leitner & Miller, 2007). This research challenges both positions, suggesting horizontal scale offers a more critical lens for analyzing spatial organization, yet vertical models must not be overlooked, as they dominate the consciousness of actors involved in arranging sociopolitical systems (Jones et al., 2017). This framework is relevant to the water-energy-climate change interface in Chile because of overarching neoliberal systems that influence systems of resource governance (Budds, 2004). We see power-laden relations between national, regional, and local/watershed-scale actors. However, this project analyzes how such categorizations aren't fixed and operate based on nuanced relationships that play out through resource policy (Baka, 2017; Bauer, 2009).

Through this research, the unidirectional nature of vertical models is replaced by relationality, capable of recognizing more subtle and itinerant forces of scale creation at work (Bridge, 2017; Jessop et al., 2008). Relational thinking gives agency to scalar actors, focusing on networks of interaction that ebb and flow beyond the confines of hierarchical structures and across interscalar networks (Brenner, 1998). Rather than reject hierarchy, however, relational thinking juxtaposes territorial units with sociospatial processes (Jones, 2009). Insight can be gained from how scalar actors operate in accordance with, or rejection of physical borders, thus revealing whether these boundaries represent or marginalize political goals (Boggs & Rantist, 2003). Therefore, considering the dual role of vertical and horizontal models situates scalar processes in a multidimensional and dynamic socio-spatial landscape, sensitive to unequal power relations (Bridge, 2014; Neumann, 2009).

Core components of irrigation modernization, alongside Chile's current effort to transition energy and water systems, involve the rescaling of infrastructure and associated ownership configurations (Araújo, 2014). For example, modernized irrigation practices incorporate microgrids through in-conduit hydropower, decentralized control of water allocation, and an emphasis on inclusive watershed-scale resource management (FCA, 2021). This reflects rescaling processes primarily through a shift from large centralized systems with federal control to semi-autonomous localized grids (Panez et al., 2020). Such projects align with key policies enacted in recent years, particularly Energía2050 and PANCC (Urquiza et al., 2018). Such policies promote democratized resource governance and integrated watershed management, challenging existing laws such as the CEC and CWC, that prioritize transnational corporate influence and deregulated markets (Behmel et al., 2018; Budds, 2018; Peña 2018). Applying a scalar framework rooted in energy geography and political ecology can provide insight into this disjunctive legislation, by analyzing socioenvironmental outcomes produced by different stakeholders competing for control over energy and water resources (Neumann, 2009).

Traditionally, neoliberal models permeating the Chilean political and economic system have marginalized small-scale entities such as local farmers, rural communities, and environmental organizations (Budds, 2004). This is primarily because these models support uneven power structures through open markets and anti-regulatory landscapes facilitating capital accumulation, thereby providing mechanisms for centralized control over means of resource production and provision (Jones et al., 2017). However, recent shifts in the sociopolitical landscape are beginning to contest existing organizations of power and control, illuminating how uneven nature-society relations are deeply embedded, yet not necessarily inevitable (Neumann, 2009). Resistance movements and local actors are engaging with their own capital accumulation strategies or 'jumping scale' to engage as agents driven by socioenvironmental justice as opposed to global capitalistic development (Brenner, 2001). These trends are particularly relevant in the Elqui River Valley, where decades of overallocation and water rights concentration have led to a tipping point where supply can no longer keep up with demand (Urquiza & Billi, 2018). Therefore, the watershed provides a salient area for critical interrogation because irrigation modernization is being discussed as a central solution and focuses on local empowerment and resource control, challenging existing structures that often prove difficult to dismantle (Bridge, 2017).

Further rescaling action is being driven by climate consciousness and social resistance to exclusionary resource ownership (Salas et al., 2018). Nationwide protests ignited in 2019 due to longstanding grievances against inequalities generated by neoliberal resource governance (Bremmer, 2019). Meanwhile, climate consciousness and efforts to democratize resource provision are stimulating distributed and citizen-driven renewable generation in Coquimbo (Montedonico et al., 2018). Such examples of a transitioning resource landscape reinforce the coexistence of vertical and horizontal processes (Jonas, 2006). While a neoliberal/democratic binary reduces such scalar phenomena to rigid categories, scale-making is occurring through myriad organizational structures, challenging, or supported through networks of agency or marginalization (Leitner & Miller, 2007).

This research applies scalar thinking to contemporary challenges in the Elqui Valley because social resistance and unorthodox organizations of resource governance are redefining water and energy systems in a transitioning landscape (Noseleit, 2018; Ureta, 2017). Responding to resource insecurity, WUAs have coalesced to cooperatively implement efficient allocation infrastructure and support local communities and small farmers (Salinas et al., 2016). These coalitions could be conveniently described as regional-scale entities (Donoso, 2015). However, within a shifting sociopolitical landscape, they have redefined the CWC, suggesting that their agency through scaling processes transcends fixed geographic space (Howitt, 2000). Meanwhile, however, global corporations continue to drive decision-making processes, despite efforts to democratize resource management (Panez et al., 2020). Such patterns present an opportunity to engage with scale as a social process and seek insight into how resource governance is being redefined through irrigation modernization and related resource transitions (Bridge, 2017).

1.6 Relevance of Research

This project is centered around a challenge critical to human-environment relations in the 21st century. Climate change is already disrupting existing water and energy systems and impacts will accelerate in the coming years, particularly in semi-arid regions experiencing aridification (Mundaca, 2013; Pizarro et al., 2022). The global economic sector is highly reliant on water and energy resources and pursuing solutions to address growing insecurity and scarcity is paramount (Sovacool, 2014). The Elqui Valley is a canary in the coal mine for understanding impacts linked to water and energy resources due to its uniquely acute vulnerability to climate change, rapidly transitioning energy grid, and extreme water market model (Delorit et al., 2017; Hearne, 2007).

The water-energy-climate change nexus is a vital interface through which decision-making over the coming decades will shape the future human-environment landscape (Liu, 2016). Irrigated agriculture is situated at the center of these dynamics and will play a key role in the ways water and energy resources are consumed, distributed, and potentially conserved

(Budds, 2004; Jordan et al., 2023). Through integrative analysis of such related issues, this research is positioned to add relevant insights into an emerging body of literature and help guide decision-making as disruptions to energy and water resources accelerate.

In 2022, Turlock Irrigation in California's Central Valley completed a pilot project to install PV solar panels along unlined water canals (Nugent, 2022). This process represents a leap forward in irrigation modernization and is a strategy that I had previously discussed with stakeholders in the Elqui Valley. The importance of this particular project lies not only in that that it seeks to reduce water losses during irrigation allocation but also that it integrates a renewable energy source supporting the rescaling of operations and supporting more resilient infrastructure (McKuin et al., 2021; Peña, 2018; Urquiza & Billi, 2018). While this represents but one form of modernization, the Turlock project reinforces how innovative practices are emerging and will be necessary to mitigate accelerating impacts on water security in semi-arid agricultural regions (Ayre et al., 2017).

An overview of the water-energy-climate change interface in Chile and the Elqui Watershed will be presented in chapter 2 to provide foundational context for understanding a dynamic landscape. Chapter 3 provides a more general background of central research themes and how they have played out throughout Chile's and Coquimbo's history. Empirical chapters (4-6) analyzed the complexity of 'modernization' as a concept to comprehend resource governance, climate change mitigation/adaptation strategies, and how irrigation practices encapsulate focal aspects of these interrelated processes (Vergara et al., 2017; Wiegleb & Bruns, 2018). Chapter 4 identifies and analyzes specific projects that have been implemented while subsequent chapters address links between these projects and broader themes of natural resource governance and public policy.

CHAPTER 2: RESEARCH OVERVIEW

2.1 Introduction

Figure 2.1 Coquimbo Region including major waterways (Limarí and Elqui) and key wind and solar energy sites (Source: Author).

Chile's Coquimbo Region is the geographic setting for this project. Located about 400 miles north of the capital Santiago, Coquimbo is situated in a climatic transition zone (see Figure 2.2), as the fertile corridor characterizing Chile's Central Valley begins to give way to the aridity of the Atacama Desert (Montecinos et al., 2016).

Figure 2.2 The Elqui River and surrounding semi-arid landscape (Source: Author).

The region plays host to a convergence of biophysical characteristics, including the northern extent of appreciable hydropower capacity (Maxwell, 2017). Coquimbo marks the beginning of an optimal solar irradiance zone alongside a gusty inland valley corridor producing significant wind energy potential (Feron et al., 2016; Watts et al., 2016). The substantial capacity for each major renewable energy source within a single region is unique (Becerra et al., 2017). Meanwhile, however, Coquimbo is one of Chile's most climate-vulnerable regions, having suffered upwards of a 50% decline in precipitation levels during the past century, and more than 90% during the recent 13-year drought (Rosenberg, 2022; Salas et al., 2018; Urquiza & Billi, 2018). Since the region's waterways irrigate major agricultural operations (notably table and pisco grapes, citrus fruits, and avocados), implications of this resource scarcity will manifest through the diminished capacity for crop cultivation, not to mention altered hydropower management, water market configurations, and associated socioenvironmental disruptions (Delorit et al., 2017; Hadjigeorgalis & Lillywhite, 2004). Integrative research of legal, political, and economic dimensions of Chile's energy and water policies facilitates a comprehensive understanding of a region with a strong presence of energy and water resources, yet that already has been acutely impacted by significant disruptions to these systems (Jordan et al., 2023; Liu, 2016).

2.2 The Elqui River Watershed

Within Coquimbo, the Elqui River Watershed reflects one of the region's two major waterways and major irrigation sources (Cepeda & López-Cortés, 2004). The agricultural industry has grown to consume more than 80% of surface water, dedicated to cash crops that thrive in a semi-arid climate (Montecinos et al., 2016; Novoa et al., 2019). The preponderance of remaining water resources are allocated for mining, and municipal uses (Álvarez, 2018). Urban demand has increased significantly throughout the terminus region of the region encompassing the coastal metropolitan area of approximately 400,000 inhabitants (Salinas et al., 2016). Water rights for municipal usage continue to hold precedence over other allocations, but agricultural rights hold heavy legal standing as well (Andersen & Verner, 2010; Panez et al., 2020). Meanwhile, upstream irrigation canals were primarily constructed in the early 20th century and are predominately open and unlined, reducing overall conveyance efficiency (see Figure 2.3). Although law 18.450 (a relic of the CWC) has subsidized the agricultural sector, facilitating innovation in drip irrigation technology, trans-basin diversions, crop coverings (to reduce evaporation), and other practices, overall efficiencies remain low while demand shows no sign of slowing (Bauer, 2015; Jordan et al., 2023). Therefore, current climatic trends (minimum of 40% less water by 2050) are fundamentally incompatible with ongoing water resource usage (Pizarro et al., 2022).

Figure 2.3 An unlined irrigation canal operated by a water user association in the Coquimbo Region (Source: Author).

The irrigation landscape permeates the watershed, as virtually all arable land is occupied by crop production, with water being diverted to private rights holders (Oyarzún et al., 2008). Consequently, the Elqui River is fully allocated and at times doesn't reach its terminus along the Pacific Ocean (Salas et al., 2018). Overall water demand continues to climb as multinational commercial entities such as Dole and Unifrutti purchase water rights to expand a burgeoning industry (Monardes-Concha et al., 2020; Montecinos et al., 2018).

Meanwhile, many small farms and junior rights holders are being bought out or are pressured to sell crops to large-scale entities such as the Limited Pisco Agricultural Cooperative of Elqui (CAPEL) which doesn't directly own water rights but controls 70% of the regional pisco grape market (Monardes-Concha et al., 2020).

A relic of the CWC and agricultural law 18.450, the water market is oriented around a free market designed to facilitate low prices and efficient transfers (Bauer, 2015). However, water rights have increasingly been purchased by large-scale entities, marginalizing groups such as small farmers and organizations advocating for minimum ecological flows and environmental conservation (Budds, 2004). A network of water use nodes has been implemented to monitor the increasing withdrawal of water resources (see Figure 2.4).

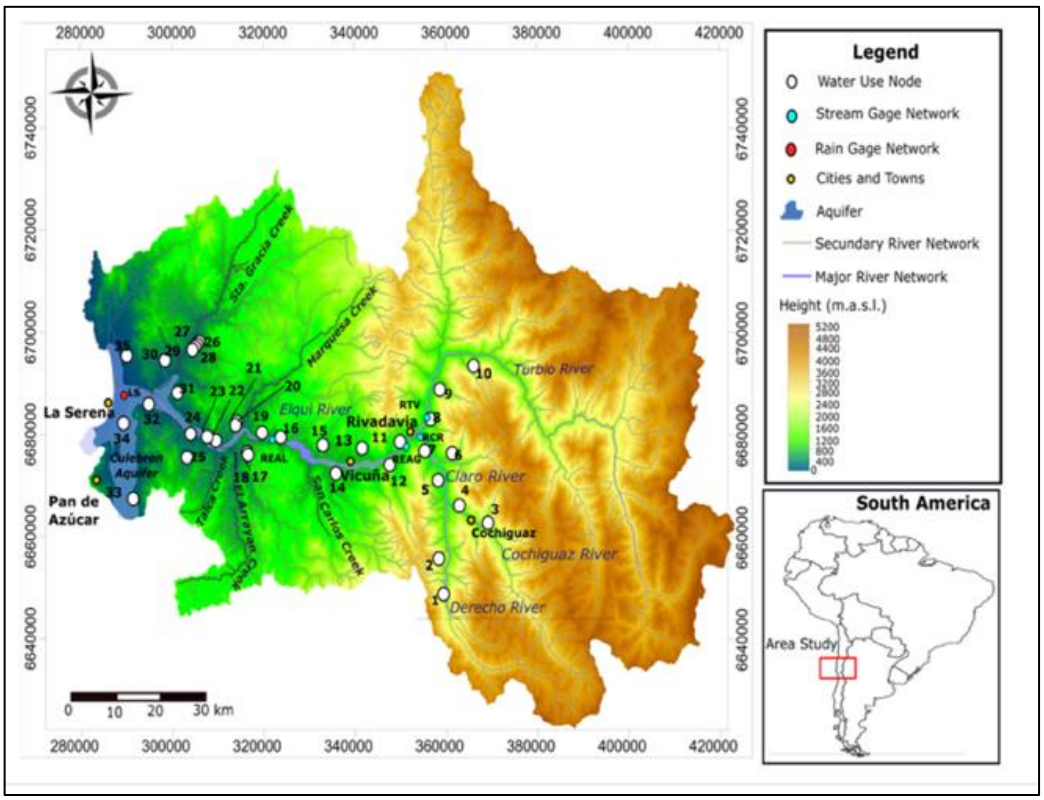

Figure 2.4 Climatological map of the Elqui Watershed with water use nodes and gaging stations (Cepeda & López-Cortés, 2004).

An emerging phenomenon poised to address the overallocation and increasingly dire situation is irrigation modernization. WUAs such as the Junta de Vigilancia del Elqui y sus Afluentes (JVRE) are beginning to advocate for retrofitting of existing systems to enhance efficiency and mitigate overallocation (Cepeda & López-Cortés, 2004; Panez et al., 2020). However, the cultural and economic values around water usage (see Figure 2.5) are oriented towards using what is available, thus maintaining low prices and urban supply, thus complicating efforts to invest in expensive equipment and technology (Salas et al., 2018). Therefore, additional research, public awareness, and economic incentives must be pursued to implement more resilient systems and address an impending water crisis throughout the basin (Salinas et al., 2016).

Figure 2.5 The world's second-largest swimming pool, located at a condominium complex in La Serena. The pool withdraws water from the Elqui River (Source: Author).

2.3 Water in Chile and Coquimbo

Chile's water landscape can be characterized by a legacy of laissez-faire policies designed to promote market-based management (Rivera et al., 2016). These models give precedence to free market-oriented systems rather than state-sponsored programs in influencing the collective good (Barandiaran, 2018). While private water rights ownership existed before the 1981 enactment of the CWC, the geographic remoteness of much of the Chilean territory inhibited state control over water rights, leading to a free for all system, with little regulation (Burgos, 2017). By the time the CWC was implemented, it was introduced into a landscape already holding a dynamic history of human presence and associated interactions with water resources (Long et al., 2017; Parraguez-Vergara & Barton, 2013). The focus of the national code was to facilitate economic growth, primarily through accommodating the aggregation of rights for hydropower and irrigated agriculture, without much consideration of social equality or environmental impacts (Nelson, 2013; Novoa et al., 2019). The system has benefitted certain entities, yet infringed upon others, and continues to play out in contentious ways, especially between indigenous groups and environmental organizations at odds with industrial and agricultural interests (Delgado et al., 2015; Ghorbani & Kuan, 2017; Kelly, 2018; Novoa et al., 2019).

Chile's contemporary water laws were codified during the height of the Pinochet regime and ideologies informing the CWC were derived from strict adherence to neoliberalism (Donoso, 2015). The process of writing the CWC into the dictatorial constitution involved the direct intervention of water managers from the California Department of Water Resources, renowned for spearheading the United States reclamation era's prior appropriation doctrine (Bauer & Catalán, 2017). However, focal aspects of the

CWC distinguishing it from the United States include the lack of a beneficial use clause alongside the presence of both consumptive and non-consumptive rights (Wilkinson, 1992). These systems have influenced trends of water rights ownership in ways that include speculation and monopolization, alongside the proliferation of hydropower, both large and small (Mundaca, 2013). Therefore, issues that have emerged include the fact that entities with capital and inside knowledge have been able to purchase rights that can be aggregated and sold during peak pricing, without fear of losing rights at any point (Bauer, 2009).

Consumptive and non-consumptive systems are intended to work cooperatively, the theory being that the latter will not impact water quality and quantity (Borzutsky & Madden, 2013; Susskind et al., 2014). However, this reveals a paradox between legal intentions and actual biophysical outcomes (Long et al., 2017). This incongruity is caused by the fact that 'non-consumptive' rights alter flows, may impact water quality, and exacerbate drought conditions brought on by dams that obstruct minimum environmental flow regulations (Hadjigeorgalis & Lillywhite, 2004). Since the CWC is especially favorable toward agriculture and hydropower development, the proliferation of dam structures across the Chilean landscape has introduced altered riparian regimes that are already proving to be susceptible to the impacts of climate change (Del Mar Rubio & Tafunell, 2014). Further, agricultural law 18.450, embedded within the CWC, continues to subsidize commercial-scale agriculture and operates with a complex balance between supporting increased efficiency, yet primarily meeting increasing demand rather than establishing mechanisms for resource conservation and socioenvironmental protection (Novoa et al., 2019; Panez et al., 2020). Drip irrigation and associated modernization technologies such as crop coverings and plastic reservoir tarps (see Figure 2.6) have been funded by law 18.450, yet overall efficiencies remain low as unlined canals and constantly increasing demand minimize the capacity for water savings (Arnold et al., 2010; Panez et al., 2020).

Figure 2.6 A lined irrigation pond in the Elqui Valley adjacent to a commercial-scale table grape growing operation (Source: Author).

Despite reforms in 2005 and 2022, the principal structures of the CWC remain intact (Budds, 2018). Meanwhile, hydrologic regimes are changing throughout the country, notably via diminishing precipitation and river discharge (Sarricolea et al., 2019). Particularly problematic is that the inexhaustible demand for both surface and groundwater has disrupted the hydrologic balance, which portends severe socioecological impacts unless aquifers can be replenished (Álvarez, 2018; Oyarzún et al., 2019). Such climatic trends alongside indigenous rights and ecological conservation are not accounted for in either the original or revised codes (Monsalves-Gavilán et al., 2013; Meza et al., 2014). Therefore, institutional reevaluation is required to realize successful adaptation to altered water availability (Long et al., 2017). While the urgency of systemic restructuring is evident, the CWC continues to prove difficult to modify. This is because central pillars have become embedded into the sociocultural, political, and economic networks of the Chilean landscape, including the agricultural sector (Bridge et al., 2013; Novoa et al., 2019).

2.4 Energy in Chile & Coquimbo

Chile's electricity laws were implemented under a similar guise to the CWC (Bauer, 2009). Upon ratification in 1982, the priorities of the CEC focused on meeting increasing energy demand, primarily via hydropower and transmission expansion along with regional integration (Dettoni et al., 2012). Also adhering to the neoliberal principles guiding broad economic policies, the CEC supported an agenda intent on the liberalization and privatization of the energy sector (Mundaca, 2013). The installation of market-based models alongside a mandate to proliferate the energy footprint had immediate effects. For example, 62% of the country had electricity access in 1982, yet this value had grown to 98% by the end of the decade (CNE, 2018). However, coal, oil, and natural gas demand rose concurrently, thereby increasing the reliance on imports and the global economic climate (Urquiza et al., 2018).

Alongside multinational trade policies came significant industrial and agricultural activity (Rector, 2005). The Chilean population saw an acceleration in vehicle and modern amenity ownership, while minerals, lucrative cash crops, and other industrial commodities were sold abroad at unprecedented levels (Hadjigeorgalis & Lillywhite, 2004; Nasirov et al., 2018). Therefore, as connectivity and living standards rose, so did air and water pollution, as

Chilean cities developed some of the highest noxious particulate levels in Latin America (see Figure 2.7) (Schueftan & González, 2013).

Figure 2.7 Air pollution in Santiago, Chile (Source: Author).

These environmental trends convey how Chile's development models have facilitated the highest socioeconomic levels in the region, yet have transpired at the expense of environmental health, notably riparian systems and remote biophysically rich environments often inhabited by indigenous or marginalized groups (Kelly 2018; Pino et al., 2015; Vega-Coloma & Zaror, 2018).

Among Chile's crucial challenges related to energy policy concerns its electricity grid (Dettoni et al., 2012). Until interconnection was achieved in 2018 to establish the National Electric System (NIC), four separate grids supplied power to Chilean communities from industrial sites (Becerra et al., 2017). Two comprised most of the transmission activity, as the Central Interconnected Systems (SIC) and the Northern Interconnected Network System (SING) constituted 75% and 20% of energy transfers respectively (Bauer, 2015). SIC territory covered much of the Central Valley where most of the population resides, while SING powered the preponderance of mining activities in the arid north (see Figure 2.8) (Ghorbani & Kuan, 2017).

Figure 2.8 The open pit Los Pelambres copper mine in the southern portion of the Coquimbo Region (Source: Author).

Meanwhile, the SIC historically harnessed a substantial supply of electricity from hydropower while the SING was almost entirely reliant on thermal combustion sources (Vega-Coloma & Zaror, 2018). As Chile seeks to expand its RE portfolio, the fragmented nature of the grid has impeded transferring clean energy from source to site (Raugei et al., 2018). Therefore, the process of rescaling grids associated with irrigation modernization has the potential to support increased resilience at the local scale, especially in rural areas detached from existing transmission infrastructure (Huber, 2015).

2.5 Climate Change in Chile & Coquimbo

Chile represents one of the most climate change-vulnerable regions in the world, particularly in the semi-arid north where water scarcity is already manifest (Burgos, 2017). Projections estimate upwards of a 45% reduction in available surface water by 2040 (World Resources Institute, 2018). Figure 2.9 illustrates how Chile leads all Latin American states with a severe decline in water availability that has accelerated in recent decades:

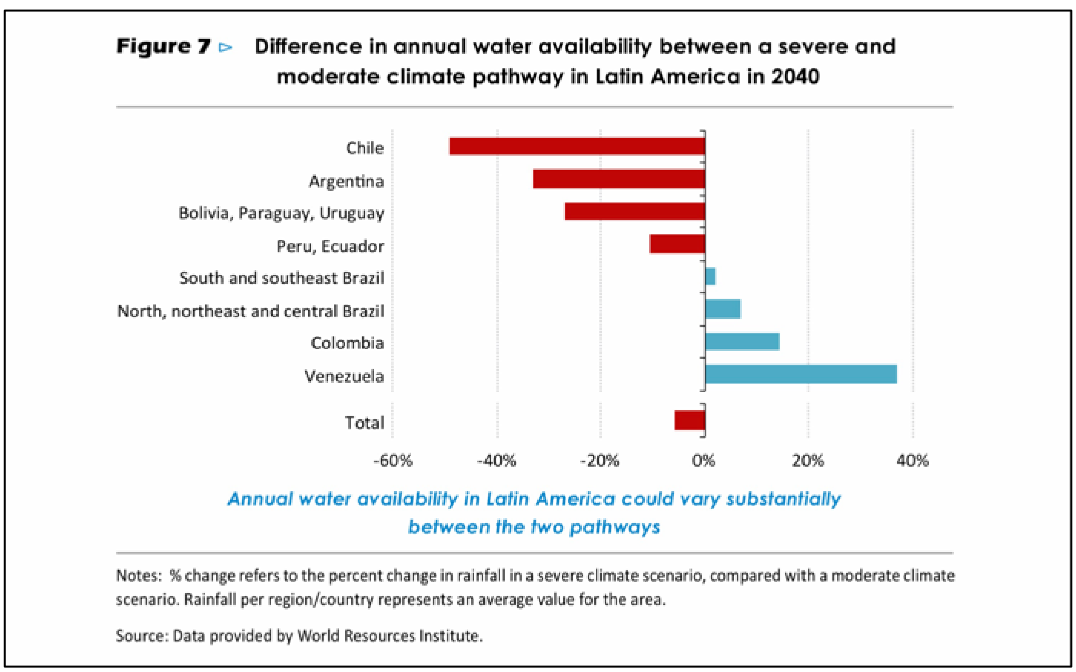

Figure 2.9 Projected water security impact for Chile by 2040 based on a severe climate pathway (World Resources Institute, 2018).

Noted projections are particularly problematic for regions that rely heavily on surface water for economic, sociocultural, and environmental purposes (Andersen & Verner, 2010). Coquimbo hosts an active water market central to the regional and national economy. The region also attracts tourism and recreation along its waterways. However, atmospheric trends illustrate a severe decline in water availability, accelerating in recent decades and that is currently causing an unprecedented megadrought, now in its 11th year (see Figure 2.10).

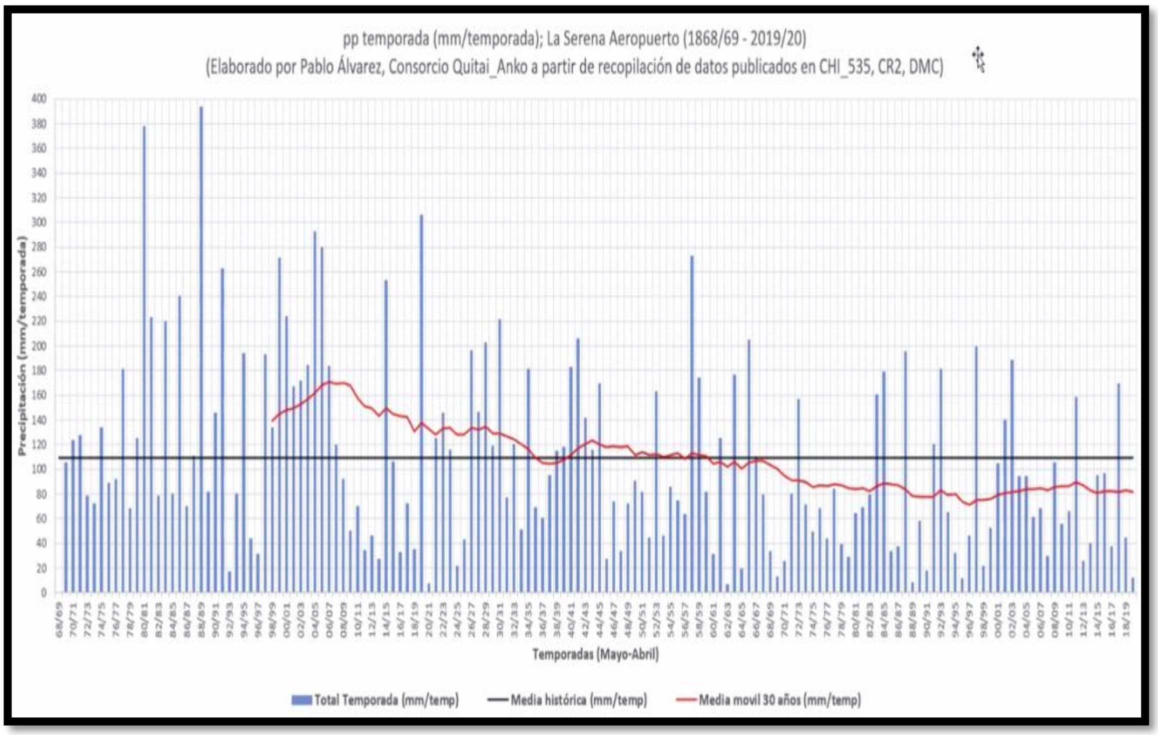

Figure 2.10 Rainfall record at La Serena (capital of Coquimbo) airport (Source: Álvarez, 2018).

Upon my arrival in Coquimbo in May of 2022, water availability had further declined from when I traveled around the region three years prior. Flying over the Embalse La Paloma, visiting the Embalse Puclaro, and analyzing corresponding data convey how demand continues to accelerate while reservoir levels continue to decline. The following photographs between 2019 and 2022 for La Paloma in the Limarí Basin (Figures 2.11 & 2.12) and Puclaro in the Elqui Basin (Figures 2.13 & 2.14) illustrate the magnitude of the current crisis:

Figure 2.11 Embalse La Paloma (Limarí Basin) in May of 2019 (Source: Google Earth, 2019).

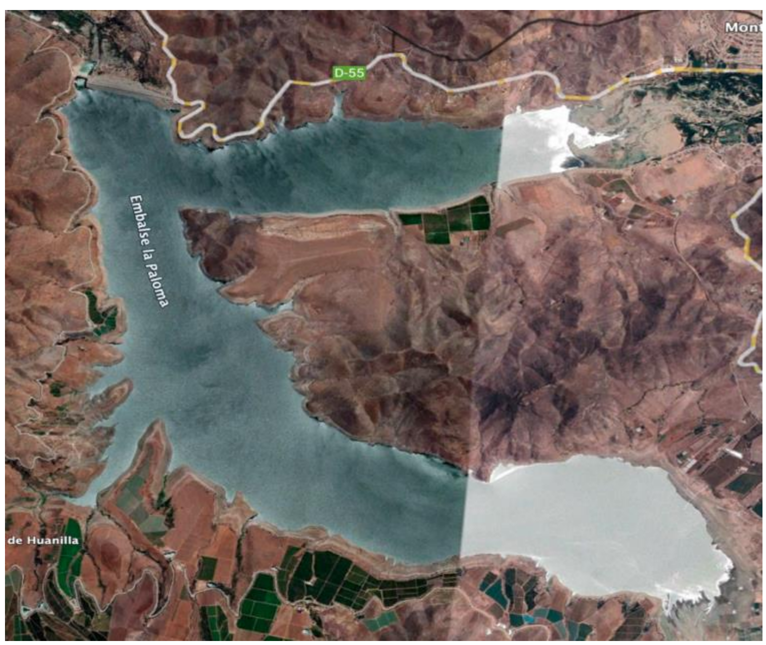

Figure 2.12 Embalse La Paloma (Limarí Basin) in May of 2022 (Source: Google Earth, 2022).

Figure 2.13 Embalse Puclaro (Elqui Basin) in May of 2019 (Source: Google Earth, 2019).

Figure 2.14 Embalse Puclaro (Elqui Basin) in May of 2022 (Source: Google Earth, 2022).

Since Chile reestablished democratic rule in 1990, certain institutional characteristics have changed concerning combating climate change, while others have remained intact. Notable examples include broad renewable energy generation goals such as Ley 20/25, enacted in 2013, that mandate 20% of all generated energy be derived from renewable sources by 2025 (Dettoni et al., 2012; Munguia, 2016). Mechanisms for achieving such goals include specific requirements for industrial entities to fulfill purchase power agreements (PPA) of at least 20% of electricity from RE (Proaño, 2018). Alongside RE initiatives, the institutional capacity for influence in energy and climate change policy has expanded substantially. The formation of the National Energy Commission (CNE) and the National Environment Commission (CONAMA) has been bolstered by a restoration of support and funding for environmental and social sciences in the university system and private sector (Bauer & Catalán, 2017). Such initiatives have positioned Chile as a regional leader in RE development and climate change mitigation (Pino et al., 2015). Adherence to the United Nations Framework on Climate Change's Kyoto Protocol and more recently the Paris Climate Accord has added international cache to clean energy and emissions reductions, further stimulating Chile's renewable and/or low emission energy goals (Barbosa et al., 2017; Monsalves-Gavilán et al., 2013).

In cooperation with international agreements, CNE and CONAMA have been instrumental in developing policy documents that outline comprehensive strategies for achieving energy, sustainability, and climate change goals (Pino et al., 2015). Notable among the documents is PANCC, which focuses on adaptation and mitigation mechanisms for the implementation management of climate change at regional and community levels (CONAMA, 2017). Another foundational publication commissioned by the Chilean government is the previously discussed Energía2050 Initiative, which provides a roadmap for achieving a more sustainable and inclusive energy future (CNE, 2018).

Meanwhile, however, key pillars of Chile's legal systems have experienced inertia to change, such as the CWC and CEC (Bauer 2009; Kelly, 2018). Associated laws continue to favor deregulation while promoting the interests of large-scale mining, hydropower, and agricultural interests (Baland & Robinson, 2012; Novoa et al., 2019). The power grid, despite being integrated in 2018 to form a nationwide system, continues to be encumbered by numerous bottlenecks, restricting the flow of RE from load to demand centers, thus causing curtailments (Zurita et al., 2018). Also, as of 2018, citizen energy or distributed generation comprised less than 1% of the energy matrix, suggesting that the energy landscape has yet to realize any significant democratization (Proaño, 2018). Consequently, the development of microgrids associated with irrigation modernization has the potential to propel community-scale energy systems yet face steep challenges despite bold goals outlined by the national government (Pizarro et al., 2022; Roddis et al., 2018).

2.6 Key Stakeholders

This research engages with organizations and individuals involved in management decisions, and/or groups impacted by the configuration of the regional irrigation landscape. Primary methods of interrogation included semi-structured interviews posing questions based on four primary lines of inquiry: 1) perceptions of climate change impacts on water and energy systems and how existing operations or livelihoods may be disrupted. 2) Power dynamics in the region and how these dynamics play out through control of water and energy resources. 3) How existing laws (CWC, CEC, agricultural law 18.450) are influencing decision-making and whether new legislation (PANCC and Energía2050) are shifting how benefits and impacts are distributed. 4) How irrigation modernization projects can either exacerbate or ameliorate ongoing impacts, both sociopolitical and ecological, and whether there is an incentive to adjust existing practices, and if not, from where such incentives are likely derived. 5). How models developed in the United States (specifically from the Farmers Conservation Alliance (FCA), can help decision-making for modernization, but equally importantly how unique features of the local landscape require alternative practices and perspectives for helping preserve resource security (Dowling, 2000; Pizarro et al., 2022). The following table (Table 2.1) depicts key stakeholders targeted for interviews involved in the water-energy-climate interface throughout the Elqui Basin. A more thorough description of each stakeholder follows the table, including my interactions with each actor, their role in the irrigation landscape, and key links between their work and my research questions.

Table 2.1 Stakeholders in the Elqui Watershed, associated descriptions, and key interview questions during fieldwork (Source: Author).

STAKEHOLDER NAME	DESCRIPTION	KEY QUESTIONS
ELQUI WATER RIGHTS USERS		
Cooperativa Agrícola Pisquera Elqui Limitada (CAPEL) **English: Pisquera Elqui Limited Agricultural Cooperative**	This agricultural collective owns substantial water rights in the Elqui Watershed and has contracts with small-scale farmers to purchase pisco grapes. CAPEL has become the biggest pisco distributor in Chile and has benefitted from a market-based water governance system. However, the entity is a non-profit and elects a new president annually.	Do you believe there is a clear system for understanding water right ownership and transfers in the Elqui Valley? What is the nature of your interactions with other water users? Do you feel there is increasing competition for water resources? Do you think climate change will impact you water availability and if so, what mitigation efforts are you engaging?
Fundo los Nichos Distillery	Smaller but long-established water holder and distillery. This distillery will likely have insight into similar themes as the Mistral distillery: how	What communications do you receive from local, regional, and national governments about water and energy usage?

Table 2.1 cont'd	water rights are impacting their business, whether there is pressure to sell to larger entities, and how climate change is impacting availability of this resource.	What would lead you to believe the CWC and CEC are working in your favor? How do you feel about the drafting of a new constitution and how this will change structures of water rights and governance?
Pisco Mistral Distillery	A large distillery in the Elqui Valley and senior water rights holder. This organization holds important perspectives on how water rights are purchased during dry periods, patterns of water usage has changed over time, climate change impacts on water supply and influences of the agri-business model on water allocation and participation in the local, regional, national, and international economy.	Are recent shifts in the energy grid (for example local solar arrays) something you view favorably, and have you noticed any changes in your energy bills, specifically for pumped agriculture? How much more would you be willing to pay for water if modernization projects were completed to increase efficiency and reduce energy bills in the long run? Have you received pressure to relinquish water rights and if so, so you think that this is tied to broader water governance trends influenced by neoliberalism?
Small Pisco Farmers	A grouping of small-scale farmers were interviewed to analyze how junior rights have changed over time and affected by neoliberal economic models and climate change. Interview questions focus on water security, the agricultural market and how new resource laws may either benefit or further marginalize these agricultural groups.	Do you believe that it will be harder to access water resources in coming decades than in the past? Have you ever felt pressure to relinquish your rights to a larger commercial entity? Have you noticed changes to water availability in your own practices? How do you feel about the new national constitution being drafted and do you think it will better represent your priorities?
RESOURCE GOVERNANCE, ENVIRONMENTAL, OR SCIENTIFIC ENTITY	**DESCRIPTION**	**KEY QUESTIONS**
Comisión Nacional del Riego **English: National Irrigation Commission**	The national commission with regional offices has an institutional mandate to ensure compliant water allocation and support the the improvement of	What are the primary challenges facing the CNR in terms of diminishing water resources in agricultural regions of the north?

Table 2.1 cont'd	the irrigated regions throughout the of the country, particularly in arid and semi-arid regions facing challenges with water security. The Commission has developed a National Irrigation Policy focused on developing generates collaborative studies, programs, contributing to the efficient use of water resources for irrigation within the agricultural sector. Primary priorities include augmenting irrigation security and creating a more inclusive, participatory, sustainable, and equitable landscape for farmers and irrigation organizations.	Through what mechanisms can both more efficient and democratic systems of water allocation be achieved? Between a new constitution, revised water code, updates to agricultural law 18.450, or other legislation such as Energía2050 or PANCC, through which legal channels can the most effective changes be enacted to coordinate sustainable water management more effectively in the Elqui Watershed and throughout Northern Chile? What mitigation and/or adaptation strategies have you developed if dire water resource projections of 50% losses transpire by the middle of the century?
Comisión Técnica Especial de Emergencia Climática y Medio Ambiental de la Región de Coquimbo (COTECMA) **English: Special Technical Commission for Climate and Environmental Emergency of the Coquimbo Region**	This regional climate committee meets periodically and holds insight into changes in water and energy resource availability as climate change impacts manifest in the Elqui Watershed. The organization is comprised of actors from academic organization, governmental departments, and indigenous communities.	Do you feel there is awareness to the increasing scarcity of water in the basin and do you think that there is a solid community focus on addressing these issues? What changes in law are most directly affecting the regional water landscape? How will a new constitution influence or change water governance in Coquimbo?
Comunidades de Agua del Cuenca Elqui **English: Water Communities of the Elqui Basin**	Regional water communities essentially function as irrigation districts that collectivize resources to allocate water resources amongst rights holders. Water users pay for the maintenance and operations of canals that transport water from reservoirs to their fields.	What information have you received about modernizing your irrigation systems and where is the information and/or support coming from? What are the primary barriers to achieving a modernized system that includes piped water, in-conduit hydropower, efficient field conveyance, etc.?
La Junta de Vigilancia de Rio Elqui y sus Afluentes **English: Elqui River and Tributaries Surveillance Board**	The JVRE is an administrative body that oversees allocation throughout the Elqui Valley. They are tasked with protecting, conserving, and distributing the available water throughout the basin. The JVRE has significant influence	How has the installation of Puclaro Dam changed water allocation in the basin and are current reservoir levels shifting the ways in which management is being administered? Do you believe the existing irrigation canal network serves

Table 2.1 cont'd	over regional water governance. They are not only involved in overseeing water allocation but also manage the Puclaro and La Laguna Dams. JVRE collaborates with a range of public and private entities to optimize water allocation and protection of water security for users.	the region effectively and if so why, does it benefit some users more than others? What changes can be made to the irrigation landscape to address increasing concentration of water rights and increased water insecurity.
Área Protegida Privada y Santuario de la Naturaleza Estero Derecho **English: Organization for the Right Estuary Private Protected Area and Nature Sanctuary**	This organization focuses on watershed protection in the upper reaches of the Elqui Basin (specifically the Estero Derecho Tributary) and is involved with conservation of resources against groundwater pumping and over-allocation.	How is the recent drought impacting runoff in the tributary and how is this impacting management of the Embalse La Laguna? Do you feel the regional government is concerned about social and environmental health, or primarily supporting profit making by agricultural industry? What are your priorities and greatest challenges going forward to protect the Elqui Watershed?
La Dirreción General de Aguas del Region Coquimbo **English: The General Directorate for Water of the Coquimbo Region**	A state agency (within the jurisdiction of the Coquimbo Region) holding responsibility over the water resources allocation. The institutional mandate is developed within the established legal frameworks and to disseminate information for regional water users. They hold a mandate to promote the national water policy that advocating sustainable water usage and promoting integrated watershed management.	Do you feel there is awareness to the increasing scarcity of water in the basin and do you think that there is a solid community focus on addressing these issues? What changes in law are most directly affecting the regional water landscape? How will a new constitution change water governance in Coquimbo? Have you been influenced by Energía2050 and PANCC?
Laboratory for Analyzing, Monitoring and Modeling Agricultural and Environmental Resources (PROMMRA)	Established in 2009 at the Department of Agronomy (University of La Serena) the research lab focuses on supporting reducing technological gaps in the agricultural sector. A diversity of tools and affiliations are utilized to detecting the regional irrigation landscape and develop knowledge	What key successes has PROMMRA had in working with actors and helping work on mitigating problems with the fair distribution of water in the basin? Between a new constitution, water code, other environmental legislation, or other mechanisms, what is most needed to ensure a secure future?

Table 2.1 cont'd	impacts of crop production on socioecological health and environmental justice.	Do you think there are good systems or incongruities between national legislation and what is truly transpiring with water resources in the basin?
Manager of Puclaro Dam	The manager of Puclaro Dam (affiliated with JVRE) provided insight into dynamics of water allocation throughout the basin, the current state of water resources and how different governance models influence operations. The dam is operational 47lan47ryly for agricultural water distribution but also produces a small amount of hydroelectricity.	Do you think beneficial change is being driven by local, regional, or national initiatives? How has the dam influenced water allocation and is there pressure coming from different water users? What are the current levels of the reservoir and are management practices shifting as the drought intensifies?
Manager of Vicuña Solar (Luna and Sol Arrays)	The manager of these solar arrays work with the National Interconnected System to help support the transition to renewable energy throughout Chile. Within the Elqui Watershed, management bodies for the arrays comply with complex systems for electricity production and are involved in complex interactions between entities involved in energy distribution alongside dynamics of land use influenced by agricultural practices and resource prices.	What are the biggest changes to your land that may be linked to climate change? How has land use shifted in the basin in recent years, and do you think there will be more opportunities for solar arrays in the valley? What potential is there for additional solar projects and has there been any consideration of solar panels over irrigation canals?
Sociedad Agricultura del Norte (SAN) **English: Agricultural Society of the North**	This group represents agricultural producers around the Coquimbo Region. SAN partners with organizations such as PROMMRA and governmental actors to work towards creating more effective agricultural practices around the region.	What communications do you receive from local, regional, and national governments about water and energy usage? In what ways have you noticed links between climate change impacts and shifts in the regional agricultural landscape?

4.9.1 Importance of Water User Associations

Agricultural cooperatives are an increasingly important player in irrigation-based systems. Capable of acting as an intermediator between national governments and local communities, WUAs often have the most direct role in on-the-ground decision-making over allocation regimes (Delorit et al., 2017). In certain cases, such as the Limarí and Elqui Basins in Chile (Vicuña et al., 2014), actors have navigated national policies and local nuances to truly redefine scale (actors within a newly defined territory) and agency (stimulating increasing autonomy at the regional-local level). These organizations can either reinforce (Urquiza & Billi, 2020), disrupt (Hoogesteger, 2015; Sanchis-Ibor et al., 2017), or redefine (Wang et al., 2018) existing systems or create multiple outcomes at once.

The aforementioned emerging actors are particularly relevant in Latin America where neoliberal policies have promoted a non-interventionist role by national governments (Pino et al., 2015). Therefore, increased management control has been attained by local and regional associations that focus on irrigation optimization within the constraints of water, environmental, and energy policies (Hearne, 2007). A relevant example is the Elqui Watershed, deemed among the world's most active markets because of its well-established WUAs and extensive canal network (Hadjigeorgalis & Lillywhite, 2004). A unique set of political, economic, and biophysical characteristics are supported by the institutional structures of the national CWC (Nelson, 2013). This system promotes agency for local entities with capital to facilitate the development of the water market and WUAs represent the interest of these parties (Borzutsky & Madden, 2013). However, they are increasingly tied to agribusiness models focused on perpetual growth (Panez et al., 2020). Therefore, looking at WUAs in this landscape (Hoogesteger, 2015) is important for identifying how other models are more effectively balancing active systems of water rights transfers and economic expansion with socioecological balance (Urquiza et al., 2018).

2.6.2 Junta de Vigilancia del Rio Elqui y sus Afluentes (JVRE)

This organization oversees water supply to more than 5,000 irrigators throughout the Elqui Basin and is comprised of water users ranging from small rural farmers to commercial-scale crop producers (Delorit et al., 2017). Members with more senior water rights influence the operations of basin-wide water distribution, which is increasingly focused on cash crops controlled by large-scale agricultural entities (Hearne, 2007; Novoa et al., 2019). The CWC specifies powers held by the Junta de Vigilancia del Rio Elqui (JVRE) which operates as a non-profit facilitator of water transfers and maintenance of canals (Borzutsky & Madden, 2013). The JVRE has been focused on expanding canals and has supported increasing water usage in past decades, despite warnings of impacts on water security (Budds, 2018). The Puclaro Reservoir was constructed in 2000 (see Figure 2.15) and has further entrenched

Figure 2.15 Puclaro Reservoir in the Elqui Watershed. The project was implemented specifically to support a growing agricultural sector (Source: Author).

Maximal water allocation due to its primary purpose of distributing water for irrigation (Oyarzún et al., 2008).

JVRE is in the initial stages of implementing modernization strategies for its territory, yet most canal infrastructure dates to the mid-20th century. This organization holds public meetings was a vital source of information in terms of analyzing how climate change is being considered through actions related to energy and water practices (Salas et al., 2018). Meeting with this organization was a key component of fieldwork and involved both presenting my research to help facilitate decision-making for irrigation modernization, as well as learning about what initiatives the association is already pursuing.

2.7 Irrigation Modernization in Chile

This research focuses on the socioenvironmental dimensions of irrigation modernization. An emerging phenomenon, this process seeks to develop policies and infrastructure focused on efficiency and environmental sustainability, especially in semi-arid regions confronting water stress (see Figure 2.16).

Figure 2.16: Agricultural land dedicated to pisco grape cultivation surrounded by semi-arid mountains in the Elqui Valley (Source: Author).

The literature surrounding these practices is developing yet thus far is predominately limited to technical and economic dimensions. Such studies offer valuable insight into opportunities and barriers that influence the financial and topographic feasibility of modernization projects. Specific to Chile, several articles analyze the potential for these retrofittings (see for example: Altieri & Rojas, 1999; Arnold et al., 2010; Molinos-Senante et al., 2016; Oyarzún et al., 2008; Playan & Mateos, 2006; Plusquellec et al., 2009; Roco et al., 2016; Vicuña et al., 2014). These studies provide a foundation for understanding the basic dimensions of upgrading irrigation infrastructure. However, they fall short in terms of critically analyzing the social and ecological nuances that create a unique set of circumstances for each project, and that cannot be fully understood simply through a technocratic lens (Nagel & Ptak, 2021; Urquiza & Billi, 2020). Critical frameworks are important because they interrogate how outcomes of projects are based on embedded sociopolitical power structures, linked to systems of resource governance (Burke & Stephens, 2018). Therefore, key takeaways from technical studies provided a platform for analysis of literature focused on socioenvironmental dimensions that more directly guide this research.

Several technical studies link prospects for irrigation modernization to Chile's neoliberal economic model. Specifically, they reference impacts on biophysical health and natural resource depletion (Oyarzún et al., 2008). The Chilean agribusiness complex, developed alongside market-oriented systems is focused on GDP growth, deregulation, and an active role in global trade networks (Altieri & Rojas, 1999). While supporting significant socioeconomic development (notably access to energy and clean water), the over-exploitation of natural resource reserves has manifested as a concurrent byproduct (Arnold, et al., 2010). Therefore, emerging literature suggests that alternatives to purely high-output agriculture need to be developed alongside more careful extractive practices because Chile is already dealing with the impact of decades of unencumbered industrial activity (Novoa et al., 2019; Plusquellec et al., 2009). Irrigation modernization offers a major opportunity to mitigate accelerating resource insecurity because while demand is expected to increase in the coming decades, productivity and efficiency can be improved significantly through infrastructural upgrades (Playan & Mateos, 2006).

What the aforementioned studies overlook, however, is the fact that water and energy productivity may appear as objective measures, yet are conceptualized differently, and often wrapped up in political power arrangements and power-laden resource governance models (Boelens & Vos, 2012). Several more explicitly critical studies identify nuanced themes that concurrently influence the underlying mechanisms behind modernization projects or lack thereof (see for example: Urquiza & Billi, 2020; Boelens & Vos, 2012; Budds, 2018; Jordan et al., 2023; Molinos-Senante et al., 2016; Panez et al., 2020; Rinaudo & Donoso. 2019; Scott et al., 2014). A key framework shared across socially sensitive studies concerns socioecological resilience (Urquiza & Billi, 2020). Even though the Elqui Basin and other intensively managed Chilean watersheds host active water and electricity markets, increasing resource scarcity and access inequalities are leading to tensions that impact socioenvironmental well-being (Fortier & Trang, 2016). These conditions are exacerbated by the neoliberal models that inhibit regulatory mechanisms required to address rapidly changing conditions (Budds, 2018). Key pathways to address such disconnects include socio-technological modernization of agricultural practices (Altieri & Rojas, 1999). Such a process involves incorporating local knowledge to promote more diverse and resilient systems

(Kelly, 2018). Efforts facilitate a greater capacity to absorb alterations and reconfigure institutions without losing core social functions and identities (Montedonico et al., 2018).

Further, critical analysis of terms such as efficiency and productivity are engaged to suggest these concepts are misleading when interpreted at face value and likely the result of embedded discourses and sociopolitical links (Boelens & Vos, 2012). This is important when considering irrigation modernization because, in the case of Chile, these narratives have been used to expand neoliberal influence, resulting in several key outcomes (Jordan et al., 2023). First and foremost, state-promoted conceptualizations of efficiency and water governance have been used to expand large-scale agriculture and codify policies that contribute to the concentration of water rights at the expense of small users (Novoa et al., 2019; Panez et al., 2020). This is problematic because less evenly distributed water allocation is not conducive to long-standing water management practices and ecosystem conservation strategies (Wiegleb & Bruns, 2018). Consequently, community erosion is ensuing from loss of income and identity, and increasingly uneven power structures are leading to social grievances that resulted in nationwide protests (Sehnbruch & Donoso, 2020). A common recognition is emerging of the importance of Chile's focus on optimizing technical aspects of hydrologic allocation and international trade efficiency (Nelson, 2013). However, the literature makes clear how this framework is narrow and overlooks severe byproducts that must be addressed as natural resources are depleted and a decline in social capital accelerates (Pino et al., 2015).

Further supporting the multidimensional nature of irrigation modernization is the idea that while individual efficiencies have increased in agricultural regions following projects, technical upgrades alone are only one component of a broader set of criteria used to determine overall outcomes (Molinos-Senante et al., 2016). For example, water demand in irrigation-heavy zones of semi-arid Chile continues to climb, as surface streams are overallocated and groundwater is being depleted at unprecedented rates (Panez et al., 2020). Therefore, integrating aspects of the market model with stipulations for socio-ecological balance is a crucial step for Northern Chile to mitigate significant water stress. Regarding this concern, key studies (Panez et al., 2020; Scott et al., 2014; Urquiza & Billi, 2020) argue for more regional coordination, integrated management, and programs toward implementing more sustainable models to meet increasing demand while preserving natural resources.

One evident dearth in literature to date, however, is a scholarship that explicitly integrates water and energy policy with climate change (Peña, 2018). Integrated watershed management must address the nexus of water and energy because these resources are intrinsically connected, as access to each relies on availability and access to the other (Behmel et al., 2018; Weigleb & Bruns, 2018). Several studies focus on this resource connection (see for example: Arnold et al., 2010; Cremades et al., 2016; Liu, 2016; Pizarro et al., 2022; Panez et al., 2020; Stang et al., 2018; Vergara et al., 2016). However, with limited exceptions (Leck et al., 2015; Scott, 2011), and notably within the geographic discipline, the literature is underdeveloped in terms of situating climate change as a core driver of how water and energy resources will be impacted in the 21st century (Delgado et al., 2015). Irrigation modernization not only offers the opportunity to integrate the nexus by creating more efficient and enduring systems of water and energy provision but also represents a template through which integrative resource governance can be evaluated (Pizarro et al., 2022). Therefore, this research is positioned to help fill this gap through critical analysis of processes operating at the water-energy-climate interface's core.

2.8 Data and Methods

Convergent parallel design mixed methodology (CPDM) is a research approach that incorporates both qualitative and quantitative data collection and analysis (Creswell, 2014). CPDM begins with qualitative techniques, which in this project included a preliminary analysis of key policy documents, followed by participant observation of energy sites and water distribution facilities. These steps informed procedures for semi-structured interviews of key stakeholders, notably including water user associations, government officials, water and energy scholars, renewable energy operators, environmental organizations, and a range of water rights holders (Montedonico et al., 2018). This suite of qualitative techniques supports the assemblage of a broad dataset that informed subsequent pathways for a more focused quantitative analysis of the irrigation landscape and water-energy-climate change interface (Cameron, 2009). As part of this process, a comprehensive assessment of notable irrigation modernization set the stage for corresponding research.

The quantitative stage of the CPDM methodology evaluated data collected from previous research steps to target specific questions that can be further elucidated through spatial analysis. (Creswell, 2013). Key datasets include GIS shapefiles depicting land ownership and crop type throughout the Elqui Watershed (PROMMRA, 2021); Elqui Basin water rights ownership and surface/groundwater transfers; Chilean water market allocation and transfers; and Chilean national and regional energy data. Central to the research process is adherence to a pragmatic approach that weighs each major aspect (qualitative data collection, quantitative analysis, and synthesis of results) equally and rigorously (Bryman, 2007; Creswell, 2014; Onwuegbuzie et al., 2009). Successful projects achieve integration of qualitative and quantitative data, even if results are varied, so long as key criteria are followed (see for example: Creswell 2014; Fetters et al., 2013; Philip 1998). Such criteria include comparing unique perspectives between different types of data; explaining quantitative results with context derived from qualitative analysis; substantiating experiments by bringing in individual perspectives; creating case studies with diverse knowledge bases; and assessing both processes and outcomes of the complex issues, people or events being studied (Cespedes, 2013; Kelly, 2018, Parraguez-Vergara et al., 2013).

As I undertook field research in one continuous segment, sequential research was practical because it follows a coordinated series of steps that facilitated data collection/analysis before, during, and after case studies and semi-structured interviews in Coquimbo. A CPDM approach was more pragmatic than exploratory or explanatory research (other common mixed-methods techniques) because instead of isolating stages of qualitative and quantitative analysis, each step was closely informed by data or observed phenomena most relevant to the research goal (Creswell, 2014). Therefore, direct attention can be paid to each segment of the research, which began with policy analysis and textual translation before fieldwork (Cameron, 2009; Onwuegbuzie et al., 2009).

Upon arrival in Chile, my primary contact, Dr. Pablo Álvarez hosted a robust network for engagement with key actors and access to relevant databases. Dr. Álvarez introduced me to managers of water distribution networks and oversees a water resource lab engaged in geospatial research. Another contact, Dr. Sonia Montecinos, coordinated visits to solar arrays in Coquimbo during fieldwork and maintains a network in multiple renewable industry sectors as well as data on energy siting and electric grid configuration. The combination of these contacts alongside critical preliminary analysis and translation of the CEC, CWC, Energía2050, and PANCC, supported a project focused on unpacking complex relationships between political and economic policy and corresponding empirical phenomena. Upon collating these sequential steps, the multidimensional nature of a completed CPDM methodology aligned with spatial dynamics underlying energy geography and nexus-based and political-ecological frameworks (Baka, 2017).

2.8.1 Elqui River Spatial Analysis

The PROMMRA water resources research lab, directed by Dr. Pablo Álvarez is actively involved in projects focused on mapping agricultural metrics in catchments around Coquimbo, conducting spatial analysis, and gathering datasets for water resource management issues in the Elqui Watershed. I worked in this lab during fieldwork and collaborated with Dr. Álvarez alongside several graduate students and/or professionals researching regional water and energy issues. The experience working in the lab facilitated access to databases of climatic statistics, land and water ownership, and geographies of canal infrastructure/allocation schemes. These data supported addressing the research questions through the evaluation of resource distribution, power structures, climate disruptions, and how these have changed over time. A primary goal was to spatially interrogate efficiencies of water allocation, changes in land use and ownership, climate change impacts, and how these metrics align with overarching trends of power concentration and the neoliberal agribusiness model (Álvarez, 2018; Pizarro et al., 2022). The following figure (2.17) depicts land use and ownership, which can be analyzed spatially and per individual plot to understand crop type, water usage, and rights appropriation throughout the basin. We can see that there is a complex landscape with a range of different users and crops that require different water and energy intensities for management.

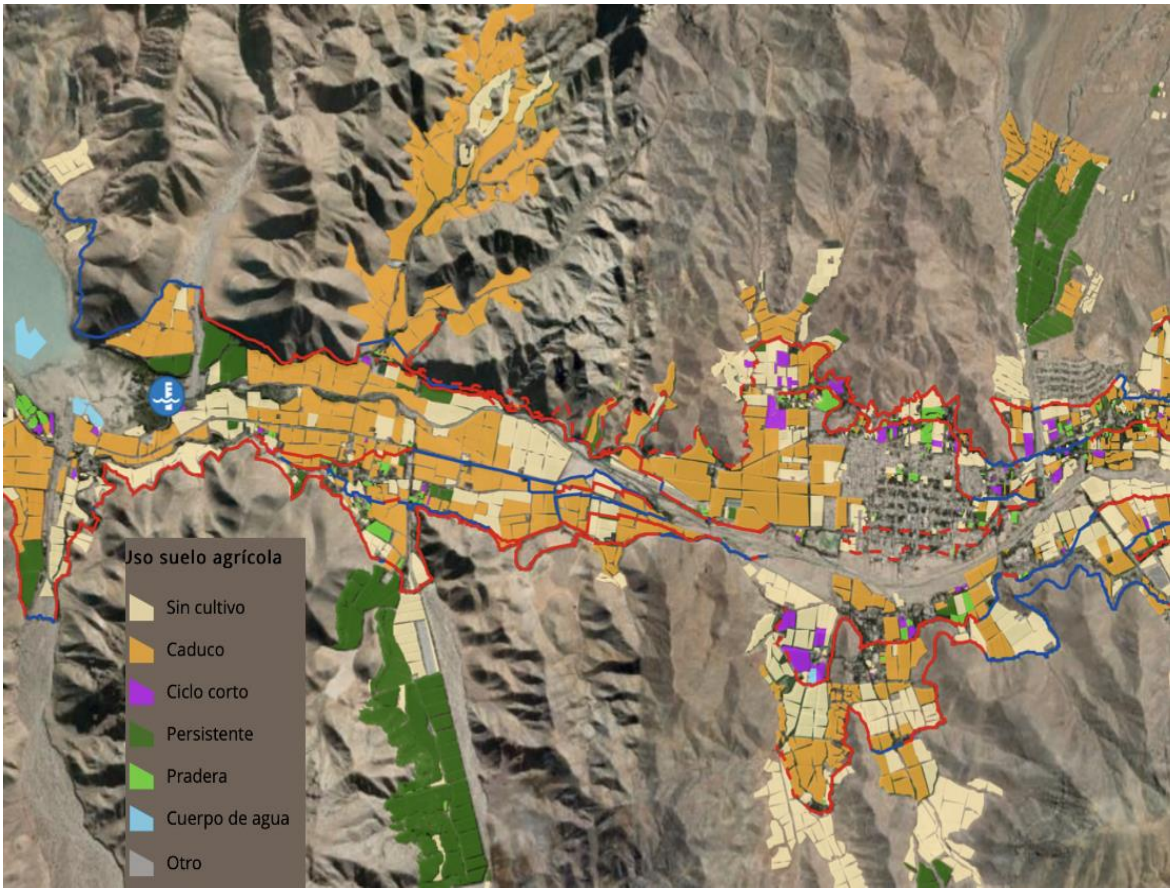

Figure 2.17 Map of the middle section of the Elqui Watershed including irrigation canals, crop type, and associated water usage and rights ownership (PROMMRA, 2022).

2.8.2 CEC & CWC; Energía2050 & PANCC

Four policy documents are translated and analyzed to better understand how national legislation is being administered throughout the Elqui Watershed. These documents contain specific mechanisms for resource governance, energy transitions, and climate change mitigation. However, the CEC and CWC function separately despite the interdependent nature of energy and water (Bauer, 2009). Further, these relics of the Pinochet era apply free market principles to the landscape, while Energía2050 and PANCC hold directly contradictory motives. Therefore, a major focus of the research was to discern where and how laws are being applied, and whether there are opportunities for cooperation and integration between the different documents (Peña, 2018). Chile anticipates further legislative changes this decade, perhaps in the form of a new constitution, which the population will vote on in September 2022 (Benedikter & Zlosilo, 2022). Therefore, identifying pathways for coordination between these documents represents a salient practice for better-coordinating laws that would likely have more sway if embedded into a national constitution (Montedonico et al., 2018).

2.8.3 Stakeholder Interview Questions

The following questions were asked during semi-structured interviews of selected stakeholders throughout the Elqui Watershed. The collection of questions was individualized based on each actor due to their unique roles in issues related to irrigation modernization and the regional water-energy-climate change interface.

- Please discuss your role in either working with or governing water and/or water and energy resources in the Elqui Watershed.
- Can you identify specific examples of projects focused on upgrading irrigation infrastructure?
- How are irrigation modernization projects addressing energy and water resource efficiency?
- What do you think are the greatest successes of regional resource governance and what are the major limitations?
- Do you believe there is a clear system for understanding water rights ownership and transfers in the Elqui Valley?
- What is the nature of your interactions with other water users? Do you feel there is increasing competition for water resources?

- Do you believe that it will be harder to access water resources in the coming decades than in the past?
- Have you ever felt pressure to relinquish your rights to a larger commercial entity?
- Have you noticed changes to water availability in your practices?
- What communications do you receive from local, regional, and national governments about water and energy usage?
- Are recent shifts in the energy grid (for example local solar arrays) something you view favorably, and have you noticed any changes in your energy bills, specifically for pumped agriculture?
- What are your thoughts about solar arrays replacing agricultural fields? Do you think this trend will continue to grow?
- Do you feel there is awareness of the increasing water scarcity in the basin, and do you think there is a solid community focus on addressing these issues?
- What would lead you to believe the CWC and CEC are working in your favor?
- Do you feel the Energía2050 Initiative and PANCC are leading to any changes in regional resource governance?
- Do you believe the existing irrigation canal network serves the region effectively and if so why, does it benefit some users more than others?
- How much more would you be willing to pay for water if modernization projects were completed to increase efficiency and reduce energy bills in the long run?
- Do you feel the regional government is concerned about social and environmental health, or primarily supporting profit-making by the agricultural industry?
- What are the biggest changes to your land that may be linked to climate change?

- Do you think beneficial change is being driven by local, regional, or national initiatives?
- How do you feel about the new national constitution being drafted and do you think it will better represent your priorities if ratified?
- What do you think are the biggest challenges facing water users in the Elqui Valley and is enough being done to address impending water insecurity?
- What key successes has PROMMRA had in working with actors and helping work on mitigating problems with the fair distribution of water in the Elqui Basin?
- What is most needed to ensure a secure future between a new constitution, water code, other environmental legislation, or other mechanisms?
- Do you think there are good mechanisms or more incongruities between national legislation and what is happening with water resources in the basin?
- How is the recent drought impacting runoff in the tributary and how is this impacting management of the Embalse La Laguna and Embalse Puclaro?
- Do you feel the regional government is concerned about social and environmental health, or primarily supporting profit-making by the agricultural industry?
- Do you think more efficient water allocation will help alleviate problems or will this just increase water demand?
- Has your organization already implemented climate change mitigation strategies? If so, please explain. If not, what barriers are preventing you from doing so?
- What specific examples of irrigation modernization have you engaged, and do you have data on either energy or water saving because of improved efficiency?

CHAPTER 3: BACKGROUND OF WATER, ENERGY, CLIMATE CHANGE INTERFACE IN CHILE, AND THE ELQUI RIVER WATERSHED

4.10 Introduction

From a geographic perspective, Chile possesses unique physical, sociocultural, and environmental diversity. A country notable for its thin profile (spanning 2,600 miles of latitude but only 110 miles across at its widest), Chile's history has been anything but narrow and linear (Rector, 2005). Testament to this is the fact that a nation with perhaps the world's most rigorously neoliberal and laissez-faire regulatory economic systems is currently undergoing efforts stimulated by the central government to become among the continent's most renewable energy-focused countries (Bauer, 2009). Such a transition involves a complex network of geographic, economic, political, legal, and sociocultural factors that are playing out at local, regional, national, and international scales (Araujo, 2014). The backdrop for a significant component of Chile's renewable energy movement is the pressing question of how to function in a 21st-century global landscape that is experiencing unprecedented magnitudes of change in climate systems, population dynamics, resource scarcity, and human-environment relations (Urquiza et al, 2014). Underpinning this broad brush of phenomena is a theme overlooked in certain parts of the globe and a daily struggle in others; the availability and characteristics of natural resource use (Sovacool & Mukherjee, 2011). To advance understanding of these patterns, the research revolves around the theme of energy and water as the linking component of the primary research framework: the water, energy, climate change (WECC) interface in Chile's Elqui Watershed. Each of these concepts cannot be fully understood in isolation, which promotes a research architecture focused on discerning the relationships between these issues to gain an understanding of why the landscape looks, feels, and operates in particular ways (Liu, 2016).

To grasp the fundamentals of Chile's renewable energy landscape, one must consider the dissonance between aspirational and achieved objectives. A highly publicized and well-cultivated image of Chile as an environmental mecca has proliferated in recent years, yet perhaps superficially (Pino et al., 2015). Certainly, comprehensive policies have been enacted to promote renewable energy development and emissions reductions. However, Chile continues to be reliant on fossil fuels and is struggling to meet renewable portfolio standard checkpoints (Herrera-León et al., 2022). Notwithstanding, the fact that a government with a history of non-intervention in economic systems is stimulating renewable energy growth supports the weight and urgency of shifting away from fossil fuel dependence (Mundaca, 2013). Programs that have been spearheaded by the Ministries of Energy (CNE) and Environment (CONAMA) include a state energy policy that reorients social, technical, political, and economic systems to favor sustainable development (Montedonico et al., 2018). Additionally, the core document of Chile's energy goals, the Energía2050 initiative, articulates a comprehensive vision for undergoing a resource transition (CNE, 2018). This strategy includes mechanisms to realize a major shift from imported fossil fuel dependence to domestically sourced renewable energy development (Becerra et al., 2014). Energía2050 also incorporates a reconfiguration of the institutional arrangements that have precluded democratic and participatory structures from having a role in Chile's energy landscape (Ureta, 2017).

A remarkable growth in Chile's renewable portfolio has transpired during the past decade. In 2010, solar and wind comprised less than 1% of the matrix, yet by 2020 this figure rose to nearly 20% (Bahamondez, 2020). Consequently, Chile has emerged as Latin America's leader in installed solar and wind generation, with respective values of 3,104MW and 2,400MW as of October 2021 (Alves, 2021; Bnamericas, 2021). However, disconnects continue between the intentions of recently established energy initiatives and empirical outcomes of the relationships between environmental laws, resource management practices (particularly water and energy), and human rights (Kelly, 2018). National decarbonization initiatives are leading to positive outcomes, yet concealed byproducts such as rare earth mineral extraction, indigenous territorial fragmentation, and socioeconomic inequalities are growing concurrently (Bauer & Catalán, 2017). Therefore, the forthcoming sections rely on a critical analysis of key geographic, historic, and policy trends to identify how and where success and failures are occurring. Specifically, the research will identify opportunities and challenges for democratizing resource governance, articulated in key initiatives and a focal point of the new national constitution currently being drafted (Harrison, 2022).

4.11 History of Chile's Economy and Energy Systems

Chile's energy history represents a contrast between an abundance of domestic natural resources, and the economic expediency of importing coal, oil, and natural gas from abroad (Dettoni et al., 2012). During the 19th and 20th centuries, Chile's abundance of lucrative minerals attracted interest from around the globe (Rector, 2005). Nitrates, copper, silver, lithium, and other valuable ores mined in the northern regions established Chile as a major trading hub, and the revenues from these activities accommodated rapid GPD growth and socioeconomic progress (Mundaca, 2013). While the Chilean economy grew, volatile Spanish leadership alongside suppression of autonomy via taxes and trade restrictions led to murmurings of independence (Chambers, 2015). Once Chile became a sovereign nation in

1818, models that facilitated free trade and significant power and agency for mining and agricultural interests were codified (Novoa et al., 2019; Nasirov & Agostini, 2018). These systems of trade and market policies were embedded into the landscape and have had a focal role in Chile's development (Bauer, 2009). Such systems continue to be relevant because mining operations demand considerable water and energy resources that are being depleted in areas such as the Elqui Basin, where water resources are already overallocated (Ribeiro et al., 2014; Salas et al., 2018).

Mining maintained its position as the backbone of Chile's economy as experimentation with systems of governance characterized the second half of the 19th century (Ghorbani & Kuan, 2017; Rector, 2005). Periodic mineral discoveries led to eras of booms and busts, yet the system exhibited overall resilience and endowed great wealth upon entities in positions of power and influence (ibid). Portions of mining generated revenue financed public works projects, leading to infrastructure development in previously inaccessible regions (Pino et al., 2015; Zurita et al., 2018). This carried both benefits and byproducts. Connectivity facilitated the transfer of knowledge and commodities, yet also led to the exploitation of indigenous and biodiverse territory as new horizons for agriculture, hydropower, and natural resource extraction were discovered (Bauer & Catalán, 2017; Kelly, 2018; Pino et al., 2015). This maintains relevance today as mining operations consume significant water and energy resources, particularly in the north (Ghorbani & Kuan, 2017).

During the first half of the 20th century, Chile undertook land tenure reforms, water market structuring, and electrical grid expansion. Despite temporary perturbations, economic growth continued, yet began to experience vulnerability as reliance on imported coal, oil, gas, and other commodities amplified (Becerra et al., 2017). As a result, the government shifted towards deregulating domestic markets and began to pursue hydropower as a source of energy (Silva, 2016). The creation of the national electricity company (ENDESA) in 1943 represented a major expansion of plans to produce and transmit electricity, emphasizing hydropower development (Nelson, 2013). This had significant implications for the trajectory of the energy market, as the broad reach of ENDESA alongside institutional mandates for energy development facilitated numerous dam projects in the Central Valley as well as oil exploration in the south (Rector, 2005). Such programs exemplified an unprecedented push for natural resources that would emerge as the source of one of Chile's crucial ongoing environmental issues (Shapiro et al., 2018).

The second half of the 20th century was perhaps Chile's most tumultuous political era. Violence-inducing shifts between left-wing socialist administrations and a conservative military dictatorship symbolize how Chile has undergone a pendulum effect resulting from extreme institutional oscillations (Bauer, 2009). Notable consequences of this dynamic include the fact that solidarity in establishing public programs was stymied and the resulting disjointed system benefitted entities such as mining and hydropower companies, more capable of navigating shifting power structures (Long et al., 2017). Efforts to nationalize certain industries and privatize others had implications that continue to influence Chile's energy landscape as well (Borzutsky & Madden, 2013).

Two movements in the second half of the 20th century were particularly consequential to Chile's energy landscape. First, the left-wing government of Eduardo Frei Montalva engaged in an initiative to nationalize the mining industry in the 1960s, namely by purchasing a majority share of the El Teniente copper mine and 25% of Chuquicamata (the largest in the country) (Rector, 2005). This event was part of a larger trend that involved the nationalization of the electric and telephone companies (ibid). Such investments were intended to achieve more coordinated economic planning, yet the program backfired due to political opposition (Montedonico et al., 2018). Second, the result of constant political gridlock exposed the vulnerabilities of national programs (Lane, 2014). After the military coup that inserted Augusto Pinochet into the presidency, energy laws and management systems especially lacked structure and coherence, preventing effective regulations from being implemented (Bustos-Gallardo, 2013). Soon after Pinochet grasped power, ENDESA was privatized and strict adherence to neoliberalism was mandated, prioritizing energy and water rights for hydropower developers and large-scale landowners (Calderón et al., 2013; Del Mar Rubio & Tafunell, 2014). This had an impact on the management capacity for riparian health and the sustainability of water governance (Bauer, 2009). While Chile has begun to emphasize environmental standards since it restored democracy, clear path dependencies remain, and the country is experiencing significant challenges in amending unregulated free market systems that omit environmental and human rights (Araujo, 2014; Mundaca, 2013).

Since Chile reestablished democratic rule in 1990, certain institutional shifts have transpired with energy governance, while others have remained intact. Notable examples include broad renewable energy generation goals such as Ley 20/25, enacted in 2013, that mandate 20% of all generated energy be derived from renewable sources by 2025 (Dettoni et al., 2012; Munguia, 2016). Mechanisms for achieving such goals include specific requirements for industrial entities to fulfill purchase power agreements (PPA) of at least 20% of electricity from renewables (Proaño, 2018). Alongside such initiatives, the institutional capacity for influence in energy and climate change policy has expanded substantially. The formation of CNE and CONAMA has been bolstered by a restoration of support and funding for environmental and social sciences in the university system and private sector (Bauer & Catalán, 2017). Such initiatives have positioned Chile as a regional leader in renewable energy development and climate change mitigation (Pino et al., 2015). Adherence to the United Nations Framework on Climate Change's Kyoto Protocol and more recently the Paris Climate Accord has added international cache to clean energy and emissions reductions, stimulating Chile's renewable goals (Monsalves-Gavilán et al., 2013).

Alongside international agreements, CNE and CONAMA have been instrumental in developing policy documents that outline comprehensive strategies for achieving energy, sustainability, and climate change goals (Pino et al., 2015). Notable among the documents is the National Plan of Action for Climate Change (PANCC), which focuses on adaptation and mitigation mechanisms for the implementation management of climate change at regional and community levels (CONAMA, 2017). Another foundational publication commissioned by the Chilean government is the previously discussed Energía2050 agenda, which provides a roadmap for achieving a sustainable and more inclusive energy future (CNE, 2018).

However, other systems have experienced inertia to change, such as the CEC and CWC (Bauer 2009; Kelly, 2018). The associated laws continue to favor deregulation while promoting the interests of large-scale mining, hydropower, and agricultural interests (Baland & Robinson, 2012; Panez et al., 2020). The power grid, despite being integrated in 2018 to form a nationwide system, continues to be encumbered by numerous bottlenecks, restricting the flow of renewables from load to demand centers, thus causing curtailments (Zurita et al., 2018). Also, as of 2018, citizen energy or distributed generation comprised less than 1% of the energy matrix, suggesting that the energy landscape has yet to realize any significant democratization (Proaño, 2018).

4.12 Physical Geography of Chile

Chile is South America's seventh largest country in area, and its territorial delineation is derived primarily from physical features, notably the Pacific Ocean and the Andes Mountains. However, successful conquests to the north and south now define Chile's latitudinal range, extending from the Peruvian border to South America's terminus at Cape Horn. Consequently, a unique configuration is characterized by a severely elongated profile that runs approximately 12˚ of latitude (4,270 km) yet is on average only 300 km wide (Garreaud, 2010). The resulting geographic heterogeneity and spatial disconnection contribute to a diverse national identity, as well as impediments to governance and solidarity (Munoz et al., 2017). Due to the nature of Chile's physical geography, it is futile to encapsulate a wide range of bioregions, climate zones, and cultural territories into aggregate statistics (Becerra et al., 2017). For example, certain microclimates in the Atacama haven't seen rainfall for centuries, while the southern reaches of Patagonia may experience as much as 400cm of annual precipitation (Garreaud, 2010). Therefore, regionality is a fundamental framework for understanding Chile's landscape.

Regarding energy and natural resources, the physical environment is conducive to mining and agricultural activities and boasts substantial potential for harnessing renewables (Ghorbani & Kuan, 2017). Beginning in the north, where some of the world's most lucrative mineral mines also reside, the Atacama Desert has the globe's highest annual irradiation, with an annual accumulated average of 3,000 kWh/m2, ideal for photovoltaic solar development (Servert et al., 2014). Wind power also has major capacity in both Chile's northern and southern regions. A notoriously blustery coastline is sparsely inhabited, yet close enough to population centers to facilitate transmission from wind farms to demand centers (Román-Collado et al., 2017). This geographic configuration has supported the development of more than a dozen wind farms with capacities greater than 50MW and leading studies suggest that there is potential for upwards of 40,000MW of wind generation nationally (Becerra et al., 2017; Raugei et al., 2018; Watts et al., 2016). Furthermore, descending from high elevations in the Andes to the Pacific Ocean over relatively short distances, Chile hosts more than a thousand major rivers, many of which possess substantial hydroelectric potential (Del Mar Rubio, 2014; Marzo et al., 2018). As of 2017, Chile maintained a network of 137 hydroelectric operations comprising more than 7,000MW of installed capacity (IHA, 2017, Maxwell, 2017). Therefore, renewable energy potential is significant, yet decision-making behind patterns of development will be contingent on a range of political, economic, geographic, and socioenvironmental factors (Bridge et al., 2013; Novoa et al., 2019).

Each region comprising the Chilean State has developed alongside an intimate relationship and reliance on the natural resources that the landscape possesses. Therefore, perturbations to natural systems have the potential to induce economic, social, and environmental devastation, situating the country in a position particularly vulnerable to climate change impacts (Garces-Voisenat & Mukherjee, 2016). Despite the spatial heterogeneity of climate change, regional climate models project alterations throughout Chile, manifesting as myriad outcomes at a range of magnitudes (Demaria et al., 2013). Notable examples include warming trends of a minimum of 0.15˚C per decade in Chile’s Central Valley, a region inhabited by over 70% of the population (Meza et al., 2014).

Concurrently, precipitation reductions may reach 30% by 2030 in South Central Chile, where most of the hydropower is generated (Pino et al., 2015). Such changes are occurring as Chile is expanding its hydroelectric footprint, and the government is 71laning to generate 45-48% of national electricity from this source by 2025 (IHA, 2017).

Decision-making surrounding energy generation must begin to rely on climate projections as a foundation for understanding how resource availability will change over time (Meza et al., 2014). This is especially pertinent in the case of hydropower because estimates for Chilean watersheds suggest hydroelectricity will likely supply 100% of the grid demand during wet years, 80% during normal years, and only 40% during dry years (Díaz et al., 2011). Since among renewable sources, hydropower has the most direct socioecological impacts, Chile's planned expansion of both large and small hydropower initiatives mandates critical analysis (Maxwell, 2017). During Chile's history since the initial development of hydropower, periods of drought have been marked by nationwide blackouts, causing political and socioeconomic instability, alongside a reliance on expensive natural gas and diesel imports from abroad to supplant electricity demand (Dettoni et al., 2015). This energy security disruption has been mitigated via grid reconfiguration and augmentation of wind and solar, yet underlying issues concerning the future capacity of hydropower remain. For example, climate change impacts often originate at high altitudes, in volatile environments, and subsequently descend the topographic gradient towards sea level (Piticar, 2018). Hence, the Andes may be seen as a canary in the coal mine. Climate observations by a noteworthy team of glaciologists contend that the Andes snowline is retreating at a rate that will result in a 50% reduction of area able to host year-round snowpack by the end of the 21st century (see Figure 3.1) (Demaria et al., 2013).

Figure 3.1 The highest volcano in the world (on the right) and the second highest mountain in South America (Ojos del Salado: elevation 22,615ft) in July 2019 (middle of winter) holding almost no snowpack (Source: Author).

This transition may incur upwards of a 33% reduction in glacial mass (Mernild, 2015). Such alterations carry major implications, as likely outcomes include a shifted hydrograph and increased drought susceptibility, causing disruptions to water management operations, agricultural practices, and hydroelectric generation capacity (Henríquez-Dole et al., 2018).

Generally, renewable energy has a smaller footprint than conventional energy sources, yet these projects also carry impacts that often shift to new environments with biophysical characteristics that facilitate their operation (Maxwell, 2017). In certain cases, in Chile, expanding not just hydropower but also wind and solar may cause encroachment upon biodiverse or indigenously inhabited territory (Zurita et al., 2017). Such phenomena lead to nebulous outcomes involving tradeoffs between greenhouse gas reductions and reconfigurations of the energy landscape via adjusted land use, areas of resource exploitation, and transmission configurations to connect renewable sources to the grid (Kelly, 2018).

4.13 Cultural Geography and History of Chile

Chile's energy landscape may be less directly tied to cultural contexts than physical phenomena, yet there exist notable parallels, nonetheless. Due to Chile's geography and history, the cultural atlas that has developed over time is highly heterogeneous. Many citizens identify more strongly with their inhabiting region rather than the nation as a whole (Rector, 2005). While the national government has consistently attempted to promote nationality and solidarity, regional uniqueness and autonomous identity are integral aspects of Chile's heritage (Kowalczyk et al., 2013). Historically, the remoteness and multifarious geography of Chile made this country a challenge among colonized realms for imposing rule and hegemony despite consistent efforts originally by the Spanish crown, and subsequently the national government (Rector, 2005). Such a dynamic persists in the sense that Chilean citizens are fiercely individualistic and resist imposition by an interventionist central government (Araujo & Martuccelli, 2014).

Fundamental to Chile's cultural legacy is the region's most prominent indigenous group, the Mapuche. As the Spanish crown expanded its reach throughout Chile during the 17th and 18th centuries, the Mapuche were an unrelenting and worthy adversary, able to successfully defend their homeland for decades (Cespedes, 2013). However, as the crown gathered strength and influence, the Mapuche territory (now circumscribed by the region of Araucanía), was eventually forced to begin to cede land for Spanish missions and land tenure transfer to agricultural entities (Montalba & Stephens, 2014). In the early 20th century, the Chilean military occupied Mapuche territory alongside efforts to assimilate and pacify the indigenous group so that the territory could be further opened for economic expansion (Rector, 2005). This influenced how land rights systems were codified throughout Chile, as the landscape began to transform agriculture, and livestock was prioritized over indigenous sovereignty (Di Giminiani, 2015). The systematic territorial fragmentation created archipelagos of reserves where indigenous groups were forced to live in collectives. By the time the Pinochet government assumed power in the 1970s, the remaining indigenous tracts were de-collectivized, further reducing the realm of autonomy (Haughney et al., 2012). This pattern of territorial disintegration is an important template for understanding key systems of energy policy and governance. As territory was acquired, the organization of the Chilean landscape prioritized resource extraction and large-scale agriculture, influencing the systems of energy production that transpired (Vega-Coloma & Zaror, 2018). Although the Mapuche marginalization in Araucanía is the most infamous, similar patterns of indigenous rights suppression have occurred throughout the country, including throughout the Coquimbo Region (Salas et al., 2018).

Such dynamics of inequality and market-centrism continue to play out in the contemporary water and energy landscape. A particularly relevant example on the topic of human rights concerns Chile's ratification of the International Labour Organization Convention No. 169. (Shapiro et al., 2018). This law states that indigenous groups are entitled to a clean environment, among other stipulations concerning cultural rights and recognition (Cespedes, 2013). While this represents significant progress in institutional acknowledgment of the Mapuche and other groups, the convention remains nebulous in practice, as the national government has failed to clearly define mechanisms for the legal agency on behalf of indigenous communities (Kelly, 2018; Tomaselli, 2012). Resulting is that hydropower development, natural resource speculation, and transmission expansion face minimal restrictions for encroachment on indigenous lands, which often correspond with sensitive biophysical habitats (Watts et al., 2017; Zurita et al., 2018). Therefore, a paradox is revealed through not only Convention 169., but also other overarching energy policies such as core tenets of Chilean national environmental law and Energía2050 (Montedonico et al., 2018). Thus far, the outcomes of the convention beg the question of why the government ratified this document in the first place if its principles aren't being adhered to. Consequently, the emphasis on inclusion and participatory initiatives characterizing pillars of Chile's aspirational resource future has yet to be realized (Dettoni et al., 2015).

Chile's socioeconomic growth led to its 2010 classification as a high-income country and inclusion as Latin America's only member of the Organization for Economic Cooperation and Development (OECD) (Pino et al; 2015; Urquiza et al., 2018). This status is reflected through noteworthy GDP per capita, educational attainment, and Human Development Index (HDI) scores (Watts et al., 2016). Nevertheless, this prosperity carries caveats, as the vehicles for growth prioritized mineral extraction and fossil fuel emissions at the expense of environmental protection, notably air and water pollution (Mundaca, 2013) (see Figure 3.2).

Figure 3.2 The Mapocho River in Santiago, Chile. Trash and other refuse line the banks of one of Chile's most polluted rivers (Source: Author).

Concurrently, Chile's wealth inequality has risen to the highest level among the 36 OECD member countries, suggesting that economic development has disproportionately benefited a small portion of the country at the expense of the rural poor and environmental health (Bauer & Catalán, 2017; Pino et al., 2015).

Concerning income distribution, regionality is a key concept in understanding Chile's configuration of economic activity, income distribution, and poverty (Rector, 2005). The concentration of affluence is particularly acute in Chile, as roughly 50% of national GDP activity emanates from the Santiago Metro area alone (Pino et al., 2015) An additional 10% is derived from the Antofagasta Region, which serves as the primary port for mining operations in the northern regions (ibid). Meanwhile, poverty rates are about 4% in Antofagasta while Araucanía sees upwards of 28% of its population living below the poverty line (Parraguez-Vergara & Barton, 2013). Therefore, while each Chilean region hosts a unique mix of economic activity, centered on its assemblage of natural resources, certain areas are experiencing inordinate marginalization, especially those inhabited by indigenous groups (Pino et al., 2015).

4.14 Energy & Economic Landscape Before, During, and After Military Dictatorship

The contemporary history of Chile's political leadership is most clearly distinguished between an era of democratic rule until the 1973 military coup inserting Augusto Pinochet into power for almost two decades, followed by the restoration of democracy in 1990 (Montedonico et al., 2018). Social programs, nationalized industries, and environmental regulations were disbanded as the Pinochet regime exercised sweeping authority, leading to the creation of a new institutional order (Rector, 2005). The rise of neoliberalism alongside anti-communist sentiment compelled the dictatorship to install economic and political programs based almost entirely on the guidance of a group of University of Chicago economists, later dubbed the Chicago Boys (Kelly, 2018; Long et al., 2017). With a mandate for reform, the constitution was rewritten to reflect a faithful and rigorous neoliberal doctrine, and that has proven to have an enduring role in Chile's systems of governance (Mundaca, 2013). The laws enacted facilitated natural resource extraction, hydropower development, and deregulation to promote free market enterprise industrial interests (Bauer, 2009). Consequently, as Chile currently undertakes initiatives to reorient political, economic, and energy policies toward environmental conservation, climate change mitigation, and renewable electricity sources, the legacy of former systems continues to generate inertia that impedes systemic change (Watts et al., 2016; Zurita et al., 2018).

Despite Chile's challenges in disentangling from the undemocratic systems of the past, the Pinochet era did successfully establish a potent economy, supporting a platform for maintaining prosperity as a leader in the renewable energy movement (Mundaca, 2013). Although institutional structures continue to reflect lock-in effects, the fact that Chile is a somewhat recently developed country (certainly among OECD nations) indicates a substantial potential to be adaptive to resource transitions (Bridge et al., 2013; Pino et al., 2015). However, the policies that facilitated Chile's economic growth are fundamentally incongruous with legislation such as the Energía 2050 initiative, Ley 20/25, and the PANCC (Dettoni et al, 2012). Consequently, Chile's energy future relies on the institutional capacity to effectuate the comprehensive restructuring of political, socioeconomic, and environmental policies such that they adhere to strict standards protecting human rights and ecological conservation (Montedonico et al., 2018) This process will rely on balancing increasingly interventionist approach from the national government, while concurrently engaging in and supporting local grassroots democratic systems of energy policy and governance (Urquiza et al., 2018).

Although Chile continues to function as a natural resource-dependent nation, the recent development of RE projects presents an opportunity to exploit inexhaustible sources, that pose fewer risks to environmental health (Vega-Coloma & Zaror, 2018). Building blocks have been established since Patricio Aylwin presided over the first post-dictatorship administration (Rector, 2005). The government reestablished social programs, scientific education, and federal departments such as the National Environmental Commission, while grassroots movements began to manifest around social inequality and opposition to large hydropower projects (Bauer, 2009; Bauer & Catalán 2016; Nelson, 2013; Silva, 2016). This conveys how achieving an energy transition is not simply technological, but involves a cooperative nexus of social, political, cultural, economic, and environmental movements (Bridge et al., 2013; Trainer, 2010). The Chilean government has to some extent acknowledged the need for fundamental restructuring, notably by the administration of Michelle Bachelet (Montedonico et al., 2018). Key initiatives include not only the implementation of robust RE goals but also the creation of multi-scalar participatory advisory committees that facilitate the wide distribution of policy decision-making mechanisms (Urquiza et al., 2018). If these new structures can work alongside the National Energy Strategies core pillars: energy efficiency, RE development, transmission expansion, market completion, and regional interconnection, a resilient and inclusive energy transition may be achieved (Dettoni et al., 2012). Since the election of Gabriel Boric in 2021, Chile holds a revitalized opportunity to further pursue sustainable and democratized resource governance through new social contracts (Fiscor, 2022).

4.15 Water Law

Chile's water landscape is characterized by a legacy of laissez-faire policies designed to promote market-based management (Rivera et al., 2016). These systems give precedence to market-oriented solutions rather than state-sponsored programs in influencing the collective good (Barandiaran, 2018). While private ownership existed before the 1981 enactment of the CWC, the geographic remoteness of much Chilean territory inhibited state influence over water rights, leading to a free for all system with minimal regulation (Burgos, 2017). By the time the CWC was enacted, the water landscape held a long-established network of human intervention and complex systems of governance (official and unofficial) over water resources (Long et al., 2015; Parraguez et al., 2016). The focus of the CWC was to facilitate economic growth, primarily through accommodating the aggregation of water rights for hydropower and agriculture, without much consideration of environmental impacts (Nelson, 2013; Novoa et al., 2019). Certain entities benefitted (notably hydropower companies, mining corporations, and large-scale agricultural entities), yet others suffered (particularly the rural poor). These dynamics continue to unfold in contentious ways, especially between indigenous groups and environmental organizations at odds with industrial and agricultural interests (Delgado et al., 2015; Kelly 2018; Ghorbani & Kuan, 2017).

Chile's contemporary water laws were codified during the height of the Augusto Pinochet military regime. Ideologies driving the CWC were derived from strict adherence to neoliberalism (Donoso, 2015). The process of writing the code into the new constitution involved the direct involvement of water managers from the California Department of Water Resources, renowned for spearheading the United States reclamation era through the doctrine of prior appropriation (Bauer & Catalán, 2017). However, focal aspects of the CWC that can be distinguished from the United States include the lack of a beneficial use clause alongside the presence of both consumptive and non-consumptive rights (Wilkinson, 1992). Such characteristics of the CWC have influenced trends of water rights ownership in ways that accommodate speculation and monopolization, alongside the proliferation of both large and small-scale hydropower projects (Mundaca, 2013). Therefore, emerging issues include the fact that entities with capital and inside knowledge have been able to purchase rights that can be aggregated and sold during peak pricing (Bauer, 2009).

Consumptive and non-consumptive systems are intended to work cooperatively, the theory being that the latter will not impact water quality and quantity (Borzutsky & Madden, 2013; Susskind et al., 2014). However, this reveals a paradox between legal and physical outcomes (Long et al., 2015). This incongruity is caused by the fact that 'non-consumptive' rights alter flows, and may impact water quality, not to mention exacerbate drought conditions brought on by dams that obstruct minimum environmental flow regulations (Hadjigeorgalis & Lillywhite, 2004). Since the CWC is especially favorable towards hydropower development, the proliferation of dams across the Chilean landscape has caused altered riparian regimes susceptible to the impacts of climate change, notably reduced runoff (Del Mar Rubio, M., & Tafunell, 2014).

Despite reforms in 2005, the principal structures of the CWC remain intact (Budds, 2013). Meanwhile, hydrologic regimes are changing throughout the country, particularly through diminishing precipitation and river discharge (Sarricolea et al., 2019). Such climatic trends alongside indigenous rights and ecological conservation are not accounted for in either the original or revised codes (Monsalves-Gavilán et al., 2013; Meza et al., 2014). Therefore, institutional reevaluation will be required to realize successful adaptation to altered water availability (Long et al., 2015). While urgency in systemic restructuring is evident, the CWC continues to prove difficult to modify, as pillars have become embedded into the social, political, and economic networks of the Chilean landscape (Bridge et al., 2013).

4.16 Understanding Water Security in Chile

As part of the United Nations' sustainable development goals, water security is defined as safe and affordable water for all, with a particular emphasis on expanding accessibility for communities susceptible to the increasing scarcity of this resource (United Nations, 2018). Although some specific mechanisms for achieving this objective are articulated, its generalized nature overlooks the fact that conceptualizations of water security vary significantly between stakeholders holding a range of relationships with water (ibid). Supporting biotic life, ecological balance, and economic activity, the water interacts between different, and often competing realms of nature and society (Bauer, 2009; Budds, 2016). Further, this resource is embedded within complex systems of sociopolitical relations, complicating access and often benefitting certain powerful actors at the expense of others (Nelson; 2013; Sovacool & Walter, 2019). For example, hydropower dams reliant on healthy river discharge support energy companies and large-scale irrigators while often displacing upstream communities and restricting or altering flows for downstream users and riparian habitats (Maxwell, 2017). The semi-arid region of North-Central Chile represents an apropos landscape for analyzing such competing factors because the previously mentioned dynamics are particularly incongruous and being exacerbated by anthropogenic climate change

(Montecinos et al., 2016; Salinas et al., 2016). Concurrent influences of both increasing water scarcity and resource demand (see Figure 3.3) are disrupting existing systems and challenging the adaptability of different sectors (Burgos, 2017; Norman et al., 2012).

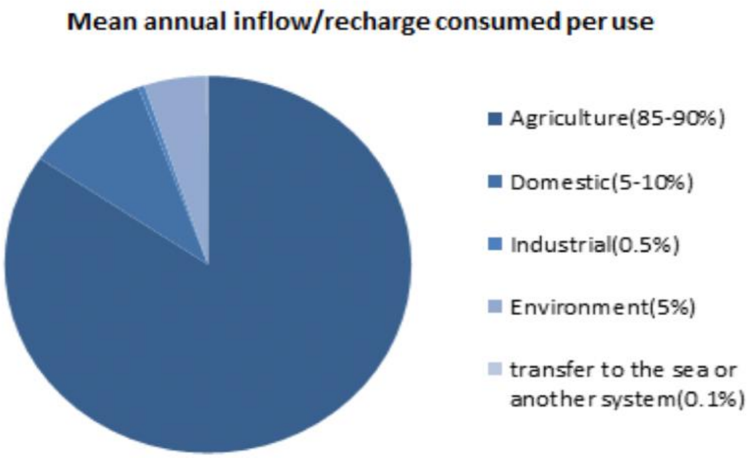

Figure 3.3 Depiction of water usage by sector in Chile (Source: OECD, 2023)

Since the CWC, which functions as the overarching public policy model for water governance is rooted in rigorously neoliberal and free market-oriented legal frameworks, water security is contingent upon the institutional influences bound up in this legislation (Vergara et al., 2017). However, regional exceptions are important to consider, a key example being Coquimbo, where a uniquely active water market is stimulated by ‘spot’ trading that diverges from the traditional property rights style of resource ownership that characterize the Chilean water landscape (Hadjigeorgalis & Lillywhite, 2004). Therefore, the forthcoming discussion will focus on the outcomes of the CWC within Coquimbo to analyze interacting socioecological stressors manifesting in uneven water security between stakeholders (Urquiza & Billi, 2018).

Semi-arid regions have minimal room for error in terms of efficient water allocation in civil and industrial societies (Pizarro et al., 2022; Valdés-Pineda et al., 2014). Correspondingly, the Coquimbo Region has developed extensive infrastructure for storing and transporting water throughout the Elqui and Limarí watersheds (Borzutsky & Madden, 2013; Ferrando, 2002; Strauch et al., 2009). However, flows have been fully allocated for decades, approaching a tipping point as annual precipitation is diminishing and water availability is projected to drop as much as 50% by 2040 (Delorit et al., 2017; Donoso, 2015; WRI, 2020). Therefore, maintaining water security will continue to rely on innovative strategies for maximizing distribution efficiencies (Budds, 2018; Harris, 2003). Irrigation modernization is a strategy that can be implemented to address ongoing water security issues (Arnold et al., 2010; Hoffmann, 2022; Roco et al., 2016).

Operating alongside the CWC, the spot market is a relevant example of such an initiative because it operates with fewer institutional constraints than traditional water rights (Hadjigeorgalis & Lillywhite, 2004). Therefore, transfers can happen almost instantaneously, reliant solely on physical factors of where water is currently available (Donoso, 2015). While this certainly improves accessibility for active traders, increasing awareness of the uneven distribution of benefits among users is challenging the idea that this privatized market is the most effective mechanism for supporting comprehensive water security (Burgos, 2017). For example, Núñez et al., (2017), suggest that vulnerabilities are geographically uneven throughout the Elqui Watershed. Further, Salinas et al., (2016) advance the idea that communities in arid zones are especially susceptible to decreased water security, as reliable supplies diminish and the CWC continues to prioritize irrigation and hydropower. Although the regional economy relies heavily on agriculture, such studies are elucidating how the status quo will exacerbate access barriers, particularly among marginalized groups (Räsänen et al., 2018). Therefore, public policymakers face challenges in whether to maintain existing water governance structures or implement more integrated watershed management to respond to the needs of a greater range of users (Behmel et al., 2018; Urquiza & Billi, 2018).

Chile’s ability to meet the United Nations’ sustainable development goal for water security will rest on the successful implementation of integrative public policy, thereby balancing the priorities of different stakeholders as water scarcity accelerates (Bazilian, 2011; Mitchell & Parker, 2017; United Nations, 2018). National initiatives such as Energía2050 and PANCC allude to water security, yet primarily focus on other initiatives that overlook, yet are inextricably linked to water resources (Bonelli et al., 2014; Urquiza et al., 2018). The 2005 CWC reforms include important language, notably concerning maintaining minimum environmental flows and limitations on water rights speculation/monopolization (Burgos, 2017; Solanes, 2013). However, these plans lack clear mechanisms for more effectively balancing socioenvironmental protectionist and pro-market values (Bauer, 2015). Operating within the constraints of the CWC, law 18.450 reflects this dynamic, as it further commodifies water by subsidizing agricultural entities to increase production (Goldberg & Palladini, 2008; Novoa et al., 2019). Economic activity has been stimulated by this legislation, yet simultaneously increased demand, impacting availability for users reliant on water resources, yet operating outside of the market (Borzutsky & Madden, 2013). Consequently, such laws must reflect a wider range of interests going forward to combat impending alterations to water regimes and reduced availability amongst stakeholders, which often lead to tension and conflict (Vergara et al., 2017). A notable initiative to support such collaboration is conveyed through the research of Salas et al., (2018), which identifies regional pathways to mainstream understandings of climate change impacts. Public policy and private industry can use such platforms to find common ground and engage in transparent dialogue to find solutions for increasing water security.

Alongside surface streams, groundwater aquifers are commonly pumped and allocated to support municipal, agricultural, and industrial uses (Pizarro et al., 2022). Subterranean water can be especially important in arid regions, often lacking substantial lakes or waterways (Scott, 2011). However, the interconnected nature of the water cycle often places strains on one type of source when the other is overallocated, thereby manifesting in river-aquifer interference (Oyarzun et al., 2014). In Northern Chile, significant mining and agricultural activity are straining groundwater sources, recently to the extent that hydrologic experts are considering the practices unsustainable (Meza et al., 2014; Milesi, 2018). Operating within the CWC, however, groundwater regulation is even less clear than surface water, not to mention accurate data collection on aquifer storage is only in the early stages of being cataloged (Harris, 2003). A 2016 OECD report articulated how limitations of the CWC have not only led to overallocation and extreme concentration of surface rights, yet also precipitated the overexploitation of certain aquifers, leading to shortages of potable water in rural communities (Burgos, 2017). Consequently, Chile is at a crossroads in determining whether to continue to treat water as a marketable commodity or instead as a scarce resource, because it has become exceedingly clear that the two frameworks are incompatible (Budds, 2004; Delgado et al., 2015). Meanwhile, nexus thinking, considering the integrated nature of water, energy, and climate change is emerging as a powerful paradigm for advancing both public and private strategies for reducing river-aquifer water conflicts (Räsänen et al., 2018; Vergara et al., 2017). Therefore, the purpose of the forthcoming discussion will be to highlight integrative pathways for collaboration between stakeholders and policymakers to manage more sustainably a vital yet dwindling natural resource (Strauch et al., 2009).

Certain features of the CWC provide strong mechanisms for reducing aquifer depletion (Lictevout et al., 2018). For example, treating water as a commodity that can be transacted in the open market supports efficient use and transfer (Donoso, 2015). Transpiring, however, is that the absence of a safety net for social and ecological uses has enabled large-scale entities to centralize ownership and increase resource extraction (Pino et al., 2015). Neoliberal systems function based on perpetual growth, and the Chilean model has become firmly affixed to expanding global trade networks (Borzutsky & Madden, 2013). The 2005 CWC reforms enacted critical public policy updates and focused on more integrative water resource management (Burgos, 2017; Peña, 2018). For example, provisions were enacted to improve water rights record keeping, enhance groundwater management, increase regulatory authority, and address minimum ecological flows of surface streams (Bauer, 2009). However, private entities continue to exploit loopholes and consolidate water rights to support economic activities, notably exporting cash crops and rare earth minerals (Flores et al., 2017; Hadjigeorgalis & Lillywhite, 2004).

Correspondingly, large-scale agricultural and industrial companies possess expanding capital to install irrigation technology and water transportation infrastructure, supporting economic growth (Daniell, & Barreteau, 2014; Goldberg & Palladini, 2008). These entities hold more institutional clout than small organizations, often hiring legal representation to purchase new water rights, especially as more groundwater sources are discovered, their depletion notwithstanding (Rivera et al., 2016; Salinas et al., 2016). Therefore, water access has become embedded in institutional systems that unevenly allocate resources between stronger and weaker actors (Budds, 2004). Consequently, researchers are beginning to recognize that the groundwater regulations of the CWC are inadequate, reducing policy parameters to quantitative characteristics, thus enabling speculation for owners of water rights, yet neglecting the health of aquifers for the common good (Delgado et al., 2017).

Nexus-oriented regulatory frameworks confronting river-aquifer imbalances can contribute to navigating the interdependent nature of surface and groundwater allocation, corresponding energy requirements for these activities, and emerging disruptions to water security caused by climate change (Ocampo-Melgar et al., 2016; Vergara et al., 2017). Therefore, policies that address these integrated issues holistically are positioned to confront impending alterations to these systems (Wiegleb & Bruns, 2018). While the 2005 CWC reforms represent progress, further public-private cooperation will be necessary to prevent the irreversible depletion of vital water resources (Burgos, 2017). Key features include facilitating transparent dialogue between stakeholders, supporting knowledge transfer to develop robust and accurate data on groundwater reserves, and continuing to expand efficient allocation and renewable technology to reduce river-aquifer interference.

4.17 Electricity Law

Chile's electricity laws were implemented under a similar guise to the CWC (Bauer, 2009). Upon ratification in 1982, the priorities of the national electricity code (CEC) focused on meeting increasing energy demand, primarily via hydropower and transmission expansion along with regional integration (Dettoni et al., 2012). Also adhering to the neoliberal principles guiding broad economic policies, the CEC pursued an agenda intent on the liberalization and privatization of the energy sector (Mundaca, 2013). The installation of market-based models alongside a mandate to proliferate the energy footprint had immediate effects. For example, 62% of the country had electricity access in 1982, yet this figure had grown to 98% by the end of the decade (CNE, 2003). However, coal, oil, and natural gas demand rose concurrently, thereby increasing the reliance on imports and the global economic climate (Urquiza et al., 2018). Alongside multinational trade policies came significant commercial activity (Rector, 2005). The Chilean population saw an acceleration in vehicle and modern amenity ownership, while minerals, lucrative cash crops, and other industrial commodities were sold abroad at unprecedented levels (Hadjigeorgalis & Lillywhite, 2004; Nasirov, & Agostini, 2018). Therefore, as connectivity and living standards rose, so did air and water pollution, as Chilean cities developed some of the highest noxious particulate levels in Latin America (Schueftan & González, 2013). These trends convey how Chile's development models have facilitated the highest socioeconomic levels in the region, yet have transpired at the expense of environmental health, notably riparian systems and remote biophysically rich environments often inhabited by indigenous groups. (Kelly 2018; Pino et al., 2015; Vega-Coloma & Zaror, 2018).

Among Chile's crucial challenges related to energy policy concerns its electricity grid (Dettoni et al., 2012). Until interconnection was achieved in 2018 to establish the National Electric System (NIC), four separate grids supplied power to Chilean communities and industrial sites (Becerra et al., 2017). Two comprised most of the transmission activity, as the Central Interconnected Systems (SIC) and the Northern Interconnected Network System (SING) constituted 75% and 20% of energy transfers respectively (Bauer, 2009). SIC territory covered much of the Central Valley where most of the population resides, while SING powered the preponderance of mining activities in the arid north (Ghorbani & Kuan, 2017). Meanwhile, the SIC historically harnessed a substantial supply of electricity from hydropower while the SING was almost entirely reliant on thermal combustion sources (Vega-Coloma & Zaror, 2018). Therefore, as Chile seeks to expand its renewable energy portfolio, the fragmented nature of the former grid has impeded transferring clean energy from source to site (Raugei et al., 2018).

Although interconnection to form the NIC has already begun to ameliorate some issues, challenges persist, as Chile's geography produces both benefits and complications (Munoz et al., 2017). Counterintuitively, while the main transmission lines run along a narrow corridor, this simplifies the system, yet subjects it to bottlenecks and curtailments (Zurita et al., 2018). The dearth of avenues for energy transfer continues to hinder the effective transfer of energy from north-south, especially since wind and solar have been introduced to the grid in recent years (Watts et al., 2017). Therefore, solutions are being explored such as establishing renewable-specific nodes that will facilitate transmission from remote areas ideal for harnessing wind and solar to demand centers (Becerra et al., 2017). However, abiding issues remain such as the environmental impacts derived by the expansion of transmission infrastructure to areas conducive to energy development, yet that requires encroachment on ecologically sensitive areas (Dettoni et al., 2012).

4.18 Renewable Energy Overview

Besides hydropower, which in Chile is now considered non-renewable above 20MW, renewable energy was practically nonexistent until the early 2000s (Raugei et al., 2018). Not until 2007 did the national government enact a policy requiring that at least 10% of electricity be derived from renewables by 2020 (Mundaca, 2013). The delay occurred despite a biophysical landscape with amongst the most substantial renewable resources in the world (Román-Collado et al., 2018). However, international treaties focused on combatting climate change, progressive leadership, and increasing vulnerability to fossil fuel reliance have contributed to the emergence of a renewable market that is now growing faster than any other nation in Latin America in terms of scale (Becerra et al., 2017; Watts et al., 2017). The new presidential administration of Gabriel Boric is particularly intent on meeting emission reduction targets (Harrison, 2022).

The forthcoming section explores both hydropower as an abiding source of electricity, alongside wind and solar, which have been introduced at scale within the last decade and are expanding rapidly as technology improves and prices reduce (Lombrana & Stillings, 2018). Through unpacking the costs and benefits of each technology, the policies and economic models driving their operation and deployment, and their role in Chile's resource transition are elucidated (Bridge et al., 2013; Proaño, 2018). There can be a tendency to greenwash certain renewable sources (Kelly, 2018). While wind and solar certainly have a smaller impact than hydropower and fossil fuels, each infrastructure has unique characteristics that affect the region hosting these energy projects (Becerra et al., 2017). Also, the analysis will explore the extent to which renewable energy is shifting the institutional structures of energy systems (Montedonico et al., 2018). Seminal documents such as Energía 2050 call for participatory structures to expand in the energy sector alongside better inclusion of communities proximate to renewable development (Urquiza et al., 2018). However, it remains to be seen if an overarching shift in decision-making capacity has been realized, or if this democratization is more commonly a superficial formality, masking continued neoliberal policies (Panez et al., 2020). Furthermore, the relationships between hydropower and agricultural expansion are key to understanding the trajectory of resource governance in the Elqui Watershed (Novoa et al., 2019; Scott et al., 2014).

3.10 Hydropower

Chile's hydropower development can be circumscribed by three distinct eras: 1940-60, 1960-90, and 1990 to the present (Bauer, 2009). The hydropower landscape during these periods serves as a microcosm for overarching political, economic, legal, sociocultural, and environmental trends (Mundaca, 2013). For example, after the establishment of ENDESA in 1943, this organization had a clear institutional mandate to expand the energy footprint, primarily via hydropower construction in the regions proximate to Santiago (see Figure 3.4).

Figure 3.4 The Embalse de La Paloma in the Coquimbo Region: The largest dam in South America constructed for irrigation-based water allocation (Source: Author).

(Nelson, 2013). The first development era (1930-50) primarily consisted of medium-sized structures in settings conducive to the short-distance transmission of electricity to demand centers (Bauer, 2009). The initial stages of this reclamation movement included massive public initiatives to improve water quality and access, representing an overall focus on state-oriented solutions to energy development and human rights (Hadjigeorgalis & Lillywhite, 2004; Pino et al., 2015).

Resulting of national riparian management strategies was the increase of access to potable water to 95% by the 1990s, not to mention an appreciable reduction in flooding and agricultural expansion, as storage reservoirs were implemented (Donoso, 2015; Novoa et al., 2019). Moreover, the period from 1960-90, predominantly comprised of the Pinochet dictatorship, saw shifts toward the privatization of hydropower ownership alongside market-based water rights in general (Borzutzky & Madden, 2013). These trends, along with improving technology and engineering capacity, facilitated larger projects that provided substantial electricity to the grid, to the extent that hydropower comprised almost 90% of the SIC energy matrix by 1995 (Vega-Coloma & Zaror, 2018). Hydropower and grid expansion have been so intertwined that key nodes of the SIC are directly oriented around dam location (Bauer, 2009). However, while environmental impacts were largely ignored at the time of construction, these large impoundments are increasingly understood to cause substantial damage to riparian systems (Moran et al., 2018; Sovacool & Walter, 2019). Chile's government, through CONAMA, has begun to confront ecological issues such as habitat fragmentation, stream temperature imbalance, water loss from reservoir evaporation, and aquatic species mortality, yet intends to continue to rely on the substantial contribution of electricity from hydropower as the RE transition transpires (CONAMA, 2017; Nelson, 2013).

The fact that Chile plans to expand hydropower in the 21st century is problematic, as grassroots movements protesting these structures expand and global public and scientific acceptance of dams diminish (Garces-Voisenat & Mukherjee, 2016; Silva, 2016). Now privatized and broken up, ENDESA constituent groups have shifted towards small-scale hydropower, pump storage, and alternatives that generate less direct impacts than reservoir-style impoundments (Raugei et al, 2018). The justification is that despite the surge in wind and solar, a base load for the grid will continue to be required, especially as coal and other fossil fuels are phased out (Susskind et al., 2014; Zurita et al., 2018). Nonetheless, the International Panel on Climate Change (IPCC) has categorized the majority of Chile as a drought-susceptible region, and these climatic alterations have already begun to manifest (Monsalves-Gavilán et al., 2013; Pino et al., 2015). For example, a severe lack of precipitation in 2009-10 caused nationwide blackouts due to hindered hydropower capacity, which in turn had environmental ripples since backup solutions involved the importation of expensive diesel and natural gas (Urquiza et al., 2017). Regional droughts persist, prompting the question of energy security for Chile if reliance on hydropower continues, despite the projection of a 15-30% overall decrease in hydroelectric potential by 2040 (Long et al., 2015; Nelson, 2013; Sovacool & Walter, 2019). Therefore, for Chile to succeed in establishing a clean and resilient energy grid for the 21st century, hydropower management bodies must be prepared to respond to unprecedented climatic, socioenvironmental, and regulatory changes (Cansino et al., 2018). This will be further complicated by a growing body of evidence linking reservoirs with greenhouse gas emissions (Johnson et al., 2021).

3.11 Solar & Wind Energy

Although Chile possesses among the most potent solar resources in the world, incorporating this technology into the energy matrix involves complex interactions between stakeholders and logistical factors (Barbosa et al., 2017; Trainer, 2010). The recent proliferation of this energy source has accelerated in response to a shifting landscape that includes renewable portfolio standards, progressive governments, technological improvements, market competitiveness, and social advocacy in favor of renewables (Hanel & Escobar, 2013). The growth of the solar market in Chile has averaged 5-10% annually since 2010, as arrays with capacities above 100MW (see Figure 3.5) are now coming online regularly (Haas et al., 2018; Marzo et al., 2018).

Figure 3.5 The Luna Solar Park outside the town of Vicuña in the Elqui River Valley (Source: Author).

However, the dynamics surrounding the actual beneficiaries of PV-generated power, as well as how this technology influences the characteristics of the energy landscape is nebulous, thus requiring critical analysis for embedded complexities and power dynamics to be understood (Bridge et al., 2013; Varas et al., 2013).

In 2016, Chile's solar market grew the fastest among Latin American nations and accumulated the globe's 10th-highest amount of newly added PV capacity (Zurita et al., 2018). Rates of growth continue to accelerate, as the ability to incorporate solar at a substantial scale has been facilitated within the last year due to the newly interconnected National Electric System (NIC) (Becerra et al., 2017). Since population centers in the central region of the country are not proximate to the highest irradiance locations, large solar arrays had often been limited to on-site or near-site of mining operations in the Atacama Desert before transmission began to accommodate north-south transfer (Ghorbani & Kuan, 2017; Marzo et al., 2017; Watts et al., 2017). This grid integration has significant potential to boost solar and wind, yet efficient renewable grid incorporation is still in the early stages of operation, and bottlenecks and curtailments continue (Zurita et al., 2018). However, Chile will need to ramp up this interconnection to meet impending national goals, such as 20% renewable production by 2025 (Watts et al., 2017). This will require faster energy system transitions than are currently transpiring since in 2016 more than 85% of electricity was still supplied by fossil fuels and large hydropower (Bridge et al., 2013; Nasirov et al., 2017).

A noteworthy aspect of solar power is its potential to provide electricity to small-scale operations such as microgrids, irrigation systems, or single residences (see Figure 3.6).

Figure 3.6 An example of household-scale photovoltaic solar power generation in the upper reaches of the Elqui Valley (Source: Author).

(Alavi & Aliakbar, 2015). This can be an effective means of facilitating energy security and socioeconomic progress in geographically remote communities (Dettoni et al., 2012; Londoño, 2017). Currently, the Chilean government is more concerned with developing large solar arrays and wind farms to power the national grid and mining operations in the arid north (see Figure 3.7) (Del Sol & Sauma, 2013; Ghorbani & Kuan, 2017).

Figure 3.7 A substation located in the northern section of the Coquimbo Region, with wind turbines in the background (Source: Author).

During fieldwork, however, I noticed small-scale solar arrays and household scale panels regularly. Small-scale participatory initiatives are being conducted by organizations affiliated with Chilean energy research, such as the Energy Center at the University of Chile (Montedonico et al., 2018). Such programs involve community engagement through intercultural dialogue, and citizen participation in each stage of the renewable implementation process (Urquiza et al., 2018). Localized initiatives promote solutions to grid expansion, that often encroach on sensitive biophysical regions (Gaete-Morales, 2018). Therefore, it is evident that the synchronization of a mix of grid scales will most effectively accommodate the seamless integration of renewables and augment the capacity to meet greenhouse reduction targets (Dettoni et al., 2012; Trainer, 2010).

The national government has committed to follow through on key pillars of Energía2050 and PANCC (Pino et al., 2015). However, the current lack of local-scale initiatives suggests that grassroots projects must be prioritized via institutional shifts for a more participatory energy system to be realized (Urquiza et al., 2018). Solar power has emerged as a potent component of a low-carbon future, yet its current role is predominant in powering mining operations and accounts for increasing electricity demand (Ghorbani & Kuan, 2017; Mundaca, 2013).

Chile's wind industry has developed in close alignment with solar, together representing a new era of renewable-centered energy policies (Raugei et al., 2018). Wind energy has major potential throughout Chile's rugged coastline and gusty valleys yet has only been tapped at a substantial magnitude within the last decade (Román-Collado et al., 2018). As of 2018, wind power had expanded to comprise 6% of the national energy portfolio, while installation costs have dropped more than 20% from 2010 metrics (Proaño, 2018). There is no doubt about the prolific physical capacity for developing wind energy in Chile (Becerra et al., 2017; Rufin. 2015). However, pertinent to understanding the trajectory of this technology are the intertwined political, economic, and socioenvironmental trends influencing the nature of the growth and characteristics of this market (Gil & Aravena, 2014; Mundaca, 2013). As Chile undergoes a resource transition, interactions between government initiatives and public policy, alongside abiding fee market systems portend a challenging balance (see Figure 3.8).

Figure 3.8 A recently installed wind turbine in the Coquimbo Region (Source: Author).

Like solar and hydropower, certain structural dynamics of the wind industry continue to resemble traditional top-down energy systems, that facilitate profit for multinational entities, while participatory structures and environmental regulations are cast aside (Barbosa et al., 2017; De Souza et al., 2017; Ureta, 2017). An apropos example is that Chile's largest wind farm, El Arrayán, was financed by a U.S. conglomerate (Pattern Energy), functions with German turbines (Siemens), and channels 70% of generated electricity to the Las Pelambras copper mining operation of its majority owner, multinational Antofagasta Minerals corporation (Choi & Song, 2017; Long, 2014). Such arrangements continue to permeate the energy landscape, despite the Chilean government promoting democratization as a focal point of the renewable transition (Montedonico et al., 2018; Urquiza et al., 2018).

Another issue confronting the Chilean wind market concerns a legacy of disorganization surrounding scientific data for effectively siting wind farms (Watts et al., 2017). The spatial characteristics of this infrastructure not only influence the surrounding landscape, but also are typically chosen based on physical characteristics discerned through optimization assessments, wind resource data maps, and levelized cost analyses, all of which are lacking in Chile (Haas et al., 2018; Raugei et al., 2018). This dynamic is somewhat attributable to the embeddedness of Pinochet-era scientific repression and is currently diminishing the performance of wind farms while hindering their capacity to contribute to the national grid (Bauer & Catalán, 2017; Gil & Aravena, 2014; Watts et al., 2017). However, there has been a push in recent years to expand the scientific body of wind siting models to overcome the inertia currently holding back a nation with wind and solar resources sufficient to completely replace thermal energy sources (Vega-Coloma & Zaror, 2017). National initiatives such as Energía 2050, spearheaded by the Michelle Bachelet administration have had a focal role in prioritizing growth and grid integration for renewable energy (Montedonico et al., 2018; Ureta, 2017).

Meanwhile, the national focus continues to be on increasing the scale of wind farms, while small operations receive relatively little attention (Bakken et al., 2014). National assessments have determined that micro-wind has substantial potential, primarily because these operations can exploit lower wind speeds and provide electricity to remote off-grid communities. (Becerra et al., 2017). Nonetheless, integration with the NIC continues to be an issue for wind energy, due to the spatial disconnection between the existing transmission system and optimal sites (Gil & Aravena, 2014). Therefore, it seems evident that supporting the multi-scalar growth of this market can mitigate existing geographic limitations and decentralization of existing structures that inhibit citizen agency in the renewable energy market (Raugei et al., 2018).

3.12 Renewable Energy in the Coquimbo Region

The Coquimbo Region is situated in a geographic transition zone, as the fertile corridor characterizing Chile's Central Valley begins to give way to the aridity of the Atacama Desert (see Figure 3.9) (Montecinos et al., 2016).

Figure 3.9 A visual depiction of the semi-arid nature of the Elqui Valley, contrasted by irrigated and non-irrigated land, and including two solar arrays (Source: Author).

Therefore, Coquimbo hosts a convergence of biophysical characteristics, including the northern extent of any appreciable hydropower capacity, alongside the beginning of the optimal solar PV irradiance zone, not to mention a rugged coast hosting substantial wind potential (Feron et al., 2016). This level of concentration for each major renewable source is unique and presents a template for analyzing the interaction between these infrastructures (Becerra et al., 2017). Furthermore, Coquimbo is among Chile's most climate change-susceptible regions, having suffered upwards of a 50% decline in precipitation levels during the past century (Salas et al., 2018; Urquiza & Billi, 2018). Since the region's waterways irrigate major agricultural operations, the implications of this resource scarcity will manifest in multifarious ways, including altered hydropower management, water market configuration, and socioenvironmental wellbeing (Delorit et al., 2017; Hadjigeorgalis & Lillywhite, 2004). Incorporating the legal, political, and economic dimensions of Chile's energy and water policies facilitates a comprehensive understanding of a region at the center of the WECC nexus (Liu, 2016).

3.13 Background on Irrigation Modernization in the Elqui Valley

Irrigation practices in the Elqui Valley date back to Pre-Columbian times, as water was diverted from the mainstem river to support subsistence agriculture (Embid & Martin, 2022). Indigenous settlements developed innovative strategies for crop cultivation, transforming a semi-arid landscape into a fertile region (Jordan et al., 2023). When mechanized agriculture began to develop in the early 20th century, water rights purchases expanded, and cooperatives formed to collectivize resource distribution (Budds, 2004). The Junta de Vigilancia del Rio Elqui y sus Afluentes (JVRE) emerged as the primary administrative body overseeing water allocation, which propelled the basin forward in terms of infrastructure development supporting irrigation (Nelson, 2013). The construction of La Laguna Reservoir in the upper reaches of the basin further embedded the region's focus on agriculture, as storage expanded allocation capacity and enabled yearlong water distribution (Moran et al., 2018). By the 1970s the Coquimbo Region was among the major cash crops exporters in South America, supported by a burgeoning economy throughout the Elqui and Limarí Watersheds (Rector, 2005; Urquiza et al., 2018).

During the 20th century, the Elqui Basin transitioned from a region hosting primarily subsistence foods for domestic consumption to being a major player in the international food market (Panez et al., 2020). Cash crops such as citrus fruits, avocados, and pisco/table grapes thrived so long as water was available (Urquiza et al., 2018). These commodities were especially in demand around economic centers of the northern hemisphere, with an inverse growing season to Chile (Embid & Martin, 2022). Meanwhile, the Chilean market model that emerged in the 1970s accommodated an anti-regulatory environment favorable to large-scale commercial entities (Bauer, 2009). Water rights purchases were increasingly concentrated and peasant farmers often became reliant on corporations for processing and exporting their crops (Panez, 2020). Consequently, Coquimbo experienced wealth accumulation alongside increasing social inequality and ecological damage exacerbated by agricultural runoff, mining, and other heavy industry (Ghorbani and Kuan, 2017).

Spearheaded by JVRE, water users in the Elqui Basin further committed to the agricultural sector through the construction of Puclaro Dam in 2000 (Budds, 2018). One of the largest irrigation-specific reservoirs in South America, this project enabled enhanced control over water allocation for a robust network of water users reliant on this source (Delorit et al., 2017). Interestingly, however, the irrigation canals connected to the reservoir mirrored those built in the early part of the 20th century, even though law 18.450 channeled significant subsidies to the agricultural sector (see Figure 3.10) (Bauer, 2015).

Figure 3.10 Irrigation canals flowing downstream from the Embalse de Puclaro Dam in the Elqui Basin (Source: Author).

This represented a missed opportunity to install closed pipes and in-conduit hydropower thus retrofitting existing infrastructure to establish a modernized system (FCA, 2021). Meanwhile, the regional water landscape has seen a consistently increasing demand for water resources as more land is purchased for crop cultivation (Borzutsky & Madden, 2013). Several water communities that work cooperatively to maintain and operate irrigation canals have experienced increasing pressure to improve methods for water distribution because fewer water rights holders receive their allocation during dry periods (Jordan et al., 2023).

Recently, the National Irrigation Commission (CNR) presented goals for agricultural practices in the 21st century, which include upgrading existing canal infrastructure (Embid & Martin, 2022; Novoa et al., 2019). Working within the confines of the CWC, however, large-scale water rights holders and irrigation districts have yet to engage in such projects to any significant extent (Jordan et al., 2023). The agro-industrial complex continues to thrive under existing regulatory systems, meaning that national laws will need to change to require modifications to water allocation and usage (Panez et al., 2020). The CNR will therefore need to proactively promote a new culture around water and energy use that better aligns with public sentiment, and new policies such as the Energía2050 Initiative and PANCC (Embid & Martin, 2022: Montedonico et al., 2018).

During my time in the Elqui Valley, I visited key water/energy sites, interviewed stakeholders, and worked in the PROMMRA lab to gain a more complete understanding of the irrigation landscape. The combination of these activities supported the development of a comprehensive framework for analyzing key dynamics surrounding irrigation modernization and its relationship to broader themes of resource governance, uneven power dynamics, and human-environment relations (Budds, 2018). The following chapters (4-6) tackle these topics through a CPDM methodology. The sections are also intended to be sequential in nature, with data collection and analysis from chapter 4 informing the methodology and analysis for subsequent research questions.

CHAPTER 4: UNDERSTANDING THE WATER-ENERGY-CLIMATE CHANGE INTERFACE THROUGH IRRIGATION MODERNIZATION IN THE ELQUI WATERSHED

4.1 Introduction

This chapter analyzes the emerging phenomenon of irrigation modernization and its role at the center of water and energy governance in the Elqui Watershed, particularly as climate change is increasingly impacting resource security (Novoa et al., 2019). The research aims to identify examples of technification projects and contrast them with ongoing areas where economic, environmental, political, or sociocultural barriers are preventing implementation (Arnold et al., 2010). Such a process can advance knowledge surrounding drivers and impediments of agricultural reform (Plusquellec, 2009). Since more than 80% of Chilean freshwater withdrawals and 30% of overall energy usage are dedicated to irrigation, decision-making within this sector has major implications for resource management (Errázuriz, 2019; Jordan et al., 2023).

Distinctive and generalizable characteristics of the Elqui Watershed's irrigation landscape are analyzed, thus revealing links between modernization projects and transitions toward adaptive resource governance (Panez et al., 2020; Urquiza et al., 2018). 'Modernization' processes are considered multidimensionally, and in consultation with stakeholders planning a range of upgrades to existing irrigation systems (Behmel et al., 2018). Such projects represent a critical bridge between key water, energy, and climate change interactions in the 21st century (Liu, 2016). To identify and analyze key examples of irrigation modernization throughout the basin, three complimentary mixed methods are engaged to explore the following research question:

What examples of irrigation modernization are present in the Elqui River Watershed, how are they addressing energy and water resource security, and where are there gaps that are yet to be filled?

Including comprehensive literature review, onsite participant observation, semi-structured interviews, and quantitative data analysis, results are translated and evaluated to identify examples of modernization or lack thereof. Takeaways inform the development of a multi-criteria analysis tool (MCAT) designed to support decision-making around core opportunities and barriers for different stakeholders (Nagel & Ptak, 2022). This template can inform the targeted assessment of a range of characteristics surrounding the irrigation landscape to better understand how projects are shifting systems of water and energy use and who is primarily benefitting (Panez et al., 2020). A combination of these methods seeks to develop a robust understanding of core dynamics surrounding irrigation modernization and why they are a vital component of water and energy governance as climate change further disrupts resource security in certain geographic regions (Jordan et al., 2023).

Chile's irrigation landscape represents a salient example of how free-market-oriented, anti-regulatory economic models can support an active agricultural sector (Fortier & Trang, 2016). However, historic laws and political structures are concurrently leading to water and energy stress, as demand rises exponentially while energy and water are increasingly insecure (Sovacool & Walter, 2019). Further, unequal resource access and wealth disparity are amongst the most severe in Latin America, indicating that a rising tide hasn't lifted all boats along the Chilean coast (Pino et al., 2015). Underlying these trends is a lack of inter-scalar coordination, as there continue to exist disparities between national legislation and on-the-ground dynamics at the local/watershed scale (Nagel, 2017). Chile is thus trapped between embedded and aspirational systems of resource governance, despite multiple attempts at institutional reform (Gómez-Barris, 2022; Oyarzún et al., 2008). The drafting of a new constitution in early 2022 symbolized a major opportunity to proactively support the transition toward more democratic and adaptive water and energy governance (Nicas, 2022). However, the failure to enact this charter further reinforces the major hurdles in moving away from abiding neoliberal systems, an issue that continues to divide Chileans (Burgos, 2017; Nicas, 2022). Therefore, a complex landscape holding both new and old models is playing out through irrigation, which speaks to broader issues of natural resource policy (Jordan et al., 2023). A growing number of regions across the globe reliant on agriculture. but susceptible to resource insecurity, can learn from outcomes manifesting throughout the Elqui Watershed. The research engages in an integrative analysis of the basin to develop a better understanding of opportunities and barriers behind engagement in modernization projects, and how different stakeholders are affected.

Chile has developed several very active markets, that can serve as models for other irrigation-centric regions across the globe (Hoffman & Vilamayor-Tomas, 2022). Categorizing water as a fully commodified resource in the Chilean Water Code (CWC), the capacity to transact and transfer available resources has supported lucrative economic growth (Bauer, 2009; Panez et al., 2020). However, the nation has fallen into the same trap as several other Latin American countries (Saldi et al., 2014) in that industrial development has superseded socioecological sustainability and is approaching a tipping point where insatiable demand overwhelms available resources, that in the case of Chile are rapidly depleting (Salinas et al., 2016). Chile's government has prioritized funding for the Ministry of

Agriculture (CNR) which has subsidized select irrigation modernization projects, thereby stimulating the growth of the economic sector (see Figure 4.1) (Errázuriz, 2019).

Figure 4.1 A public information campaign in the Elqui Valley highlighting a canal lining project intended to increase allocation efficiency for a local canal network (Source: Author).

Meanwhile, though, national policies focused on climate change mitigation, renewable energy, and integrated resource management have largely not worked in coordination with regional and/or watershed-specific projects commissioned by the CNR (Behmel et al., 2018). Therefore, growing research is calling for more coordinated strategies that consider the clear impacts of cash crops, mining, hydropower, and other practices that threaten natural resources, yet have been allowed to continue unabated for decades due to embedded neoliberal economic and political systems (Budds, 2018). Irrigation modernization can either disrupt or further entrench, existing top-down models that are increasingly being challenged by new paradigms of more democratic resource policy. To understand such complexities, three specific projects are identified and analyzed to better understand how vital natural resources are used and shared between stakeholders with varying power levels (Liu, 2016).

4.2 Resource Efficiency Paradox and Surface/Groundwater Interactions

Alongside surface streams, groundwater aquifers are commonly pumped and allocated to support municipal, agricultural, and industrial uses (Ghorbani & Kuan, 2017). This is increasingly the case in the Elqui Basin, despite surface resources being overallocated, symbolic of ongoing neoliberal market models and challenging the capacity for irrigation reform to truly lead to water and energy savings, as demand continues to rise despite modernization initiatives (Grafton et al., 2018). Subterranean water can be especially important in arid regions, often offsetting unreliable lakes or rivers (Scott, 2011). However, the interconnected nature of the water cycle often places strains on one type of source when the other is overallocated, thereby manifesting in river-aquifer interference (Oyarzun et al., 2014). Throughout the Elqui Watershed, significant mining and agricultural activity is straining groundwater resources, recently to the extent that hydrologic experts are considering current practices unsustainable (Meza et al., 2014; Milesi, 2018). Operating within the CWC, however, groundwater regulation is even less clear than surface water, not to mention accurate data collection on aquifer storage is only in the early stages of being cataloged (Valois et al., 2020). In fact, a 2016 OECD report articulated how limitations of the CWC have not only led to overallocation and extreme concentration of surface rights, yet also precipitated the overexploitation of certain aquifers, leading to shortages of potable water in rural communities (Burgos, 2017). Consequently, Chile is at a crossroads in determining whether to continue to treat groundwater as a marketable commodity or instead as a scarce resource, because it has become exceedingly clear that the two frameworks are incompatible (Budds, 2004; Delgado et al., 2015). Meanwhile, nexus thinking, considering the integrated nature of water, energy, and climate change is emerging as a powerful paradigm for advancing both public and private strategies for reducing river-aquifer water conflicts (Räsänen et al., 2018; Vergara et al., 2017). Therefore, the purpose of the forthcoming discussion will be to highlight integrative pathways for collaboration between stakeholders and policymakers to manage more sustainably a vital yet dwindling natural resource (Strauch et al., 2009).

Certain features of the CWC provide strong mechanisms for reducing aquifer depletion (Lictevout et al., 2018). For example, treating water as a commodity that can be transacted in the open market supports efficient use and transfer (Donoso, 2015). Transpiring, however, is that the absence of a safety net for social and ecological uses has enabled large-scale entities to centralize ownership and increase resource extraction (Pino et al., 2015). Neoliberal systems function based on perpetual growth, and the Chilean model has become firmly affixed to expanding global trade networks (Borzutsky & Madden, 2013). The 2005 CWC reforms enacted critical public policy updates, focused on more integrative water resource management (Burgos, 2017). For example, provisions were enacted to improve water rights record keeping, enhance groundwater management, increase regulatory authority, and address minimum ecological flows of surface streams (Bauer, 2009). However, private entities continue to exploit loopholes and consolidate water rights to support economic activities, notably export cash crops and rare earth minerals (Flores et al., 2017; Hadjigeorgalis & Lillywhite, 2004).

Correspondingly, large-scale agricultural and industrial companies possess expanding capital to install irrigation technology and water transportation infrastructure to support growth (Daniell, & Barreteau, 2014; Goldberg & Palladini, 2008). These entities hold more clout than small organizations, often hiring legal representation to purchase new water rights, especially as more groundwater sources are discovered, their depletion notwithstanding (Rivera et al., 2016; Salinas et al., 2016). Therefore, water access has become embedded in institutional systems that unevenly allocate resources between stronger and weaker actors (Budds, 2004). Consequently, researchers are beginning to recognize that the groundwater regulations of the CWC are inadequate, reducing policy parameters to quantitative characteristics, thus enabling speculation for owners of water rights, yet neglecting the health of aquifers for the common good (Delgado et al., 2017).

Nexus-oriented regulatory frameworks confronting river-aquifer imbalances can contribute to navigating the interdependent nature of surface and groundwater allocation, corresponding energy requirements for these activities, and emerging disruptions to water security caused by climate change (Ocampo-Melgar et al., 2016; Vergara et al., 2017). Therefore, policies that address these integrated issues holistically will be positioned to confront impending alterations to these systems (Wiegleb & Bruns, 2018). While the 2005 CWC reforms represent progress, further public-private cooperation will be necessary to prevent the irreversible depletion of vital water resources (Burgos, 2017). Key features include facilitating transparent dialogue between stakeholders, supporting knowledge transfer to develop robust and accurate data on groundwater reserves, and continuing to expand efficient allocation and renewable technology to reduce river-aquifer interference. To successfully implement modernization projects that lead to meaningful outcomes not only for improving water and energy efficiency but also facilitating socioenvironmental benefits will rely on continued engagement and research into these complex interactions (Ramirez, 2022).

4.3 Irrigation Modernization Projects

The following three sites (Puclaro Dam, Elqui Watershed Smart Metering System, and Bellavista Canal Lining Project) represent key examples of irrigation modernization projects. The efforts were selected for analysis because they specifically address energy and water insecurity resulting from climate change impacts (FCA, 2021). While other examples of technification exist throughout the basin, the chosen projects have the most complete data and were all visited during fieldwork. Key metrics and semi-structured interviews alongside indicator identification inform the structure for an MCAT that can be used to understand opportunities and barriers for other projects, certainly anticipated to accelerate as infrastructure ages and natural resource efficiency becomes increasingly important. Therefore, this representative sample provides a model capable of customization for stakeholders and decision-makers in agricultural regions across the globe (Panez et al, 2020).

4.3.1 Puclaro Dam (Embalse de Puclaro)

Situated in the lower Elqui Watershed after the confluence of three major tributaries, Puclaro Dam was constructed (quite recently) in the year 2000 (see Figure 4.2) to upgrade management capacity over agricultural water allocation (Budds, 2018).

Figure 4.2 Puclaro Dam from directly below the powerhouse during a tour in June 2022 (Source: Author).

This effort represented a significant step towards modernizing watershed-scale irrigation practices increasing capacity for harnessing runoff, controlling flows, expanding irrigation diversions, and generating hydropower (see Figure 4.3) (Scott et al., 2014).

Figure 4.3 The powerhouse at Puclaro Dam. Two turbines with 2.5 MW capacity can be seen in the background (Source: Author).

Tasked with coordinating basin-wide water distribution, the Junta de Vigilancia de Rio Elqui y sus Afluentes (JVRE) is the primary oversight body working in collaboration with a complex network of water users and irrigation associations (JVRE, 2022). However, as demand curves continue to rise (for both surface and groundwater), annual discharge has been anything but reliable, placing stress on the management system and agricultural sector (Salinas et al., 2016). Such trends reveal the challenges already emerging as the basin grapples with increasing water resource exploitation on an over-allocated system. The disparities offer a relevant lens for analyzing how modernization projects may be able to help mitigate an unsustainable agricultural management landscape. To understand the outcomes of this project, key reservoir metrics are assessed alongside interviews with JVRE and a range of associated stakeholders throughout the watershed

4.3.2 Elqui Watershed Smart Metering System

Throughout select sections of the Elqui Watershed, JVRE has engaged in a project installing smart metering to more efficiently allocate water amongst water user associations (see Figure 4.4). Partnering with Australian irrigation company Rubicon, efforts include solar-powered self-sustaining telemetry systems, and upgraded diversion infrastructure, alongside ongoing research and development for more efficient water distribution water to users (Rubicon, 2021). JVRE has touted this effort as a major step in reducing inefficiencies in the network (JVRE, 2022).

Figure 4.4 A campaign aimed at improving irrigation canals with smart metering systems and telemetry data to distribute water more accurately and efficiently (Source: Author).

While improved data and control over the canal system have led to modest water savings and lower energy bills, the upgraded system represents a fraction of the watershed's full irrigation network, and many analog systems remain (see Figure 4.5) (JVRE, 2022).

Figure 4.5 An irrigation diversion location with old technology that hasn't been upgraded and paired with smart metering systems (Source: Author).

Also, Bellavista District, the collective that has engaged in this modernization project is among the longest-standing canal associations in the basin and is primarily comprised of senior rights holders with more capital and influence over decision-making than other entities (Borzutsky & Madden, 2013). Therefore, a central focus of this analysis involves looking at the types of entities that can invest and reap the benefits of these infrastructural upgrades. JVRE and Rubicon have leveraged this program as a leap in irrigation technification, yet funding for this project is supported by law 18.450 from the CNR, which continues to incentivize unencumbered market growth (Panez et al., 2020).

4.3.3 Elqui Watershed Canal Lining/Piping Project

Spearheaded by the CNR and JVRE, a watershed-scale project to either line or pipe a network of irrigation canals is underway yet still in its early stages of development (JVRE, 2022). Because of the significant water loss from evaporation and seepage along unlined canals, this strategy represents an effort to mitigate resource insecurity through higher conveyance efficiency (McKuin et al., 2021). The fieldwork process included several site visits (see Figure 4.6) and meetings with local experts to understand opportunities and barriers to implementing these upgrades.

Figure 4.6 An unlined canal currently being reviewed for a piping project in the Elqui Watershed. This project is funded by the CNR and Bellavista WUA with subsidized support from law 18.450 (Source: Author)

While successful efforts have the potential to reduce source-to-site water loss by up to 50%, uncertainties remain in whether the lack of groundwater recharge, cost, distribution of benefits, and overall water security will be appreciably improved (Sishodia et al., 2018). Furthermore, interviews with stakeholders revealed how benefits are primarily channeled to water users with substantial capital and power, while small-scale peasant farmers are increasingly marginalized from the system.

Based on an initial evaluation of the three modernization projects, each represents an effort to address the interdependence of water and energy more directly. Consequently, the next section discusses some key frameworks for considering these resources as a nexus, directly impacted by climate change impacts. Context developed in the analysis supports the indicators that are selected for the MCAT.

4.4 The Nexus in Water and Energy Governance

Core to this research is a critical analysis of the interface, or nexus, between water, energy, and climate change issues. While ‘nexus thinking’ is an interpretive concept and can broadly be considered as any paradigm that examines issues from perspectives of integration, a more precise definition grew out of the World Economic Forum in 2008 (Wiegleb & Bruns, 2018). Including climate as a driver of energy and water issues, this summit sought to address long-overlooked connections between natural resources that are essential to supporting human life (WEF, 2020). Although this new policy framework has promoted discourse between stakeholders, nexus thinking is only recently beginning to be considered, or remains absent, in governance settings (Räsänen et al., 2018). However, as administrative bodies begin to implement climate change mitigation and adaptation policies, this represents a critical juncture for confronting water and energy issues in a coordinated manner, since these resources will be directly impacted by impending alterations (Bazilian et al., 2011). Clearly, agriculture resides at the center of the interface, since substantial energy and water resources are allocated to this sector (Panez et al., 2020).

Emerging research from Wiegleb & Bruns (2018), suggests interpreting nexus agendas at face value is problematic, as such schemes often reflect neoliberal models that perpetuate socioeconomic inequalities. The authors argue that 'alternative' frameworks, grounded in political ecology are crucial for critically analyzing how power-embedded nature-society relations influence and are influenced, by water, energy, and climate change policies. Therefore, detailing dimensions of both 'traditional' and 'alternative' nexus discourses, highlighting barriers and opportunities for each to inform resource governance is an important strategy (Vergara et al., 2017).

Despite increasing academic engagement with nexus frameworks, governance models often confine policies to, or at least favor, only one of the elements, as opposed to pursuing integration (Bazilian, 2011). This is particularly problematic in the global south, where populations often suffer from a lack of access to water, energy, or food (Sovacool & Mukherjee, 2011). However, underlying drivers behind such fragmentation are often bound up in sociopolitical power structures, restricting coordinated reforms due to vested interests within discrete sectors (Robbins, 2012). Growing research suggests that more holistic policies will facilitate economic efficiency and improve socioenvironmental conditions much more significantly than if decision-making continues to be confined to singular aspects of increasingly codependent phenomena (Stang et al., 2018). Relevant illustrations can be found in certain national climate change policies, that include specific mechanisms for mitigating impacts on water, energy, food, and ecosystem services (Liu, 2016). For example, PANCC discusses adaption strategies focused on addressing socioenvironmental health, integrated water resource management, sustainable food production, urban and coastal infrastructure, as well as a secure and low carbon energy supply (Behmel et al., 2018; Ministry of Environment, 2016; Peña, 2018). However, existing policies in Chile, notably the CWC and CEC hold more legal clout than this aspirational document and continue to influence the fragmented governance of these resources (Bauer, 2009). Therefore, researchers are searching for mechanisms to implement or operationalize nexus thinking into policy landscapes, since this framework has primarily been confined to theoretical 'paper exercises' that don't influence empirical outcomes (Leck et al., 2015). This is not to say that PANCC doesn't have any legal standing, yet such strategies often confront existing governance structures that are locked into existing models based on embedded sociopolitical power relations (Araújo, 2014; Bridge et al., 2013).

Traditional nexus approaches generally emphasize resource security, ecological modernization, and methods for economic efficiency, and thus are predominantly prescriptive and utilitarian (Wiegleb & Bruns, 2018). These methods certainly can have an important role in efforts to mitigate resource scarcity, yet such approaches often fail to critically analyze the multidimensional nature of the nexus and its sociopolitical undertones (Räsänen et al., 2018). Emerging alternative approaches are challenging the limitations of traditional nexus frameworks, primarily by engaging with constructivist principles to suggest that the 'science' driving nexus approaches are subject to political constructs, power dynamics, and economic interests (Sovacool & Walter, 2019; Wiegleb & Bruns, 2018). Therefore, decision-making regarding nexus resource management is political, often aligning with neoliberal models permeating most global institutions (Budds, 2018). Such processes often lack transparency, perpetuate power inequalities, and overlook the sociocultural significance of these resources (Bazilian, 2011; Pino et al., 2015). Critical analysis of these dimensions must be taken into account so that nexus resources are more holistically managed and allocated based not solely on economic value, but also evaluate socioenvironmental factors (Smajgl et al., 2016).

Another consideration for nexus governance is spatial heterogeneity, which is crucial to understanding how the nexus functions based on scale-sensitive nature-society relationships that play out in disparate ways in different geographic settings (Wiegleb & Bruns, 2018). For example, Stang (2018) discusses how altered and diminished water resources in the American Southwest will require increases in chemical treatment processes, thus demanding additional energy. Meanwhile, the Northeast United States is not likely to face water scarcity soon and is projected to see energy use drop. This suggests that geographic characteristics are important in determining future water-energy nexus relationships. Thus, connecting water and energy apparatus between regions represents a realm of opportunities and challenges for creating more efficient shared systems (Foden et al., 2019; Liu, 2015).

Irrigation is a key link between energy and water, and Chile has had a particularly important role in bridging two sectors that are regulated separately, yet deeply interdependent (Vergara et al., 2017). Since water is often conceptualized as a natural resource and electricity as an activity, the legal frameworks for regulating irrigation fall into an ambiguous middle ground, leading to incongruous policies (Nelson, 2013). For example, the CEC and CWC were written entirely in isolation from one another, even though irrigation, one of the nation's biggest economic sectors, operates at the intersection of these issues (Scott et al., 2014; Bauer, 2009).

Analysis of relationships between dominant traditional, and emerging alternative frameworks, reveals that nexus thinking is socially produced and context-sensitive (Cremades et al., 2014; Liu, 2016). Applying a broad brush to conceptualize the interface as a specific concept when it functions through embedded sociopolitical contexts and discourse is thereby inadequate. Engaging in an interface model for decision-making must consider dynamic and coexistent networks of biophysical and sociopolitical relations (Smajgl et al., 2015). Therefore, this research engages in a comprehensive analysis of a dynamic watershed to gather a robust understanding of key characteristics of irrigation modernization and its role in resource governance. The selected projects support a template for unpacking such complexities and help provide a framework that can be individualized for other projects.

4.5 Major Themes in the Irrigation Modernization Landscape

Key indicators are identified based on a review of literature related to socioenvironmental aspects of irrigation modernization (Sovacool & Mukherjee, 2011). The concepts help thematically ground the research and provided a compass for organizing interviews and conducting data analysis. They help form the key indicators comprising the MCAT, in turn helping understand key drivers, opportunities, and barriers for irrigation modernization projects. The following themes are also analyzed based on feedback from a range of stakeholders. Such a process helps to better understand whether these projects have the potential to increase resilience, and potentially help democratize water and energy systems (Urquiza et al., 2018).

4.5.1 Resource Efficiency (Positive)

Perhaps the most fundamental aspect of irrigation modernization is the idea that upgraded infrastructure will mitigate losses from inefficient resource provision (Baka, 2017). Examples include lining or piping canals, improving energy distribution facilities at pumping locations, reducing reservoir evaporation, or installing new renewable energy facilities to reduce reliance on distant transmission systems (Huber, 2015). While these figures can be challenging to quantify, a central focus of technical research in irrigation modernization literature considers these improvements, usually one at a time (for example Embid et al., 2022; Panez et al., 2020; Roco et al., 2016). Instead, this research seeks examples from multiple dimensions and considers byproducts, such as the impact on groundwater recharge when canal conveyance efficiencies improve, yet less water is returned to the basin as a result (Ghorbani & Kuan, 2017). Another common outcome is better practices leading to energy and water savings only increase demand and don't truly address resource security (Budds, 2018). Applying this lens to different projects will help set the stage for understanding whether they meet the fundamental criteria of an irrigation modernization project.

4.5.2 Adaptive Capacity (Positive)

Within irrigation modernization literature, adaptive capacity generally refers to the ability of stakeholders to respond or adjust to changing conditions. This term is often related to the embeddedness of institutions, either creating pathways or erecting barriers to carrying out modernization projects (see: Ayre & Nettle, 2017; Roco et al., 2016; Vicuña et al., 2014). Adaptive capacity includes both technical and sociopolitical factors, and limited literature is developing around key conditions that either enable or hinder project implementation. The Chilean Ministry of Agriculture has a set of criteria used during the drafting of system improvement plans, yet primarily focuses on technical aspects. During fieldwork, conversations with stakeholders sought to identify pathways toward adaptation based on a range of factors. For example, JVRE staff discussed their capacity to install modernized irrigation infrastructure based on shifting climate models and how this is influencing resource governance and financing from local, regional, and national entities.

4.5.3 Adaptive Governance (Positive)

Related to capacity, adaptive governance is a somewhat more specific term that concerns the dynamics of power and control over resource management decisions. Critically analyzed by several authors (see: Ayre & Nettle, 2017; Birkenholtz, 2009; Wang et al., 2018), governance structures function between a range of scales and involve both enabling and restricting conditions. Therefore, social analysis of irrigation modernization must consider several actors involved in legislative decisions that influence the resource landscape.

4.5.4 Social-Ecological Resilience (Positive)

Resilience is a central concept within irrigation modernization literature. Often a driving factor behind projects, resource security considerations inform where and how adaptive strategies can be implemented. A common goal of retrofitting projects is oriented toward increasing resilience to changing circumstances, particularly as climate change disrupts water and energy landscapes (Urquiza & Billi, 2020; Fortier & Trang, 2016; Roco et al., 2016; Scott et al., 2014). While there is a developed body of literature on energy and water security (see: Budds, 2018; Pasqualetti & Sovacool, 2012; Rodilla & Batlle, 2012; Sovacool & Walter, 2019) only limited research has been conducted on security considerations shaping irrigation modernization as a specific phenomenon (see: Berbel et al., 2019; Maraseni et al., 2012; O'Donnell et al., 2019; Parvin & Rahman, 2009). An important area for developing research involved developing indicators of social-ecological resilience and analyzing how these change before and after modernization projects. Such studies (Panez et al., 2020; Urquiza et al., 2018) helped develop more comprehensive templates for considering relationships between updating irrigation infrastructure and how surrounding human and environmental landscapes respond.

4.5.5 Hydropower (Positive)

Chile has seen several irrigation districts install in-conduit hydropower as a part of irrigation modernization projects (Rubicon, 2022). However, it is important to consider that there is a significant dearth of examples and research surrounding hydropower coupling with canal retrofitting, a central component of development strategies, yet a topic practically absent in the international literature. Although the dam-irrigation nexus is commonly discussed, the installation of canal-based hydro hasn't permeated global development agendas (Scott et al., 2014). One partial exception is Berbel et al., (2019), who discuss the integration of irrigation modernization and renewable energy yet makes no specific mention of in-conduit hydropower (Peña, 2018). Therefore, this strategy, promoted by the CNR, seems to be in the infant stages of development, despite growing dialogue surrounding grid resiliency, water security, and integrated water resource management (Behmel et al., 2018; Errázuriz, 2019).

In the Elqui Valley, two hydropower dams (La Laguna and Puclaro) produce modest electricity, as they are focused primarily on irrigation (JVRE, 2022). However, investments in turbines suggest that the Chilean government continues to focus on hydroelectricity as a central component of national energy development strategies (IHA, 2017). Visiting the facilities at Puclaro revealed a complex relationship between managing flows to produce optimal electricity without compromising allocation to irrigation canal networks so that each water user can receive their allotment. Minimum ecological flows are not considered, which is continuing to cause environmental impacts (Budds, 2018). However, JVRE (responsible for dam management and corresponding basin-wide allocation) is focused on complying with abiding laws, which may soon change and require alterations to current flow and distribution patterns. A tour of the facilities illuminated the delicate balance that JVRE is attempting to maintain, alongside its partners (see Figure 4.7).

Figure 4.7 Water distribution pipes leading to the powerhouse at Puclaro Dam, which generates about 5MW of electricity (Source: Author).

Hydropower has the potential to increase resilience through less reliance on central grids, and lower costs for stakeholders. However, the parties that are benefitting often don't represent those most vulnerable to the socioenvironmental impacts of hydropower structures, representing ongoing unequal power relations playing out through the dam-irrigation nexus (Scott et al., 2014).

4.5.6 Stakeholder Tension (Negative)

Water governance and allocation structures involve numerous stakeholders that either cooperate or compete with one another (See: Scott et al., 2014; Vicuña et al., 2014). These relationships are often complex and involve longstanding legacies of economic, legal, political, and social dynamics that determine how water is used and where benefits and impacts are distributed. A key component of certain irrigation modernization projects is identifying pathways for dialogue between stakeholders, often vying for increasingly scarce resources. Certain research discusses how the outcomes of projects are often bound up in unequal power dynamics, commonly exacerbated by neoliberal resource governance models. Therefore, certain literature (see: Panez et al., 2020; Wiegleb & Bruns, 2019) focuses on critiquing these institutional constraints and seeking out pathways toward more equally distributed energy and water allocation systems.

My experience in Coquimbo revealed both significant collaboration and tension between stakeholders. The former is particularly true with water user associations, academic/scientific institutions, and governmental entities. For example, PROMMRA works with JVRE, SAG, DGA Coquimbo, and a range of other water user associations working to address resource insecurities through better irrigation practices (see Figure 4.8).

Figure 4.8 A meeting I attended at the Coquimbo regional governmental office In La Serena. Attendees and presenters ranged from water user/canal associations, governmental entities, academic/scientific institutions, and environmental/Indigenous groups (Source: Author).

Also, however, small stakeholders have expressed grievances against large-scale commercial entities that have purchased and expanded control over water rights (Budds, 2018). The failed constitution was a narrow defeat for many Chileans who identify neoliberal governance, agribusiness, and other corporate industrial models as a source of socioenvironmental ills (Panez et al., 2020). Therefore, a major focus of this research involves discussing such dynamics with stakeholders and identifying better pathways through adaptive resource governance and irrigation modernization.

4.5.7 Unequal Resource Distribution (Negative)

Although irrigation modernization supports more efficient water allocation and energy savings, the capital required to invest in such projects remains cost-restrictive for many irrigators in the Elqui Basin. Several authors (see for example: Birkenholtz, 2009; Panez et al., 2020; Scott et al., 2014) critically analyze water resource distribution and the embedded nature of allocation systems, that may be challenged by modernization efforts, yet often remain intact. Increasing concentration of rights aligns with neoliberal privatized models that have permeated the globe, primarily because capital investment has driven large-scale infrastructure projects that facilitate economic development, yet that is often tied up with socioecological byproducts (see: Shand & Kalirajan, 1991). Consequently, the dynamics of water and energy allocation can reflect broader systems of power distribution, which manifests patterns often marginalizing local and indigenous entities in favor of large-scale commercial and industrial entities (Budds, 2018).

4.5.8 Institutional Inertia (Negative)

Irrigation modernization is often interpreted as a resource transition (see: Cremades et al., 2016; Fortier & Trang, 2018; Panez et al., 2020). For example, Mustafa and Qazi (2007) suggest that the "transition from one resource regime to another, further involves, at times unanticipated changes in social geographies and organization." This paradigm aligns with the overarching literature within social science that has advanced critical tools for considering resource transitions. Political ecology (particularly articles focused on water and energy) is also relevant to the process (or lack thereof) of democratization or more participatory structures that may ensue from changes to resource regimes (Castelli et al., 2018). However, these processes can also further entrench unequal power dynamics, which is a common theme in Chilean resource governance, and that is being critically analyzed through this research (Panez et al., 2020).

4.5.9 Technological Inequality (Negative)

Although social dynamics are emerging as core considerations for determining project feasibility, irrigation modernization involves several core technical components (see Figure 4.9) (see for example: Ojeda-Bustamante et al., 2018, Tyagi, 2015).

Figure 4.9 A recently installed pumping system between a dam irrigation canal diversion system in the Coquimbo Region (Source: Author).

However, technical biases are being critiqued by certain scholars considering the social implications of irrigation modernization (see: Bolding et al., 1995; Deverre, 2004; Hoogesteger, 2015). Achieving a balance between social and technical considerations is being developed in energy and water literature (see: Cherp et al., 2018; Späth & Rohracher, 2010; Sareen & Haarstad, 2018). Such research provides important insights into how successfully implementing infrastructure can also take into consideration the socioecological dynamics that exist in the regions surrounding these projects. Examples include public sentiment about water rights, natural resource security, and perceptions about climate change impacts (Burgos, 2017).

4.5.10 Legal or Permitting Barriers (Negative)

There are several necessary criteria for policy and/or permitting requirements that if not met result in the delay or cancellation of projects. Also, an inability to engage with all required permitting agencies or a lack of pre-development capital to advance projects is a further barrier to implementing irrigation modernization projects.

4.6 Data and Methods

To address the research question, a convergent parallel design methodology (CPDM) was applied to integrate qualitative and quantitative data and develop a robust understanding of key processes influencing irrigation modernization (see section 2.5). Fieldwork focused on participant observation and semi-structured interviews while quantitative data was derived from GIS application and watershed energy and water statistics. The first step of participant observation involved visits to key sites throughout the Elqui Watershed. These experiences facilitated semi-structured interviews with stakeholders connected to irrigation infrastructure. A combination of these steps alongside the integration of core components of irrigation modernization informed the development of a multi-criteria analysis tool (MCAT) to analyze the irrigation modernization landscape and the ability of these projects to support more resilient infrastructure, thereby addressing water and energy insecurity (Urquiza et al., 2018).

4.6.1 Participant Observation & Data Collection

During fieldwork, I visited key sites that included: irrigation canals, irrigation dams, farms (pisco, table grapes, citrus fruits, avocados), factories (pisco distillation, fruit processing), key river locations (diversion sites, above/below dams, gaging stations) and other relevant locations. This informed a foundation understanding of where and how modernization is manifesting. Semi-structured interviews either took place at these sites or other locations and were focused on gathering information from stakeholders or regional experts deeply familiar with the irrigation landscape.

Regarding Puclaro Dam, what is most evident in the following table (4.1) is the significant volatility in annual reservoir volumes during the last decade. The ongoing megadrought, including even more challenging years within the cycle, is limiting resilience capacity for the basin because there simply isn't as much water as there used to be. Meanwhile, demand continues to rise as agricultural law 18.450 continues to incentivize practices of using every available drop of water, evidenced by the fact the Elqui River hasn't reached its terminus in decades. With a 20% reservoir fill level in the past two years, water rationing has been required, yet the underlying principles that drive inequality are still allowing big companies to have purchase power in the regional economy.

Year	Volume La Laguna	Volume Puclaro	Watershed Total	Snowpack (Meters)	Reservoir Fill Level
31-Dec-11	27,529,022	85,511,462	113,040,484	1.15	37%
31-Dec-12	34,035,080	34,703,203	68,738,283	1.69	36%
31-Dec-13	23,931,097	18,908,862	42,839,959	1.55	26%
31-Dec-14	26,804,852	22,366,914	49,171,766	0.57	20%
31-Dec-15	20,529,314	26,035,045	46,564,359	3.26	23%
31-Dec-16	38,197,084	148,308,552	186,505,636	3.58	45%
31-Dec-17	38,134,138	208,869,347	247,003,485	1.99	45%
31-Dec-18	38,071,197	208,229,443	246,300,640	0.79	37%
31-Dec-19	38,092,174	184,234,283	222,326,457	0.77	30%
31-Dec-20	35,889,051	140,550,056	176,439,107	0.53	25%
31-Dec-21	28,393,444	91,708,708	120,102,152	0.48	20%
31-Dec-22	21,805,269	52,015,772	73,821,041	1.80	20%

Table 4.1 Statistics for Elqui Basin Reservoirs (Source: JVRE, 2022).

For the Elqui Watershed smart meter project, JVRE is working with Australian irrigation company RUBICON to coordinate management strategies for a new network of allocation infrastructure. During a pilot project in 2020, several system improvements were installed that include a series of solar-powered 'FlumeGate' flow measurement and control gate systems for precise canal regulation. Upgrades also include remote monitoring systems alongside ongoing research and development for optimizing water allocation practices (Rubicon, 2021). The following table (4.2) provides an overview of real-time data for canal flow metrics since the installation of the upgraded infrastructure.

Compuertas		
Aforador canal Pampa		
Caudal En Linea	236.01	Lt/Seg
Aforador El Romero		
Caudal En Linea	505.27	Lt/Seg
Aforador San Pedro Nolasco		
Caudal En Linea	326.07	Lt/Seg
Aforador canal Mainten		
Caudal En Linea	261.57	Lt/Seg
Aforador canal Miraflores		
Caudal En Linea	235.84	Lt/Seg
Aforador canal Bellavista		
Caudal En Linea	1,768.61	Lt/Seg

datos en tiempo real, ultima lectura;
09 Feb 2002 20:57 48.000

Table 4.2 Statistics for upgraded flow data since the installation of new meters in the Elqui Basin (Source: JVRE, 2022).

The data illustrates that smart metering has led to more accurate information and real-time statistics on flow data for the primary irrigation diversions throughout the Elqui Watershed. Such improvements are important for resource management because decision-making can better adapt to shifting conditions and use water more efficiently during periods of water scarcity (Jordan et al., 2023). Incorporating solar power (see Figure 4.10) also makes the system resilient against disruptions to the power grid (Sovacool & Walter, 2019). Meanwhile, the ongoing rise in demand for water and energy throughout the region limits the extent to which these upgrades can have meaningful improvements to resource security.

Figure 4.10 Recently installed solar panels and associated smart meters powering irrigation pumping/diversion station below Puclaro Dam. JVRE owns and manages these stations that are being installed throughout the basin (Source: Author).

These complexities make it difficult to gauge exactly how impactful the smart metering project is in isolation. More important considerations are the symbolism of these efforts in initiating resource transitions by engaging adaptive water and energy governance together (see Figure 4.11) rather than as separate issues (Wiegleb & Bruns, 2018).

Figure 4.11 Solar panels installed at the La Laguna Reservoir. These panels power all the electricity required to manage flows from the dam, located just upstream, as well as the facility inhabited by dam managers (Source: Author).

Concerning the Elqui Watershed Canal Lining/Piping Project, data collection conducted in the PROMMRA lab supported the process of collecting key information about locations and metrics for these modernization projects. The following figures (4.12 & 4.13) were accessed with PROMMRA data and analyzed with a GIS application to display relevant statistics for technification efficiencies throughout the watershed. Different colors (green, yellow, green, orange, and red) depict water loss rates ranging from 0-20% (green), 20-40% (yellow), 40-60% (orange), and 60-80% (red). Important takeaways from these shapefiles are less so in the specific water retention rates of canals, but in the fact that there is a range of allocation efficiencies and that efforts at addressing water loss have been engaged. A diversity of canal types means that certain water user associations and rights holders have been incentivized to invest in upgraded infrastructure while others lack the capacity.

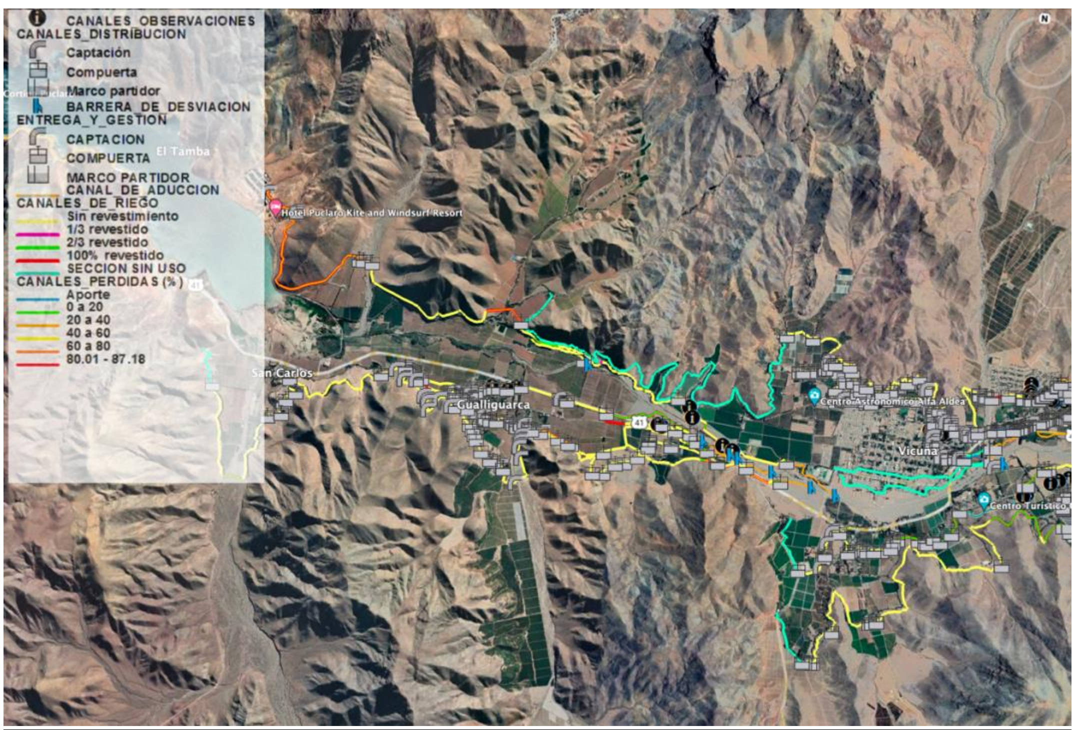

Figure 4.12 Irrigation canal network directly upstream from Embalse Puclaro, including allocation efficiencies indicative of whether modernization has occurred (Source: PROMMRA, 2022).

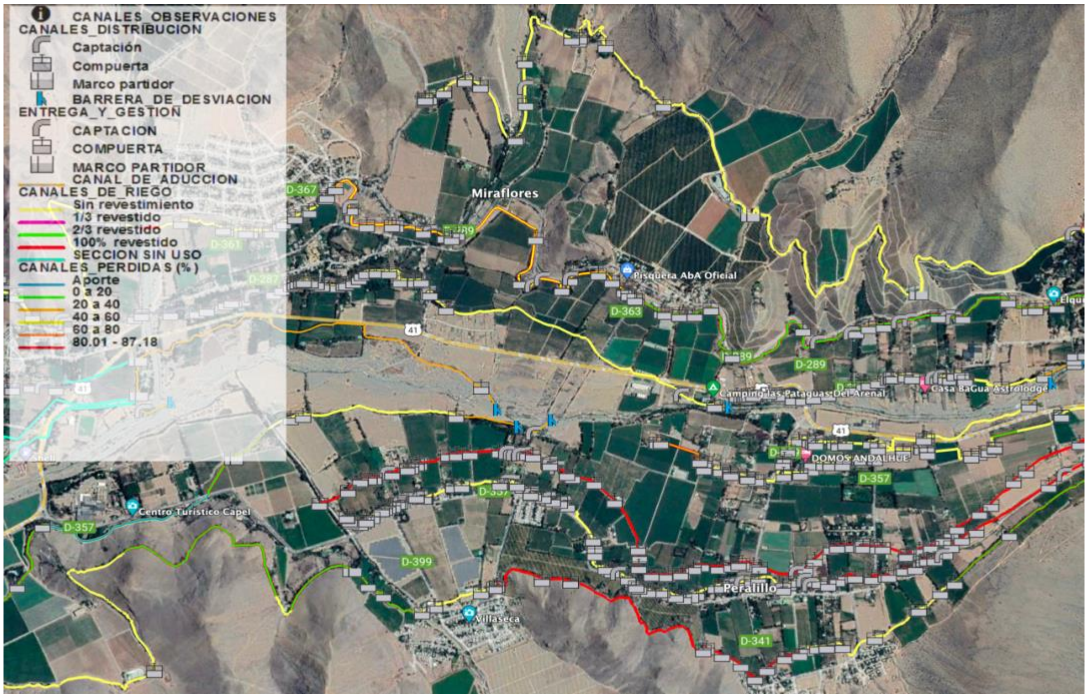

Figure 4.13 The irrigation landscape further upstream from Puclaro Dam in the Elqui Watershed (Source: PROMMRA, 2022).

4.6.2 Semi-Structured Interviews

Interviews were conducted with key stakeholders directly involved in irrigation activities throughout the Elqui Watershed. For this chapter, a particular emphasis was placed on three different types of entities: management bodies, large-scale commercial agricultural companies, and small-scale peasant farmers. The reasoning behind this is to develop a structure for understanding the core opportunities and barriers for stakeholders with a range of power over resources in the basin. These key passages were selected to convey different messages based on whether the entity is being empowered or marginalized by new irrigation modernization projects. First, from a small-scale peasant pisco farmer in the basin:

> *"Because of the years with drought, we have been shrinking much more than this was and now we are undergoing a reconversion of water policy. For other items and not necessarily agricultural, due to the issue of water, there is no water for small users, not even the producers of the crop have been growing for decades. We are even having a hard time with the drinking water of our houses, because the irrigation canals have a shift frequency of 40 days and then in that space of 40 days it does not*

allow us to plan or program, or grow something right now, until further notice or until it rains a lot, and we allow you to have the peace of mind of being able to grow something or plant something. The upgrades to certain canals have helped a little bit but don't really change the situation for us."

Clearly, this farmer hasn't benefitted from irrigation modernization projects to any significant degree. Interviews with other small-scale water rights holders supported this sentiment that only modest improvements at best have come from infrastructural improvements and these are largely enjoyed by other entities. We can see the contrast from a commercial-scale agricultural company involved in the global crop market:

" Climate change has wreaked more havoc on our region than prolonged friendly cycles. We as agriculturalists in the Elqui Valley need to balance our industry with our drinking water. The canal network provides all these resources so investing in this infrastructure is important. We have a network of 43-channel channels with different retention rates and without upgrades, we wouldn't have been able to endure this period. In other words, two or three seasons ago we would have been very restricted, perhaps only delivering the water for the technical link itself. Therefore, as clear as La Laguna, when they came to work a certain power, our workers had in the reservoir. She has allowed agriculture in the valley to continue to develop. Today you saw our climate event and the truth is that it is appreciated, that it is renewed, we didn't expect it anywhere, it was formed, and it happened, and it gives us one more season, one more relief about developing agriculture."

Although resource security challenges impact all agricultural stakeholders throughout the watershed, commercial-scale organizations have been more capable of tapping subsidies such as agricultural law 18.450 because they operate at a scale more conducive to infrastructural investment. The disparities between small and large-scale users are articulated by a management body actively involved in allocating water throughout the basin and overseeing modernization projects:

"*What will be the priority to mitigate the changes requires more government support, more capacity for the technification of the channels and needs, for example, to use solar panels above the canals. The thing is that there are many options, of course, but there are two things if we are an oversight board and our users are a channel, not a channel, but in the canals, there is industrial agriculture, there is mining, there is drinking water. For us all are the same, from the bus, of course, farmers are the*

> *majority, and farmers in the interior still have a lot to do. Here 70% of irrigation is technified, but 30% is not. Yes, we must. And so, what I'm telling you is that the oversight board now must think like the entire watershed. Yes, this is what we could do. Hopefully, we understand the movement of surface water and groundwater together in such a way that there will be no less water, we will resort to groundwater. Okay, and we're going to run out of groundwater, and that's going to affect surface water and we're going to have less surface water to distribute. This is the main thing to understand and modulate the basin. This way of using surface water drains sustainably when it comes to leaving it. And that is what we need more important now and power than we do today."*

The message from this stakeholder conveys the complexities surrounding modernizing irrigation infrastructure and how these processes intersect with both water and energy governance. More specifically, the sentiment is expressed that despite a significant overall level of technification, challenges remain, and resource insecurity endures. This calls into question whether the projects are actually creating more basin-wide reliance or if they are more designed to benefit stakeholders who already hold power in the system (Budds, 2018).

4.6.3 Multi-Criteria Analysis Tool

The MCAT can be used as a template to evaluate the overall feasibility of irrigation modernization projects based on the opportunities and barriers that will likely unfold for irrigation districts, local farmers, and surrounding communities. Based on a social analysis of the underlying dimensions either supporting or challenging the implementation of modernization projects, key criteria are selected that can be scored as indicators. For example, an irrigation district or farm considering a project can be evaluated based on whether they have engaged in a system improvement or modernization plans, and/or seeking financing. Evidence of this scores a positive. Five categories for both opportunities and barriers have been identified and individualized for the Elqui Watershed. These indicators are established based on a background analysis of existing modernization projects alongside local dynamics that influence local water and energy resource management. Several data sources reveal the multidimensional nature of irrigation modernization, particularly when social criteria are considered. For each criterion (five positive and negative indicators), data collection and validation were derived from an array of sources, ranging from qualitative interviews to government documents to geospatial tools. So long as the data is carefully considered and integrated with other sources, the more robust the criteria for considering whether indicators are met the better (Behmel et al., 2018).

The goal of this analysis was to support decision-making, based on whether local landscapes create enabling conditions to facilitate irrigation modernization opportunities for a range of stakeholders. Alternatively, challenges and barriers were assessed within the same framework yet conveyed roadblocks that may impede successful project implementation. The two criteria were added to determine whether opportunities or challenges are more prevalent across the district, supporting a tool for stakeholders to consider whether to engage in a project or also identify key areas to build upon or address outstanding barriers. As social dynamics have an increasingly central role in the emerging phenomenon of irrigation modernization, this tool can contribute to decision-making for several stakeholders who often have competing interests yet may be able to use these criteria to identify pathways for cooperation. The MCAT opportunities and barriers are illustrated below (tables 4.3 & 4.4). The results were derived for three different modernization projects most notable throughout the basin. Results can be used as a representative sample for engaging in modernization projects and understanding project feasibility based on local political, economic, and socioenvironmental factors.

Table 4.3 Multi-criteria analysis tool for irrigation stakeholders in the Elqui Watershed (positive indicators of irrigation modernization projects)

INDICATOR:	**Resource Efficiency**	**Adaptive Capacity**	**Adaptive Governance**	**Social-Ecological Resilience**	**Hydropower**
Criteria and description	Project demonstrates a successful reduction in water loss or energy intensity.	Stakeholders demonstrating the ability to respond or adjust to changing conditions through irrigation upgrades.	Generation of income (hydroelectricity purchase power agreements, higher crop yields).	Increases resilience to climate change (diversified agriculture, distributed energy generation, improved infrastructure, etc.).	Enhances community cohesion through benefits of cost-effective electricity, microgrids etc.
Metrics used for determining whether indicator is met/not met	System improvement and/or modernization plans undertaken. Upgrades successful in using water and energy more effectively.	Lower incident rate following IM completion. Positive feedback from community	Revenue generation plan for IM developed and discussed with district, city, family, other stakeholders.	New hydropower facilities installed and diversification of crops, co-location of fiber optic cables, buried distribution lines, mitigation of fire impacts.	Evidence of public forums and increased cooperation, absence of intra-district conflicts & competition. Community development plans.
IRRIGATION MODERNIZATION PROJECT					
Puclaro Dam	Puclaro Dam harnesses more water for agricultural distribution and hydropower. Evaporation is a concurrent byproduct.	The dam provides several services to the community and represents a response to less water and energy security.	The construction of a hydropower dam does increase management capacity but is representative of existing neoliberal systems of resource governance.	Puclaro has increased the management capacity for annual runoff and supported agricultural development.	The dam produces a modest amount of hydropower (5 MW), which helps support the renewable energy portfolio of the region.
Elqui Watershed Smart Metering System	Project has improved allocation efficiency through more precise flow metrics and diversion management.	Installing smart meters represents a response to resource insecurity and directly addresses these issues.	Supported by the national government, the JVRE can conduct this project based on understanding that adapting resource practices is necessary.	Improved data for watershed allocation to irrigators supports greater capacity to mitigate impacts to water and energy resources.	While this process isn't directly related to hydropower, upgraded systems for diversion support greater capacity for managing the powerhouse at Puclaro Dam efficiently.
Elqui Watershed Canal Lining/Piping Project	The patchwork nature of the project hasn't made a meaningful impact on overall watershed water security.	Funded by agricultural law 18.450 and water user associations, canal lining is a direct adaptation to insecurity through improved resource efficiency	The National Irrigation Commission has subsidized select projects, indicating that governance entities are focusing on addressing resource insecurity.	These projects have the capacity to increase resilience, but so far, they have excluded small-scale users and overall resource demand continues to rise.	No evidence of any in-conduit hydropower or solar panels along modernized irrigation canals.

Table 4.4 Multi-criteria analysis tool for irrigation stakeholders in the Elqui Watershed (negative indicators of irrigation modernization projects)

INDICATOR:	**Stakeholder Tension**	**Unequal Resource Distribution**	**Institutional Inertia**	**Technological Inequality**	**Legal or Permitting Barriers**
Indicator and description	Legacy of unhealthy competition, inequality, or legal disputes in the district. (between stakeholders) or external (NGO suing over environmental impacts or federal/state agency suing irrigation district.	Resistance to projects due to cultural inertia and/or perceptions of uneven benefit distribution.	Potential for legal challenges surrounding water rights (junior vs senior right holders) or land ownership issues (i.e private vs. public land).	1: District ineligible for (federal, state, local) funding or unwilling to engage steps needed for eligibility. 2: Evidence of resistance to certain types of funding sources.	1: Necessary criteria for policy and/or permitting requirements not met, delaying or canceling projects. 2: Inability to engage with all required permitting agencies or lack of pre-development capital to advance project.
Metrics used for determining whether indicator is met/not met	Evidence of court cases, stakeholder tensions revealed through interviews, participant observation.	Lack of initiative from district to go through necessary steps to begin IM process (no grant seeking, engagement with JVRE/other entities)	1: Coquimbo water rights database can indicate risk of legal challenge/ history of transfers. 2: Determine who has right of way for project.	Ineligible funding determination identified through modernization plan.	Policy roadblocks identified, permitting delays evidenced. 2: Environmental compliance failure. 3: Absence of pre-development capital identified.
IRRIGATION MODERNIZATION PROJECT					
Puclaro Dam	Construction of Puclaro had wide approval from agriculturalists but flooded indigenous grounds and resisted by environmental groups .	Benefits from Puclaro have primarily been for commercial-scale entities, despite somewhat higher overall resource security.	Puclaro represents a bold program for harnessing water and energy and is aligned with national development goals.	Puclaro is funded by the government to boost economic activity. The technology is confined to management bodies and not shared throughout the basin,	Puclaro continues to receive support from the national irrigation commission and the JVRE has significant autonomy over management practices.
Elqui Watershed Smart Metering System	The infrastructure is not invasive and was favorably received by stakeholders who were interviewed.	Although system is owned and operated by JVRE, it's the most comprehensive tool shared amongst all water users.	This project is focus on resilience and innovation, therefore the opposite of inertia.	Although this technology is expensive, data is shared openly for stakeholders throughout the watershed.	JVRE and Rubicon were able to get the smart meters and new gauges installed throughout the basin with governmental support.
Elqui Watershed Canal Lining/Piping Project	Small peasant farmers have expressed how project hasn't included them and has just diverted more water to senior rights holders	A couple districts have been able to afford and navigate this process, but benefits aren't widely distributed.	The lining/piping projects are attempting to adapt management practices.	The lack of widespread access to benefits of these projects indicates a continuation of neoliberal governance models.	Although in-conduit hydropower to support microgrids is a central component of irrigation modernization, these projects haven't implemented the technology.

4.7 Results

To depict MCAT results, the following radar charts (Figures 4.14-4.19) provide a visual representation useful for understanding the overall strengths and weaknesses of current irrigation modernization projects in the Elqui Watershed. Neither the MCAT results nor the charts are an attempt to be rigid or all-encompassing, but rather a guide to support stakeholders in making informed decisions around existing and future projects (Nagel & Ptak, 2022). Such a process can help mitigate barriers to implementing successful upgrades and provide awareness about inequalities that continue to pervade the irrigation landscape (Budds, 2018; Parra et al., 2020). Coupling reform with comprehensive information and support tools can be applied to a range of landscapes considering engaging modernization strategies. It should also be noted that engaging in modernization projects and increasing irrigation efficiency doesn't necessarily improve basin-wide water/energy savings and lead to improved socioenvironmental outcomes (Grafton et al., 2018). Certainly, in the case of Chile, the neoliberal agribusiness complex has supported economic development at the expense of social equality and a natural resource governance prioritizing environmental protection (Panez et al., 2020). Although completed projects in the basin have improved knowledge surrounding allocation efficiencies, microgrid resiliency potential, and associated benefits related to upgraded infrastructure, efforts ranging from cultural values to economic incentives to regulatory structures must all coalesce to create comprehensive and meaningful reform (Jordan et al., 2023). The Elqui Watershed, and broader Chilean agricultural landscape, have begun to address some of these key resource issues as climate change impacts security. However, challenges endure as fragmented governance structures impede comprehensive transition strategies promoted by the national government and civil society (Nicas, 2022).

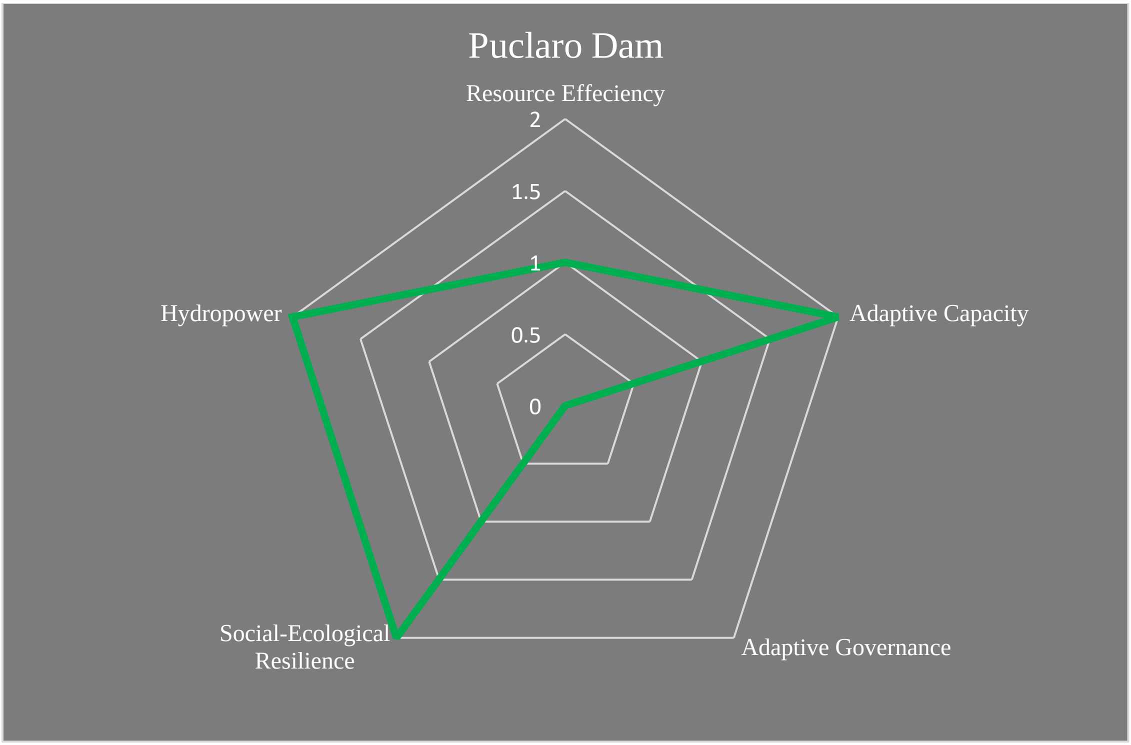

Figure 4.14 MCAT Results for positive indicators of Puclaro Dam irrigation modernization project (Source: Author).

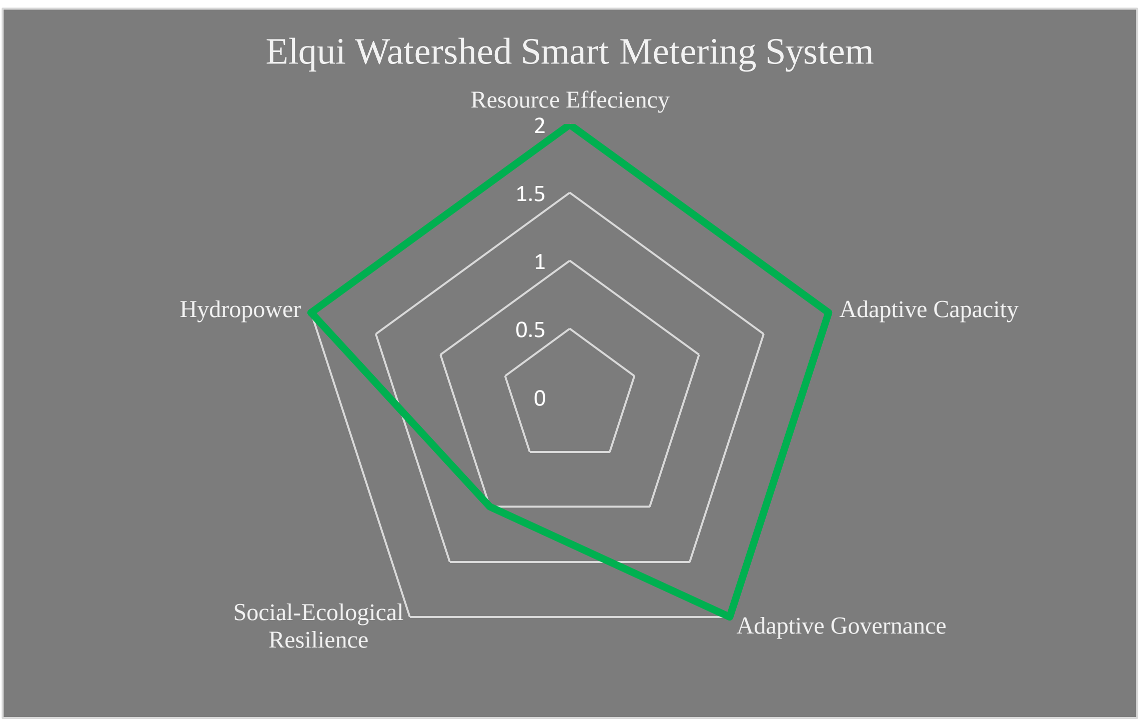

Figure 4.15 MCAT Results for positive indicators of Elqui Watershed Smart Metering System irrigation modernization project (Source: Author).

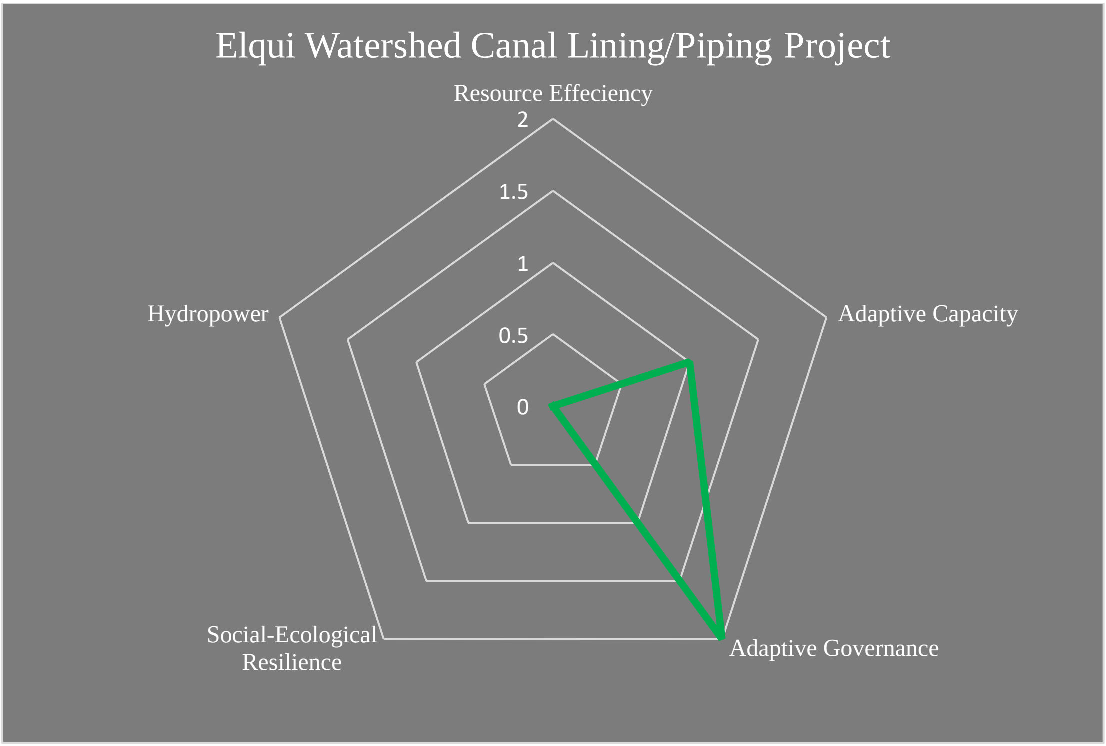

Figure 4.16 MCAT Results for positive indicators of Elqui Watershed Canal Lining/Piping Project irrigation modernization project (Source: Author).

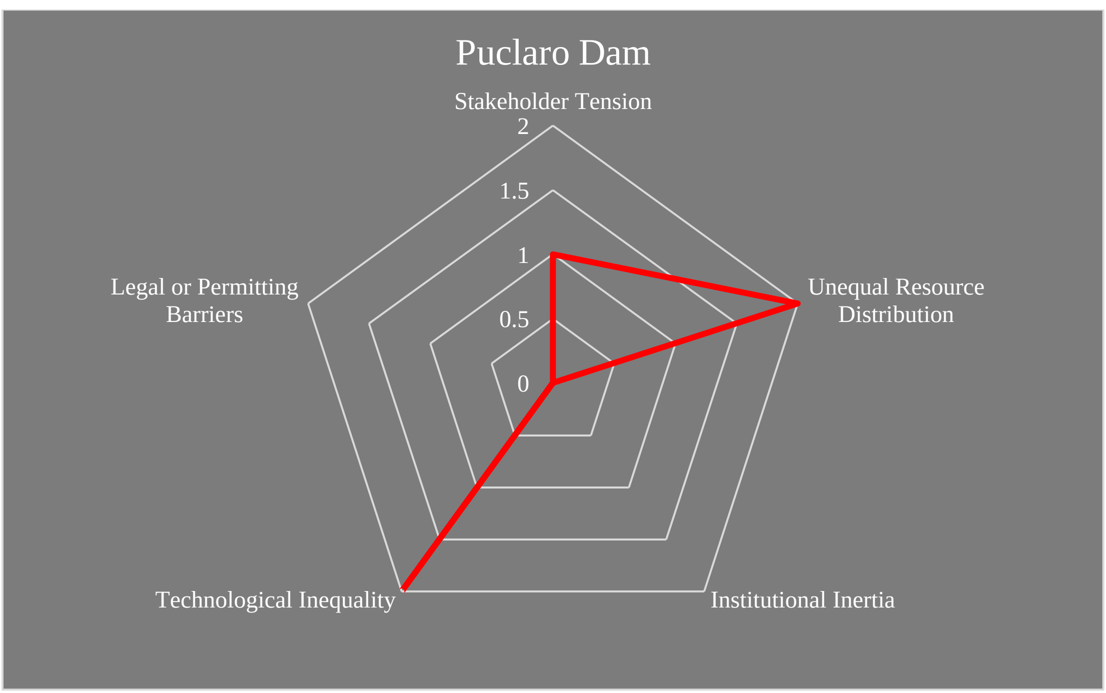

Figure 4.17 MCAT Results for negative indicators of Puclaro Dam irrigation modernization project (Source: Author).

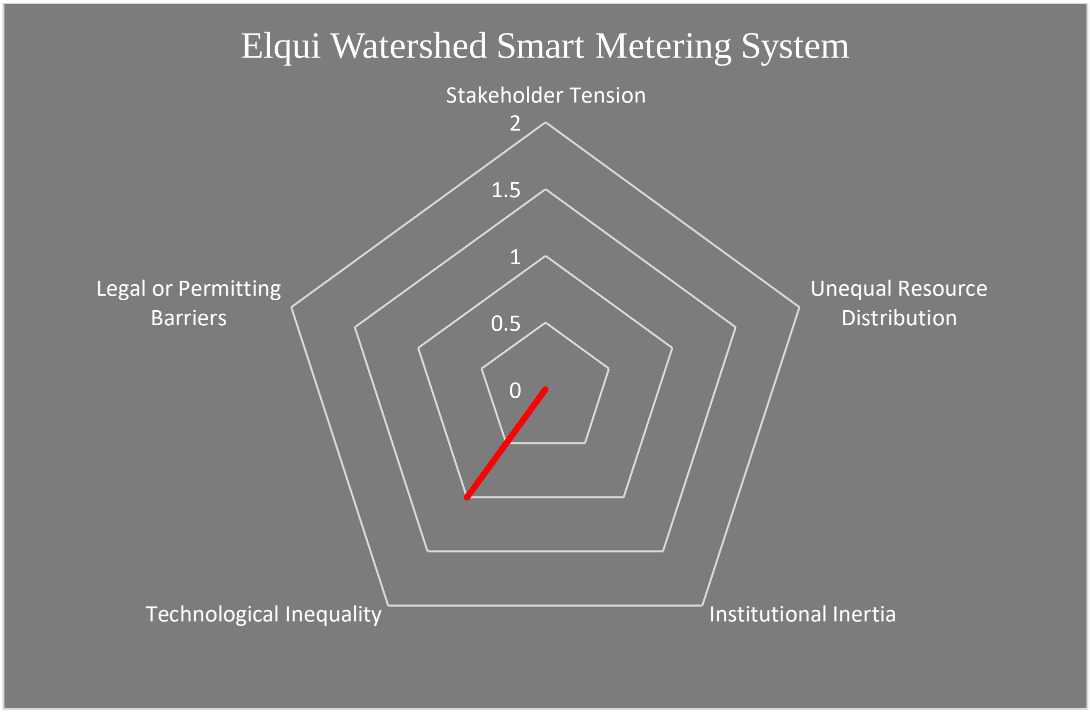

Figure 4.18 MCAT Results for negative indicators of Elqui Watershed Smart Metering System irrigation modernization project (Source: Author).

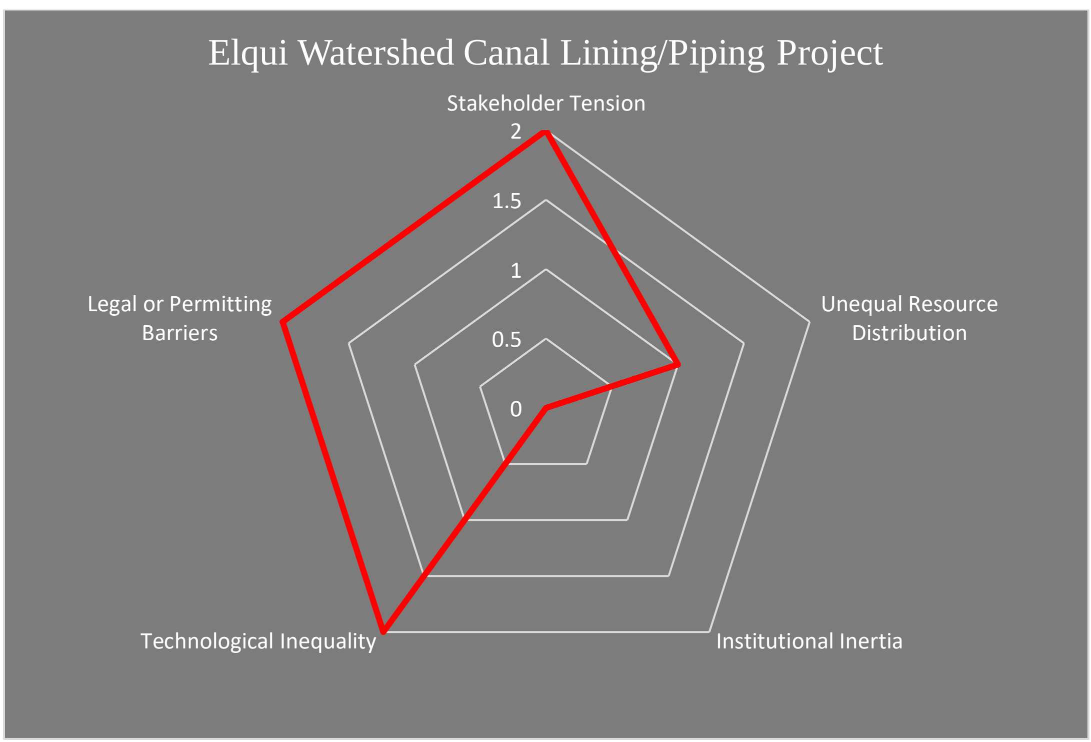

Figure 4.19 MCAT Results for negative indicators of Elqui Watershed Canal Lining/Piping Project irrigation modernization project (Source: Author).

Based on the methodology, key understandings of irrigation modernization projects can be better understood. Takeaways reveal some clear outcomes from efforts that have been undertaken in the Elqui Watershed:

- Puclaro Dam has increased management capacity over water allocation to irrigation rights holders in the Elqui Basin.
- The ongoing megadrought has impacted overall water availability and is placing major stress on basin-wide water security.
- Hydropower development from Puclaro Dam helps make the project economically feasible, but electricity is channeled to the central grid rather than supporting resilient microgrid development central to more comprehensive irrigation modernization strategies.
- The Elqui Watershed Smart Metering Project has helped stakeholders better understand how much water is available and supports the capacity for resource rationing during especially dry periods.
- Several modernization projects incorporate solar power, which reduces reliance on the grid and is a more resilient and less expensive long-term solution.
- The Elqui Watershed Canal Lining/Piping Project is in its early stages but has seen limited success through less water loss along certain corridors. Only a select few senior water rights holders are reaping the benefits thus far.
- Ongoing inequalities highlight the influence of neoliberal agribusiness models in the agricultural sector, despite efforts in improving conditions for small-scale peasant farmers and environmental health.

4.8 Conclusions

Irrigation modernization is emerging in the Elqui Watershed to adapt infrastructure in a shifting natural resource landscape. The region's extreme vulnerability to climate change impacts has provided motivation to improve the resilience of water and energy systems that comprise the backbone of economic activity and social welfare (Urquiza et al., 2018). Key projects discussed in this chapter have supported the noteworthy development of better practices for efficiently using water and incorporating renewable energy. For example, Puclaro Dam has increased management control over fluctuating annual runoff and accommodates greater water security during dry periods (Sovacool & Walter, 2019). Smart metering and canal lining projects have further supported a movement towards reducing system from inaccurate allocation between water rights holders in a dynamic market (Jordan et al., 2023). Although projects are not as comprehensive as leading efforts from organizations such as FCA, who engage targeted efforts to modernize full irrigation districts, stakeholders in Chile are navigating a complex set of legal, economic, and socioenvironmental challenges to address disruptions to vital resources (FCA, 2021).

Despite success in upgrading certain irrigation infrastructure, efforts are patchwork and convey inconsistent outcomes that continue to be influenced by neoliberal policies such as the CEC, CWC, and agricultural law 18.450. Small-scale peasant farmers and junior water rights holders struggle to invest in upgrades that commercial-scaler entities can more often realize (Panez et al., 2020). Further, the limited completed projects haven't changed broader patterns of increasing resource demand, groundwater exploitation, and environmental degradation that continue to impact the watershed (Budds, 2018). Therefore, irrigation modernization in the Elqui Watershed remains in its infancy and continues to be reliant on ongoing governance models at the national scale.

CHAPTER 5: A POLITICAL ECOLOGY OF RESOURCE TRANSITIONS IN CHILE'S ELQUI WATERSHED

5.1 Introduction

This chapter investigates social and political dynamics surrounding transitioning systems of water and energy governance in Chile's Elqui River Valley. Transitions are important because they represent shifts in the status quo and can create opportunities for better practices of resource use (Bridge et al., 2013; Cherp et al., 2018). Chile represents a particularly salient region to study because of the significant disparities between a legacy of rigid neoliberal economic models alongside current attempts to rewrite these institutional structures to prioritize progressive, democratized, and socio-environmentally conscious systems (Yajima, 2022). An area where these divides are playing out intensely is the agricultural sector, in which governance models directly influence how water and energy are used, and benefits distributed (Jordan et al., 2023; Pizarro et al., 2022). These competing ideologies influencing public policy in Chile can be analyzed through a framework of political ecology (see section 1.4) which applies a critical lens to better understand the underlying drivers between power structures over natural resources (Budds, 2018).

Resource transitions stem from a range of sources and are embedded in complex landscapes of human-environment interactions (Hansen & Coenan 2015). Particularly relevant is climate change, due to its sweeping alterations of water and energy availability (Salas et al., 2018). For example, a central outcome of climate change is reduced water security, which impacts the timing and amount of freshwater used for human consumption, energy production, and myriad other vital practices (e.g., hydropower, mining, transportation) (Nelson, 2013; Pino et al., 2015). Corresponding drivers of resource transitions include political, economic, and sociocultural factors (Araújo, 2014; Hansen & Coenan, 2015). For instance, Chile's 2022 constitutional charter, despite failing to be enacted, represented an effort to reform core structures of resource governance based on shifting sociopolitical ideologies (Nicas, 2022). Calls for more equality and democratic structures hold popular support amongst the Chilean people, despite setbacks (Urquiza et al., 2018). Protests in 2019, expressing grievances over increasing energy costs and wealth disparity, made international news and specifically speak to the magnitude of dissent that has emerged (Sehnbruch & Donoso, 2020). Operating the intersection of these issues is irrigated agriculture, which is responsible for approximately 84% of freshwater withdrawals and 30% of total energy demand throughout Chile (Errázuriz, 2019; Jordan et al., 2023). Climate change is significantly impacting the security of these resources, especially in semi-arid landscapes heavily dependent on reliable access (Parraguez-Vergara et al., 2016; Pino et al., 2015). As resource scarcity intensifies, power dynamics shaping winners and losers become more acute (Cherp et al., 2018). To better understand how on-the-ground outcomes are being shaped by different governance models, this research conducts a comprehensive analysis of Elqui Watershed's irrigation landscape through field visits, semi-structured stakeholder interviews, and quantitative assessment of key resource data. The process supports a novel approach to considering water, energy, and climate change issues through the lens of irrigation modernization, which focuses on increasing resilience through the implementation of more efficient management practices (FCA, 2021; Pizarro et al., 2022).

The research addresses examples of energy and water transitions through patterns of irrigation development to analyze distributions of benefits and impacts, and how these either reinforce or disrupt existing systems of power relations in the Elqui Watershed (Bustos-

Gallardo et al., 2013; Parra et al., 2020). Specifically, the neoliberal agribusiness complex is introduced because of its complex role in supporting economic growth, yet also contributing to social inequality and environmental degradation (Panez et al., 2020). Applying a political ecological framework supports the targeted evaluation of the following research question: **How are the benefits and adverse outcomes of irrigation modernization projects distributed between different irrigation stakeholders in the Elqui Valley?**

Understanding power dynamics is particularly important in Chile during a time when the fundamental soul of the nation is at a crossroads (Yajima, 2022). Few countries have held such extreme neoliberal governance models yet also entertained socioenvironmental policies that would rank among the most progressive in the world (Pizarro et al., 2022). Therefore, the following section details key dimensions of Chile's legacy of resource governance to set the stage for analysis of the current landscape.

5.2 Transitioning Socioenvironmental and Political Landscapes

The contemporary history of Chile's political leadership is most clearly distinguished between an era of democratic rule until the 1973 military coup that installed Augusto Pinochet in power for almost two decades (Rector, 2005). Restoration of democracy didn't occur until almost two decades later in 1990 (Montedonico et al., 2018). Social programs, nationalized industries, and environmental regulations were disbanded as the Pinochet regime exercised sweeping authority, leading to the creation of a rigidly top-down institutional order (Rector, 2005). The rise of neoliberalism alongside anti-communist sentiment allowed the dictatorship to install economic and political programs based almost entirely on the guidance of a group of University of Chicago economists later dubbed the Chicago Boys (Kelly, 2018; Long et al., 2017). With a mandate for reform, the Chilean constitution was rewritten to reflect a rigorous neoliberal doctrine, which has an enduring role in systems of governance to this day (Mundaca, 2013). Enacted laws facilitated natural resource extraction, agricultural/hydropower development, and environmental deregulation to promote free-market enterprise and industrial growth (Bauer, 2009). Consequently, as Chile currently undertakes initiatives to reorient political, economic, and energy policies toward environmental conservation, climate change mitigation, and renewable electricity sources, the legacy of neoliberal systems continues to carry inertia that impedes meaningful systemic change (Watts et al., 2016; Zurita et al., 2018).

Notwithstanding Chile's challenges in disentangling from the undemocratic systems of the past, the Pinochet era did successfully build a potent economy, supporting the process of becoming a regional agricultural power (Mundaca, 2013). Although institutions continue to reflect lock-in effects, the fact that Chile is a somewhat recently developed country (certainly among OECD nations) indicates the potential to be more adaptive to resource transitions (Bridge et al., 2013; Pino et al., 2015). However, the systems that facilitated Chile's economic growth are fundamentally incompatible with new policies such as the Energía2050 Initiative, Ley 20/25, and the National Climate Change Action Plan (Dettoni et al, 2012; Urquiza et al., 2018). Chile's energy and water future relies on institutional capacity to restructure policies so that they adhere to standards adequately addressing environmental conservation, human rights, and sustainable resource governance (Montedonico et al., 2018). Such a process depends on balancing national-scale legislation with support for local grassroots democratic systems of energy policy and governance (Budds, 2018). For example, irrigation modernization projects will continue to reflect existing top-down power structures unless they actively engage the range of affected stakeholders, including disempowered groups throughout the basin (Urquiza et al., 2018).

Although Chile continues to function as a natural resource-dependent nation, the presence of a strong agricultural sector focused on cash-crop exportation has been an economic lifeblood for regions in the semi-arid north (Montecinos et al., 2016). Also, the recent development of renewable energy presents an opportunity to tap inexhaustible sources with lower impacts on socioenvironmental health (Vega-Coloma & Zaror, 2018). Building blocks have been reestablished since Patricio Aylwin presided over the first post-dictatorship administration (Rector, 2005). The government reestablished social programs, scientific education, and federal departments such as the National Environmental Commission (CONAMA), while grassroots movements began to manifest around social inequality and opposition to large hydropower projects (Bauer, 2009; Bauer & Catalán 2017; Nelson, 2013; Silva, 2016). Such trends convey how achieving a comprehensive resource transition is not simply technological, but involves a cooperative nexus of social, political, cultural, economic, and environmental movements (Bridge et al., 2013; Trainer, 2010).

The Chilean government has—to some extent—acknowledged the need for fundamental restructuring, notably through the administrations of Michelle Bachelet (2006-2010; 2014-2018) and Gabriel Boric (2022-) (Benedikter & Zlosilo, 2022; Montedonico et al., 2018). Key initiatives include not only the implementation of robust renewable energy goals but also the creation of multi-scalar participatory advisory committees that rescale decision-making mechanisms (Urquiza et al., 2018). If these new structures can work alongside the core pillars of the 1) the National Energy Strategy (energy efficiency, renewable energy development, transmission expansion, market completion, and regional interconnection) and 2) Integrated Watershed Management (sustainable agricultural development, democratization, environmental protection) a resilient and inclusive energy transition may be achieved (Behmel et al., 2018). The role of irrigation modernization across these interdependent challenges (see Figure 5.1) sets the stage for analysis of early outcomes to identify patterns of transition or lack thereof (Panez et al., 2020; Wiegleb & Bruns, 2018).

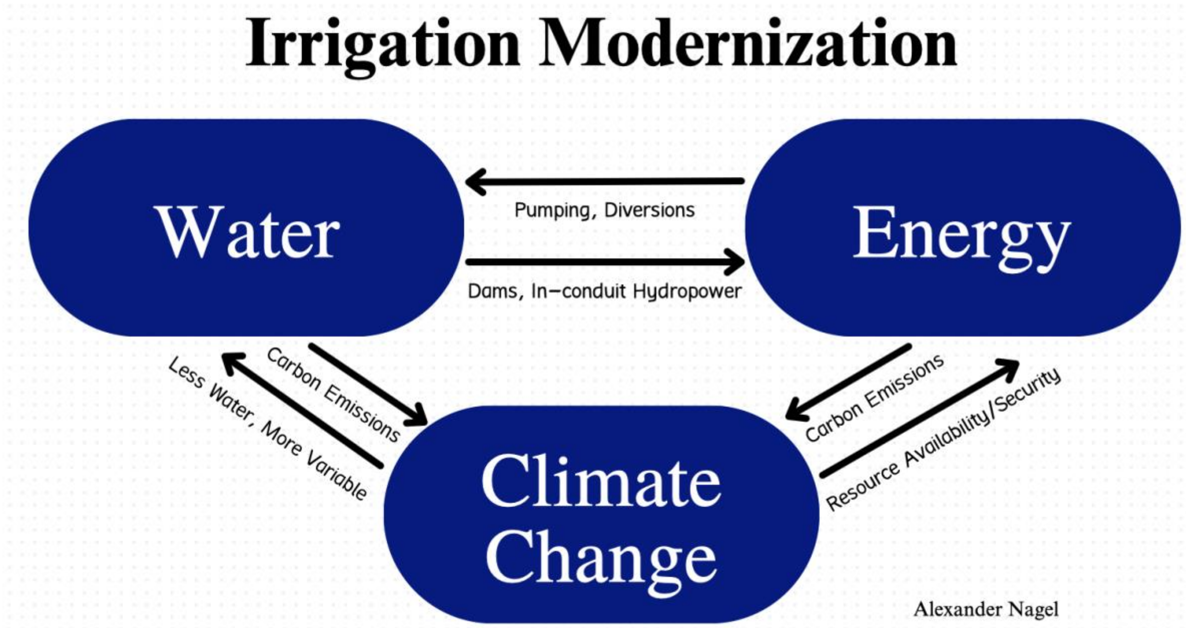

Figure 5.1 Depiction of how the water-energy-climate change interface flows through irrigation modernization projects to illustrate the extent to which these issues are intertwined (Source: Author).

5.3 Data and Methods

This analysis draws on data from semi-structured interviews, which support a multidimensional understanding of resource transitions through irrigation modernization in the Elqui Watershed. Interviews with key stakeholders focused on water rights ownership, benefits and impacts of agricultural development, perspectives on policies and governance models, and overall impressions of the water and energy landscape (Bridge et al., 2013). Specifically, this chapter considers how different stakeholders are being either supported or marginalized by the implementation of modernized agriculture (Panez et al., 2020). Key examples include interviewing stakeholders about how their water rights have been impacted since the construction of Puclaro Dam, The Elqui Watershed Smart Monitoring System, and the Elqui Watershed Canal Piping/Lining Project. The outcomes of these projects play a central role in regional dynamics supporting the continued subsidization of commercial-scale irrigation and whether this is further concentrating power.

Initial interviews with management bodies in the basin revealed an interesting perspective on how the agricultural sector is organized through water rights dynamics. The following passage conveys this sentiment:

> *"The power of large companies is still growing in most ways. Their activities are not monitored. The government has turned a blind eye over time. Here in Coquimbo, the powerful players continue to use the resources they desire without restrictions on environmental damage. During bad years, everyone suffers but the big companies are better insulated because of government support and small farmers pay the price. The system that was built originally doesn't exist anymore.*

Takeaways from this quote and interview more broadly illustrate that the overall balance of power is still quite uneven, despite reforms of the CWC and attempted democratic transitions (Panez et al., 2020; Ramirez, 2022). The institutional inertia that exists in resource governance takes a long time to reorient, even if new policies are targeted and ambitious (Parra et al., 2020; Urquiza et al., 2018). Therefore, large-scale companies that have been supported by the federal government and agricultural law 18.450 (through national irrigation subsidies) have been able to protect themselves against impacts on resource security more effectively than small-scale peasant farmers and other marginalized groups (Budds, 2018; Neumann, 2009). In a system where water and energy are scarce when access dries up, they are the first to be impacted because the neoliberal laws are designed to favor capital investment and minimal social safety net (Bauer, 2009). The following quote from another

Elqui management entity suggests that now is the time for collaboration between stakeholders or else the entire basin will suffer:

> "*There is not enough water left in the river and the current water usage must stop. We are talking about the fact that we have regulated management with reservoirs down to about 20% of their historic capacity. At a certain point, nobody will have water access unless we reform and use less. Automated management through telemetry and remote control has begun to work. We also have models and accumulated statistics from the beginning of the century until now. What they tell us is that we need to rethink how much water we must deliver. And the big companies are the ones knocking at our door to ask for guarantees. The small farmers try to form collectives but are just absorbed by the giants. The time has passed to think about how we use water and electricity differently.*"

The fact that an oversight organization whose central focus is to allocate water to users throughout the watershed articulated such concern with trends for resource security carries significant weight. Leaving aside clear power disparities, the entire basin is approaching a tipping point unless reforms are made to current levels of resource consumption (Pizarro et al., 2022). Recent updates to the CWC attempt to address some of these problems but they haven't had enough time to play out meaningfully and still lack targeted mechanisms for mitigating inefficiencies (Ramirez, 2022). Therefore, looking at irrigation modernization projects can help support a better understanding of how transitions are beginning to shape the irrigation landscape. Speaking to a local farmer and irrigation about the current situation helped explain the magnitude of current challenges:

> *"It is true, when Puclaro was built they said that water would always be there for* our *crops. We have had our water, yes, but at what cost? The reservoirs are low, and the crops still grow but the people see the changes taking place before our eyes. Our small parcel has rights, and we can sell but the big companies haven't been looking out for the river and communities. Some good changes take place with innovation, and we have hope, but the dry years have been tough and further divide those in places of influence with the rest of the basin."*

Clear patterns expressing grievances against the uneven nature of the irrigation landscape can be seen through these quotes and represent a shared message from most interviews across a range of stakeholders. However, contrasting messages between commercial-scale entities and small-scale farmers reinforce disparities in control and access that are important to consider. Speaking with a large-scale organization active in the global export market revealed the following passage:

> *"We are aware of the challenges facing the region and are working with our partners to find solutions. In terms of overall water, the rights are secure for most users who actively participate in the market. Some will be bought out, yes. But it is important to consider how much Elqui has grown its production of grapes, citrus, and other valuable commodities. We can continue through investing in our infrastructure and market and hopefully, there will be better water years ahead.*

Although this organization expressed more optimism about the agricultural landscape of the basin, they possess a senior water right and have seen consistent profits even during the drought (Pizarro et al., 2022). Furthermore, there is little incentive for their practices of resource use to change so long as efficiency isn't mandated and the updated CWC still lacks legal teeth for enforcing a central benefit of irrigation modernization projects (Ramirez, 2022). The following passage from a small-scale farmer illustrates how differently stakeholders without significant power are faring when asked about the three irrigation modernization projects and the security of their water rights:

> *The projects you are referring to mostly help the government's GDP and the big economic players. Puclaro certainly helped us expand our cropland, but these other projects are limited and nobody in my area has been contacted. We need more support but even the new water code does little to help us find better security. We would use our own solar or hydro if we had some capital.*

A similar sentiment is expressed by another farmer:

> *The water rights have been exploited. Now that the water is drying up, we must look for solutions and the drip irrigation helped a lot. With the laws though there was more land and crops and only more growth. Now the government wants to talk about equality but doesn't talk about efficiency or reducing usage. The options we have are the same. The amount of water we have changes for each stock, but there isn't much more water here."*

Overall, divides between stakeholders continue to be stark and large-scale organizations have a much greater capacity to exploit natural resources. Irrigation modernization offers the potential to democratize the irrigation landscape, but current projects haven't permeated enough to have made a significant impact on marginalized groups (Panez et al., 2020). Therefore, elements of a transition may be taking place, yet the process seems to be in its early stages and still embedded within neoliberal governance models (Jordan et al., 2023).

A recent study on the concentration of water rights in Chile provides a comprehensive source of information on agricultural trends and supports the messages from stakeholders that water inequality is acute in Coquimbo. Applying a Gini Index Coefficient, a robust measure of water rights inequality, the authors calculated that the top 1% of owners hold upwards of 85% of the total surface water available in the Elqui Basin (Parra et al., 2020). The following table (5.1) depicts how unequal these relationships are, with 1.00 being complete inequality and regions most commonly in the 70-80% range (Rauf et al., 2021).

Surface Water Consumption Rights					
Region	No Rights	Sum of L/s	National Percentage Rights	National Percentage L/s	Gini Index
Arica y Parinacota	336	16,944	0.8%	0.5%	0.8993
Tarapacá	285	30,596	0.6%	0.9%	0.9499
Antofagasta	446	11,554	1.0%	0.3%	0.8980
Atacama	212	11,672	0.5%	0.3%	0.8309
Coquimbo	695	58,671	1.6%	1.7%	0.9329

Table 5.1 Summary of water rights inequality based on Gini Index Scores for different regions of Chile based on score of 0-1 (Source: Parra et al., 2020).

Since the Gini Index for surface water rights is highly unequal, groundwater is likely worse since tapping these resources is more expensive and has been exploited primarily by large-scale mining and commercial-scale crop companies (Ghorbani & Kuan, 2017; Parra et al., 2020). The following figure (5.2) depicts the substantial increase in groundwater rights and pumping as surface water becomes less secure (Pizarro et al., 2022).

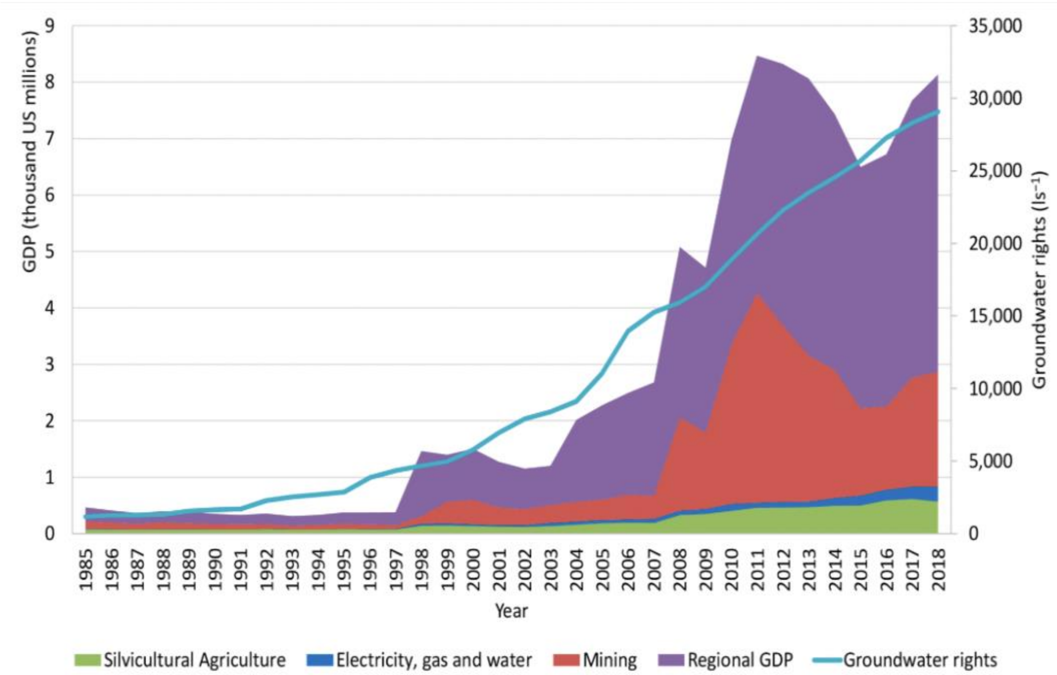

Figure 5.2 Trends in agricultural demand and water use around the Coquimbo Region (Source: Pizarro et al., 2022)

Such patterns are concerning because both types of water are seeing rising demand and even the 2022 reforms to the CWC provide minimal mechanisms for addressing water and energy efficiency (Ramirez, 2022). Therefore, expanding the portfolio of irrigation modernization projects throughout the basin ought to be seriously considered, while acknowledging that existing projects continue to reflect patterns of resource inequality (Parra et al., 2020).

5.4 Discussion and Results

The water-energy-climate interface throughout the Elqui Watershed is nuanced, rapidly changing, and cannot be encapsulated within a narrow lens (Wiegleb & Bruns, 2018). Looking at how different users are responding to irrigation modernization processes reveals that these projects yield inconsistent results based on a range of factors. For example, the largest commercial-scale agricultural organization in the Elqui Watershed is CAPEL, who produces the pisco grape for spirit production and began as a collective of small farmers who wanted to aggregate their products to scale up activities (Monardes-Concha et al., 2020). CAPEL, therefore, represents large and small-scale interests all at once and claims to be the 'heart of the Elqui Watershed' (see Figure 5.3).

Figure 5.3 A billboard from CAPEL advertising the message that the Pisco company represents the "heart" of the Elqui Watershed (Source: Author).

A paradox of CAPEL rests in the fact that although they purchase grapes from a range of farmers throughout the basin and themselves don't hold significant rights, their profits have continued to climb while inequality grows, and small-scale peasant farmers are increasingly bought out (Parra et al., 2020). This contradicts the spirit of their founding, not to mention that homeless camps (see Figure 5.4) are located nearby their elaborate facility. CAPEL has an opportunity to be a leader in the basin, should they decide to advocate for more equality and sustainability (González-Eguino, 2015). However, current laws continue to favor unmitigated resource use, with senior rights holders able to tap water despite diminishing annual streamflow and take advantage of regional renewable energy development for lower prices (Burke & Stephens, 2018). Therefore, large-scale development (see Figure 5.5) continues to be targeted more than microgrids characteristic of more democratized resource landscapes, as well as comprehensive irrigation modernization projects (FCA, 2021).

Figure 5.4 A homeless camp located on the banks of the Elqui River right outside the town of Vicuña and closely downstream from the CAPEL headquarters (Source: Author)

Figure 5.5 Large-scale wind and solar facilities alongside the Pan-American Highway in the Coquimbo Region (Source: Author)

An important consideration in analyzing the power dynamics of the irrigation modernization landscape is that all projects have benefits and impacts (Nagel & Ptak, 2022). For example, the construction of Puclaro Dam in 2000 flooded the historical lands of the Indigenous Diaguitas People (see Figure 5.6). The Elqui Watershed Smart Monitoring Project was implemented by a foreign company and doesn't provide many local jobs (Rubicon, 2021). The Elqui Watershed Canal Lining/Piping Project has been confined to a certain group of water user associations with senior rights and more capital in the basin than most other stakeholders. However, each project does address resource efficiency and can help set the stage for more comprehensive modernization efforts going forward.

Figure 5.6 An information board on the top of Puclaro Dam detailing how the Indigenous Diaguitas saw their historical lands flooded by the construction of Puclaro Reservoir (Source: Author).

Overall, these projects mirror consistent patterns with Chilean resource governance. While efforts are being made to improve efficiency and equality, the system can only bend so much towards the vision Chile is envisioning because of the embeddedness of neoliberal structures (Budds, 2018; Panez et al., 2020). Dislodging will continue to require adaptive resource governance and these transitions take time to achieve (Bridge et al., 2013).

The process of evaluating how irrigation modernization projects are either disrupting or reinforcing existing uneven power structures yielded some clear results in some areas and illustrated complexity in other areas. Key takeaways include:

- The legacy of social and environmental inequality is significant in the Elqui Watershed based on economic statistics, water rights ownership, and power imbalance between commercial-scale companies and small-scale users.
- Puclaro Dam increased water security in the short term but didn't fundamentally alter the structures behind access and influence over water and energy resources.
- Small-scale farmers interviewed aren't aware of the Elqui Watershed Canal Lining/Piping Project and/or haven't been approached to participate in the modernization effort.
- The projects themselves aren't addressing inequality. Therefore, we must look to the policies to see where there are areas for changes in governance that can create actual change on-the-ground.
- Agricultural modeling, performed through the Gini Index of water rights inequality shows that Elqui, Coquimbo, and Chile broadly host significant disparities in power concentration. Therefore, reforms to environmental and resource law are still developing and have failed to address the central aims of new governance structures.
- Irrigation modernization has the potential to democratize the irrigation landscape yet continues to fall into the trap of being influenced by neoliberalism and the agribusiness complex. Projects thus far aren't engaging with participatory structures or actively seeking to reorient power structures.

5.5 Conclusions

Applying a political ecological framework to the Elqui Watershed's irrigation landscape reveals significant power imbalances over natural resource access and control. A combination of stakeholder interviews and Gini Index scores for water rights inequality suggests that the legacy of neoliberal policies in Chile remains embedded in governance and public policy (Parra et al., 2020; Valdés-Pineda et al., 2014). Irrigation modernization projects such as Puclaro Dam, Elqui Watershed Smart Monitoring Project, and Elqui Watershed Canal Lining/Piping Project have the potential to mitigate issues through more efficient resource practices, which will allow for more availability across the basin (Castelli et al., 2018). However, the current lack of environmental and economic regulations allows speculation and aggregation of water rights and energy control so that demand continues to increase, thus offsetting savings from irrigation upgrades (Ramirez, 2022).

Resource transitions are certainly occurring throughout the Elqui Watershed and are present in the selected irrigation modernization projects. Nonetheless, characteristics continue to reflect neoliberal power dynamics contributing to social inequalities and environmental impacts (Panez et al., 2020). As climate change outcomes manifest, incorporating policies that reorient resource governance towards participatory and democratized structures has the potential to support structures more consistent with newly drafted resource policy. Such systems can cut through inefficiencies in top-down neoliberal structures characterized by the natural resource landscape throughout Chile. Opportunities such as renewable microgrids, integrated watershed management, and participatory governance structures can help shift towards a future more aligned with newly enacted policies and social sentiment of the Chilean people.

CHAPTER 6: NEOLIBERALISM AND ENVIRONMENTAL WATER LAW: COMPARING THE UNITED STATES AND CHILE'S HYDROELECTRIC DAM NETWORKS

**Note: A similar version of this chapter has been published in the Journal of Water Law as:*

Nagel, Alexander. (2021). Neoliberalism and environmental water law: Comparing the United States and Chile's hydroelectric dam networks. Journal of Water Law, 27(2).

6.1 Introduction

This chapter conducts a comparative analysis between the legal dimensions of the United States Clean Water Act (CWA) of 1972[1] and the Chilean Water Code (CWC) of 1981,[2] alongside associated environmental assessment policies related to hydropower/irrigation projects. The United States had a direct influence on the composition of Chile's national legal frameworks (particularly the water code, electricity code, and agricultural policies), manifesting in a unique situation where laws were imposed over a short timeframe, rather than decades of development characterizing United States environmental policies.[3] Trajectories of the respective federal laws, however, have evolved in disparate ways, due to a host of spatially correlated political, economic, environmental, and sociocultural factors. Consequently, the research seeks to provide insights into complex outcomes generated by two landmark legal policies that may mirror one another superficially yet exist in heterogeneous landscapes.[4] Legal analysis and on-the-ground fieldwork address the research question:

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[1] 33 U.S.C. §1251 et seq. (1972)
[2] Código de Aguas [Cód. Aguas] [Water Code], Diario Oficial de Chile [D.O.], Oct. 29, 1981,
[3] *See* Carl Bauer, Water Conflicts and Entrenched Governance Problems in Chile's Market Model, Water Alternatives, 8(2): 147-172 (2009)
[4] *See* Silvia Borzutsky & Elisabeth Madden, Markets Awash: The Privatization of Chilean Water Markets, J. Int. Dev. 25, 251–275 (2013)

How can differences between the Chilean Water Code (CWC) and the United States Clean Water Act (CWA) pertaining to the dam-irrigation nexus inform policy decisions for reforming water and energy governance?

6.2 Research Topic

The research investigates sections 401[5] and 404[6] of the CWA, and hydropower-specific language of the CWC, the latter of which having only recently emerged as a topic for critical analysis to be examined by legal scholars[7]. The characteristics of these acts are particularly relevant for examining hydropower dams, which serve as a robust template for understanding environmental and agricultural policy because they are often situated at the confluence of water, energy, and climate change issues[8]. This paper will focus on water law yet apply an integrated approach toward understanding the relationships between dams and an emerging research framework called the water-energy-climate change interface.[9]

A major sticking point for legal action against dams is that these structures can have a negative impact on water quality.[10] Specific examples include disrupted temperature regimes and suspended sediments, hazardous algae blooms, and depleted dissolved oxygen levels.[11] Water quantity is often affected as well, yet much more ambiguous because it is challenging to accurately quantify evaporation from reservoirs, or the specific outcomes of changes in the

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[5] (33 U.S.C. § 1341)
[6] (33 U.S.C. § 1344)
[7] *See* Guillermo Donoso (Ed), Water Policy in Chile, Global Issues in Water Policy Series, 1-224 (2018)
[8] *See* Benjamin Sovacool & Goetz Walter, Internationalizing the Political Economy of Hydroelectricity: Security, Development and Sustainability in Hydropower States, Review of International Political Economy, 26(1): 49-79 (2019)
[9] *See* Larry Dale et al., An Integrated Assessment of Water-Energy and Climate Change in Sacramento, California: How Strong is the Nexus? Climatic Change, 132: 223–235 (2015)
[10] *See* U.S. Environmental Protection Agency, Frequently Asked Questions on Removals of Obsolete Dams, Office of Water, EPA-840-F-16-001 (2016)
[11] *See* Liba Pejchar & Keith Warner, A River Might Run Through It Again: Criteria for Consideration of Dam Removal and Interim Lessons From California, Environmental Management 28(5): 561-75 (2001)

hydrograph regimes of hydropower hosting rivers[12]. Both the CWA and CWC address water quality, yet the characteristics of the language vary substantially, thus conveying how the CWA has developed relatively rigorous criteria aligning with protectionist values[13], while the CWC focuses much more on opening up water markets for speculation while minimizing restrictions for agriculture, industry, and hydropower operators.[14] For example, a United States congressional mandate (dating back to 1970 and prior to the enactment of the CWA) maintains that polluters should not have the ability to delay or obfuscate federal licenses or permits in order to intentionally side-step water quality standards.[15] While this language is clear, there continue to be stark disconnects between elements of the CWA and the obstinate nature of dam decommissioning.[16] Despite an aging fleet (now on average 63 years) corresponding with diminishing performance and structural risk, only about 1,900 of the nation's more than 91,000 dams have been removed.[17]

The policy landscapes discussed stimulate the question of whether the CWA and CWC actually have teeth as effective mechanisms for dam removal and riparian habitat rehabilitation.[18] Evidence suggests that there are many limitations to CWA stipulations, creating loopholes that have been exploited by industrial polluters.[19] Similar outcomes

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[12] *See* Lori Pottinger, How Dams Affect Water Supply, World Rivers Review (2009)
[13] *See* John Attey & Drew Liebert, Clean Water, Dirty Dams: Oxygen Depletion and the Clean Water Act, Ecology Law Quarterly, 11(4): 703-729
[14] *See* Carl Bauer, Dams and Markets: Rivers and Electric Power in Chile, Natural Resources Journal, 49 Nat Resources J. 3 (Summer-Fall) (2009)
[15] 116 Cong. Rec. 8984 (1970).
[16] *See* Francis Magilligan et al., The Social, Historical and Institutional Contingencies of Dam Removal, Environmental Management, 59(6): 982-994 (2017)
[17] *See* Francis Magilligan et al., Immediate changes in stream channel geomorphology, aquatic habitat, and fish assemblages following dam removal in a small upland catchment. Geomorphology 252: 158-170 (2016)
[18] *See* Cody Kozacek, U.S. Clean Water Law Needs New Act for the 21st Century, Circle of Blue: Where Water Speaks (2015)
[19] *See* Hannah Duus, Waters of the United States: How the Governmental Branches Struggled to Settle the Jurisdiction of the Clean Water Act, Georgetown Environmental Law Review, 30(2): (2018)

transpire in Chile, as laissez-faire and neoliberal-driven regulations,[20] alongside soft-policy, have for decades accommodated commercial-scale agriculture, mining interests, and hydropower developers[21], rather than ecological balance and social welfare.[22] These concepts will be addressed through a series of analytical dimensions and legal cases throughout the paper, yet also transition into the concurrent incongruities between motions towards dam removal in the United States,[23] as Chile meanwhile plans to expand its hydropower network as a major component of national energy development strategies[24]. While each Act has its priorities, strengths, and limitations, Chile (as it has developed numerous federal policies historically) can look to U.S. law, specifically the CWA, a much more developed legal framework, as it seeks to reform its water code.[25] Implementing reforms that mandate adherence to key components of criteria outlined in sections 401[26] and 404[27] of the CWA will help Chile facilitate a future policy landscape supporting increased resilience to climate change impacts,[28] successful implementation of integrated watershed management,[29]and

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[20] *See* Shahriyar Nasirov et al., Renewable Energy Transition: A Market-Driven Solution for the Energy and Environmental Concerns in Chile, Clean Technologies, and Environmental Policy, 20: 3–12 (2018)

[21] *See* Yousef Ghorbani & Seng How Kuan, A Review of Sustainable Development in the Chilean Mining Sector: Past, Present and Future, International Journal of Mining, Reclamation and Environment, 31(2): 137-165 (2016)

[22] *See* Sarah Kelly, Megawatts mask impacts: Small hydropower and knowledge politics in the Puelwillimapu, Southern Chile, Energy Research & Social Science, 54: 224-235 (2019)

[23] *See* Brian Chaffin & Hannah Gosnell, Beyond Mandatory Fishways: Federal Hydropower Relicensing as a Window of Opportunity for Dam Removal and Adaptive Governance of Riverine Landscapes in the United States, Water Alternatives, 10(3): 819-839 (2017)

[24] *See* Lawrence Susskind et al., The Future of Hydropower in Chile, Journal of Energy & Natural Resources Law, 32(4): 425-481 (2014)

[25] *See* Roberto Pinto, The Current Reform of the Chilean Water Code: An Attempt to Contest the Commoditised Treatment of Water, A Dickson Poon Transnational Law Institute, King's College London Research Paper Series, 82: 1-39 (2017)

[26] (33 U.S.C. § 1341)

[27] (33 U.S.C. § 1344)

[28] *See* Luis Mundaca, Climate change and energy policy in Chile: Up in smoke?, Energy Policy, 52: 235-238 (2013)

[29] *See* Anahí Urquiza & Marco Billi, Water Markets and Social–Ecological Resilience to Water Stress in the Context of Climate Change: An Analysis of the Limarí Basin, Chile, Environment, Development and Sustainability: (2018)

optimization of the capacity to achieve sustainable development goals[30] articulated in a seminal document, the Energía2050 initiative[31]. Meanwhile, United States policy can look to other nations' clean water models to see what is and isn't working, to enact more precise language concerning dams, thereby supporting more streamlined pathways for either maintaining or decommissioning structures in the 21st century.[32]

6.3 Clean Water Act and Hydropower in the United States

The United States CWA[33] was enacted in 1972, an era during which major environmental reforms were implemented.[34] Particularly relevant to the CWA is the fact that many of the nation's waterways had become polluted to the point of major health concerns and certain rivers (such as the Cuyahoga in Ohio) actually catching fire.[35] Since, expanded regulations and certain landmark cases (for example: Rapanos v. United States;[36] Entergy Corp v. Riverkeeper Inc.;[37] Hanousek v. United States;[38] South Florida Water Management District v. Miccosukee Tribe of Indians;[39] S.D. Warren Co. v. Maine Board of Environmental Protection[40]) has helped advance statutory clarity[41], associated with improvements in the

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[30] *See* Marcia Montedonico et al., Co-Construction of Energy Solutions: Lessons Learned from Experiences in Chile, Energy Research & Social Science: (2018)
[31] *See* Anahí Urquiza et al., Participatory Energy Transitions as Boundary Objects: The Case of Chile's Energía2050, Frontiers in Energy Research, 6(34): 1-17 (2018)
[32] *See* Valerie Rapp, The River Fix: Dam Removal Isn't Simple, Neither Are Rivers, Oregon Humanities, Spring 2015: 22-27 (2015)

[33] 33 U.S.C. §1251 et seq. (1972)
[34] *See* James Turner, The Republican Reversal: Conservatives and the Environment from Nixon to Trump, Harvard University Press, (2018)
[35] *See* David Stradling, Perceptions of the Burning River: Deindustrialization and Cleveland's Cuyahoga River, Environmental History, 13(3): 515-535 (2008)
[36] 547 US 715 (2006)
[37] 556 US _ (2009)
[38] 176 F.3d 1116 (9th Cir. 1999)
[39] 541 US 95 (2004)
[40] 547 US 370 (2006)
[41] *See* U.S. Environmental Protection Agency, Clean Water Act Methods Update Rule for the Analysis of Effluent, 84 FR 56590 (2019)

health and quality of the nation's waterways. Hurdles persist, however, as non-point source pollution[42] especially continues to pose regulatory challenges for state and federal environmental and oversight entities.[43]

An area within CWA policies that have only recently begun to receive attention is dams, particularly hydroelectric structures, and their influence on characteristics of water quality and quantity.[44] More than two-thirds of United States waterways host dams, and there are currently approximately 6,400 facilities[45] capable of generating 322,390 GW of electricity, second only to China[46]. Correspondingly, dams had a foundational role in the reclamation of the American West, and the infrastructural development of the country, thus embedding these structures into sociocultural, political, economic, and environmental landscapes,[47] as well as imbuing them with symbolism of American ingenuity and progress.[48] Therefore, despite growing evidence that thousands of dams have already reached, or are nearing obsolescence,[49] meaning that they no longer serve their original functions and generate more costs than benefits,[50] decommissioning proposals have been consistently been

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[42] (33 U.S.C. § 502(14))
[43] *See* Michael Kaplowitz & Frank Lupi, Stakeholder Preferences for Best Management Practices for Non-point Source Pollution and Stormwater Control, Landscape and Urban Planning, 104(3): 364-372 (2012)
[44] *See* Dana Saeger, Affirming State Authority to Regulate Hydroelectric Dams under the Clean Water Act, Great Plains Natural Resources Journal, 11: 1-2 (2006)
[45] *See* David Rosenberg et al., Global-Scale Environmental Effects of Hydrological Alterations, BioScience, 50(9): 746-751 (2000)
[46] *See* International Hydropower Association, 2018 Hydropower Status Report (2018)
[47] *See* Gavin Bridge, Geographies of Energy Transition: Space, Place, and the Low-carbon Economy. Energy Policy, 53: 331-340 (2013)
[48] *See* Marc Reisner, Cadillac Desert: The American West and it's Disappearing Water, Penguin Books (1993)
[49] *See* Michael Kuby et al., A Multiobjective Optimization Model for Dam Removal: An Example Trading Off Salmon Passage with Hydropower and Water Storage in the Willamette Basin, Advances in Water Resources 28(8): 845-855 (2005)
[50] *See* Paulo Branco et al., Prioritizing Barrier Removal to Improve Functional Connectivity of Rivers, Journal of Applied Ecology, 51(5): 1197-1206 (2014)

met with ideological extremism and legal ambiguity,[51] rather than stakeholder cooperation and best management practices.[52]

In order to achieve increased transparency, sections 401[53] and 404[54] of the CWA[55] can be advanced to more precisely categorize dam outcomes, creating mechanisms for determining dam management strategies, as many face license expiration[56] and growing structural risk as they age.[57] To some extent, this has already occurred through updated EPA policies,[58] yet case law is still relatively underdeveloped.[59] What is clear, however, is that the EPA and U.S. Army Corps of Engineers (USACE), who jointly manage issues related to sections 401 and 404 of the CWA[60], have cooperatively drafted documents elucidating hydropower and clean water relationships, despite the fact the EPA leans against hydropower while the USACE promotes this energy resource. However, codification through statutory or case law remains sparse, perpetuating uncertainties and creating loopholes for hydropower stakeholders. To develop a more comprehensive understanding of how these sections of the CWA are influencing dam legislation, the forthcoming cases (#1, #2 & #3) will interrogate the roles that statutory language has had in determining outcomes of key hydropower cases.

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51 *See* Margaret Bowen, Legal Perspectives on Dam Removal, BioScience, 52(8): 739-747 (2002)
52 *See* Anal Misra et al., Watershed Management Structures and Decision-Making Frameworks, Water Resources Management, 29(13): 4849–4861 (2015)
53 (33 U.S.C. § 1341)
54 (33 U.S.C. § 1344)
55 33 U.S.C. §1251 et seq. (1972)
56 *See* Randy Showstack, Weighing a Dam's Economic and Environmental Impact, Eos Transactions American Geophysical Union, 80(29): 318-318 (1999)
57 *See* N. Leroy Poff & David Hart, How Dams Vary and why it Matters for the Emerging Science of Dam Removal, Bioscience 52(8): 659–668 (2002)
58 *See* U.S. Environmental Protection Agency, Permit Program under CWA Section 404, (2019)
59 *See* Amena Saiyid, Aides Say Hydropower Bills Will Streamline Permitting, Not Remove State Authority, Daily
Environment Report, A-10: (2015)
60 *See* U.S. Environmental Protection Agency, CWA Section 401: State Certification of Water Quality (2019)

Alongside this theme, elements of tribal law[61] will be co-presented as an increasingly important component of policy decisions, and potential avenues for expanding and clarifying understandings of the relationships between dams, riparian ecosystem health, and social justice.[62]

6.4 Chilean Water Code and Hydropower

Chile's federal water code was enacted in 1981, an era characterized by the forced transition from a socialist democratic system to a military dictatorship.[63] Between 1973 and 1990, Augusto Pinochet, an Army General, occupied the presidency and mandated strict adherence to neoliberal, free market systems that facilitated economic development through natural resource extraction and open trade policies.[64] Chile experienced significant GDP growth, setting the stage for its position as Latin America's wealthiest nation and the region's only member of the Organization for Economic Cooperation and Development (OECD).[65] Examples of these circumstances include high GDP per capita, universal literacy, and noteworthy Human Development Index scores.[66] However, alongside these successes, severe air and water pollution,[67] acute wealth inequality[68] and trade reliance[69] inhibit and

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[61] *See* Jerilyn Church et al., Tribal Water Rights: Exploring Dam Construction in Indian Country, Journal of Law, Medicine & Ethics, 43(s1): 60–63 (2015)
[62] *See* Julian Kircherr & *See* Julian Kircherr & Katrina Charles, The Social Impacts of Dams: A New Framework for Scholarly Analysis, Environmental Impact Assessment Review, 60: 99-114 (2016)
[63] *See* John Rector, The History of Chile, Palgrave Essential Histories. St. Martin's Griffin: (1998)
[64] *See* Jerrold Long et al., Chile, the Biobío, and the Future of the Columbia River Basin, Idaho Law Review, 53: 239-285 (2017)
[65] *See* Paulo Pino, Chile Confronts its Environmental Health Future After 25 Years of Accelerated Growth, Annals of Global Health, 81(3): 2015.
[66] *See* David Watts et al., Assessment of Wind Energy Potential in Chile: A Project-Based Regional Wind Supply Function Approach, Renewable Energy, 96(A): 738-755 (2016)
[67] *See* Luis Mundaca (2013)
[68] *See* Carl Bauer and Luis Catalán, Water, Law, and Development in Chile/California Cooperation, 1960–70s. World Development, 90: 184-198 (2017)
[69] *See* Juan Coeymans, Effects of a Free Trade Agreement Between Chile and United States: A General Equilibrium View, Cuadernos de Economia, 94: 357-399 (1994)

misrepresent social wellbeing[70], leading to grievances that manifested in violent nationwide protests during 2019.[71]

Deployment of the CWC occurred alongside the Chilean Electricity Code (CEC), with both oriented towards market-based economic development and natural resource extraction,[72] rather than environmental health, and certainly not in anticipation of climate change.[73] Despite the return to democracy in 1990, the codes have proven obstinate, and remain predominately intact with minimal reform (notably in 2005), and multiple failed attempts.[74] Meanwhile, emerging academic literature suggests that while both the CWC and CEC are overseen by environmental departments within the federal government,[75] outcomes of industrial development and hydropower expansion favor the CEC,[76] which is important because despite the lack of teeth in the CWC, certain statutes do address water quality.[77]

Concerning specific characteristics of the CWC, a glaring difference from the United States CWA is the fact that environmental flows are virtually absent from this legislation.[78] Since Chile plans to generate 45-48% of electricity from hydropower by 2050,[79] representing

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[70] *See* Elvis Parraguez & Johnathan Barton, Poverty and Dependency in Indigenous Rural Livelihoods: Mapuche Experiences in the Andean Foothills of Chile, Journal of Agrarian Change, 13(2): 234 (2013)
[71] *See* Emiliano Mega, What the Protests and Violence in Chile Mean for Science, Nature, 575(7782): 265-266 (2019)
[72] *See* Diego Rivera et al., Legal disputes as a proxy for regional conflicts over water rights in Chile, Journal of Hydrology, 535(C): 36-45 (2016)
[73] *See* Sonia Salas et al., Coquimbo Region, Chile: Mainstreaming Climate Change. Community Conservation Research Network: (2018)
[74] (Project No.7543-12)
[75] *See* CONAMA, Plan de Acción Nacional de Cambio Climático (2017-2022), Comisión Nacional del Medio Ambiente. Informe, Santiago, Chile: (2017).
[76] *See* Michael Pollitt, Electricity Reform in Chile Lessons for Developing Countries, Center for Energy and Environmental Policy Research: (2004)
[77] *See* Carl Bauer (2009)
[78] *See* P. Wagnitz et al., Cost of Environmental Flow During Water Scarcity in the Arid Huasco River basin, Northern Chile, Hydrological Sciences Journal, 59 (3–4): 700–712 (2014)
[79] *See* Lawrence Susskind et al., (2014)

a substantial expansion of its current network,[80] policymakers will be required to reconcile with the reality that this nation is among the most climate change susceptible in the world, and has already seen disproportionate hydropower reliance cause nationwide blackouts during drought events in 1999 and 2010.[81] Therefore, institutional reevaluation will serve a vital role to achieve outcomes that meaningfully mitigate and adapt to diminished altered water resource availability.[82] However, while legal restructuring is urgent, reforms remain nebulous, as the tenets of the CWC are firmly embedded into socioeconomic and political systems throughout the Chilean landscape.[83]

6.5 Hydropower and Environmental Impact Assessments in the United States

Related to the CWA, Environmental Impact Assessment (EIA) procedures can be a specific mechanism through which hydropower cases can be analyzed and resolved.[84] However, since the preponderance of United States dams were constructed between 1930 and 1970,[85] some of which requiring licensing from the Federal Energy Regulatory Commission (FERC)[86] and others receiving exemptions,[87] most structures were constructed before the enactment of the National Environmental Policy Act (NEPA).[88] Therefore, many dams were

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[80] *See* Michael Nelson, Fifty Years of Hydroelectric Development in Chile: A History of Unlearned Lessons, Water Alternatives 6(2): 195-206 (2013)

[81] *See* Mabel Vega-Coloma & Claudio Zaror, Environmental Impact Profile of Electricity Generation in Chile: A Baseline Study over Two Decades, Renewable and Sustainable Energy Reviews, 94: 154-167 (2018)

[82] *See* P. Monsalves-Galiván et al., Climate Change and its Effects on Urban Spaces in Chile: A Summary of Research Carried Out in the Period 2000-2012. Atmósfera, 26(4): 2013

[83] *See* Gavin Bridge (2013)

[84] *See* Robert Mcmanamay et al., Evidence-Based Indicator Approach to Guide Environmental Impact Assessments of Hydropower Development. Ecological Indicators, 107(C): (2019)

[85] *See* Mark Hemphill, Big Projects: The United States from 1930 to 1970--When Most of Us Were Youths--Was a Nation of Big Projects: High Dams, Soaring Bridges, Long Canals, Interstate Highways, Trains Magazine, 63(11): 4.

[86] *See* Brian Chaffin & Hannah Gosnell (2017)

[87] *See* Dan Tarlock, Hydro Law and the Future of Hydroelectric Power Generation in the United States:Supply and Demand: Barriers to a New Energy Future, Vanderbilt Law Review, 65(6): 1723-1768 (2012)

[88] *See* Michael Blumm, Debunking the "Divine Conception" Myth: Environmental Law before NEPA, Ecology L.Q., 7: 269-1217 (2010)

introduced to rivers without the procedures that now characterize environmental alterations to the magnitude often caused by dams[89] and that are occurring even in nations with bold hydropower development goals and minimal regulations.[90]

A fundamental demarcation within dams and EIA processes concerns whether the motion is for a new project, an ongoing issue (often surfaced during relicensing periods), or a removal proposal.[91] Since removals are not centralized processes, typically coordinated through federal and state entities, dam owners, and management bodies, the decommissioning process has EIA obligations of its own since the "restoration" of a waterway has short-term impacts as well.[92] Nonetheless, there exists irony in the fact that the removal of a potentially harmful or obsolete structure faces more regulatory hurdles than the implementation of the dam in the first place. Also, there are relatively few examples of dams that have been removed specifically due to the failure to submit and pass an EIA, conveying that hydropower continues to occupy a nebulous grey area in which a potentially extensive area of NEPA violations isn't being addressed.[93]

6.6 Hydropower and Environmental Assessment in Chile

Environmental Assessments (EAs) in Chile are much less developed than in the United States. However, they have evolved in recent years since the establishment of the System for Environmental Assessment in 1994.[94] A conflict that gathered international

[89] *See* Stewart Rounds, Thermal Effects of Dams in the Willamette River Basin, Oregon. USGS Scientific Investigations Report, 5153: 1-74 (2010)
[90] *See* Femi Olokosusi, Environmental Impact Assessment in Nigeria: Current Situation and Directions for the Future, Journal of Environmental Management, 35(3): 163-171 (1992)
[91] *See* Amy East et al., Reprint of: Large-Scale Dam Removal on the Elwha River, Washington, USA: River Channel and Floodplain Geomorphic Change, Geomorphology, 246: 687-708. (2015)
[92] *See* Margaret Bowman (2002)
[93] 42 U.S.C. §§4321-4370h
[94] Law No. 19,300

attention over hydropower and environmental impacts was the HidroAysén[95] project, intended to construct a series of mega-structures in the southern reaches of Patagonia (discussed in a forthcoming section), which brought to attention the shortcomings of legal language concerning these cases.[96] Consequently, there has been increased attention on solidifying the dynamics of EA procedures, primarily through the Environmental Evaluation Service (SEA).[97] The SEA, alongside the Ministry of the Environment (CONAMA) has created a system for EA procedures that include either a Declaration of Environmental Impact (DIA) for proposals smaller in magnitude,[98] or a Study of Environmental Impacts (EIA) for projects anticipated to have major environmental implications assuming they are realized.[99] Part of this process was the establishment of environmental courts[100], which didn't occur until 2012, representing tremendous progress towards environmental stewardship, yet quite late in the game. Therefore, continued organization between these entities will be required to combat the continued trends of resource extraction and tenuous regulatory power.

Associated with hydropower and EA policy, an ongoing loophole has emerged as a major issue concerning the development of small hydropower (SHP) projects.[101] Particularly common in the southern part of the country, where abundant rainfall accommodates tributaries ideal for harnessing small amounts of hydropower, developers are able to

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[95] *See* Ernesto Silva, Patagonia, without Dams! Lessons of a David vs. Goliath campaign. The Extractive Industries and Society, 3(4): 947-957 (2016)
[96] *See* Amanda Maxwell, Protect Chile's Patagonia with Clean Energy Alternatives to Mega Dams. Promote Clean Energy in Chile. National Resource Defense Council (2017).
[97] *See* Alberto Cardemil & Tomás de la Maza, Chilean Environmental Evaluation Service Releases New Guide for Determining the Environmental Flow for Hydropower Plants, Mondaq (2016).
[98] *See* Claudio Agostini et al., Failure of Energy Mega-Projects in Chile: A Critical Review from Sustainability Perspectives, Sustainability, 9: 1073-1100 (2017).
[99] *See* Jose Urrutia & Sebastián Avilés, Environmental Law and Practice in Chile: Overview, Thompson Reuters Practical Law (2015)
[100] Law No. 20,600
[101] *See* Sarah Kelly (2019)

implement dams without a full EIA if the generation capacity is below 3 MW. A specific discussion will occur in a forthcoming case study (#4), yet overall conveys how despite advancements in establishing environmental courts, federal agencies, and assessment processes, fragmentation persists surrounding the impact of riparian ecosystems and marginalized indigenous communities.[102]

6..7 Case #1: Hoopa Valley Tribe v. FERC

In 2005 a legal dispute between the Hoopa Valley Tribe and the states of Oregon, California, and local hydropower operator PacifiCorp ascended to the D.C. circuit court.[103] The legal structure of this case was focused on CWA section 401[104] permitting for federal hydropower licenses by the Federal Energy Regulatory Commission (FERC). This case evolved into a monumental ruling for the CWA and hydropower because it concerned a series of four dams on the Klamath River, that have been on the docket for decommissioning since the beginning of the 21st century.[105] This case is particularly important in establishing standing for dam removal, because the projected restoration of the Klamath system would represent the nation's, and in fact, the world's largest removal project to date, and is thus a relevant template for understanding the complex nature of decision-making and stakeholder relationships.[106] Situated at the center of these relationships are Tribal rights, as both the

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[102] *See* A. Tomaselli, Natural Resources Claims, Land Conflicts and Self-Empowerment of Indigenous Movements in the Cono Sur - The Case of the Mapuche People in Chile. International Journal on Minority and Group Rights, 19(2):153-174 (2012)

[103] Hoopa Valley Tribe v. FERC, 913 F.3d 1099 (D.C. Cir. 2019).

[104] (33 U.S.C. § 1341)

[105] *See* Jeffrey Jenkins, The Reproduction of the Klamath Basin: Struggle for Water in a Changing Landscape, Yearbook of the Association of Pacific Coast Geographers,.73: 69-78 (2011)

[106] *See* Brian Tilt et al., Social Impacts of Large Dam Projects: A Comparison of International Case Studies and Implications for Best Practice. Journal of Environmental Management, 90: S249-S257 (2007)

Hoopa Valley and Yurok Nations of Northern California have been advocating for personhood status to support the rehabilitation of the Klamath River for decades.[107]

To gain an in-depth understanding of the overall substance of the case, the following passage presents an insightful analysis of the major outcomes of Hoopa Valley Tribe v. FERC: This case "challenged the intentional and continual delay of state water quality certification review of water discharged from a series of dams on the Klamath River in California and Oregon. The Federal Energy Regulatory Commission (FERC), the states of Oregon and California, and PacifiCorp, a hydroelectric operator, were implementing an administrative scheme designed to circumvent a one-year temporal requirement for review imposed on states by the CWC. This scheme allowed PacifiCorp to operate the series of dams for over a decade without proper state water quality certification. The United States Court of Appeals for the District of Columbia Circuit held in favor of the Hoopa Valley Tribe and vacated FERC's ruling while also holding that Oregon and California had waived their Section 401 water quality certification authority."[108] The information contained in this passage is relevant to the general nature of common intersects between CWA sections 401[109] and 404[110] and hydropower because there are often disparities between legal language and on-the-ground outcomes, that are only recently becoming elucidated. This is among the reasons why the upcoming removal of the Klamath Dams[111], as well as previous

[107] *See* Tara Lohan, What We're Learning Ahead of the World's Largest Dam-Removal Project, Earth Island Journal (2019)
[108] *See* Aaron Rains, Hoopa Valley Tribe v. FERC, Public Land & Resources Law Review, 0(22): (2019)
[109] (33 U.S.C. § 1341)
[110] (33 U.S.C. § 1344)
[111] *See* Undam it? Klamath Tribes, Social Ecological Systems, and Economic Impacts of River Restoration. American Indian Culture & Research Journal 38(3): 25-53 (2014)

decommissioning projects such as Oregon's Marmot Dam[112] and Washington's Elwha and Glines Canyon Dams[113], deserve critical analysis. Each project tells a story about how a convoluted set of legal, social, political, economic, and environmental circumstances resulted in outcomes that continue to be disparaged by the U.S. Department of Energy and several hydropower advocacy groups.[114] Therefore, sophisticated monitoring of the successions (both social and ecological) following removal projects to date[115] must contribute to having a role in helping clarify the CWA and hydropower-related statutes, thus promoting more comprehensive standards as more structures approach this juncture.[116]

Hoopa Valley Tribe v. FERC also represents one component of the contemporary movement towards establishing additional rights throughout personhood to river systems.[117] Within Tribal Law, the Yurok Nation recently granted personhood rights to the Klamath River to protect its biological integrity. Forthcoming cases (notably in Chile) will explore this mechanism to interrogate the extent to which they may shape policy going forward.

6.8 Case #2: S.D. Warren v. Maine Board of Environmental Protection

This 2006 federal ruling focuses on the concept of 'discharge' about hydroelectric dams and their operation. This case ended up in the United States Supreme Court[118] after a local hydropower company faced off against the Maine Board of Environmental Protection

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[112] *See* Yantao Cui et al., Lessons Learned from Sediment Transport Model Predictions and Long-term Postremoval Monitoring: Marmot Dam Removal Project on the Sandy River in Oregon. Journal of Hydraulic Engineering, 140(9): (2014)

[113] *See* Amy East et al., (2015)

[114] *See* Dolly Jorgensen & Birgitta Renofalt, Damned If You Do, Dammed If You Don't: Debates on Dam Removal, Ecology and Society 18(1): (2013)

[115] *See* K. Kibler et al., Learning from Dam Removal Monitoring: Challenges to Selecting Experimental Design and Establishing Significance of Outcomes, River Research and Applications: (2010)

[116] *See* Pearl Zheng & Benjamin Hobbs, Multiobjective Portfolio Analysis of Dam Removals Addressing Dam Safety, Fish Populations, and Cost. Journal of Water Resources Planning & Management, 139(1): 65-75 (2013)

[117] *See* Cristy Clark, Can You Hear the Rivers Sing? Legal Personhood, Ontology, and the Nitty-Gritty of Governance, Ecology Law Quarterly, 45: 787-844 (2017)

[118] 547 U.S. 370 (2006),

(MBEP), the latter party claiming that the S.D. Warren Co. should be required to obtain a section 401[119] state permit under the CWA to operate their five projects.[120] Specifically, the permitting was called under question because S.D. Warren Co. claimed that the quantity and composition of the water flowing through their hydroelectric turbines were not affected,[121] while concurrently the MBEP argued that the discharge from the Presumpscot River was influenced, and ultimately diminished by the presence of the network of hydropower dam structures.[122] This case had landmark implications, primarily because the clout of section 401 was significantly expanded,[123] opening up the door for legal action against thousands of dam structures similarly poised to face license expiration during the coming decades.[124] Therefore, this section discusses some of the specific details of the case, yet also interrogate why this ruling hasn't had the impact that was anticipated.

The ruling of the case affirmed that hydropower facilities raise the potential for discharge,[125] a term that remains relatively ambiguous, but fundamentally focuses on the idea that water is either polluted or affected due to an industrial operation.[126] FERC and EPA have had a major role in advancing language to include releases from hydroelectric dams, yet there remains a lack of clarity because opponents argue that discharge must involve the addition of

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[119] (33 U.S.C. § 1341)
[120] *See* Daniel Pollack, S.D. Warren and the Erosion of Federal Preeminence in Hydropower Regulation, Ecology Law Quarterly, 34: 763-800 (2015)
[121] *See* Christopher Scoones, Let the River Run: Strategies to Remove Obsolete Dams and Defeat Resulting Fifth Amendment taking Claims, Seattle Journal of Environmental Law, 2(1): (2012)
[122] *See* Ashleigh Allione, The Battle Over U.S. Water: Why the Clean Water Rule "Flows" Within the Bounds of Supreme Court Precedent, American University Law Review, 66:1(4): (2017)
[123] *See* Lisa Bogardus, State Certification of Hydroelectric Facilities Under Section 401 of the Clean Water Act, Virginia Environmental Law Journal, 12(1): 43-101 (1992)
[124] *See* Brian Chaffin & Hannah Gosnell (2017)
[125] *See* U.S. Environmental Protection Agency, Frequently Asked Questions on Removals of Obsolete Dams, Office of Water, EPA-840-F-16-001 (2016)
[126] 33 U. S. C. §1362(16)

a foreign substance into the water.[127] Example cases, where a plaintiff claims that one or multiple hydropower dams are impacting water quality, yet is unable to prove a direct link are numerous.[128] However, the affirmation of discharge as a potential area for section 401 noncompliance has been a notable aspect of the decision to remove the four Klamath River Dams,[129] and will likely emerge as a common avenue for other decommissioning efforts, as the aging United States dam fleet faces unprecedented levels of license expiration over the next two decades.[130]

The outcome of the S.D. Warren v. Maine Board of Environmental Protection case brings to the forefront the question of why despite clear language highlighting the relationships between hydropower structures and discharge,[131] many dams continue to operate unencumbered. Addressing this issue is convoluted, because of the multifaceted nature of dam removals.[132] Documents focused specifically on the legal mechanisms for dam removal are expanding,[133] yet the fact that there are so many avenues for removal, yet few with well-developed precedent actually manifesting in decommissioning.[134] Therefore, the host of potential, yet vague statutes may actually overcomplicate and muddy the waters,

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[127] *See* Daniel Pollock (2015)
[128] *See* Enron Rhead, Rethinking National Wildlife Federation v. Gorsuch: The Case for NPDES Regulation of Dam Discharge. (National Pollutant Discharge Elimination System), Ecology Law Quarterly, Vol.38(4): 797-850 (2011)
[129] *See* Daniel Graham et al., Certainty and Uncertainty in Federal Government Contracts Law, Public Contract Law Journal: 473-479, 481-526 (2011)
[130] *See* Felicity Barringer, As Relicensing Looms, Aging Dams Face a Reckoning, Stanford University Bill Lane Center for the American West (2019)
[131] *See* U.S. Environmental Protection Agency, National Management Measures to Control Nonpoint Source Pollution from Hydromodification, Office of Water, EPA 841-B-07-002 (2007)
[132] *See* Margaret Bowman (2002)
[133] *See* Peter Carney, *See* Peter Carney, Dam Removal: Evolving Federal Policy Opens a New Avenue of Fisheries and Ecosystem Management, Ocean and Coastal Law Journal, 5:2(6): (2000)
[134] *See* Christina Tonnito & Susan Riha, Planning and implementing small dam removals: lessons learned from dam removals across the eastern United States, Sustainable Water Resources Management, 2(4): 489-507 (2016)

creating ambiguity that dam operators can hide behind.[135] Due to this current removal landscape, the likelihood is that firmer language and more robust mechanisms for removal will rely on the gradual, yet inevitable growth of dam removal projects, that will continue to face bureaucratic roadblocks but transpire more often simply because more dams are reaching obsolescence and untenable costs rehabilitation costs. However, clarifying legal parameters for removal and coordinating different pathways will be crucial to conduct efficient assessments, and preventing delays that ultimately may lead to severe ecological debilitation and human catastrophe from impeding structural failure experienced at more sites, notably Oroville Dam, the nation's highest structure, in 2018.[136]

6.9 Case #3 (PUD No. 1 of Jefferson County v. Washington Dept. of Ecology)

Expanding on previously discussed legal cases and developing standards for interpreting hydropower's CWA compliance, the following case relates to section 401[137] of the CWA, yet also focuses on section 303[138], an alternative pathway for ruling on the relationships between hydropower and water quality.[139] The 1994 case titled PUD No. 1 of Jefferson County v. Washington Dept. of Ecology[140] ascended to the Washington State Supreme Court and concerned a somewhat unique plan to develop the Elkhorn Hydroelectric Project on the Dosewallips River.[141] Section 401 compliance by the Washington Department of Ecology was sought because the planned project was assessed and projected to reduce minimal flows to around 65 cubic feet/second (cfs), while fishery health required a minimum

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[135] *See* Christopher Scoones (2012)
[136] *See* Dana Nuccitelli, expect to see more emergencies like Oroville in a hotter world. The Guardian: Climate Consensus, 20: (2017)
[137] (33 U.S.C. § 1341)
[138] (33 U.S.C. § 1313): Water Quality Standards and Implementation Plans
[139] *See* Brenda Pracheil et al., A Checklist of River Function Indicators for Hydropower Ecological Assessment, Science of the Total Environment, 687(C):1245–1260 (2019)
[140] 511 U.S. 700 (1994)
[141] *See* Christopher Dunagan, Dosewallips: Ruling Reaches Beyond River Dam, Kitsap Sun (1994)

flow regime of 100-200 cfs.[142] Despite appeals by the hydropower developer, the State Supreme Court maintained that antidegradation laws mandate environmental flows exceeding what would likely transpire upon implementation of the dams, advancing the argument for stream condition to be employed as a mechanism for preventing the construction of harmful new hydropower projects.[143]

Along section 401, the section 303 aspect of this case concerned the requirement for states to seek federal approval to "institute comprehensive standards establishing water quality goals for all intrastate waters, and requires that such standards consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses."[144] Section 303 compliance was evidently impacted by the proposed construction, thus bolstering the standing of the complaint against the Elkhorn Hydropower Project.[145] The issue that persists, however, is that relatively few dams are still being constructed and if this case presented a clear violation of water standards, many intact dams likely have been impacting riparian health for decades.

6.10 Case #4 (Hidroeléctrica Las Flores v. Chilean Environmental Evaluation Service)

A particularly relevant case that focuses upon both EA processes and indigenous rights was the 2011-2016 small hydropower project legal battle between the regional dam developer (Hidroeléctrica Las Flores) the Chilean Environmental Evaluation Service (SEA), and local indigenous communities.[146] This case will be presented first among the Chilean

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[142] *See* Eric Pryne, Hydro Project Sparks Big Battle Over Small River, The Seattle Times (1994).
[143] *See* Katherine Ransel, The Sleeping Giant Awakens: PUD No. 1 of Jefferson County v. Washington Dept. of Ecology, Environmental Law, 25(2): 255-283 (1995)
[144] 121 Wash. 2d 179, 849 P. 2d 646
[145] *See* Mike Blake, Water: PUD No. 1 of Jefferson County v. Washington Department of Ecology: State Water Quality Certification of Federally Licensed Hydropower Projects. Oklahoma Law Review, 48: 817–817 (1995)
[146] *See* Sarah Kelly (2019)

studies because it elucidates the legal loopholes within the CWC and CEC commonly exploited by industrial entities in Chile. The forthcoming cases focus on larger projects, one that transpired, and one that was defeated, but that can be both linked to policy shortcomings that continue to facilitate hydropower expansion and natural resources extraction, without sufficient assessment of environmental and sociocultural impacts[147].

The Hidroeléctrica Las Flores v. SEA case concerns the construction of a small hydropower dam (originally 2.2 MW, yet upgraded to 4.4 MW) in Chile's Araucanía Region, which is inhabited by the indigenous Mapuche.[148] This multidimensional issue intertwined indigenous rights, specifically the 2012 ratification of International Labour Organization Convention No. 169,[149] alongside elements of the CWC that create loopholes for hydropower projects generating less than 3 MW of electricity.[150] The justification for this policy is that small operations have lower impacts, and would be hindered by the gamut of steps required to complete a full EIA. Meanwhile, however, Convention No. 169 articulates that indigenous groups are legally entitled to a clean environment, and also includes language concerning the codification of cultural rights and legal recognition in cases relevant to their causes.[151] Fundamentally, the Mapuche are at odds with dam development in their territory, due not only based on their determination to maintain healthy waterways for domestic consumption and source of sustenance but because their spiritual cosmovision is grounded in free-flowing

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[147] *See* Julian Kircherr et al., Cleaning Up the Big Muddy: A Meta-synthesis of the Research on the Social Impact of Dams, Environmental Impact Assessment Review, 60: 115-125 (2016)
[148] *See* Servicio de Evaluación de Impacto Ambiental, Informe Consolidado de Solicitud de Aclaraciones, Rectificaciones y/o Ampliaciones Complementario a la Declaración de Impacto Ambiental del Proyecto, Ampliación Minicentral Hidroeléctrica Las Flores (2017)
[149] *See* Daniel Shapiro et al., Natural Resources, Multinational Enterprises and Sustainable Development. Journal of World Business, 53(1): 1-14 (2018)
[150] *See* Javiera Barandiarán, The Authority of Rules in Chile's Contentious Environmental Politics, Environmental Politics, 25(6): 1013–1033 (2016)
[151] *See* R. Cespedes, Indigenous Peoples' Human Right to Clean Environment, Environmental Impact Assessment and ILO-Convention 169. Warwick Student Law Review, 3(1), 71-79 (2013)

rivers as a central component of their identity and cultural customs.[152] While Convention No. 169 has facilitated opportunities for improved indigenous rights recognition,[153] the outcomes of cases incorporating this convention have been unfulfilling since the federal government has largely neglected the processes for advancing a clear definition of legal mechanisms supporting environmental and social agency.[154]

The outcome of the legal case was that Hidroeléctrica Las Flores was able to bypass a full EIA process during initial construction in 2011, since the project was less than 3 MW. Then in 2015, the company proposed the addition of a new turbine to boost production to 4.4 MW.[155] Despite resistance from local Mapuche communities, the developer was only required to fill out a streamlined DIA, which excluded indigenous consultation.[156] Consequently, the dam now operates with additional adherence to hydropower output, further impacting the flow regime of the Quimán River, a waterway vital to the Mapuche community. Such an outcome suggests that Chile's policy landscape continues to accommodate hydropower development and natural resource extraction despite goals outlined in national documents such as Energía2050 and the National Climate Change Action Plan (PANCC).

Issues surfaced in the Hidroeléctrica Las Flores v. SEA case present challenges in Chile's ability to meet sustainable development goals. Since continued laissez-faire regulations continue to accommodate industrial activities throughout indigenous territory,[157]

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[152] *See* Juana Aigo & Ana Ladio, Traditional Mapuche Ecological Knowledge in Patagonia, Argentina: Fishes and other Living Beings Inhabiting Continental Waters, as a Reflection of Processes of Change, Journal of Ethnobiology and Ethnomedicine, 12(1): 56 (2016)
[153] *See* Sarah Kelly (2019)
[154] *See* A. Tomaselli (2012)
[155] *See* Sarah Kelly (2019)
[156] Ids.
[157] *See* Rene Montalba & Niall Stephens, Ecological Change and the "Ecological Mapuche": A Historical Sketch of the Human Ecology of Chile's Araucanía Region. Human Ecology, 42(4): 637-643 (2014)

these patterns will inhibit the ability to realize proposed water, energy, and climate change transitions.[158] Therefore, the current configuration of attempts to reform laws in favor of socioenvironmental health, while maintaining support for extractive-based economic growth appears incongruous. Clearly, despite certain accomplishments, the fundamental transition to democratized and participatory systems[159] characterizing central tenets of Chilean legal reforms are yet to be fulfilled.[160]

6.11 Case #5 (AES Gener v. Constructora Nuevo Maipo)

The case presented in this section focuses on a 2012 ruling in Chile's 8th Civil Court[161] in favor of a run-of-river hydropower development outside of the national capital of Santiago.[162] The Maipo River Watershed, which hosts what became known as the AltoMaipo hydroelectric project[163], is the primary source of electricity and municipal water for a burgeoning city that now hosts a population of 7.5 million[164]. This riparian network begins its course in the high Andes, yet reaches its terminus as among the most polluted waterways in the country.[165] Urbanization has severely impacted the characteristics of the lower river, causing certain periods where the water isn't considered potable.[166] However, this river continues to be heavily relied upon, as upwards of 60% of water consumed in the Santiago

[158] *See* Adriana Zurita et al., State of the Art and Future Prospects for Solar PV development in Chile, Renewable and Sustainable Energy Reviews, 92: 701-727 (2018)
[159] *See* Marcia Montedonico et al., (2018).
[160] *See* Jacopo Dettoni et al., Chile's Power Challenge: Reliable Energy Supplies, Power 156(9): 61–70 (2015)
[161] 8th Civil Court of Santiago
[162] *See* Lenin Henriquez-Dole, Integrating Strategic Land Use Planning in the Construction of Future Land Use Scenarios and its Performance: The Maipo River Basin, Chile, Land Use Policy, 78: (2018)
[163] *See* Sophia Borgias, Subsidizing the State: The Political Ecology and Legal Geography of Social Movements in Chilean Water Governance, Geoforum, 95: 87-101 (2018)
[164] *See* Francisco Meza et al., Assessing Water Demands and Coverage Sensitivity to Climate Change in the Urban and Rural Sectors in Central Chile, Journal of Water and Climate Change, 5: 192 (2014)
[165] *See* Adrian Piticar, Changes in Heat Waves in Chile. Global and Planetary Change, 169: 234-246 (2018)
[166] *See* Lenin Henriquez-Dole (2018)

Metropolitan Region stems from the Maipo Watershed.[167] Meanwhile, climatic alterations are anticipated as was discussed in the section focused on HidroAysén, complicating the push to add hydropower to the network.[168]

The AltoMaipo hydroelectric project developed in a watershed already playing host to 12 hydropower facilities.[169] However, the project was pursued due to increased energy demand in Santiago, and the fact that a successful project would double the hydroelectric capacity of the network.[170]. This series of dams brings about significant diversions that would remove the ability of the basin to maintain environmental flows. Further, several notable studies have suggested that the manifestation of the AltoMaipo project would cause waves of severe desertification of many areas of the Maipo River Watershed as a result of diversion practices and channel fragmentation.[171] The Santiago Metro Region additionally suffers from an abundance of impoverished rural communities that disproportionately inhabit settlements close to the existing and proposed dam sites and would be severely impacted by reduced "resource access due to declines or losses of livelihoods, threats to food security and loss of traditional lifestyles."[172] Grassroots movements have been able to stop the construction of several major dam proposals in Chile, notably, the Baker and Pascua projects initiated by HidroAysén in Patagonia.[173] However, the tale of the Maipo River Watershed is a powerful example of uneven power relations that often manifest in terms of large-scale infrastructure projects. While the preponderance of the benefit is seen by developers,

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[167] *See* Juan-Pedro Garces-Voisenat & Zinnia Mukherjee, Paying for Green Energy: The Case of the Chilean Patagonia, Journal of Policy Modeling, 38(2): 397-414 (2016)

[168] *See* Nico Varas, Latin America Goes Electric: The Growing Social Challenges of Hydroelectric Development. IEEE Power and Energy Magazine, Volume 11(3), Pages 66-75.

[169] *See* Carl Bauer, (2016)

[170] *See* Lenin Henriquez-Dole (2018)

[171] *See* Paulo Branco (2016)

[172] *See* Giovani Siciliano (2018)

[173] *See* Eduardo Silva (2016)

policymakers, and urban dwellers this often at the expense of communities living proximate to the dam sites, who may in certain citations have lower electric bills, yet are bear the brunt of environmental impacts that occur after riparian habitats are altered, as well as disruption of their ways of life, cultural customs, and cultural identities.[174]

6.12 Case # 6 (HidroAysén)

A series of cases that manifested into an international movement against the proposed construction of five mega-dams in Chile's remote Patagonia Region[175] represent a unique set of legal outcomes incongruent with the country's legacy of hydropower proliferation.[176] Currently, 137 large dams comprise Chile's hydroelectric grid.[177] Dating back to the 1940s and the establishment of the National Electricity Company (ENDESA), hydropower has been developed as the backbone for meeting electricity demand and facilitating socioeconomic development during the 20th century.[178] However, spatiality and climate change emerged as vital issues at the beginning of the 2000s, as diminished water availability for a series of large dams in the central region, responsible for generating the majority of the nation's hydropower led to nationwide blackouts.[179] These events exposed water and energy security vulnerabilities, that are projected to exacerbate throughout the coming decades as climate change becomes increasingly acute.[180] In order to respond to diminished generation capacity

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[174] *See* Juan-Pedro Garces-Voisenat & Zinnia Mukherjee, Paying for Green Energy: The Case of the Chilean Patagonia, Journal of Policy Modeling, 38(2): 397-414 (2016)
[175] *See* Marina Tagliaferro, Dams in the Last Large Free-flowing Rivers of Patagonia, the Santa Cruz River, Environmental Features, and Macroinvertebrate Community.
[176] *See* Ricardo Raineri, & Gonzalo Contreras, Efficient Capacity Investment and Joint Production Agreements in an Oligopolistic Electricity Market: The HidroAysén Joint Venture Project, Energy Policy, 38(11): 6551–6559 (2015)
[177] *See* Amanda Maxwell (2017)
[178] *See* Javiera Barandiarán, Science and Environment in Chile: The Politics of Expert Advice in a Neoliberal Democracy. Cambridge, Massachusetts: The MIT Press (2015)
[179] *See* Amanda Maxwell (2016)
[180] *See* Juan-Pedro Garces-Voisenat & Zinnia Mukherjee, (2016)

in the central region, ENDESA, and multinational hydropower developers proposed the HidroAysén mega-project in Patagonia.[181] This region experiences abundant rainfall and significant hydropower capacity, yet is among the most biodiverse and well-preserved regions in the world.

Ultimately, HidroAysén was struck down despite multiple appeals and EIA processes, in large part due to an unprecedented anti-dam social movement called *Patagonia sin Represas.*[182] However, similar projects loom large, as seven major hydropower proposals are currently undergoing environmental review[183]. Although the current executive administration has pledged to support multiple forms of renewable energy, there continues to be debate over whether wind and solar will preclude mega-projects from reemerging[184], or whether ENDESA and other multinational companies will continue to influence energy policy[185]

6.13 Conclusions

Dams and hydropower structures are by their nature, complex. Consequently, multidimensional, and multi-scalar research must be advanced, as this infrastructure is at a crossroads both among nations considering removal and proliferation of their networks. Especially neglected is analysis at the watershed scale[186], which can precisely determine how certain structures are performing relative to others in often coordinated systems, to have tools

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[181] *See* Marcus Pearson et al., Chile's Environmental Laws and the HidroAysén Patagonia Dams Megaproject: How is this Project Sustainable Development? Denver Journal of International Law & Policy, 41(4), (2013) .

[182] *See* Eduardo Silva, Patagonia, without Dams! Lessons of a David vs. Goliath campaign. The Extractive Industries and Society, 3(4): 947-957 (2016)

[183] *See* Claudio Broitman & Pablo Kreimer, Knowledge Production, Mobilization and Standardization in Chile's HidroAysén Case, Minerva, 56(2): 209–229 (2018)

[184] *See* Carla Rúa-Goméz et al., Construction of a Chilean Energy Matrix Portraying Energy Source Substitution: A System Dynamics Approach, Journal of Cleaner Production, 162: 903-913 (2017)

[185] *See* Michael Nelson (2013)

[186] *See* Paulo Branco et al., Prioritizing Barrier Removal to Improve Functional Connectivity of Rivers. Journal of Applied Ecology 51(5): 1197-1206 (2014)

for prioritizing either removal or rehabilitation and continued management.[187] Hydropower will continue to have a major role in energy matrices and development strategies, yet policies such as the CWA and CWC are necessary instruments for maintaining healthy waterways and decommissioning dams that aren't serving their intended purposes and/or negatively impacting riparian ecosystems.[188]

Based on the clear shortcomings of the statutes of the CWA and CWC, there is a critical need to develop better tools and systems of dialogue for objective analysis. Relevant to the cases presented, roadblocks, factious disagreements, and legal ambiguity that characterize many legal dam cases are preventing rational decision-making and best management practices from being prioritized.[189] Countries around the globe are at crossroads regarding their hydropower infrastructure, low-carbon development strategies,[190], and related policies toward the extent to which dams will be part of their future.[191] Therefore, cases such as those articulated in this paper, alongside cited articles analyzing dams from multidimensional paradigms will be stepping stones upon which future research can rely and advance. Most rivers respond positively to removal.[192] However, these systems are bound up in more nuanced phenomena than solely riparian dynamics, thus making it vital to also consider the range of sociopolitical, cultural, and economic factors embedded around a dam and its surrounding area.

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[187] *See* Rebecca Quiñones et al., Dam Removal and Anadromous Salmonid (Oncorhynchus spp.) Conservation in California. Reviews in Fish Biology & Fisheries 25(1): 195-215 (2015)

[188] *See* U.S. Environmental Protection Agency, Frequently Asked Questions on Removals of Obsolete Dams, Office of Water, EPA-840-F-16-001 (2016)

[189] *See* Anal Misra et al., (2015)

[190] *See* Giovani Siciliano et al., Hydropower, Social Priorities and the Rural–Urban Development Divide: The Case of Large Dams in Cambodia. Energy Policy 86(C): 273-285 (2015)

[191] *See* Patrick Wang et al., A Framework for Social Impact Analysis of Large Dams: A Case Study of Cascading Dams on the Upper-Mekong River, China. Journal of Environmental Management 117: 131 (2013)

[192] *See* Functional Diversity Responses of a Nearshore Fish Community to Restoration Driven by Large-scale Dam Removal. Estuarine, Coastal and Shelf Science 213: 245-252 (2018)

Overall, there are key similarities and differences between how the CWA and CWC have contributed to decision-making about hydropower projects, management, and potential removal. Overarching neoliberal structures persist in both countries, as water is marketized and has evolved into a commodity, rather than a human right. However, changes are taking place in disparate contexts because we can see certain outcomes aligned with the CWA that can either support or challenge hydropower operation, as well as CWC programs that may generally facilitate hydropower expansion and resource extraction, yet that has been contested in certain situations, particularly through social rather than legal mechanisms. Therefore, pursuing research avenues that solidify and clarify how dams should align with water law will be an important issue for both the United States and Chile, especially as water regimes change alongside energy transitions and climate change impacts.

CHAPTER 7: BROADER RESEARCH IMPACTS AND CONCLUSIONS

During fieldwork, a core focus was the examination of resource management practices, particularly through upgraded energy and water systems. The research sought to illuminate the critical need for climate change mitigation, which was explored through irrigation modernization because it directly confronts each of these issues through improved resilience (Errázuriz, 2019). Such measures have supported improvements in agricultural efficiency, yet as seen through ongoing dynamics in the Elqui Watershed continue to skew towards increased concentration of power and resource ownership at the expense of marginalized groups, local entities, and environmental health (Kelly, 2018). However, making assumptions about how a WUA, community, or peasant farmer may feel about disruptions to the existing landscape is problematic, even if my academic background suggests my advice will lead to improved conditions. Therefore, maintaining this critical reflexivity (Dowling, 2000) as I met with stakeholders was imperative, because while I expressed my concerns for ecological health and social justice, substantive change must flow through local and watershed-scale initiatives (Montedonico et al., 2018).

This research is centered on critically investigating how humans interact with vital natural resources, namely water, and energy. Critical assessment of irrigation landscapes and the spatial distribution of power and marginalization sought to reveal how fundamental human rights are configured through national, regional, and local complexities (Neumann, 2009). The theoretical fusing of political ecology and resource geography placed a particular focus on the uneven dimensions of nature-society relations that play out through unequal resource access and environmental exploitation in environments inhabited by marginalized groups and vulnerable ecosystems (Budds, 2004).

While the research did not purely focus on social justice and environmental advocacy, these dynamics represent a key lens through which analysis was channeled (Sareen & Haarstad, 2018). For example, the stakeholders targeted for semi-structured interviews ranged from groups with considerable influence over regional decision-making for resource management within the irrigation sector (Urquiza & Billi, 2018). The narratives of these parties were juxtaposed against the perspectives of local peasant farmers, community members, and environmental organizations. This process of both interviewing divergent groups and working cooperatively to identify pathways for constructive dialogue and cooperation was important for a landscape that has seen growing inequalities as neoliberal market systems permeate the region (Onwuegbuzie, 2012).

Takeaways from this project reflect both human-centered issues that can be better understood through critical social analysis. Considering both climate change mitigation opportunities through irrigation modernization and dynamics of power distribution between existing neoliberalism and recent democratic, policy initiatives will elucidate opportunities and barriers for a more equitable future (Andersen & Verner, 2010). Through water and energy, which are crucial to life and livelihood, irrigation serves as a template for advancing insights into how humans interact with their environment, and where opportunities reside for more sustainable and democratized systems going forward.

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