The impact of drought on agricultural activity in northern Chile: the case of Chilean Pisco

Executive Summary

At the request of the Chilean Ministry of Agriculture, **the NGO Latin American Development Dialogue** conducted a comprehensive assessment of the extreme drought and the resulting process of desertification and aridification affecting the Elqui River basin in the Coquimbo region. The study, which is expected to be part of a global report on drought prepared by the Economics of Land Degradation Initiative (ELD), with the relevant support of UNU-INWEH and within the framework of the 16th Conference of the Parties (COP16) of the United Nations Convention to Combat Desertification (UNCCD), analyzes the impact of these phenomena on the ecosystem, biodiversity and agricultural activities, with special emphasis on the production of pisco grapes, a critical activity for the national productive heritage.

The current situation is critical: the basin is experiencing a 32% reduction in flows (2023), with reservoirs operating at 18% of their capacity. This water crisis has severely impacted the production of the CAPEL Cooperative, the central case study of this research, which has seen its volumes reduced from 200,000 tons in 2000 to barely 50,000 tons in 2024. The situation is aggravated by the fact that water management in the basin depends exclusively on scarce rainfall, with no external inputs or desalination systems implemented in the region.

The study, developed using qualitative and quantitative methodologies with a focus on innovation, identified two main adaptation strategies among producers. The first, adopted by 70% of the cooperative members, focuses on irrigation technification. The second, emerging but promising, combines this technification with agroecological practices and nature-based solutions. Comparative economic analysis revealed that the complemented agroecological system is significantly more profitable, with a Net Present Value 36.5% higher than the purely technified system (USD 34,084 versus USD 24,895).

Beyond the direct economic benefits, the agroecological system proved to generate important additional ecosystem services, including greater biodiversity, improved water retention in the soil, natural pest control and preservation of traditional knowledge. In economic terms, this system also showed significant advantages such as a drastic reduction in input costs (5% versus 27% in the conventional system) and greater income diversification.

The study underscores the urgent need to move towards resilient and sustainable agricultural practices that not only improve productivity, but also conserve ecosystems and mitigate the effects of climate change. The recommendations are structured at three levels:

1. Public Policy: Develop valuation frameworks for ecosystem services, create incentives for mixed systems, and strengthen research on nature-based solutions.

2. Productive Sector: Gradually implement complementary agroecological systems, invest in training and preserve effective traditional practices.

Environmental Management: Establish ecosystem monitoring systems, create biodiversity preservation programs, and implement integrated water management strategies.

The research concludes that agroecological systems complemented with technification are not only economically viable, but also offer greater profitability and resilience in the face of the water crisis. CAPEL's experience demonstrates that it is possible to develop production systems that harmonize economic viability with environmental sustainability, even in conditions of extreme drought. This learning is valuable not only for the preservation of a heritage productive activity, but also as a model for other regions facing similar challenges arising from climate change.
The results and recommendations of this study provide a solid basis for developing strategies to ensure both the sustainability of pisca grape production and the preservation of the environment in the Elqui River basin, recognizing that the survival of this traditional activity must go hand in hand with the protection of local ecosystems.

At the same time, the findings indicate that water management in the Elqui River basin depends solely on scarce rainfall, as no external water resources are provided and no desalinization systems have yet been implemented in this region of Chile. Current climate changes, such as rising temperatures and decreasing rainfall, project an intensification of extreme weather events, which increases the challenges for agriculture in the region.

The economic, social and environmental impact of the drought on agricultural production in the basin are part of this study, and will require an exhaustive analysis in order to seek solutions that will benefit grape and pisco production under conditions that will enable the sustainability of the business and the cooperative members.

The study also underscores the importance of moving towards resilient and sustainable agricultural practices that not only improve productivity, but also help conserve ecosystems and mitigate the effects of climate change. This includes the use of nature-based solutions and the integration of new technologies, as well as a cultural shift towards greater ecological resilience. A comparative technical-economic study is included between a production intensive in the use of technified irrigation and one that benefits agroecology.

Finally, the results of the study provide valuable information to develop strategies for the sustainability of pisca grape production and the preservation of the environment in the Elqui River basin.

1. Introduction

This report, commissioned by the Ministry of Agriculture of Chile with the professional and technical support of the Sociedad de Fomento Fabril within a framework of public-private collaboration, is particularly relevant in the current context. Its presentation coincides with the approach of the sixteenth session of the Conference of the Parties (COP16), the twenty-second session of the Committee for the Review of the Implementation of the Convention (CRIC22) and the sixteenth session of the Committee on Science and Technology (CST16) of the UNCCD, events that will be held in Riyadh, Saudi Arabia, from 2 to 13 December 2024, under the significant theme “Our Land, Our Future”.

The study focuses on the Elqui River basin, Coquimbo region, Chile, a territory that represents much more than a geomorphological unit. This basin constitutes a morpho-functional unit in an ecological sense, which provides vital environmental services to the human communities that inhabit it and depend on it for their subsistence. The analysis comprehensively addresses the geography and climate of the area, the complex dynamics of both surface and groundwater resources, and the various environmental problems that affect the valley's biodiversity and its sustainability.

The consequences of climate change in the basin are multiple and worrisome. There are direct effects on the natural productivity of the ecosystem, significant changes in biodiversity -particularly in the Andean zone- and alterations in the dynamics of local populations, including the emergence of previously latent pests. As pointed out by IPCC experts (2001), arid and semi-arid regions, along with transition zones, mountain ecosystems, snow basins and coastal zones, are particularly vulnerable to the effects of climate change, a reality that is clearly manifested in the Elqui River Basin.

Methodologically, the study integrates qualitative and quantitative approaches, supported by extensive empirical field work. This approach has allowed access to updated data and information directly from the actors and stakeholders of the ecosystem, evidencing their resilient capacities to maintain their productive activities and living conditions. Particular attention has been paid to documenting scenarios with and without drought, analyzing their effects on soil and climatic conditions and local biodiversity.

A distinctive element of this research is its emphasis on nature-based solutions (NBS). The study has paid special attention to identifying and documenting best practices in historical and ancestral pisca grape production, particularly those that demonstrate natural harmony with the ecosystem. This approach is complemented by a comparative analysis of the economic performance of different production models, evaluating their sustainability both in periods of drought and under normal climatic conditions.

The research is being carried out at a critical moment, when the region is facing not only extreme drought but also a growing process of aridification. The conclusions of this study seek to contribute to the development of a new productive culture that will preserve both the environment and the biodiversity of the ecosystem. The ultimate goal is to keep alive a centuries-old tradition that, with pride and passion, produces a unique pisca grape, whose attributes are decisive in the flavor and aroma profiles that characterize pisco from this region of Chile.

The cross-cutting inclusion of environmental and climate change variables in the analysis responds to the need to establish a solid foundation for future territorial management initiatives. This approach recognizes that we are facing complex changes that require immediate and well-founded measures for their proper management, for the benefit of both the ecosystem and the communities that depend on it.

2. Conceptual framework and methodological approaches

Target 2.4, SDG, Chile
“By 2030 ensure the sustainability of food production systems and implement resilient agricultural practices that increase productivity and production, contribute to the maintenance

of ecosystems, strengthen resilience to climate change, extreme weather events, droughts, floods and other disasters, and progressively improve soil and land quality".

The study that has been developed links systemic aspects that are occurring due to the daily presence of drought scenarios in the Elqui River basin, Coquimbo region, which are affecting the biodiversity of the valley, and of the ecosystem where agriculture is developed, mainly focused on fruit growing, and in particular the production of pisca grapes.

For the exploration of conceptual frameworks and methodological approaches, the study has had a multidisciplinary and systemic approach. The topic addressed by this work requires a novel and broad observation with emphasis on nature, exposing and defining concepts that contribute to the systemic understanding of the strategic effects of the phenomena of droughts, climate change and desertification. Due to the interdisciplinary nature of the interaction between ecosystems and human societies, and because of the enormous complexity involved, several groups of researchers in different parts of the world are proposing different ways of approaching this type of study.

Many of these authors propose the need to identify different social actors that benefit differentially from ecosystems. They propose characterizing the components and properties of the ecosystem from a functional perspective and suggest the integration of the needs of multiple stakeholders based on community management of natural resources.

Water is a determining factor in economic and social development and, at the same time, it fulfills the basic function of maintaining the integrity of the natural environment. However, water is only one of the vital natural resources and it is therefore imperative that water issues are not treated in isolation (1).

The traditional fragmented approach is no longer valid and a holistic approach to water management, in quantity and quality, in relation to its uses and abuses, is essential as a natural good of high value for life.

2.1 Conceptual Framework

Climate change
"Climate change is not something abstract, it is very concrete and we see it in Chile: temperatures have risen, heat waves have increased, precipitation has decreased. Projections indicate that extreme weather events are going to increase. The frequency, intensity and duration of heat waves will increase, the frequency of droughts will increase, tidal waves and loss of beaches will increase", commented the Minister of the Environment, Maisa Rojas, in her last public activity before traveling to COP27 in Egypt a short time ago.

In a TED presentation in Europe, Johan Rockström, director of the Potsdam Institute for Climate Impact Research and one of the most influential scientists in the study of climate change, presented a critical assessment of the state of the planet. Rockström warned that climate change is proceeding at an alarming rate, with the global average temperature reaching levels not seen in the last 125,000 years. Despite the seriousness of the situation, Rockström was not without hope. He noted that solutions to avert climate disaster are within reach, but require swift and coordinated action at the global level. This includes an accelerated transition to renewable energy, a drastic reduction in the use of fossil fuels, and the adoption of more sustainable agricultural and land management practices.

Climate change is affecting areas considered traditionally agricultural. The best soils, with the greatest availability of water, have now been transformed into large cities. Population growth and the need to feed people, in a context of increasing life expectancy, means that a healthy lifestyle must be encouraged in order to promote a better quality of life for the elderly.

Agriculture, and with it, food production has moved to marginal areas such as the desert. Cultivation in desert or desertified areas has two major challenges for its expansion and development. On the one hand, the water scarcity typical of a territory, such as that of pisca grape production, characterized by its increasing aridity, linked to low rainfall and very high solar radiation. On the other hand, the limited presence of territories with soils that have the minimum conditions to support the development of a crop (Mazuela, 2024).

There is a broad scientific consensus that climate change is mainly an anthropogenic and possibly irreversible phenomenon (IPCC, 2019).

Since 2010, an uninterrupted sequence of dry years has been observed in central Chile, with annual precipitation deficits varying between 25 to 45% (R. D. Garreaud et al., 2017, 2021). Regarding the future, a reduction in annual precipitation of 30% is expected between the regions of Valparaíso and Los Lagos, by the end of the century (ECLAC, 2016); it is also estimated that, as a result of the costs associated with climate change, Chile could reach an annual loss of 1.1% of GDP until the year 2100.

Climate change can have an impact through various phenomena: floods, droughts, intensification of cyclones, etc. However, there is one phenomenon in particular that sets off alarm bells in Chile, which is the precipitation deficit. As documented in R. Garreaud et al., (2021) and R. D. Garreaud et al., (2017), an uninterrupted sequence of dry years has been observed in central Chile since 2010, with annual precipitation deficits varying between 25 and 45%.

According to the authors, several implications of the mega drought are recognized: decrease in surface and groundwater resources, decrease in the supply of nutrients to the coastal zone, decrease in the greenness of natural vegetation, increase in the area consumed by forest fires and supply of drinking water in rural areas, (8).

Drought

Drought is a climatic phenomenon characterized by a prolonged shortage of precipitation, which causes a significant decrease in the water resources available in a specific region. Some of the causes of drought are low rainfall, climate change and overexploitation of agricultural land, among others.

In addition, all the consequences of drought are negative, such as loss of agricultural production, loss of biodiversity and/or malnutrition. The types of drought that can occur:

- Meteorological drought: this type of drought is due to the absence or scarcity of precipitation during a given period.
- Agricultural drought: this type of drought affects crops the most. It may be due to a lack of rainfall or poorly planned agricultural activity.
- Hydrological drought: this type of drought occurs when water reserves in the area are below average. It may be due to lack of rainfall or inadequate human activity (9).

Expanding the definition of drought, it occurs when the scarce rainfall decreases water levels - far below what is appropriate - in a certain geographical area, affecting all the species that grow and develop in that area, (10).

According to Mishra et al. (2007), a drought can mean different things to different people. For example, it is a deviation from normal precipitation to a meteorologist; a drop in flow, lake level or groundwater level to a hydrologist; lack of soil moisture to sustain crop growth to an agricultural scientist; a famine condition to an economist; and a shortage of drinking water to a land planner (Dracup et al., 1980).

Drought indices are quantitative measures that characterize drought levels by incorporating data from one or more variables (indicators) such as precipitation and evapotranspiration into a single numerical value. The use of this index is more convenient than the indicator data. The nature of drought indices reflects different events and conditions; they can show anomalies related to climate dryness (mainly based on precipitation) or delayed agricultural and hydrological impacts, such as loss of soil moisture or declining aquifer levels.

In addition, the classification of drought indices can also be based on the data and technology used. For example, a considerable number of indices use satellite imagery to detect vegetation condition as an indicator of drought. Along with precipitation deficit, additional variables such as evapotranspiration and flow are similarly used to characterize drought in a more consistent manner, (13).

Since 2010, central Chile has experienced drought and water scarcity in some areas. Although there is no single definition of drought, they all begin with a lack of rainfall compared to historical behavior. Water scarcity, on the other hand, is a more complex condition, which occurs when the available water is less than that demanded for social and environmental uses, such as human and animal consumption, ecosystem maintenance, agriculture, mining, industry and others. Thus, water scarcity depends on the decisions made regarding water uses and there may be scarcity even in the presence of normal rainfall.

However, according to Chilean law, a water scarcity zone, a situation in which the territory of the Elqui basin finds itself today, is decreed by the authority in times of “extraordinary drought” which are determined according to hydrometeorological conditions established in the regulation without indicators, (14), (5).

Externally to what we are witnessing today in the region, part of this study refers to a growing process of desertification, which is nothing more than the gradual passage of the land surface from a fertile to a more desert-like state, caused by both climatic variations and human activity, and its aridification, which is the process by which a region becomes more arid, that is, it dries out and loses humidity, which may negatively affect the ecosystem and the availability of water. These phenomena can be caused by various factors, both natural and anthropogenic, and are associated with climate change (Boletín Ceazamet.cl).

In the scientific debate on these issues, the concept of water scarcity is a complex term because it involves hydrological and meteorological processes and also the uses given to water (Zambrano-Bigiarini, 2019 a and b).

Some authors point out that in order to solve the problem of water scarcity in a basin, an integrated management of water resources is necessarily needed, with basin organizations where all stakeholders can sit at the same table, despite their differences, and can make water supply and demand data transparent, in order to identify solutions that meet the needs of all those who need and occupy it, (16), taking into strategic consideration the biodiversity existing in the ecosystem.

In order to have a more complete exploration of the ecosystem and water uses, it is necessary to conceptualize that territorial realities are truly complex systems. Complex systems are systems composed of a large number of interconnected components that interact with each other, generating behaviors and properties that cannot be easily explained or understood by simply observing the individual parts (Berkes & Folke, 1998; Farhad, 2012; Liu et al.,).

The main elements that stand out in these social-ecological ecosystems are human beings and their technologies, the knowledge they possess and the rules that govern them for resource management (Berkes & Folke, 1998). All these aspects are linked to water and its management. Among the socio-ecological characteristics of complex systems, resilience (Sterk, Leemput & Thm, 2017), ecosystem services and adaptability are of special consideration (Partelow, 2018).

Resilience

Resilience has its origin in Latin, in the term resilium, which means "to go back", "to return from a jump", "to stand out", "to bounce back". Coming from the physics of materials, this concept has been used and developed in a number of scientific disciplines, both social and natural and exact, and has been adapted to the contexts of the frontiers of knowledge, but trying to preserve the initial idea of "resistance to change" (Brown, 2013).

The concept of resilience and its study began to develop during the 60s and 70s, where a group of psychologists and psychiatrists began to pay attention to the variables and capacities that made the difference between those who were able to normalize their lives, and those who maintained the situation, among a population of children living in situations of exclusion or adversity.

Other authors define resilience as "the capacity, the result of the interaction of different personal variables with environmental factors, which allows the individual to face and resolve, in an adequate and integrated manner in his/her cultural environment, different situations of adversity, risk or traumatic situations for different reasons, allowing him/her to reach a normalized situation adapted to his/her cultural environment", (25).

Considering the socio-ecological systems approach as a structuring element of environmental sciences will allow for the integration of the conditions of an evolving, adaptive and changing society, with the need to preserve the ecosystems on which social equilibrium depends. The advantage of this approach is the integration of the knowledge of society at different scales, with a more appropriate way of using ecosystem services and generating real and sustainable strategies that would allow for the reduction of the accelerated overexploitation of ecosystems. This would allow for decisive progress in the understanding that human beings are part of nature and that their well-being strictly depends on the health of ecosystems and the maintenance of their ecosystem services, and thus allow for the attainment of the sustainability of both the social and ecosystemic system, (21).

For example, from ecology, Holling introduced the concept for the first time in 1973, to understand the non-linear dynamics and processes by which ecosystems maintain themselves and persist in the face of disturbances and changes (Calvente, 2007). On the other hand, in social sciences, resilience is assumed as the ability to maintain an adaptive functioning of physical and psychological functions in critical situations (Carretero, 2010), even the word resilient has been generally applied to people who overcome difficulties (Sarkar, 2017; Villalba, 2004), (24).

When reviewing the literature on resilience, it is possible to detect that it is present in much of the analysis of global environmental change. It is important to note that social, political and cultural dynamics are already present in the literature. In this regard, on resilience, it is important to consider the three emerging themes that are pointed out: community resilience; transformations; and resilience as an organizing concept for radical change, there are relatively few analyses of social differences and resilience. (24)

In the social sciences, resilience is largely analyzed in terms of society and ecology, in the context of social and ecological systems. There is a general consensus among social science experts and natural scientists that the study of resilience involves the adoption of interdisciplinary and multidisciplinary methods, since natural and social systems are highly integrated. This recognizes the need to use tools such as systemic thinking and complexity theory. On the other hand, the concept of vulnerability appears. Resilience and vulnerability may appear to be opposite ends of a continuum if vulnerability is understood as the ability of individuals to respond to hazards, but there is no interrelationship between these terms if vulnerability is considered purely as the circumstances that put people at risk, including social, economic, political, technological, biophysical and demographic aspects (Manyena, 2006).

On the same topic, other authors, Bahadur et al., provide an operational definition of resilience, defined in ten characteristics that they consider to be the main ones of resilient systems. These are intended to make the concept of resilience operational in the context of climate change and disasters.

1. A high level of diversity in the groups that perform different functions in an ecosystem; in the availability of economic opportunities; in the voices included in a resilience-building policy process; in the partnerships within a community; in the natural resources on which communities can depend; and in planning, response and recovery activities.
2. Effective governance and institutions that can enhance community cohesion. These should be decentralized, flexible and in touch with local realities; they should facilitate learning throughout the system; and perform other specialized functions such as translating scientific data on climate change into practical guidance for policy makers.
3. The inevitable existence of uncertainty and change is accepted. The non-linearity or randomness of events in a system is recognised, shifting policy from an attempt to control change and create stability to managing the capacity of systems to cope with, adapt to and shape change.

4. There is community participation and appropriation of local knowledge in any resilience-building project; communities enjoy ownership of natural resources; communities have a voice in relevant policy processes.
5. Preparedness activities do not aim to resist change but to prepare to live with it; this could be done by building redundancy into systems (where partial failure does not lead to system collapse) or by building failure scenarios into Disaster Management plans.
6. There is a high degree of social and economic equity in systems; resilience programmes consider issues of justice and equity when distributing risks within communities.
7. The importance of social values and structures is recognized because association between individuals can have a positive impact on cooperation in a community which can lead to more equal access to natural resources and greater resilience; it can also reduce transaction costs as agreements between community members would be honoured.
8. The non-equilibrium dynamics of a system are recognised. Any approach to building resilience should not be based on the idea of restoring equilibrium as systems do not have a stable state to return to after a disturbance.
9. Continuous and effective learning is important, which can take the form of iterative political/institutional processes, organisational learning, reflective practice, adaptive management and can be combined with the concept of adaptive capacity.
10. Resilient systems take an interscalar perspective on events and occurrences. Resilience is built through social, political, economic and cultural networks ranging from the local to the global scale. (26)

From the same debate on resilience, adaptation and adaptive capacity, coined by the climate change community, also draw parallels with it, but without consensus on their conceptual overlap. There remains a significant research gap in understanding the relationship between these terms. One school of scholarly opinion holds that adaptation and adaptive capacity are terms that refer to the capacity and capability/potential of systems or components within systems to be resilient to disturbances (Berkes 2007; Osbahr 2007). Another school sees adaptive capacity as referring to that component of resilience that relates to the "learning" of systems in response to disturbances, (27), (28). From a biophysical perspective, resilience, at the local level, depends on the capacity of the landscape to maintain infiltration, water storage capacity and nutrient cycles (Tongway and Ludwig 1997), all of which are threatened by soil loss and structural change.

Resilience at the local level also depends on the structure of vegetation. Grasslands are composed of a mixture of grasses and woody plants (small trees and shrubs), (31), (32). On the other hand, other authors point out that the resilience of a system is closely related to its capacity for self-organization because the cycles of nature imply renewal and reorganization (Holling, 2001). When exploring authors who refer to the reduction of vulnerability, several aspects of self-organization deserve to be analyzed: (a) the strengthening of community management (Berkes and Folke 1998); (b) the creation of management capacities at a transversal scale (Folke et al. 2005); (c) the strengthening of institutional memory (Folke et al. 2005); and (d) the promotion of learning organizations and adaptive co-management (Olsson et al. 2004). From the scopes proposed by the different authors mentioned as part of this conceptual framework for the study, we arrive at the concept of sustainable development. Sustainability is the ability to create, test and maintain adaptive capacity. Development is the process of creating, testing and maintaining opportunity. The phrase that combines the two, sustainable development, therefore refers to the objective of fostering adaptive capacities while creating opportunities. (pp.399, 34).

This perspective allows us to understand that the conservation and sustainable management of natural resources, including water, must take into account the practices and knowledge of local communities, valuing their historical and cultural relationship with the environment, (34). Finally, the consideration that nature issues should be resolved by nature itself is directly related to resilience.

Conventional positions on nature conceive it as a set of objects that are recognized or valued based on people. In light of what has been said about resilience and other related components, it will be important to advance in a better understanding of our ecosystems, in a holistic and systemic way, in order to then explore initiatives and propose actions to solve the problems of drought and desertification from nature itself.

Nature-based solutions

Nature-based Solutions - NBS - emerged in the late 2000s as a result of a number of approaches and approaches that sought to unify and conceptualize the relationship between society and nature.
In 2016, the International Union for Conservation of Nature (IUCN) defined them as “Actions to sustainably protect, manage and restore natural or modified ecosystems that effectively and adaptively address societal challenges while simultaneously providing benefits for human well-being and biodiversity.”

BNS are innovative solutions that seek to mitigate the effects of climate change, promote adaptation to these changes, while protecting biodiversity and improving livelihoods. One of their main characteristics is their distinctive social approach, compared to other concepts with similar ecosystem approaches (i.e. ecosystem-based adaptation, landscape restoration, among others).

In summary, SbNs represent a viable and innovative alternative to address the social and environmental challenges facing the Elqui River basin and the country. Particularly for Water Security, SbNs can be used to complement, replace or safeguard traditional gray infrastructure, while increasing climate resilience, decreasing climate risk, and providing diverse social, environmental and economic (co)benefits.

By promoting the conservation and sustainable use of ecosystems, BNS can contribute significantly to advance the agenda of biodiversity conservation and protection of key ecosystem services to address the water security challenges faced by many of the territories in different areas of Chile. Finally, the generation of multiple co-benefits from the implementation of BNS can constitute a transcendental contribution to promote the sustainable development of the country.

From an international point of view, BNS are defined as “Actions to sustainably protect, manage and restore natural or modified ecosystems that address societal challenges in an effective and adaptive manner, while simultaneously providing benefits for human well-being and biodiversity” (Cohen Shacham et al. 2016, p. 2).
Current sustainable development challenges reinforce the need to seek innovative and effective solutions to move towards water security, both in water availability and quality for the present and future, as well as to reduce water-related risk, such as droughts and floods.

In this sense, BNS are presented as a viable alternative, and can be used to complement, replace or safeguard traditional gray infrastructure, while providing greater climate resilience and a series of social co-benefits. In the implementation of nature-based solutions in climate change adaptation processes, risk identification and assessment itself is considered, but at the same time it must be considered how to incorporate this concept within processes of governance, financing, monitoring and the generation of capacities and knowledge as an enabling condition, (36).

In this, Regenerative Agriculture is an agricultural approach that not only seeks to sustain natural resources, but to actively restore and enhance them. Unlike conventional practices that often degrade soil and ecosystems, regenerative agriculture focuses on regenerating soil health, increasing biodiversity, and improving climate resilience.

This approach has its roots in practices such as permaculture and biodynamic agriculture, both developed in the 20th century. Permaculture, pioneered by Bill Mollison and David Holmgren in the 1970s, focused on designing agricultural systems that mimic natural patterns. Biodynamic agriculture, introduced by Rudolf Steiner in the 1920s, emphasized the importance of the holistic interaction between soil, plants and animals.

Over time, these ideas evolved into regenerative agriculture, a movement driven by the need to reverse the environmental degradation caused by conventional farming practices.

Natural Capital

Natural Capital is the set of natural assets and the resulting ecosystem services that make human life possible and sustain the productivity of the global economy, according to the United Nations.

In other words, natural capital is the total set of natural resources and processes that make human life and its activities possible. This concept encompasses everything from basic elements such as air and water to the resources that sustain economies.
The elements that make up natural capital are both renewable and non-renewable resources that contribute to human well-being, including elements such as land, atmosphere, water resources and biodiversity. Their capacity to generate benefits depends mainly on two aspects: their quantity available and their level of conservation.

The benefits we obtain from natural capital, known as ecosystem services, fall into three main categories:
- Provisioning Services: They provide tangible elements such as food, raw materials and drinking water.
- Regulating Services: Maintain environmental balance through processes such as climate regulation, water purification and pollination.
- Cultural Services: Offer intangible benefits such as recreation, spiritual values and aesthetic experiences.

In the current context of global environmental challenges, it has become crucial to develop accurate systems for measuring natural capital. This measurement is done through accounting systems that evaluate both physical and economic aspects of natural resources, seeking to incorporate this information into decision making.

Natural capital accounting is structured through the System of Environmental and Economic Accounting (SEEA), which has two main components:
This statistical framework of environmental and economic accounting SEEA, is composed of two methodological approaches:

- The Core Framework (SEEA-CF): it is considered the first international standard for environmental and economic accounting. It was established by the United Nations Statistical Commission in 2012. The Central Framework analyzes environmental assets in terms of their use in the economy and their return to the environment, in the form of waste or emissions (measured in physical form). Additionally, complementary methodological documents have been developed to give it sector-specific approaches, such as SEEA-Energy, SEEA-Water and SEEA-Agriculture, Forestry and Fisheries (AFF).

- Ecosystem Accounting (SEEA-EA): Complements the Central Framework and was adopted by the UN Statistical Commission in 2021. It focuses on ecosystem inputs and interactions of environmental assets, part of natural processes in a given geographical area, and can be used in national accounts systems. It also provides a consistent framework for integrating the measurement of ecosystem and ecosystem service flows with measurements of human activities. The SEEA-EA consists of five main accounts that allow a complete quantification of natural capital, its status, inputs and valuation. Specifically, it allows biophysical information on ecosystems to be organized geographically; ecosystem services to be measured; changes in their extent and condition to be tracked; ecosystem services and assets to be valued; and this information to be linked to measures of economic and human activity. SEEA-EA data on ecosystems can be combined with data from the SEEA Central Framework accounts on environmental pressures, individual resource stocks, and environmental responses in the form of expenditures, taxes, and subsidies, thus providing a complete picture of the economic-environmental relationship. The SEEA-EAE consists of five main accounts:

1.Ecosystem extent accounts: They record the area and distribution of the different types of ecosystems in a region and can be compared over time.
2. Ecosystem condition accounts: Evaluate the quality and condition of ecosystems in terms of their ecological integrity.
3. Ecosystem service flow accounts: Quantify the benefits that ecosystems provide to people in physical and economic terms.
4. Ecosystem asset monetary account: Records the economic value of natural resources and ecosystem services.
5. Ecosystem asset value change accounts: Record changes in the value of ecosystem assets over time.

This system, supported by international organizations such as the UN and the World Bank, seeks to provide a comprehensive view of the relationship between the economy and the environment, facilitating more sustainable decisions in the management of natural resources.

On the other hand, the Natural Capital Coalition - https://capitalscoalition.org/ - defines natural capital as "the inventory of renewable and non-renewable natural resources that, when combined, provide benefits to people". Under this approach, the different types of natural capital that exist can be classified as renewable, non-renewable, recoverable and cultivated.

- Renewable: this type of capital refers to ecosystems and the living species that inhabit them; they are renewable since both are self-sustaining thanks to processes. Some of the commercial goods that this type of capital can offer are wood fibers, or essential services such as climate regulation.
- Non-renewable: regardless of the ecological time scale, those non-renewable resources are minerals or fossil fuels, the use of these means the depletion of their reserves.
- Recoverable: within this type of capital are aquifers, fertile soils or the ozone layer.
- Cultivated: these are areas that are used for forestry and agricultural production.

To mention examples of natural capital, we will divide them into goods and services:
- Goods: trees, soil, food, medicinal plants, minerals, living organisms, among others, are those resources that human beings take advantage of for their own use and consumption. They are goods that are transformed and depleted.
- Services: refers to the capacity of ecosystems to generate wellbeing and benefits for people and communities, including gas regulation (carbon sequestration and oxygen production) or water regulation, among others that help improve the quality of land, water and air. These services are neither transformed nor depleted, (37).
In the context of the Elqui Valley, natural capital should include the following components:
1. Water resources: rivers, reservoirs, groundwater;
2. Soil: suitable for agriculture, livestock and conservation;
3. Biodiversity: native, endemic and migratory flora and fauna;
4. Mineral resources: copper, gold, silver, among others;
5. Landscapes and ecosystems: valleys, mountains, deserts, forests.

The conservation and sustainable management of natural capital is crucial to ensure the resilience and sustainable development of the Elqui Valley, especially in the face of challenges such as drought and climate change. The sustainable management of natural capital is fundamental to ensure the conservation and rational use of natural resources.

Some strategies to achieve this in the Elqui Valley may include:
1. biodiversity conservation: protect natural areas and promote sustainable agricultural practices;
2. Efficient water management: implement precise irrigation systems and promote the reuse of wastewater;
3. Sustainable agriculture: promote practices such as permaculture, agroecology and organic production;
Soil management: implement soil conservation practices and reduce erosion; 5;
5. Sustainable use of mineral resources: promote responsible mining and reuse of materials; 6;
6. Education and awareness: sensitize the community on the importance of natural capital and the need for its conservation; 7;
7. Public policies: implement policies and regulations that promote the sustainable management of natural capital; 8;
8. Community participation: involve the local community in decision making and management of natural capital;

Finally, the implementation of these strategies can help guarantee the conservation of natural capital in the Elqui Valley and ensure a sustainable future for future generations.

2.2 Methodological approaches

The study considers different methodological approaches that are part of the architecture of our global work, whose contents have been built from the professional contribution, experiences, lessons learned and the analysis of the results of our work, which are nourished by different types of tools and techniques, whether qualitative or quantitative, which are used according to the problems and situations to be detected and then solved, thinking of doing so in the shortest possible time, accelerating the work processes as any innovative initiative.

At the beginning of the work, there must be an approximation and exploration of the reality to be studied. In this, the methodological model used to determine the roadmap of the study is based on three pillars. These are: The What, the Who and the How, (40).

Figure N° 1 shows the dialectic relationship between the basic pillars of the model, the meaning of the work between pillars and what is sought as the final result.

The diagram in Figure N° 1 shows the basic pillars, arranged in the three vertices of an equilateral triangle, configuring the three central components of the general model of the study. The trilogy of pillars presented by the methodology allows working under different types of methodological approaches, which enable an investigation of each one of them, in a systemic and experiential way, according to the purpose of the work, exploring and building links between what is being investigated and the actors that are part of the ecosystem, revealing the productive, economic and social attributes of those who are part of the unit of analysis for this study, in this case the CAPEL Cooperative.

To achieve this, the elaboration of value propositions becomes the most relevant component of the first part of the methodology, facilitating the identification strategy of data and information related to the effects of extreme drought, climate change and the desertification process in full development in the Elqui valley basin.

That said, the methodology operates initially by determining the lower left vertex of the triangle, i.e., the What. The What, for the purposes of this work, is represented by the requirements and products for the elaboration of the study, in its different meanings, actors and nature as parts of an ecosystemic whole, empirical evidence of the problems and solutions based on nature present or proposed, to mitigate the effects of droughts, and others, which are identified and integrated to the development of the study, to achieve a better response and greater value to the products requested.

The identification of the contents of the What, requires the application of two important capabilities that are used in innovation processes. That is, the Exploration and Selection capabilities. The quality of the results obtained for the contents of the What, will be mainly due to the good design of the value propositions for the Who. Each actor of the ecosystem may have its own value proposition, and this is obtained by the commitment assumed by the role it plays, which is expressed by the contribution it makes to find the data or information it is interested in obtaining, and by the understanding of the benefits it will obtain from the results of the study.

The construction, precision and presentation of the What is key to identify and then engage the Who in contributing to the purposes of the study.

In the upper vertex of Figure N° 1, the Who is located, that is, all those stakeholders of the ecosystem that have something to contribute in the construction of the inputs of the study and even participate in determining and specifying the contents of the study. In this work, the Who can be represented by CAPEL stakeholders, researchers, universities, public and private entities, and other stakeholders identified as providing data and information of value to the study (41).

Finally, there is the How, which is the part of the effort that reflects all the activities - such as interviews, field visits, meetings, literature reviews, visual records, and others, that are required to achieve the objectives of the study. Its results depend mainly on what is achieved by the Who, to value the results, thinking of a cultural, organizational and management transforming process, which enables the installation of capacities for the development of sustainable territories with emphasis on mitigating the effects of drought and aridification and adaptation to climate change.

3. Description of the Elqui River basin under an ecosystem approach in the context of the drought.

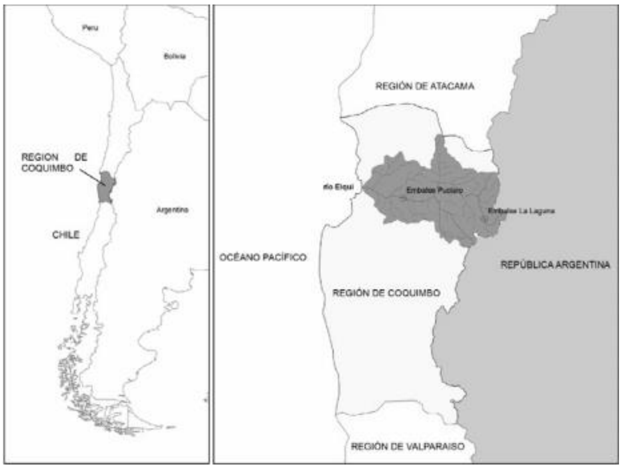
“The variable of greatest uncertainty for the future of regional agriculture corresponds to climate change and its consequences, especially variations in precipitation and temperature in coastal and mountain areas, which increase irrigation requirements and the thermal stress of plants. In this context, agricultural activity needs to increase its resilience in the face of the changes that are coming” ... (Regional Development Strategy, 2030, Coquimbo Region, Chile).

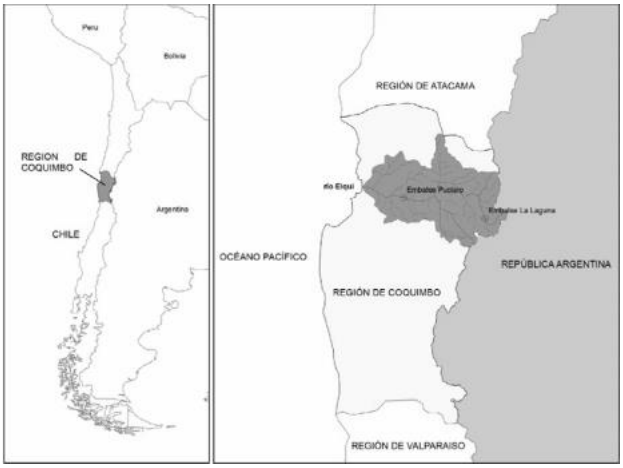
For a better understanding of the drought process affecting the CAPEL Cooperative's pisca grape growers, the Elqui River basin, of which the Cooperative's headquarters, located in the city of Vicuña, is a part, has been taken as a reference. Due to its characteristics, it can explain the climatic effects on agricultural productive activity in the region. However, since the cooperative members are also present in the Limarí River basin, and the study refers to piscic vineyards that are produced in that valley, a brief description is included at the end of this chapter.

3.1 Elqui River Basin

The Elqui River basin extends from 29º 40' S to 32º 10' S, in the north of the Coquimbo Region, Chile (Figure N°1). Its entire surface area is 9,657 km2, with the farthest part of its

basin, which borders Argentina, being about 150 km away from its mouth in the Pacific Ocean, which is in the city of La Serena.
The following figure shows the basin of the Elqui River, where the part of the Coquimbo region where it is located, bordering Argentina, can be seen.





The basin is located on the border between the desert climate of northern Chile and the semi-arid climate of central Chile. The vegetation is in accordance with the scarce rainfall, and with the exception of the valley floor, populated by plantations in which the vineyards that produce the grapes that generate the famous “pisco” of the region stand out, only sparse vegetation can survive, composed of shrubs, cacti, bushes and species typical of high mountains. In the distribution of the vegetation, the beneficial influence of the coastal fogs is noted, which, although they do not provide significant amounts of water, they reduce evapotranspiration and are largely responsible for the fertility of the valley. Usually the influence of the neblinas does not exceed the strait where the Puclaro reservoir is located, thus being limited to the lower part of the basin.(J. Conejo, et al; 2014).

The Coquimbo region can be defined as semi-arid, with around 100 mm of precipitation distributed irregularly, since the months of May-August receive 85% of the water that falls, with 5 or 6 months free of precipitation (November to April). The years are extraordinarily irregular in terms of precipitation, a dry year can follow a rainy year or a rainy period or prolonged drought for several years.

In general terms, it can be said that there is a tendency for total precipitation to decrease by approximately 13% over the last 30 years. (2) The north of the Coquimbo Region has a semi-arid climate in transition to the desert, which is more evident in the Elqui River basin, bordering the Atacama Region. Hydrologically, the basin is characterized by a pluvionival regime. The average rainfall oscillates around 100 mm per year, reaching its maximum values at the headwaters of the La Laguna River, with average annual rainfall of over 200 mm. Significant variations occur as a result of the El Niño-Southern Oscillation (ENSO), which is a natural phenomenon involving fluctuating ocean temperatures in the equatorial Pacific. The "El Niño" phenomenon refers to the large-scale ocean-atmosphere climate interaction associated with a periodic (recurring and recurring) warming of sea surface temperatures (SST), extending throughout the central equatorial Pacific Ocean and the east-central Pacific (approximately between the date line and 120°W), (https://www.imn.ac.cr/enos).

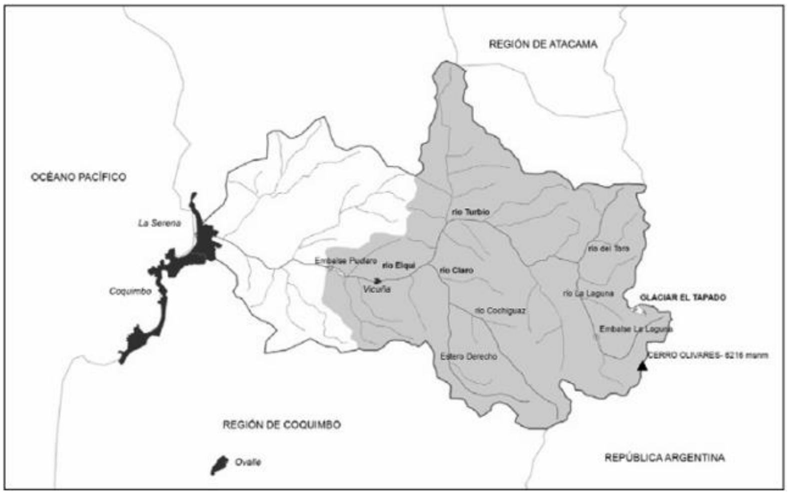
Unfortunately, the opposite situation is more common, especially in the last 5 years when the average precipitation has been reduced by 25 to 50%. The average annual inflow in the last 10 years (2003-2013) is about 225 hm3 at the "Algarrobal" gauging station, which would show a strong reduction compared to the 370 hm3 of the historical average inflow, associated with an average flow of 11.84 m3/s (Zavala H. & Trigos H, 2009).

The administration of the canals and water rights of the Elqui River basin is made up of the Junta de Vigilancia del Río Elqui (JVRE), which has authority over all the canals in the basin, except for those located in the Estero Derecho and Quebrada Paihuano sub-basins, both located in the Claro River basin. In these basins there is a separate organization with authority for the internal management of its water resources, with no obligations to deliver downstream flows. (2)

The basin can be divided into three zones for a better analysis: upper basin (5,650 km2), which includes the highest sectors up to the source of the Elqui River -at the confluence of the Turbio and Claro rivers-; intermediate basin (accumulated: 6,600 km2), which ends at the Puclaro reservoir; and lower basin (accumulated: 9,657 km2), which includes the final stretch of the river from this reservoir to its mouth.

Translated with DeepL.com (free version)
In the upper basin the snow phenomenon is predominant, as its average altitude is 3,450 masl (which corresponds approximately to the zero winter isotherm), with several peaks that exceed 5,000 masl, such as the Olivares (6,216 masl) and Las Tórtolas (6,160 masl). Twenty-seven percent of the upper basin (1,500 km2) has an altitude above 4,000 masl. One of the headwaters of the La Laguna River is home to the only uncovered glacier in the basin, the El Tapado Glacier, and there are other unnamed glaciers with permafrost, snowfields or rock glaciers.

The equilibrium line altitude (ELA) of the glaciers in the study area exceeds 5,000 masl at 30° S (Cerro Tapado: ELA at 5,300 masl; Kull et al., 2002). The 0°C mean annual average temperature (MAAT) isotherm at this latitude is located at 4,000-4,100 m above sea level. The main tributaries to the Elqui River are the Turbio and Claro Rivers, Figure N° 3.



In the middle course of the Elqui Valley there is a predominance of alluvial soils called brown-calcareous or alfisols. These soils originate both from sediments contributed by the Elqui River and from materials coming from the mountainous interfluves.

Agricultural activity is developed in the Elqui River Valley, where the main crops are papaya, avocado, cherimoya, figs, peaches and grapes. This activity has given rise to important fruit drying plants and the production of liquors such as pisco, brandy and wine. There are two agricultural cooperatives in the basin that extract their raw material from muscatel grapes: Capel Ltda. and Cooperativa Agrícola Control Pisquero de Elqui Ltda.

Agricultural land use in the basin comprises 27,713 ha, equivalent to 3% of the total area. Agricultural land is mainly found along the Elqui River valley, downstream from the town of Vicuña to the mouth of the river in La Serena. This land is found only in areas bordering the river terraces, mostly between the town of Almendral and the city of La Serena. In the upper sector of the river (source at the confluence of the Turbio and Claro or Derecho rivers) the area of agricultural land is very small, but a small area is developed in some sectors of the Claro or Derecho river and the Cochiguaz river, a tributary of the latter.

The most extensive and important agricultural sector, according to the above types of crops, is located in the municipalities of Coquimbo and La Serena, also highlighting the agricultural area used for fruit trees, vineyards and grapevines in the municipality of Vicuña. The surface water present in a river basin can be used in different ways. There are different types of water uses, which have been grouped into in-situ uses, extractive uses, uses for biodiversity and ancestral uses.

The use of water for irrigation is that which includes the application of water from its natural origin or from treatment. A distinction is made between unrestricted and restricted irrigation. The former includes water whose physical, chemical and biological characteristics make it suitable for regular use in each stage of development of agricultural crops, forestry plantations or natural grasslands. In restricted irrigation, on the other hand, the application must be controlled, since its characteristics are not suitable for use in all stages of crops and plantations. In this section, however, these irrigation classifications are not disaggregated because there are no precedents to do so.

Puclaro Reservoir is located in the Elqui Valley, about 50 km east of the city of La Serena, IV Region of Coquimbo, at 432 meters above sea level. The climate of the area is arid Mediterranean, with highly irregular annual rainfall. This is a serious constraint for the area's thriving agriculture, which due to its climate allows for high quality crops, especially fruit and vegetables. The Puclaro project is a 175 million m3 regulation reservoir for a total irrigated area of 65,849 Hás.

The reservoir - of multiannual generation - regulates the Elqui River, allowing adequate irrigation security for approximately 20,700 hectares, which more than doubled the irrigated area. The natural quality of the surface water of the basin is strongly influenced by the following characteristics that explain the current quality of the Elqui River and its tributaries:
- The natural quality of the tributaries in the upper part of the basin has an abundance of metals, which are of natural and anthropogenic (mixed) origin due to the mining activity that takes place in this area;
- In the lower part, the interaction between the river-aquifer and the Puclaro Reservoir means that groundwater plays an important role in the natural quality;
- Due to the intense mining activity in the basin, sediments with heavy metal content are produced in the Puclaro reservoir.

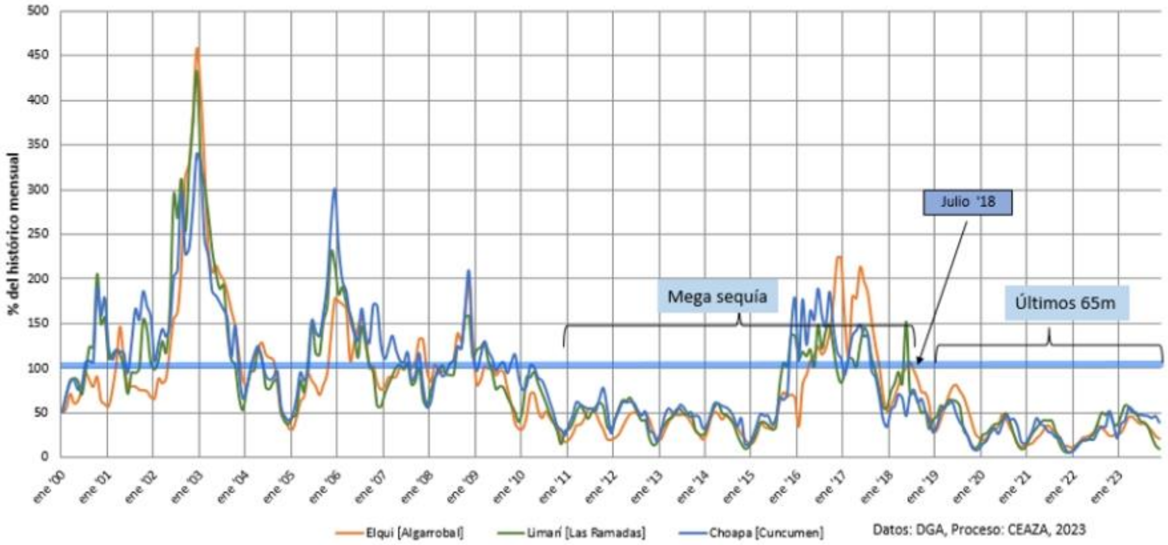
Knowledge of the hydrology of the basin is a key element for the current and future sustainable management of the basin. Since the Elqui River basin does not receive, to date or in any historical period, water transfers from neighboring basins and there are no desalination systems, all the activities developed in its interior must be carried out, in terms of their water requirements, with the contribution of water provided by rainfall, which is scarce and variable from year to year.

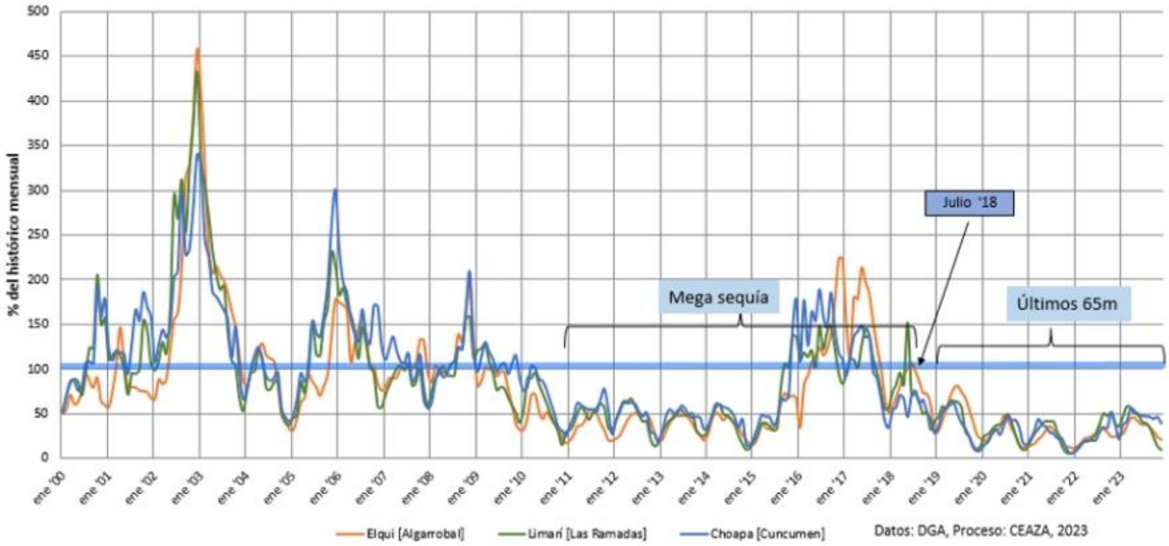
This implies accentuated variability in the surface runoff regime of the natural watercourses in the basin, with dry years tending to generate droughts, as well as rainy years. Regardless of the type of hydrological year - wet, medium or dry - rainfall is concentrated during the autumn and winter seasons. On the other hand, the greatest water requirements occur in the warmer months - spring and summer - in contrast to the rainfall regime.

Each of these problems means that the water system has various sources of fragility and, therefore, water management is crucial both for sustainability and for resource planning and management. (9) The reduction in precipitation has had a negative effect on the entire water system; the main rivers of the three provinces of the region, Elqui, Limarí and Choapa, have significantly reduced their flow in the last 5 years. In the year 2023, flows will be reduced by

32% in the Elqui, 24% in the Limarí and 44% for the Choapa River (CEAZA Climate Bulletin, December 2023).

The flows that are linked to the basin present very low levels since the spring of 2017 (Figure N° 4), due to low rainfall and snowfall in 2018, 2019 and 2020, with 2021 being the fourth consecutive year in this situation, a situation that was not reversed by rainfall around normal in 2022 and that already past winter 2023 implies that the shortage will worsen, at least until spring 2024.

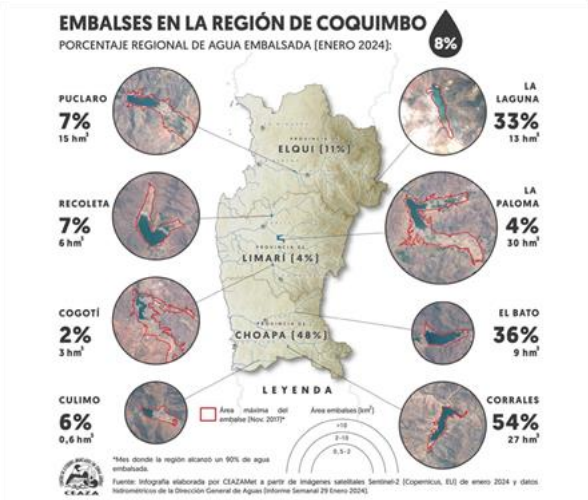


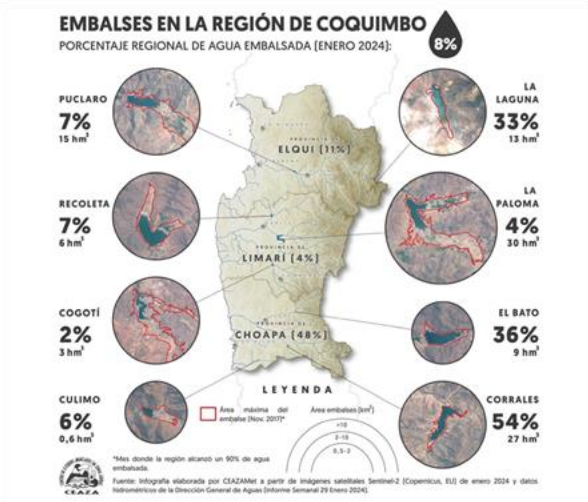

% del histórico mensual
Julio '18
Mega sequía
Últimos 65m
Elqui [Algarrobal]
Limarí [Las Ramadas]
Choapa [Cuncumen]
Datos: DGA, Proceso: CEAZA, 2023

Along with rainfall and flows, the amount of water contained in the Region's reservoirs has also been affected. At the end of January 2024, the amount of water impounded in the Region was between 2% and 54%, for a regional capacity of just 8%. This episode has been repeated since 2018 in all reservoirs, due to below normal rainfall.

Specifically, in the province of Elqui, 18% of reservoir water is currently maintained, where its headwater reservoir (La Laguna) has 33% and 7% in the Puclaro reservoir. The province of Limarí has 4% in reservoirs, with the Recoleta reservoir storing 7% of its capacity, La Paloma

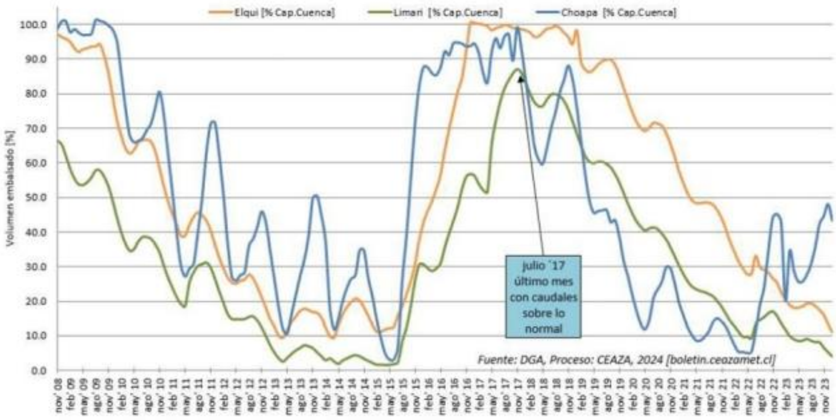
4% and, the most critical being Cogotí, with 2%. Choapa has a 43% reservoir capacity in the province and presents values similar to those observed in 2014 (Figure N° 5; CEAZA Climate Bulletin, February 2024).





In the provinces of Limarí, Elqui and Choapa, agriculture is an important economic activity that consumes 81% of the water resource in the Coquimbo region (CAZALAC, 2014). The growing economic demand for water in the last two decades has increased pressure on an already over-allocated system (Oyarzún and Oyarzún, 2011; Chávez et al., 2016; Aitken et al., 2016, DGA, 2017b).

Consequently, during periods of water stress, artificial storage in surface reservoirs is usually not sufficient to fully meet demand (as evidenced by the evolution of water stored in reservoirs over the last 14 years in the Region, Figure N° 6).



The Elqui River basin has historically maintained high quality soils for agriculture. However, as mentioned in the Regional Development Strategy of the Coquimbo Region, "...healthy soils act as reservoirs of essential nutrients, providing the necessary support for root development and facilitating water absorption by plants. They are also a key component in the mitigation of climate change, as they store carbon and contribute to the reduction of greenhouse gas emissions" ...which means that the actions taken, and it is already late, must be in harmony with the sustainable maintenance of the environment and its rich biodiversity.

Finally, it is necessary to comment that, in the Elqui River basin, it has been observed that the drought of recent years has generated fruit with a higher concentration of sugar and phenolic compounds, but with a decrease in acidity levels. This has influenced the final products - especially in the production of pisco and wine - where piscos tend to be more robust and sweet, while wines can become more tannic and astringent.

Years with normal conditions or better water availability allow a more controlled development of these compounds, resulting in more balanced products in terms of acidity, sweetness and phenolic complexity. In the case of the Elqui River basin, there are two well-defined geographical locations where pisca grapes are produced, mainly Moscatel de Alejandría, Rosada and Pedro Jiménez: those of the plains and those of the highlands.

In the case of the flatland grapes in the Elqui River basin, for example, the average estimated water consumption for a technified drip irrigation system is between 7,000 and 9,000 liters per hectare/year. On the other hand, for tended irrigation, water consumption can rise to 10,000 to 12,000, and according to CAPEL specialists, it can be as much as 14,000 liters per hectare/year. This represents a use of approximately 19 to 25 liters per plant per day, under normal irrigation conditions.

On the other hand, at altitude - more than 800 meters above sea level - where the most common varieties are the same vines, Moscatel and Pedro Jimenez, but with some adaptations to the more extreme altitude conditions. Estimated water consumption may be slightly lower due to cooler temperatures and less evaporation. On average, it is estimated to use between 5,500 and 7,500 liters per hectare/year with technified irrigation. In line irrigation systems, consumption can be in the range of 8,000 to 10,000 liters per hectare/year.

It is important to mention that the process of implementation of technified irrigation in some of CAPEL's cooperative members and other pisco producers began in the 90s of the last century. However, it is in the first decade of the 21st century that the use of technified irrigation expanded considerably within the CAPEL Cooperative, driven by water scarcity and improvements in available technology.

This expansion was supported by state programs such as those of the National Irrigation Commission (CNR), which provided subsidies for the installation of more efficient systems. By the end of 2010, a large part of the vineyards associated with CAPEL had adopted some type of technified irrigation, such as drip or micro-sprinkler irrigation.

In a comparison between pisca grape production available in high altitude and lowland conditions, it can be commented that, at altitude, less water is required due to lower evaporation rates and temperatures, but soil and wind conditions may increase the need for water in some situations. On the other hand, in the plains, plants are exposed to higher temperatures, which increases evaporation and, therefore, water demand is higher, especially during the summer months.

The challenge due to the extreme drought affecting the basin will be to carry out efficient irrigation management, thinking about the sustainable development of the territories, which is critical to reduce the impact on the production and quality of pisca grapes.

3.2 Limarí River Basin:

Agricultural land use in the basin comprises 80,011 ha, equivalent to 7% of the total area. Agricultural land is mainly found in the Limarí River valley in the area around the city of Ovalle and downstream from there to the Punitaqui Estuary, where it covers the largest areas (10).

In the Hurtado River sub-basin downstream from the Recoleta reservoir to the confluence with the Grande River, there are also very small areas of agricultural land compared to those in the valley of the basin's main riverbed. These agricultural areas are found only in the sectors adjacent to the fluvial terraces of the Hurtado riverbed.

The Limarí River basin has 466 canals and 3 major reservoirs within its irrigation infrastructure. Of the 7,398 users, 1,679 are organized into 3 canal associations and 15

water communities. There are 3 surveillance boards in the basin for the Grande, Rapel and Cogotí rivers.
The Limarí River basin extends from latitude 30º09' in the north to latitude 31º22' in the south. It is located in the IV Region of Coquimbo, between the valleys of the Elqui River to the north and Choapa to the south. It extends approximately between 30°15' and 31°20' south latitude, covering an area of approximately 11,800 km2.

The Limarí River is formed by the union of the Grande and Hurtado rivers, of which the former has a larger hydrographic basin. In fact, the Grande River, which drains the southern part of the Limarí watershed, has a basin more than twice as large as that of the Hurtado.

Both rivers originate in parts of the mountain range where the peaks reach an average of 4,500 m a.s.l. and receive abundant snowfall. The Hurtado River has no major tributaries and is the only major drain in the northern part of the Limarí basin. The Recoleta reservoir is located in its lower course, with a useful capacity of 100 million m3.

The Grande River receives a series of important tributaries, including the Rapel River (with its tributaries Palomo and Molles), the Mostazal River and the Guatulame River (with its tributaries Cambarbalá, Pama and Cogotí). The Guatulame runoff is regulated by the Cogotí reservoir with a capacity of 150 million m3.

At the confluence of the Guatulame River with the Grande River is the La Paloma reservoir, with a regulation volume of 750 million m3. The Grande and Hurtado rivers meet approximately 4 km upstream from the city of Ovalle. From the confluence of the two rivers, it takes the name of Limarí River, which after about 60 km flows into the sea in the town of Punta Limarí.

Between the city of Ovalle and its mouth, the Limarí River receives two tributaries of little importance, the Ingenio estuary to the north and the Punitaqui estuary to the south, both of which have their origins in the Coastal Mountain Range. The Limarí River basin has three climatic types, Semiarid with abundant clouds, Semiarid temperate with winter rains and Cold Semiarid with winter rains.

In general, this basin is under the influence of a bioclimate with scarce precipitation and during nine months of the year there is a water deficit. Like the Elqui River basin, this basin is also within the second regional grouping of the Coastal Plains and Basins of the Andean-Coastal Mountain System, with similar geomorphological characteristics.

The soils that have formed on the lower terraces and in the Limarí River basin are poorly evolved, shallow and have limitations for cultivation due to their low natural fertility, with nitrogen being the critical element.

4. The Capel Cooperative and its situation in the face of the drought affecting the basin.

Pisco, "is an eau-de-vie that is characterized by the genuine aroma of the fruit of origin, especially of the muscatel type, produced in a dry and highly luminous climate. The aroma comes from the fruit itself and not from an aging process". Hernán F. Cortés Olivares, (2005). The origin, production and trade of Chilean pisco, 1546-1931.

It is estimated that the area planted with pisca grapes is approximately 10,000 hectares. According to information from the Association of Pisco Producers, “85% of the vine growers have areas of less than 5 Há and with very low productions, mainly due to the age of the plants, in fact, about 50% of them have vines over 20 years old” ..., (INIA - INDAP Bulletin, 2017, Manual of Pisco grapevine production).
Pisco has existed since the 16th century. Pisco producers - ancestors of today's cooperates - watched this market, but did not participate in it. The vast majority only produced pisca grapes, which were traded in bulk in the form of wines or musts that were then sold to the Spanish Crown or to local merchants.

The specific territories where CAPEL has its facilities, which are part of the Elqui River basin, are as follows:
- Elqui Valley: The valley is located northeast of the city of La Serena and extends from the Pacific Ocean to the Andes Mountains. It is the main territory since it is where the Cooperative is born, where the Pisco grapes are grown, many of them, at altitude, Terroir type, with high Brix percentage - sugar level - aromas and flavors, due to the unsurpassable climatic conditions, and it is the territory where CAPEL's main facilities are located.
Some of the characteristics of this valley, which account for the goodness oriented to the production of grapes for Pisco,

o Climate: This territory has a mostly semi-arid climate, with mostly clear skies during most of the year, which provides a large amount of light and solar radiation, which is key to the ripening process of the grapes called pisqueras. In general, its summers are hot and dry, with relatively mild winters, with very clear skies, which has meant the installation of astronomical observatories, among the most important in the world.
o Altitude: This valley has an altitude that varies from sea level to more than 2,000 meters in more mountainous areas. This allows the production of grapes for Pisco, from different microclimates and altitudes, which impact the concentration of sugars and the quality of the grapes, mainly in drought conditions. For example, Moscatel de Alejandría, Rosada and Pedro Jiménez.
o Soils: The soils in this valley are generally stony and poor in nutrients, which means that the roots of the vines dig deep in search of water and minerals. This process allows the grapes to achieve better quality by concentrating their flavors and aromas.

- Limarí Valley: This other valley has an important production of pisca grapes, with larger volumes than the Elqui Valley. It is currently affected by drought, mainly in the town of Río Hurtado, but has favorable climatic conditions for the production of wine and pisco. This valley is located south of the Elqui Valley, towards the interior of the city of Ovalle. Like the Elqui Valley, it extends from the coastal areas to the Andes Mountains.
Some of the characteristics of this valley, which account for the goodness for the production of grapes for Pisco, are:Climate: This territory has a mainly semi-arid coastal climate, with a greater marine influence than the Elqui Valley. This means that its temperatures are a little more moderate. It also has a low rainfall, which means that viticulture depends largely on irrigation systems that take advantage of the waters of the Limarí River and reservoirs in the area.
- Soils: The soils of this valley have a greater amount of minerals. Among these minerals is calcium, due to the proximity to ancient marine geological formations. This gives special characteristics to the Pisco grapes grown in this valley, as they have a slightly more mineral flavor.

- Altitude: This valley has less variation in altitude compared to the Elqui Valley; however, there are some mountainous areas where grapes are also grown, allowing for a diversity of types of pisco production. Among the most common features in grape production that both valleys have in common are the following:
o Irrigation: Both valleys sustain their irrigation from canals and reservoirs, since rainfall is scarce, there are prolonged periods of drought, water scarcity conditions, especially during the summer period.
o Grapevines: Pisco grape varieties are in production (for example: different types of Moscatel, Pedro Jiménez and Torontel). These varieties are perfectly adapted to the arid, semi-arid and sunny conditions of these valleys, which allows the production of piscos with high Brix -sugar content and intense aromas, which are related to the value finally achieved by pisco, and which allowed it to achieve its denomination of origin.
These geographical and climatic conditions are ideal for the production of high quality pisco, as they allow the production of grapes with a unique organoleptic profile, which are then distilled to obtain aromatic piscos with a great richness of flavors.

That said, the CAPEL Cooperative was born in the mid 1930's. At that time, 12 winemakers from the Elqui Valley got together and decided to sell some of their properties, joining their efforts to obtain a greater good. To do so, they leased two small plants with the capacity to process a little less than 1,000 tons of grapes per year, in total.

As the development of their business allowed them to grow, it became necessary to have an organization that would allow them to achieve better prices for their products, improve their governance, production and project themselves into the future, so they had to adopt another form of organization that would help them achieve their objectives. One of these objectives was to maintain economies on a minimum scale in order to be able to transform their grape production into Pisco and thus be able to offer it to consumers through intermediaries.

In 1938, in order to achieve the proposed objectives, they formed the Cooperative. In 1960, CAPEL built its own winemaking and distillation plant in the city of Vicuña, supported by CORFO resources, making a great leap in its growth and becoming an important support for the cooperative members in the Atacama and Coquimbo regions.

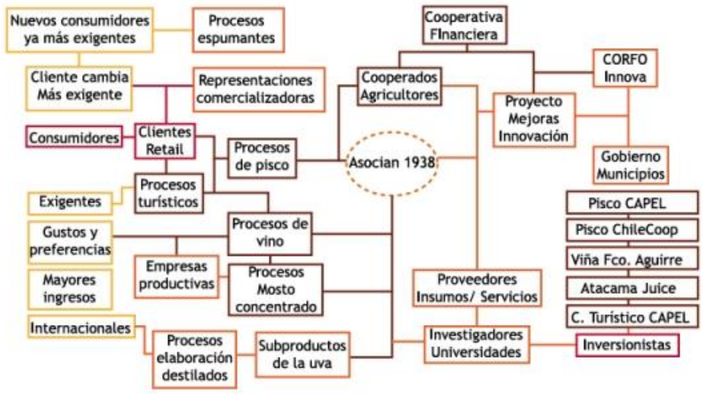
At the end of the 1990s, it marked an important milestone in the history of the Cooperative by installing the must plant in the town of La Chimba, Province of Ovalle, with state-of-the-art technology, becoming the most modern plant in South America (Báez, Contreras, 2012). Currently, the Capel Cooperative has a head office, a bottling plant located in Vicuña and 9 grape receiving plants that cover the grape growing valleys of Copiapó, Huasco, Elqui, Limarí and Choapa, with an annual processing capacity of 200 thousand tons of grapes. It has 4 business lines: Pisco and other distillates; sparkling and still wines; non-alcoholic beverages; and representation.

In those years, the cooperative members acquired French stills to distill Pisco wines. Through manual labor, these burning waters were poured into bottles to take the product to the final consumer, (Báez, Contreras, 2012). The CAPEL pisca grape producers saw that all these changes required investments in the production of Pisco, but also in their fields, because they had to improve their work and the quality of their fields.

For CAPEL, the changes that were initiated and materialized are part of its innovative history, which began with the development of Pisco and the formation of the Cooperative at the beginning of the 20th century. With the new innovations that were made, the Cooperative acquired a size and presence in the market that allowed it to obtain convenient financing from the banks. However, for small producers, who have always been the vast majority, they did not have the size, knowledge and guarantees to apply for credit.

However, the alliance of all the cooperative members and their innovative and transforming will, decided to form a Financial Cooperative called ChileCoop, which could finance the changes and improvements in their grape vineyards, (Báez, Contreras, 2012).

The diagram in Figure N°6 shows the innovative organizational development process of the Cooperative since its first major association in 1938.



“CAPEL”, as it is called in the localities where its facilities are located in the basin, is a Cooperative that currently belongs to more than 700 farmers in the regions of Atacama and Coquimbo. It is important to mention that, since its origins, it has maintained a democratic organization where one cooperative member represents one vote.

In its historical process, it has been developing an associative and solidary model implementing the best management practices, ensuring the quality and satisfaction of its clients, consumers, collaborators and cooperative members. One of its most important purposes is to promote the sustainability of the business in harmony with the environment and the communities.

The Assembly, made up of all its members, is the highest authority of the Cooperative. It meets in the first half of each year to learn the details of the Cooperative's future and elect its representatives to the Board of Directors and the Supervisory Board.
The Board is a collegiate body in charge of the superior management of the social business. It is made up of 9 members who are directly and democratically elected. Their term of office is three years and they are renewed in installments.

The Cooperative has a management structure, which leads the Pisco production process throughout its industrial value chain. It is managed by a General Manager, who is appointed by the Board of Directors, and also organizes and manages the Cooperative administratively and appoints the rest of the personnel.

Among the managements that participate in the executive management are those of Production, Technicians and Cooperative Members, Logistics and Sales, Administration and Finance, Marketing and Communications. These managements work in a coordinated manner with 400 employees distributed in 9 production plants and 11 branches and administrative offices throughout the country.

CAPEL's organization has members with an average age of 70 years, working 3,200 hectares of pisca grapes between the regions of Atacama and Coquimbo, approximately 70% of which are single growers. In addition to receiving their monthly payment for the grapes, the cooperative members have access to a series of technical benefits to improve their production and also highlight the social benefits that demonstrate the community and solidarity spirit, given that the cooperatives fall into the category of Solidarity Economy Enterprise. The most important of these benefits are the complementary insurance, medical agreements, solidarity fund and scholarships for children and/or grandchildren.

Among its activities to sustain environmental conditions and maintain nature, CAPEL, at four of its facilities, contributes to eliminating pollutants from waste liquids, transforming them into treated water, which is used to irrigate green areas and its own forests.

For the cooperative members, the importance of reducing water consumption is key in the midst of the water crisis that the region and the country are experiencing. For this reason, it uses tools and techniques from nature and others, together with more current technical knowledge, generating a novel combination of solutions, typical of a resilient daily activity. For this reason, and given the serious environmental conditions, the Cooperative is one of the pioneers in implementing clean technologies in its plants.

4.1 Pisco grape production localities most affected by the drought.

The pisca grape-producing localities of the Elqui and Limarí Valleys have been exposed to extreme difficulties in their activity and business due to drought for more than two decades (late 1990s), although some actors point out that it has had ups and downs.

But it is since 2010 that the country and especially the Elqui Valley region have been facing a severe and prolonged drought, which has manifested itself more intensely in the following periods, according to data provided by specialists.

Period 2010 - 2015: During this period the drought has been considered the most critical, according to records of both CAPEL and other agricultural cooperatives and organizations in the area. The lack of rainfall and the decrease in the availability of water in the reservoirs led to a drop in the production of pisca grapes. The CAPEL cooperative, together with its cooperative members, had to resort to mitigation strategies, such as the massive implementation of technified irrigation and more efficient management of water resources.

Period 2015-2019: The year 2019 is the hardest year for farmers in the Elqui Valley. Extremely low rainfall was recorded and the Elqui River basin suffered one of its worst water crises in its recent history. The Puclaro reservoir, which supplies the region, reached historic low levels, generating a generalized crisis in agricultural production.

2020-2024 period: During these last years, the critical situation generated by the drought was prolonged. Although in 2021 and 2024 there has been rainfall, the drought situation continues to be extremely fragile, with insufficient rainfall and low water availability in irrigation systems. The mega drought, as pointed out by CEAZA, which has been affecting the area for more than a decade, has had the greatest negative impact on the volumes of pisca grape production and, consequently, has generated the main effects on the ecosystem of the valleys of the basin.

As a result, all the localities located in the Elqui River Basin, Coquimbo region, are suffering permanent periods of drought and desertification processes caused by climate change (Ceaza, 2024).

In this situation, drought, frost and other climatic phenomena affect the volume and quality of the pisca grapes produced during the season, seriously compromising the volume necessary to guarantee production under adequate economic conditions. In general, all the localities in the valleys of the basin linked to the production of pisca grapes are highly dependent on irrigation, which is aggravated by the scarcity of rainfall.

4.2 Affected localities in the Limarí Valley

The extreme drought that has affected the localities of the Limarí Valley has had devastating impacts, especially in rural communities that depend on agriculture and mainly on irrigation. This valley, known for its abundant production of pisca grapes, has suffered the consequences of the lack of water for several consecutive years, generating a water crisis with social, economic and environmental effects.

In that sense, the localities that have been most affected by the drought have had a significant reduction in:

Pisco grape production volume, which is manifested in the decrease of hectares produced; competition between the use of water for consumption versus irrigation, which has put at risk the continuity of some farms; diversification in mainly fruit production; acute processes of desertification of productive soils; the increasing decrease in employment and sustainability of grape producers such as cooperative producers, due to climatic uncertainty and the absence of economic resources, to at least have minimum subsistence conditions.

The following are some particularities of those localities most affected by the drought, detailed by valley:

4.2.1 Limarí Valley.

Río Hurtado:
The town of Río Hurtado is located in the province of Limarí, Coquimbo region, Chile. It is located east of the city of Ovalle, in a mountainous area that is part of the foothills of the Andes. This locality is immersed around the valley of Río Hurtado, which extends along the course of the river of the same name, which is a tributary of the Limarí River.

Its approximate coordinates are: Latitude: 30°15' S; Longitude: 70°35' W, and its distinguishing characteristics are its medium altitude, with mountainous terrain and semi-arid climatic conditions. Its climate is mostly dry, with low annual rainfall, so grape production depends mainly on irrigation.

Access to Río Hurtado is by roads that are connected to Ovalle, which is the nearest city, and other towns in the province of Limarí.

Coquimbo, Chile

Monte Patria:

The town of Monte Patria is located in the province of Limarí, within the Coquimbo region of Chile. It is located in the Limarí Valley, southeast of the city of Ovalle, at an altitude of approximately 740 meters above sea level. Its main geographic coordinates are: Latitude: 30°41' S; Longitude: 70°57' W; and its distances to important cities in the region are, 30 km southeast of Ovalle; and approximately 120 km southeast of La Serena, which is the capital of the Coquimbo region.

Monte Patria is one of the towns most affected by the drought in the Coquimbo Region. This locality is highly dependent on the La Paloma reservoir, which is at historically low levels, around 8%, which has limited irrigation and put the production of pisca grapes at risk (Ceaza, 2024).

A large number of pisca grape growers have seen their production reduced due to the lack of water, despite the fact that many have technified irrigation installations on their farms and others have temporarily abandoned their crops.

The extreme drought in Monte Patria has had devastating effects, especially in the pisca grape growing sector. As a consequence of the drought, there are also serious problems in access to drinking water for the population.

In particular, the ecosystem has been complicated due to the prolonged drought, which has generated job losses; migration of people to other parts of the country and a growing environmental challenge and weakening of biodiversity as a result of the desertification process. Local stakeholders and the community are still looking for medium and long-term solutions, but drought conditions have aggravated the situation, making it increasingly critical and difficult to reverse.

The main effects of the drought in this locality, according to the opinion of the cooperative members interviewed and information gathered from secondary sources, are as follows:
Difficulties in the production and quality of pisca grapes.
Dramatic decrease of water and therefore of irrigation hours, to achieve the production of pisca grapes, which makes possible the balance, at subsistence level. This is aggravated by the absence of precipitation; by the desertification of soils, and by the weakening of existing flows.

The presence of dry rivers or rivers with insufficient flows for irrigating the vines. The Limarí River and other bodies of water have experienced very low flows, which has further reduced the availability of water for irrigation.

The reduction in the size and cultivated area of pisca grapes has drastically decreased due to insufficient irrigation. There is a population of cooperative members, called inactivos, who have stopped producing. Small producers have had to leave plots uncultivated because they cannot guarantee irrigation.

Most of the cooperative members continue to produce without the help of hired workers. For several years the productive tasks of the entire grape production process have been carried out by the owners and some family members.

Economic conditions are mostly subsistence. Some cooperative members, such as the Milla family, generate new resources by producing food products that they sell to tourists.

Significant crop losses in Monte Patria, which is an agricultural zone par excellence, known for the production of pisca grapes, vegetables, and fruit trees. The lack of water has led many farmers to reduce or abandon their crops, especially those that require large quantities of water, such as pisca grapes.

Drought has not only reduced the quantity of production, but has also affected the quality of the crops. Water stress in the plants has generated products of lower size and quality, which has an impact on the income of the Cooperados.

Limitations with the irrigation water storage and management ecosystem.

The La Paloma reservoir, located in this valley, has been experiencing prolonged periods of critical water accumulation levels for irrigation, which is one of the main sources of irrigation water in the area, due to the scarcity of water in the rivers that feed it. This has severely restricted access to water for Monte Patria's pisca grape growers, generating strong competition for water resources.

Sustained decrease in minimum river flows. The rivers and canals that traditionally supply Monte Patria's pisca grape growers have recorded very low flows, which has made it necessary to impose restrictions on the use of water for irrigation.

The water crisis due to the drought is causing water shortages for human consumption. A significant number of families in rural areas of Monte Patria depend on water trucks for drinking water, as the water supply systems have been unable to maintain the supply due to the lack of aquifer recharge.
Water quality problems. In some areas of the valley, water quality has declined due to overexploitation of wells and aquifers, which has led to an increase in the concentration of minerals and salts.

Reservoirs, which are the main source of water for irrigation, such as La Paloma, Recoleta, and Cogotí, have been at critical levels in recent years. This has led to a reduction in cultivated area and significant economic losses for grape growers.

Problems with governance in irrigation water management. It is mainly manifested by the existing Water Code, which does not recognize all irrigators as equals and generates an abusive use of the same in favor of a few producers, mainly those who have greater water shares.

Desertification and soil degradation

Soil erosion and loss of soil fertility: Prolonged drought has led to increased soil erosion and degradation of agricultural land, further complicating the short- and medium-term resilience of crops. Desertification is a growing problem in the area, and more and more agricultural areas are losing their productive capacity.

Decrease in biodiversity, seriously affecting the valley's biodiversity. The lack of water has affected natural ecosystems, reducing the biodiversity of the territories. This includes the loss of native vegetation and the decrease of fauna, which depend on water courses that are now dry or with minimal flows.

The concept of day-cold hours, its decrease and its effects on the pisca grape. The concept of chilling hours refers to the cumulative time that a plant experiences cold temperatures - generally below 7°C - during the winter. This period is crucial for many plants, including grapevines, as it allows dormancy, a period of inactivity in proper plant growth, and ensures good budding and flowering in the following season.

In recent years, in the Elqui Valley, with the periods of drought, winter temperatures have tended to increase slightly, which has led to a reduction in the number of cold-day hours experienced by the plants, affecting the development of the vine, as a warmer winter could lead to irregular budding, late or reduced flowering and lower yields.
Affectations that affect social impact

An emotional and social toll has been generated that is new to local rural realities. The water crisis has generated high levels of stress and concern among producers of pisca grapes and other agricultural products, and local families, who face uncertainty about the future of their crops and their ability to sustain themselves economically. The impact has affected the social cohesion of rural farming communities.
Increased unemployment and loss of income. The reduction in the production of pisca grapes and other crops has resulted in the loss of jobs, both for farmers and seasonal workers. A significant portion of the population depends on agriculture for subsistence.

Worsening conflicts over water management. Competition for limited water resources has generated tensions among water users, particularly among producers of different sizes and sectors, and between rural and urban areas. This is even more conflictive because of the legislation in force in the Water Code that has been in force since the 80s of the last century.

Significant rural migration has been taking place. Given the lack of job opportunities in the agricultural sector, many people have migrated to urban areas in search of better living conditions, which is contributing to rural depopulation in Monte Patria.

4.2.2 Elqui Valley

Vicuña
The town of Vicuña is located in the Elqui Valley, in the province of Elqui, within the Coquimbo Region, Chile. Vicuña is located on the banks of the Elqui River, surrounded by hills and vineyards, and is one of the main centers of pisco production in the country and an important tourist destination, especially for astronomical observation. Its approximate geographic coordinates are: Latitude: 30°2' S; Longitude: 70°43' W. The regional capital, which is La Serena, is located about 60 km to the east.

This locality is key for the production of pisco, but the drought has also impacted the production of pisca grapes. Although the Elqui River basin has historically been more stable, in recent years water levels have decreased, affecting agricultural production.
Irrigation difficulties have forced a reduction in crop hectares in some areas, affecting both large and small producers.

Paihuano
The town of Paihuano is located in the Elqui Valley, in the province of Elqui, in the region of Coquimbo, Chile. It is a small and picturesque town located near the Elqui River, surrounded by mountains and vineyards. Its approximate geographical coordinates are: Latitude: 30°2' S; Longitude: 70°30' W. It is located approximately 40 km southeast of Vicuña.
This has been another of the localities whose pisca grape production has been affected by the drought. Like other locations in this valley, Paihuano has experienced a reduction in water levels in its irrigation systems.
Pisco grape growers have had to look for alternatives to cope with the lack of water, but the prolonged drought has made the situation difficult for many.

In this high altitude production locality, there are 83 Cooperative members who have less than 2 hectares of land for pisca grape production. Their maintenance is considered strategic because the grapes they produce have the best value attributes, which are manifested in their flavor profiles and aromas. These are the so-called Terroir, which are located in the foothills of the valley.


In both localities, the drought has affected production to a lesser extent than in the Limarí Valley. The most relevant problems are described below:

The drought in these valley localities has had a devastating impact on the pisca grape producing localities, as the lack of water affects both the quantity and quality of the grapes.

In addition to the reduction in production, water stress in the vines has also affected the quality of the grapes, which may affect the quality of the pisco produced in these areas. The conditions have led some producers to seek solutions such as the implementation of more efficient water use technologies, but the situation remains difficult due to the lack of rainfall and climatic uncertainty.

There have been processes of crop change. Some pisca grape growers have had to change or reduce crop diversity, focusing on species that are more resistant to drought or require less water, which has affected the profitability of the farms. This is the case of citrus and avocado.

Lower product quality has been experienced. Water stress in grapevines not only reduces yields, but also affects the quality of the grapes, with negative impacts on the production of pisco and other derivatives.

4.3 Critical factors in the production of pisca grapes depending on drought periods, compared to normal conditions.

Among the critical factors, necessary to comment on since they determine the most recognized value attributes of Pisco production, are the flavor profiles of Pisco grapes, and how they have been affected by periods of drought.

Strictly speaking, these periods of high drought tend to intensify certain flavor profiles in grapes and other fruits, highlighting more concentrated and deeper flavors. This is very relevant for the grape production located in the foothills of the Elqui Valley, called “Terroir”, whose grapes, mainly of the Muscat of Alexandria variety, are the ones selected for the production of high value Pisco, in quality and price.

Grapes can develop riper notes, with flavors of dried fruits, raisins, or higher concentration of sweet notes, which may be desirable in some products.
However, a situation of prolonged drought can cause imbalances such as overripening, loss of freshness and a sensation of heaviness in the final product.

On the other hand, under normal conditions of irrigation water availability, flavor profiles tend to be more balanced, with an appropriate mix of freshness and sweetness. Pisco produced under these conditions tends to be fresher, with lively fruity notes and greater aromatic complexity.

That said, it is important to add that, in general, in the Elqui River basin, it has been observed that the drought has produced fruit with a higher concentration of sugar and phenolic compounds, but with a decrease in acidity levels. This has influenced the final products - especially in the production of pisco - as they tend to be more robust and sweeter.
On the contrary, in years with normal conditions or better water availability there is a more controlled development of these compounds, resulting in more balanced products in terms of acidity, sweetness and phenolic complexity.

Variation in sugar content - measured in degrees Brix -, acidity levels, phenolic compounds and flavor profiles in crops such as grapevines - used for pisco production in the Elqui Valley - is closely related to climatic conditions, especially water availability. Drought can significantly influence these parameters.

The survival of the plants is determined by the evolution of climatic conditions after planting and throughout their development, and this depends on rainfall that ensures the initial rooting of the plant, and then on a sufficiently long vegetative period before the arrival of the summer period.

In relation to the two conditions of grape production, either in drought and normality, specialists in the production of Pisco from Capel, state that the three conditions to achieve a grape with sufficient attributes of value, mainly of altitude, such as: cold hours, radiation and relatively poor soils, have been maintained, despite the increasing decrease in the volume of grapes produced, which in 2024 reached only 50 million kilos of grapes, considering all the valleys involved that belong to CAPEL.

Nevertheless, the cooperative members are resilient and use ancestral techniques for better management of the quality and quantity of water available, bringing to the present the knowledge of their ancestors to achieve the flavors and aromas that distinguish this pre-mountain range locality.
In relation to this, the case of a CAPEL cooperative producer is presented, who belongs to the town of El Maitén, located in the commune of Monte Patria, which belongs to the province of Limarí, in the region of Coquimbo, Chile. It is located in the rural sector of Monte Patria, known for its production and cultivation of pisca grapes and other agricultural products such as olives and fruit.

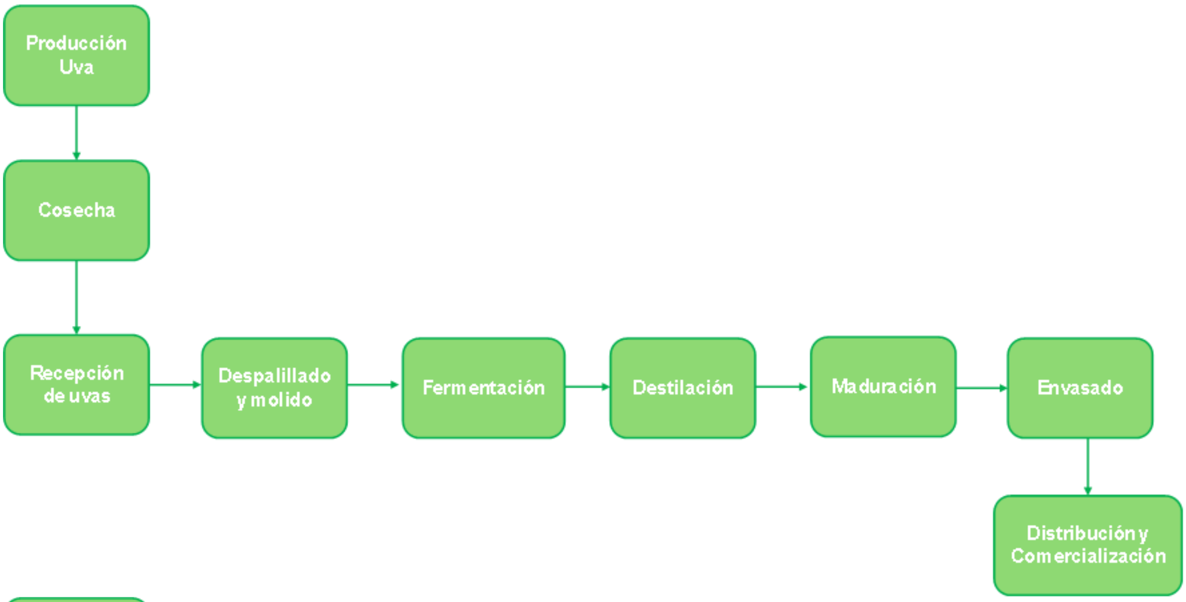
4.2 The effect of drought and aridification on the Pisco production value chain (or sensitivity at each point of the value chain)

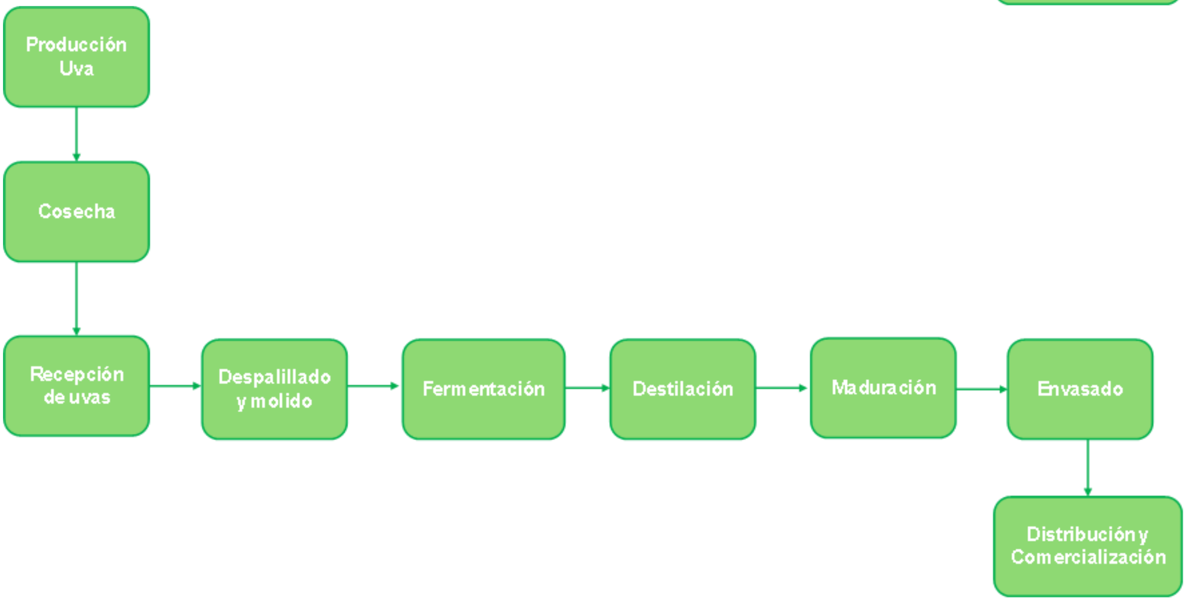
Pisco production in the Coquimbo and Atacama regions, with extreme drought, related to the condition of grapes with Designation of Origin since 1931, the production of grapes and Pisco are of high relevance for our country. In this regard, some statistical data provided by the Integrated Territorial Program (PTI) for the Pisco Industry, Pisco, Chile's Heritage, which denote the value of this ancestral economic activity and its externalities, stand out.
- 10 thousand hectares planted with pisca grapes.
- 36 million liters of pisco produced per year.
- 90% of pisca grape producers are associated with the cooperative model.
- 175 million kilos of grapes produced in the last harvest.
- Approximately 4 kilos of grapes are required to make a bottle of pisco
- 2,800 pisca grape producers
- 3,500 permanent jobs 85% of pisca grape growers farm less than 5 hectares
- 40,000 indirect jobs
- 11 grape varieties are considered by the legislation to make pisco
- 1931: the Pisco Denomination of Origin is established.

The effects of the drought on grape production have already been discussed mainly in the previous point, and in this point, we wish to detail those of greater sensitivity affected by the drought process, which are determinant in each link of the value chain of the production of Pisco, which is the final product that is achieved with the use of grapes from the Pisco vines.

From the point of view of the Pisco Denomination of Origin, it is established that the production of this distillate consists of four main phases, which must be carried out in the pisca zone of Chile's Norte Chico:
- Cultivation and harvesting of the Pisco grapes;
- Vinification;
- Distillation;
- Bottling in consumer units.

However, from the point of view of this study, 9 links or processes have been considered for the analysis, which constitute the Pisco production value chain. Figure N° 7 shows a diagram of the Pisco production value chain, indicating the processes sensitive to the effects of the drought, including bottling, sensitive to bottle volumes, and distribution and marketing, sensitive to costs and sales, due to the decrease in final products.





The effects of the extreme drought and the process of aridification are detailed below, with emphasis on the value attributes of each link.

4.3.1 Pisco grape production

This process, which is one of the most important in the Pisco production value chain, explains the quality of the main value attributes of the final product. The quantity and quality of pisco is highly dependent on the grapes produced, in terms of variety, soil and climatic conditions, where the central factor is the cold hours to which the plant is subjected, which account for the moisture levels in the soil and the transpiration process that occurs in the leaves of the vine, and complementarily, the levels of radiation, generating a harmonious whole with nature and biodiversity existing in the territories, which must successfully achieve a novel combination of flavors and aromas, which are the main value attributes of pisco.

Therefore, this link is the most sensitive in terms of achieving a final result in pisco that has a positive impact on the most demanding palates of consumers. In general, the most sensitive effects and points involved in the process of aridification in this process of grape production are the following:
- Desertification: which is the loss of fertile soil, affecting vines and grape production, facilitating a decrease in the quantity and quality of pisca grapes;
- Biodiversity: Aridification can reduce the diversity of species present in nature, as many plants and animals cannot adapt to drier conditions;
- Soil Salinization: The decrease in humidity can lead to the accumulation of salts in the soil, deteriorating its quality, flavors and aromas, as well as the shelf life of the vines.

In relation to drought and aridification processes, grape crops themselves are sensitive to:

sensitive to:
- The grape varieties planted: The selection of the grape variety is crucial. The quality and aromatic profile of pisco depends largely on the variety used, e.g. Moscatel, Pedro Jimenez or Torontel.
- Prevailing climatic conditions during cultivation: Climate affects grape growth and ripening. Excesses or deficits of water, extreme temperatures or diseases can compromise grape quality. The handling, quality and management of water is crucial to obtain a product with the demanding standards required for the production of Pisco. This process is highly dependent on drought conditions, since humidity and evapotranspiration are determinants of the final quality of the grapes.
- Irrigation, quantity and quality of water. The main function of irrigation is to make water available to the plants so that it is absorbed by the roots and transpired by the leaves at a rate that allows them to maintain a good internal water status and perform their productivity functions. As in other crops, in the case of pisca vines, inadequate irrigation management can lead to inadequate crop development, which translates into productivity failures. The amount and timeliness of irrigation provided to the crop will therefore be fundamental for its development and the productive levels achieved.
- Pest and disease management is key to grapevine health: Pests and diseases can reduce grape yield and quality. Similarly, irrigation water control mitigates the presence of pests and fungi, such as powdery mildew, for pisca grapes, a case present in the production of the Cooperados de Alcohuaz, Elqui Valley. The trend is the use of biological pest controls, which is already present in the Capel Cooperatives.
- The loss of vigor of the plants and, as a consequence, the severe reduction in production and grape quality, a problem known as decay, has forced many pisca grape growers to renew the old vines. To do this, grafted plants are used that allow planting in the same place where the old plant was, without affecting their development. Studies carried out by INIA indicate that the use of rootstocks allows a significant increase in plant vigor, production and fruit quality (INIA - INDAP Newsletter, 2017).

That said, as grape varieties are one of the most sensitive productive factors in the production of pisco, the effects of drought and climate on the two most significant varieties are detailed. That is: Moscatel and Pedro Jimenez.

Muscatel:

The Moscatel grape, is sensitive to climate change due to several factors that affect its growth and yield. This type of grape, especially appreciated for its aromatic flavor and high sugar content, requires specific climatic conditions to thrive.

However, climate change is altering these conditions, creating challenges for growers. The sensitivities of Muscat grapes to drought and the process of aridification are detailed below:

Increased temperatures

Accelerated ripening: Increased temperatures cause a faster ripening of these grapes, which can reduce the optimal accumulation of aromas and sugars that are essential for the quality of pisco. This accelerated process can generate imbalances in acidity, affecting both the flavor and structure of the wines and distillates produced.

Heat stress: Intense heat waves, increasingly frequent due to climate change, can damage grape clusters, causing sunburn or heat stress that affects grape quality.

Water scarcity
Dependence on irrigation: In semi-arid regions such as those of the Elqui River basin, Muscatel grape production is highly dependent on irrigation. The decrease in water resources due to prolonged drought, reduced rainfall, and reduced snowfall in the Andes Mountains have affected water availability, forcing the Cooperados to reduce the amount of water available for their crops.

Water stress: Water shortage can generate stress in plants, which affects both yield and grape quality. If the plant does not receive enough water, it may produce fewer grapes and these may be smaller, which negatively affects yield.
Changes in crop cycles
Modification of the agricultural calendar: Changes in seasonal temperatures have altered the natural growth and harvest cycles of Muscat grapes. Warmer winters may not provide the necessary rest period for the vines, affecting their ability to produce high quality fruit.

Earlier harvest: With warmer temperatures, harvest is earlier, which can impact fruit quality if conditions are not optimal for proper ripening.

Loss of fertile soils and desertification:
Soil erosion and degradation: lack of rainfall and intensive agricultural practices in drought conditions can lead to soil degradation, reducing its fertility and ability to sustain crops such as Muscat grapes. Climate change aggravates desertification, putting the long-term viability of vineyards in affected areas at risk.

Soil salinization: In areas where irrigation is carried out with low quality water or from overexploited wells, an accumulation of salts in the soil can occur, affecting the growth of the grapevines.

Changes in the chemical composition of the grapes:
Alteration in aromatic compounds: Muscat grapes are famous for their aromatic profile. However, climatic changes can affect the production of volatile compounds responsible for aroma, which affects the quality of pisco and Muscatel wines.
Reduced acidity: Higher temperatures tend to reduce acidity in grapes, which affects the balance between acidity and sweetness, a key element for the quality of distillates.

Some measures that have been implemented by the Capel Cooperative, for adaptation for Muscatel grapes in the face of climate change, are as follows:

- Efficient irrigation technologies: Implement drip irrigation systems or controlled deficit irrigation to optimize the use of available water.
- Change in vineyard location: Move vineyards to cooler areas or higher altitudes to reduce the impact of high temperatures.
- Selection of more resistant varieties: Research and promote grape varieties that are more resistant to heat and water stress.
- Pest and disease monitoring: Develop monitoring and control programs to reduce the impact of new pests and diseases that may emerge with climate change.

In summary, it is emphasized that the Muscat grape is sensitive to the effects of climate change, especially in terms of extreme heat, drought and alterations in its growth cycle, which can affect both the quantity and quality of production.

Pedro Jiménez
The production of the Pedro Jiménez pisca grape has faced serious problems due to the prolonged and extreme drought affecting the area. This type of grape is highly sensitive to water and climate variations. The main problems that have arisen due to the drought are detailed below:
- Decrease in crop yields: Water shortages have significantly reduced the productivity of Pedro Jimenez vines. As a grape that requires constant irrigation to maintain its quality, water use restrictions have negatively impacted the quantity of grapes harvested.
- Reduced fruit quality: Water stress has led the grapes to develop unfavorable characteristics, such as smaller size and lower sugar content, affecting the quality of the pisco produced from them.
- Soil erosion: Lack of rainfall and the constant use of subway irrigation systems have led to soil degradation.
- Economic problems: Small and medium-sized pisca grape growers have seen production costs increase due to the need to implement more efficient irrigation technologies and purchase water in tanker trucks. This, coupled with reduced yields, has severely impacted their income.
- Adaptations to climate change: The Cooperados have begun to look for more resistant varieties and experiment with new water management techniques to adapt to drought, although this implies additional costs and does not guarantee long-term success.

In summary, the extreme drought has jeopardized both the quantity and quality of Pedro Jimenez grapes, severely affecting the pisca industry and the local economy. The situation has led to an urgent need for new adaptation strategies, such as the efficient use of water and the search for varieties that are more resistant to climate change.

4.3.2 Harvest

The harvest of Pisco grapes begins in mid-February of each year, usually with the earliest variety -Moscatel de Austria-, and concludes with those of longer cycle -Moscatel de Alejandría and Pedro Jiménez. The harvest will be determined by the probable alcohol content, GAP, of the grapes in the bunch, which, according to regulations, must be equal to or higher than 10, 5º G.A.P. (Escobar, Flores et al., PTI).

The ideal time for harvesting grapes is sensitive to volume and quality: Harvesting should be done at the optimum moment of ripening to ensure the best quality of the must. Harvesting too early or too late can affect the pisco profile. For example, in the high altitude production of grapes in the Elqui Valley, the buds of the vines have begun to emerge in September, in normal conditions it would be in the month of October. The late harvest is an effect of climate change and drought.

4.3.3 Reception of Grapes

The grapes received for the distillation process are separated from residues such as leaf and stalk. The reception of grapes determines the volumes for pisco production. The harvested grapes are transferred to the production cellars. This process is critical, since the selection must be made, which is related to the variety and quality of the grapes. The volumes are relevant, and they are highly sensitive to irrigation conditions, which ultimately depends on the aggressiveness of the drought at the time of production.

4.3.4 Destemming and crushing of grapes

Destemming involves separating the grapes from the bunches and then crushing them to obtain the must. In this case, drought can have several effects on the destemming of grapes, influencing both the quality of the grapes and the vinification process, which is part of the production of Pisco. Here are some examples of these effects:
- On mechanization and efficiency: drier grapes can be more fragile and prone to breakage, which can complicate mechanical destemming. This could lead to a greater amount of fragments from destemming in the blend.
- On processing time: Drought conditions can lead to earlier harvesting, which can affect processing time and destemming planning.

4.3.5 Fermentation

Drought can affect the fermentation process in pisco production in several ways. Some of the most relevant effects are mentioned below:
- Grape Quality: Drought tends to concentrate sugars in the grapes, which can result in higher alcoholic potential. This can alter the flavor and aroma profile of the final pisco.
- Loss of Acidity: Grapes affected by drought may have lower acidity, which can affect the balance of the pisco and make the product less fresh.
- Yeast Stress: Water stress can affect the health of yeasts, making them less efficient during fermentation. This can result in slower or incomplete fermentations. The choice of yeast can affect the aromas and flavors of pisco.
- Production of Undesirable Compounds: Stress on yeasts can lead to the formation of undesirable compounds, such as sulfides, which can negatively affect the aroma of pisco.

4.3.6 Distillation

Drought can have a considerable impact on pisco production, from grape quality to the distillation process. It is essential that producers adapt to these changing conditions by adjusting their growing and distillation techniques to maintain the quality of the final product. Of the most important variables to consider are:
- Distillation temperatures: Variations in grape quality may require adjustments in distillation temperatures. If the grapes have a higher sugar content, this may influence the process and distillation efficiency.
- Aromatic compounds: The concentration of aromatic compounds due to drought can enrich the pisco profile, but may also require greater control during distillation to avoid the extraction of undesirable flavors.
- Concentration of sugars: Grapes can become smaller and more concentrated due to lack of water, resulting in an increase in sugars and aromatic compounds. This can result in a more intense pisco with higher alcoholic potential.

4.3.7 Ripening
Drought can have multiple effects on the pisco ripening process, from grape quality to storage conditions. Pisco grape growers must adapt to these conditions to ensure that the pisco maintains its desired quality and character. The changes that maturation undergoes are reflected in the following points:
- Concentration of compounds: Drought can lead to a higher concentration of sugars and aromatic compounds in the grapes, which can result in a pisco with a richer and more complex profile. This can influence how it develops during maturation.
- Maturation and Oxygenation: During maturation, pisco interacts with oxygen through the wood in the barrels. The quality and quantity of the aromatic compounds developed in this process may be different if the grapes were affected by drought.
- Environmental conditions: Drought can affect the temperature and humidity in the cellars, which influences the evaporation rate and how the pisco behaves during maturation. A drier environment can accelerate evaporation, which in turn can further concentrate flavors.
- Duration of maturation: If the pisco has a more concentrated profile due to drought, producers may choose to shorten or lengthen the maturation time to achieve the desired balance in flavor
- Production and Availability: Drought may reduce grape yields, which could limit the amount of pisco available for maturation. This may affect the supply and overall quality of the product in the market.
- Storage conditions: Pisco can be stored in stainless steel tanks or wooden barrels. Storage conditions (temperature, humidity) affect the final profile of pisco.
- Contamination: Contamination in the maturation process (e.g. bacteria or fungi) can negative

4.3.8 Canning
This process is not influenced by drought conditions, which affect grape production. The problems are mostly related to hygiene and quality control.

4.3.9 Distribution and Marketing
This process will be affected by the drought only in terms of transportation logistics, in terms of the quantity of containers to be distributed and marketed, which will be determined by the volume of pisco produced, which depends on the quantity and quality of grapes processed, and is certainly related to the effects of the drought and aridification.

5.Solutions and actions developed by grape grower cooperative members based on nature and drought resilience.

5.1 Initiatives carried out to mitigate the effects of the drought
Faced with drought and aridification, producers have resorted to various solutions to continue grape production. Some of these are technological and others respond to ancient traditions or solutions based on nature.

5.1.1 Technological (irrigation, humidity, information systems)
The CAPEL Cooperative and its Cooperative Members have taken several measures to mitigate the impact of drought in the most critical years. These measures include the following:

1. Massive implementation of technified irrigation: To optimize the use of available water and ensure the sustainability of production, many CAPEL cooperatives adopted drip irrigation systems and other efficient technologies. This has made it possible to reduce water losses and improve water resource management in years of extreme drought. The massive

implementation of technified irrigation systems, such as drip or micro-sprinkler irrigation, has been one of the most important measures to improve water use efficiency. These systems allow water to be applied directly to plant roots, reducing evaporation and runoff losses. This implementation has allowed the Cooperados to save up to 50% in water consumption compared to irrigation by laying, increasing the sustainability of the vineyards in drought conditions.

2. Application of soil moisture sensors. Some of CAPEL's Cooperatives, approximately 56 of them, have been using humidity measurement sensors for some years. The characterization of the soil wetting and drying cycles is carried out by these capacitance sensors buried at different depths, which make it possible to keep track of the irrigation times, the areas wetted at each irrigation, as well as the depletion of the soil

3. Use of reservoirs and water storage: The Cooperative has actively participated in projects to improve water storage in the region, such as the Puclaro reservoir and other storage systems in the Elqui River basin.

4. Research on drought-resistant varieties: CAPEL has been involved in research projects to develop or identify pisca grape varieties that are more resistant to water stress, in conjunction with INIA.

5. Wastewater treatment and reuse. Certain Cooperatives have begun to implement gray or wastewater treatment systems for reuse in irrigation. This involves the use of filtering and biological treatment technologies that make it possible to reuse the water used in other agricultural or domestic activities. The reuse of treated water reduces pressure on local water resources and allows the Cooperatives to maintain grape production even in extreme drought conditions.

6. Renewable energy and energy efficiency. Certain cooperatives have begun to install solar panels to reduce the use of conventional energy in their vineyards, particularly to power technified irrigation systems. Solar energy is used to pump water and operate other agricultural machinery. Solar energy not only reduces the cooperatives' energy costs, but also reduces the carbon footprint of pisca grape production, improving environmental sustainability.

7. Optimizing the use of agricultural machinery: The cooperative has adopted practices to improve efficiency in the use of agricultural machinery, reducing the unnecessary use of tractors and heavy fuel-consuming equipment. This includes careful planning of farm operations to optimize energy consumption. Optimizing machinery use reduces both energy costs and greenhouse gas emissions, contributing to more sustainable production.

8. Reuse of wastewater in pisco production. Pisco production at CAPEL generates a considerable volume of wastewater as part of the distillation process and other industrial operations. The Cooperative has taken measures to treat this water and, in some cases, reuse it in a sustainable

a. Wastewater treatment plants: CAPEL has implemented wastewater treatment plants to process effluents generated during pisco production. These plants use technologies such as filtration, biological treatment, and other processes to purify the water prior to discharge or reuse. Wastewater treatment helps minimize contamination of local water bodies by ensuring that the wastewater leaving the plant complies with environmental regulations. This process also reduces the environmental impact of pisco production and ensures a more sustainable operation.

b. Reuse of treated water for irrigation: In some cases, treated water can be reused for irrigation of green areas or for agricultural purposes not directly intended for consumption, such as reforestation or revegetation of areas affected by drought. This secondary use of treated water has been explored by CAPEL and some of its Cooperated Companies. The reuse of treated water reduces pressure on local water resources, especially in a context of water scarcity. Although this practice is not yet widespread in all vineyards, it has been explored as an option to increase the sustainability:

9. Improvements in waste management: In order to minimize the environmental impact of this waste, the following improvements have been proposed and in some cases implemented:

a. Improvements in the treatment of vinasse: CAPEL and other cooperatives are exploring options such as the production of biogas from the vinasse, which would not only reduce its environmental impact, but would also generate a renewable energy source.

b. Community composting programs: Cooperatives such as CAPEL have begun to establish community composting programs, where pomace, stalk and pressed residues are managed in a centralized manner, producing compost in large volumes for agricultural use.

c. Research on waste reuse: New uses are being investigated for the by-products of the pisca industry, such as the production of Biochar (charcoal) from pomace to improve water retention in soils and carbon sequestration.

CAPEL has been a pioneer in the pisco industry in developing innovation processes, which have included R&D projects such as the one mentioned above. Other projects of the same nature have been: Development of water from grapes; functional juices using pisco grapes, with the inclusion of Omega 3; exploration of solutions to mitigate the effects of hangovers caused by alcohol; and liquid and solid treatment plants, among others.

5.1.2 Based on Nature

The case of the town of Caracoles, El Maitén sector, Monte Patria, Ovalle, Coquimbo region, has been explored, where nature-based solutions are presented for the sustainability of the town's ecosystem. In fact, there are three relevant events:

1. The practices of organization and resistance: in places of Monte Patria, since 2015 a group of farmers organized to add their water rights and gather the necessary votes to integrate the board of directors of the local Board.(Castillo et al. 2024).

2. Biodiversity maintenance through “teja”. The concept corresponds to a small flow that circulates through the common channel, which is used for human consumption and maintenance of the ecological flow necessary for the maintenance of flora and fauna. This small flow is expected to flow at all times at the disposal of the irrigators. Although there are some communities that have managed to maintain the “tile” in their canals, providing water both for human consumption and for the consumption of animals and plants, most do not have this right, affecting consumption and ecosystem diversity (Castillo et al., 2024). (Castillo et al., 2024).

3. Lining of irrigation ditches with recycled geomembranes. These are strips of geomembrane of the order of 2 meters, leaving at least 1 meter inside the irrigation ditch, embedded in the soil, to allow the irrigation water to move well in the canal, leaving the spaces uncovered with plastic material, to maintain the biodiversity of flora and fauna of the ecosystem. (Cortés, Cooperado de Capel, 2024).

Other solutions along the same lines as those implemented in El Maitén, which are part of other pisca grape production sites, are the following:

4. Improvement of soil fertility:
a. Composting and use of organic fertilizers: Several Cooperatives have adopted composting as a key practice to improve soil fertility and reduce reliance on chemical fertilizers. They use plant remains, pruning residues and organic waste from grape production to create compost, which is then applied to the vineyards as organic fertilizer. Composting improves soil structure, increases its water retention capacity and reduces erosion, which is critical in semi-arid areas such as the Elqui Valley. It also reduces input costs and minimizes the environmental impact of chemical fertilizers.
b. Incorporation of cover crops: Cover crops are plants that are planted between vineyard rows to protect the soil, increase its organic matter content and prevent erosion. These plants also help improve water retention in the soil. By increasing soil biodiversity and improving soil structure, cover crops contribute to the long-term sustainability of vineyards and reduce the need for synthetic fertilizers.

c. Crop rotation and diversification: Some Cooperatives have begun to diversify their crops or practice crop rotation to improve soil health and reduce nutrient depletion. Although pisca grapes remain the main crop, the introduction of other crops, such as fruit trees or legumes, helps to maintain soil fertility. Crop diversification not only improves soil sustainability, but also reduces economic dependence on a single product and provides an alternative source of income.
5. Adaptation and water conservation: CAPEL cooperatives have implemented buffer zones in areas near bodies of water, such as the Elqui River, to protect the banks and prevent erosion. These areas also contribute to the conservation of local biodiversity. These zones protect water resources and prevent river sedimentation, while providing habitat for wildlife species, improving the ecological sustainability of the plantations.

6. Controlled deficit irrigation practices: Certain Cooperatives have applied controlled deficit irrigation, a technique that consists of applying less water than the plant would need at certain stages of its development, without compromising the quality of the fruit. This optimizes the use of available water, concentrating the application in the critical stages of the crop. This practice reduces water consumption by up to 30% without affecting the quality of the pisca grapes, which is especially useful in times of drought.
7. Sustainable waste management: Some Cooperatives have established recycling programs for plastics used in agriculture, such as irrigation pipes, phytosanitary product containers, and other waste generated in agricultural operations. This practice reduces environmental pollution and encourages the reuse of materials, contributing to a circular economy within the agricultural sector.
8. Sustainable pesticide management: Many Cooperatives have adopted more sustainable pesticide management practices, reducing the use of chemicals and opting for biological control or integrated pest management, which reduces the environmental impact of production. This sustainable management helps protect biodiversity, improves soil quality and reduces groundwater contamination.

9. Reduction of water consumption in the production process: CAPEL has implemented measures to reduce water consumption in the pisco production process through technologies that allow recirculating the water used in certain industrial processes. Water efficiency has

been significantly improved in pisco production, reducing the total volume of water required by the plant and minimizing water waste in an environment where this resource is scarce.
10. Solid waste management: Solid waste generated in the production of pisco, such as grape skins, is processed and used in the manufacture of compost or as animal feed. This approach allows for more sustainable management of organic waste, avoiding landfill disposal. By transforming solid waste into useful products, CAPEL contributes to a circular economy, reducing the environmental impact of its operation (see the case of Alejandro and Laura, Cooperados de El Maitén, Monte Patria, Limarí Province).

11. Incentives for sustainable practices: CAPEL has encouraged sustainable practices among its cooperative members through incentives and training programs that promote efficient water management, the use of efficient irrigation technologies, and the reduction of the environmental impact of agricultural production.

6. Differences in productive and ecosystem impacts between irrigation techniques.

The Elqui Valley currently presents a scenario where different irrigation and agricultural management systems coexist for pisca grape production. On the one hand, we find technified irrigation (mainly drip and micro-sprinkler), which represents approximately 70% of the productive area, and additionally, traditional systems based on mixed irrigation combined with ancestral water management techniques. This duality of approaches to water management offers a unique opportunity to comparatively analyze their impacts both in productive and ecosystemic terms.
The evaluation of these systems is particularly relevant in the current context of extreme drought, where the valley is facing a 32% reduction in flow (2023) and its reservoirs are operating at 18% of their capacity. Under these conditions, it is essential to understand how each irrigation system not only affects the yields and quality of the pisca grape, but also its interaction with the surrounding ecosystem and the long-term sustainibity.

In the Elqui River Valley area, there are agroecological ecosystems that, to date, have not been fully valued due to the lack of baseline information that would allow the development of the required indicators. In a future study, various tools will be used, such as the Integrated Valuation of Environmental Services and Trade-offs (InVEST) of the projects carried out by the Natural Capital Committee or the Artificial Intelligence for Ecosystem Services (ARIES) modeling platform. These tools aim to help map the provision of ecosystem services and model their evolution over time, associate them with an economic value, identify scenarios and help decision-makers evaluate the trade-offs between these scenarios for informed decision making.

In this study on the Elqui Valley, the ecosystem services generated by two pisca grape production systems are comparatively analyzed: the traditional method with technified irrigation and the agroecological system with nature-based solutions (NBS). Both systems generate differentiated impacts in terms of ecosystem, social, economic and health benefits, affecting both the crop and the cooperative members. The analysis is based on the categorization established by the Millennium Ecosystem Assessment (2005), a conceptual framework currently used by the United Nations. The basic information on the stocks and flows of ecosystem services comes from extensive field work that included interviews with farmers, CAPEL executives and experts in agriculture, environment and social sciences in the region.

As an introduction, the following table presents a categorization of the ecosystem services generated by pisca grape plantations in the Elqui Valley for both types of crops. Some of these variables will be analyzed qualitatively and others can be incorporated into the cost-benefit analysis into the cost-benfit analysis that follows.

Procurement Services

1. Raw Material

Pisco grape production as the main raw material is expected to show similar marginal yields in both technified and agroecological systems under optimal conditions. This is because both systems have managed to optimize their specific practices to maintain commercially viable production levels. In the technified system, this is achieved through the precise application of inputs and irrigation, while in the agroecological system it is achieved through integrated ecosystem management that favors the natural resistance of the plants and their adaptation to the environment.

- Description: Direct production of grapes for pisco production.
- Comparison: Similar yield in both systems (=, =).
- Observation: Average marginal yield is comparable, although it may vary according to specific conditions.

Biodiversity

The difference in biodiversity between the two systems is notable. While the technified system tends to simplify the ecosystem to facilitate mechanized management, agroecological systems actively promote biological diversity. This is evidenced by the presence of multiple species of plants, insects and animals that coexist with the main crop. The integration of animals such as goats and chickens not only contributes to biodiversity, but also provides services such as weed control and natural fertilization.

- Description: Diversity of living organisms associated with the crop.
- Comparison: negative in technified (-) vs very positive in agroecological (++).
- Observation: Agroecological systems maintain greater diversity from microorganisms to larger animals.

3. Genetic Resources

In terms of genetic resources, both systems maintain the traditional varieties of pisco grapes such as Moscatel de Alejandría, Pedro Jiménez and other historical grape varieties of the valley. This ecosystem service is equally valued in both approaches, as the quality and specific characteristics of these varieties are fundamental to maintaining the denomination of origin and quality of pisco.

- Description: Conservation of pisca grape varieties.
- Comparison: Similar in both systems (=, =)
- Observation: Both systems contribute equally to preserve traditional varieties.

Regulatory Services

Climate Regulation

Agroecological systems demonstrate a greater capacity for microclimatic regulation due to their greater vegetation cover and structural diversity. The presence of different strata of vegetation, including cover crops and associated vegetation, generates a buffering effect on temperature extremes and helps maintain humidity. In contrast, technified systems, with less vegetation cover, are more vulnerable to thermal fluctuations.

- Description: Local temperature control by vegetation cover
- Comparison: Negative in technified (-) vs positive in agroecological (+)

- Observation: More vegetation in agroecological systems improves thermal regulation.

Sediment Retention

In terms of erosion control, agroecological systems show a clear advantage. The combination of cover crops, organic matter management and soil conservation practices results in greater stability and resistance to erosion. Technified systems, although they can implement anti-erosion measures, are more susceptible to soil loss, especially in extreme climatic events.

- Description: Soil erosion prevention
- Comparison: Negative in technified (-) vs positive in agroecological (+)
- Observation: Agroecological systems prevent soil loss better.

3. Pest and disease control

The most marked difference is observed in pest and disease control. Agroecological systems develop natural biological control through functional biodiversity, where natural predators and ecosystem balance prevent severe pest outbreaks. The technified system depends mainly on programmed applications of pesticides, which can generate resistance problems and affect beneficial organisms.

- Description: Natural pest management
- Comparison: Negative in Technified (-) vs. very positive in Agroecological (+++)
- Observation: Agroecological systems achieve natural control without pesticides.

5. Natural Pollination

Agroecological systems create ideal conditions for natural pollinators by maintaining flowers throughout the year and avoiding the use of harmful pesticides. This results in a complex network of pollinators that benefit not only the main crop but the entire ecosystem. Technified systems, on the other hand, tend to rely more on directed or managed pollination, with less presence of natural pollinators.

- Description: Wild pollinator services
- Comparison: Negative in technified (-) vs very positive in agroecological (+++)
- Observation: Greater biodiversity attracts more natural pollinators.

6. Water regulation

Water management shows significant differences. Agroecological systems favor natural infiltration and water retention in the soil through practices such as organic mulching and soil structure management. Technified systems, although efficient in the direct application of water, have less natural retention capacity and depend more on artificial infrastructure.

- Description: Natural water management
- Comparison: Negative in technified (-) vs very positive in agroecological (++)
- Observation: Natural systems improve aquifer recharge.

Cultural Services

Recreation and Tourism

The tourism potential is significantly greater in agroecological systems, which offer a more authentic and educational experience for visitors. These systems showcase traditional and sustainable practices that attract tourism that is increasingly interested in sustainability and connection to local culture. Technified systems, although efficient, have less tourist appeal.

- Description: Attractive for visitors
- Comparison: Negative in technified (-) vs positive in agroecological (+)
- Observation: Agroecological systems attract sustainable tourism.

Cultural Values
The preservation of cultural values is more evident in agroecological systems, where ancestral knowledge and practices are maintained and transmitted. These systems act as living repositories of the valley's traditional agricultural culture, while technified systems tend to standardize practices and reduce the transmission of traditional knowledge.
- Description: Preservation of traditions
- Comparison: Negative in technified (-) vs very positive in agroecological (++)
- Observation: Agroecological systems

3. Spiritual Development
The contribution to spiritual development is more pronounced in agroecological systems, which maintain a deeper connection with natural cycles and local traditions. These systems integrate better with the mystical character of the Elqui Valley, while technified systems have a more productive and less spiritual orientation.
- Description: Connection with the territory
- Comparison: Negative in technified (-) vs positive in agroecological (+)
- Observation: Complements the mystical character of the valley.

4. Territorial Identity
Agroecological systems strengthen territorial identity by maintaining traditional practices and landscapes that characterize the Elqui Valley. These systems contribute to preserving the cultural heritage of Pisco in a more comprehensive manner, while technified systems, although efficient, have less impact on the preservation of local identity.
- Description: Sense of belonging
- Comparison: Negative in technified (-) vs. positive in agroecological (+).
- Observation: Strengthens local pisca

Support Services
Environmental Support
Agroecological systems provide more robust support for local flora and fauna, creating diverse and connected habitats. The interaction between different species and the maintenance of biological corridors favors ecosystem resilience. Technified systems, with their more simplified approach and use of agrochemicals, provide less support for local biodiversity.
- Description: Biodiversity support
- Comparison: Negative in technified (-) vs very positive in agroecological (++)
- Observation: Agroecological systems support more wildlife.

2. Nutrient Cycling
Nutrient cycling is more efficient in agroecological systems due to the diversity of organisms and active biological processes. Incorporation of organic matter, composting and soil biological activity create more closed and self-sufficient cycles. Technified systems are more dependent on external nutrient inputs and have more linear cycles.
- Description: Natural soil fertility
- Comparison: Negative in technified (-) vs positive in agroecological (+)
- Observation: Better nutrient cycling in natural systems.

3. Soil Formation

Agroecological systems are more effective in the formation and continuous improvement of soil through the accumulation of organic matter and biological activity. Integrated soil management favors soil structure and natural fertility. Technified systems, although they can maintain productivity, have less capacity to build new soil and improve its quality.
- Description: Fertile soil development
- Comparison: Negative in technified (-) vs. positive in agroecological (+).

7. Cost Benefit Analysis with an ecosystem approach based on the information collected from CAPEL cooperative members in the Elqui Valley.

Currently, 70% of the cooperative members have implemented irrigation technology to combat drought. This technification has significantly reduced water consumption from 18,000-20,000 m3 to 6,000-8,000 m3 per hectare. The systems include drip irrigation and optimized practices such as night irrigation to minimize evaporation.

Some cooperatives are also experimenting with Enviroscan and Drill & Drop probes that allow real-time soil moisture measurement. These tools are complemented by remote sensing systems to assess crop conditions, allowing precise telematic control of irrigation. This technology is being adopted by the larger cooperatives and as this exercise will be done on the basis of a 1 hectare producer, this innovation will not be evaluated.
Additionally, nature-based solutions have proven to be particularly effective in the fight against desertification. Soil management has focused on organic practices, including the extensive use of compost, humus and natural fertilizers from goat, sheep and donkey guano. These practices not only improve soil fertility, but also increase its water retention capacity.

Biological control of pests and diseases has become a fundamental strategy. The integration of chickens has been effective in controlling the “vine burrito”, while sheep help with weed control. The incorporation of bees improves pollination, and the installation of living barriers, such as maitenes, helps control bacteria. These practices not only control pests, but also contribute to maintaining the biodiversity of the ecosystem.
In terms of water management, traditional practices are maintained, such as the “tile” system, which ensures a minimum ecological flow. Partially open canals maintain biodiversity, and buffer zones have been established near water bodies. Controlled deficit irrigation has been implemented as a strategy to optimize the use of available water.

Finally, community organization has been crucial in the fight against desertification. Water communities and cooperative surveillance boards have developed effective systems for water distribution, including collective agreements and irrigation shift systems. These organizational structures have allowed a more efficient and equitable management of water resources.
Technical support and training have been fundamental.

CAPEL provides ongoing technical advice to its cooperative members and develops training programs in sustainable management. Emphasis has been placed on the transfer of ancestral knowledge and support in applying for government funds such as INDAP and CNR.

7.1 Economic analysis with emphasis on sustainability

The Elqui Valley is currently facing a critical process of aridification, with a 32% reduction in water flow during 2023 and reservoirs operating at 18% of their capacity. In this context, pisca grape growers have developed different adaptation strategies that can be classified into two large groups: those who have opted for irrigation technification as the main response (70% of the cooperative members), and those who, in addition, have implemented (or maintain) agroecological systems with nature-based solutions.

This economic analysis seeks to compare the financial viability of both productive models, considering not only direct monetary aspects, but also incorporating a sustainability perspective that includes ecosystem services and resilience to climate change. The study is based on real data from CAPEL cooperative members, which show contrasting experiences such as the case of Mrs. Ninfa Galleguillos (conventional technified system) and Alejandro Cortés (biodynamic agroecological system).

The evaluation considers a 10-year horizon (2024-2034) for a productive unit of 1 hectare, with a density of 1,600 plants per hectare. The flows have been discounted using a discount rate of 8%, reflecting the opportunity cost of capital in the Chilean agricultural sector. The analysis incorporates the following differentiating elements:

- Cost structure: While the conventional system requires investment in technification and chemical inputs, the agroecological system minimizes external inputs, but requires more labor and knowledge of the ecosystem.
- Productive yields: Documented historical yields are considered, which show greater stability in agroecological systems in the face of extreme climatic events.
- Ecosystem services: The qualitative valuation of services such as natural pest control, improved water retention and increased biodiversity is incorporated.
- Resilience: The capacity of each system to maintain production under conditions of increasing water stress is evaluated.

7.2 Description of costs of a traditional and an agroecological 1-hectare crop

The economic evaluation of the pisca grape production systems in the Elqui Valley requires a detailed analysis of the costs associated with both the conventional system with technified irrigation and the agroecological system with nature-based solutions. This analysis is based on data collected directly from the cooperative members.

The conventional system with technified irrigation requires a substantial initial investment of USD 8,300 per hectare for the installation of the drip irrigation system. This investment is typically financed through INDAP, which contributes 90% (USD 7,470), while the cooperative contributes the remaining 10% (USD 830). Annual operating costs are distributed mainly in three categories: labor (60%), machinery (7%) and inputs (27%).

Labor in the conventional system represents the highest operational cost, reaching USD 2,901 per hectare per year. This amount is broken down into different tasks: USD 800 for pruning and tying (25 days), USD 128 for vineyard maintenance (4 days), USD 384 for irrigation (12 days), USD 256 for phytosanitary applications (8 days) and USD 1,333 for harvesting (50 days). Machinery costs total USD 320 per hectare per year, divided between agrochemical application (USD 256) and internal harvest hauling (USD 64).

Inputs in the conventional system represent a significant cost of USD 1,412 per hectare per year. This includes fertilizers such as diammonium phosphate (USD 89), urea (USD 173), sulfuric acid (USD 29) and potassium nitrate (USD 99), as well as compost (USD 523) and agrochemicals such as fungicides (USD 53), insecticides (USD 29) and herbicides (USD 24). Energy costs for irrigation, including water and electricity, amount to USD 379 per year.

On the other hand, the agroecological system presents a significantly different cost structure. The initial investment is lower, approximately USD 3,400 per hectare, distributed between the adaptation of the traditional irrigation system (USD 2,130), implementation of biodiversity zones (USD 850) and establishment of cover crops (USD 420). Operational costs show a higher proportion of labor (75%) but a significant reduction in external inputs (5%) and energy costs.

Labor in the agroecological system increases with respect to the conventional system, reaching USD 2,927 per hectare per year, due to the additional management required for biodiversity. However, machinery costs are significantly reduced, reaching USD 218 per hectare per year. Inputs are drastically reduced by using own compost and biodynamic preparations, with an approximate annual cost of USD 204 including water and electricity.

The analysis is based on several key assumptions: a 10-year time horizon (2024-2033), a discount rate of 8%, an average yield of 26,000 kg/ha and an initial expected price of USD 0.235/kg rising to USD 0.32/kg in real terms at the end of the period. Planting density is maintained at 1,600 plants per hectare, with 45% of the vines being over 25 years old.

It is important to note that there are aspects not monetized but considered in the analysis, such as some of the ecosystem services described in the previous chapter, climate resilience, biodiversity, soil quality, input autonomy and preservation of traditional knowledge. Methodologically, all prices include VAT, input costs consider the value placed in the field, labor includes taxes and levies, and an additional 5% is applied for contingencies on variable costs.

7.3 Basis for estimating the price of pisca grapes and grape yield per hectare

The price of pisca grapes is determined in the market, a market that is not regulated and that, conceptually, results from the relationship between the quantity of grapes available and the demand for grapes by the pisco producing companies.

The total area planted with pisco grapes in the regions of Atacama and Coquimbo, as reported in the 2023 national vineyard cadastre, is 9,122 hectares. Of this total, about 85% corresponds to small producers, with plantations of less than 4.0 hectares. Although the producers are atomized, most of them are associated in agricultural cooperatives, such as the Cooperativa Agrícola Pisquera Elqui Ltda, Capel and the Cooperativa Agrícola Control Pisquero de Elqui y Limarí Ltda. Control.

These cooperatives are the main buyers of their members' grapes, which they use as the main input in the production of pisco, an alcoholic distillate with a denomination of origin (D.O.) in the area, defining a market structure of vertical integration between producers of pisca grapes and producers of pisco and its by-products. This, together with the cooperatives' bylaws that prohibit their members from marketing grapes to third parties, allows inferring that the cooperatives have a degree of market power over their members. However, although the cooperatives concentrate the purchasing power of the pisca grapes, they do not use their power to unilaterally fix the price of the grapes, due to their organic structure as cooperatives which, unlike the rest of the companies, do not try to obtain their raw materials at the minimum cost to maximize their corporate profits, but rather the benefit of their cooperative members.

Thus, the demand for pisca grapes by the cooperatives depends directly on the demand for pisco in the final market. For this study, it was assumed that the demand for pisco in the domestic market would remain at the current level (around 2 liters per capita per year) during the ten years considered in the cost-benefit evaluation, a conservative estimate considering the stable behavior of the domestic market for distilled spirits and the projected increase in pisco exports. In numbers, this means an annual production of 36 million liters of pisco and an approximate demand of 150,000 tons of pisco grapes per year.

Being more specific and focusing on Capel's cooperatives, this study is based on the results of the pisca grape harvest corresponding to the 2023-2024 agricultural season, which did not exceed 50,000 tons. In the current drought conditions, this season's production represents only 25% of the 200,000 tons produced and demanded in the year 2000. In this production scenario of deficit in the supply of pisca grapes, which is not enough to cover Capel's historical demand, added to the fact that it is not technically feasible to reduce the amount of grapes per liter of pisco, the assumption is that grape prices will not be affected downwards by the lack of demand for pisca grapes in the coming years.

On the contrary, the projection of the supply of pisca grapes in the 10-year horizon is complex and highly variable, since climatic conditions, the main variable that defines the outcome of the agricultural year's harvest in quantity and quality of grapes, which in normal periods is uncertain, is even more so is the cycle of climate change that the country is facing and in particular, the aridification of the regions of Atacama and Coquimbo. The water situation is so serious that the agents in the area point out that this year's rainfall (2024) is not a solution, since the water reservoir capacity is only enough for the 2024-2025 season.

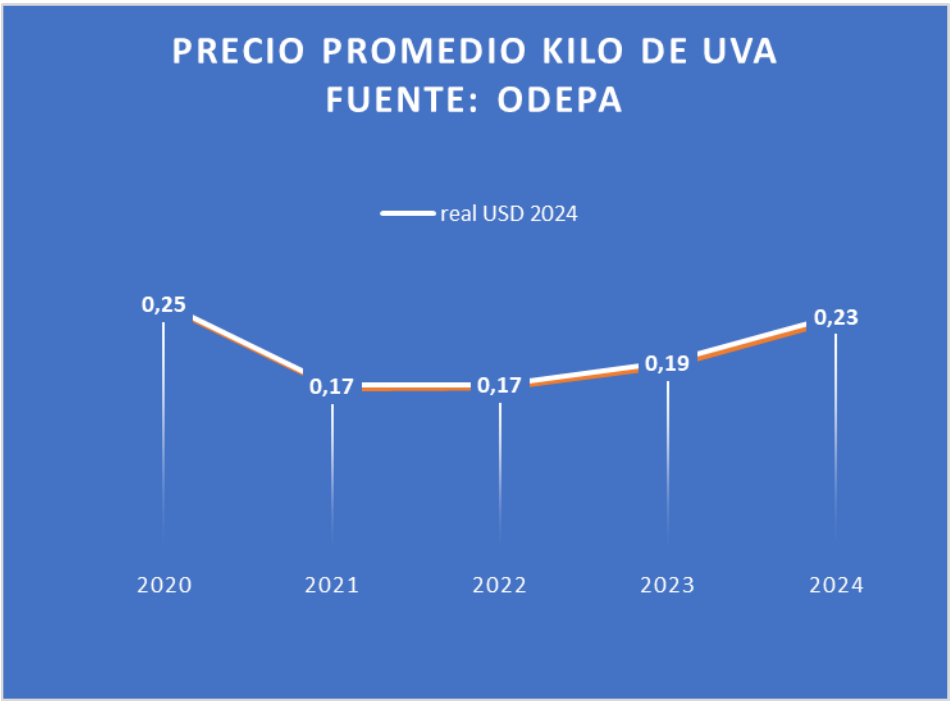
The following words of the CEAZA Scientific Center researcher, Dr. Katerina Goubanova, shed light on this during her presentation “Projections of the future climate in the Coquimbo Region: understanding uncertainties and anticipating impacts”, developed at the Future Congress 2023:
And what could happen with the climate in the Coquimbo Region in the future? The researcher mentions that with respect to changes in air temperature near the surface, “it is expected that the oceanic region in front of the Coquimbo Region will warm less rapidly than the Earth on average. Therefore, in the coastal communes the warming will be relatively moderate. However, the high mountains will experience much greater temperature changes”.

On the other hand, contrary to Central Chile, where climate models agree on a decrease in average precipitation in the future, the Coquimbo Region is associated with several uncertainties related to precipitation projections. Some models show a decrease; others show little change; while others project an increase,” she adds.

Although there has never been an abundance of water in this area, for the last decade or so, water scarcity has been increasing, forcing farmers to resort to more efficient irrigation techniques, some of which require significant amounts of investment and/or other nature-based solutions, which are cheaper to implement, but less efficient in the short term to reduce water consumption. However, the task of making more efficient use of water is increasingly difficult due to decreasing yields and, what has been happening is that the yield of kilos of grapes per hectare has been decreasing, as has the average quality of the grapes and, in parallel, there are cooperatives that have been decreasing the area of land allocated to vines and others have completely withdrawn from the activity. All of the above explains the decrease in the production of pisca grapes over the last decade.

In summary, what is observed in the pisco grape market is a stable demand and a significant decrease in supply, which, according to economic theory, should be adjusted by an increase in the price of grapes. However, in this case, the margin for the cooperatives to increase the price is very small, since they are limited by the results of the pisco production and commercialization business, which is defined by the price of pisco in the competitive domestic distilled spirits market.

In the current scenario of supply and demand of pisco grapes described above, a more extreme adverse climate environment and water supply solutions, such as the desalination plant project in Coquimbo, still far away, the assumption is that the price of grapes will grow 3% real annual, which in 10 years means reaching a price of $301 per kilo in today's currency, similar to the price of 2013 and 2014, when the cooperatives were1,050 (765 in 2024).



he average yield per hectare of the Capel cooperatives has followed a downward trend since the 2017-2018 season. The estimate for that year was 31 ton/ha, decreasing to 14 ton/ha in the 2021- 2022 season, recovering in the last two seasons, but without exceeding 20 ton/ha. The yield per hectare depends on soil quality, use of fertilizers and pesticides, grape variety, number of vines per hectare, labor occupation, irrigation technology and, mainly, climatic conditions and availability of irrigation water. While the first variables are mostly controllable, the last two are exogenous, i.e. they do not depend on the farmer's actions. Faced with the new climate change scenario, these uncontrollable variables, which are included in the assessment of the risk inherent to agricultural activity, also add uncertainty, since there is no historical information to model the expected behavior patterns of climate variables.

In order to evaluate the impact on grape yield per hectare of each of the yield variables, both controllable and non-controllable, ideally detailed historical information would be required to conduct a causal study with the objective of constructing a model of grape production behavior, using econometric and statistical estimation techniques. However, for the present study, limitations in the access to systematic historical data, both in primary and secondary sources, did not allow the development of an analysis of this nature. The information available was mainly limited to data collected in the field through interviews and direct observation, complemented with partial documentation provided by cooperative members and available literature.

For a more exhaustive interpretation to explain in greater detail and precision the way in which each variable impacts grape production yield, it would be necessary to complement the analysis with integrated biological and climatic models. This methodological limitation, together with the need to develop a robust long-term data collection and analysis system, constitutes one of the main recommendations for future research in this field.

This being said, and with the information available from public agencies dedicated to agricultural studies, we can see an average annual yield of 22 tons/ha in the last 6 years. It is important to note that these figures include a great heterogeneity of producers. Among them are cooperative members who are not exclusively dedicated to wine production, others who have diversified their sources of income due to the decrease in prices or productivity, and some who maintain their vineyards more as a secondary or traditional activity than as their main source of livelihood.

For this reason, and considering that this is a case study focused on the cooperative members of the Elqui Valley, we have chosen to use as a reference the yields reported in the field interviews by Mrs. Ninfa Galleguillos and Mr. Alejandro Cortés, cooperative members who are dedicated full time to the production of pisca grapes. In the specific case of Mrs. Ninfa, her yields have fluctuated from 37,000 kilos in her best year to 31,000 kilos last year, reaching 26,000 kilos this year due to the drought. Considering this data and the observed trend, we have taken as a reference for our analysis a yield of 27,000 kg/ha, a figure that reflects a conservative scenario with respect to the historical yields of dedicated producers, but realistic considering the current drought context. This methodological decision allows us to work with empirically more realistic data that reflect the productive potential of a hectare under dedicated and professional management, even in the current context of water restriction. In addition, it is expected that the effect of the drought will be partially offset by the actions taken by the cooperative members to optimize water use.

7.4 Description of benefits of a traditional and a 1 hectare agroecological crop.

The comparative evaluation of the benefits between the conventional technified system and the agroecological system in the Elqui Valley reveals significant differences that go beyond the traditional financial analysis. The study, based on evidence gathered from cooperators and local experts, shows distinctive patterns in terms of direct monetary benefits, ecosystem services and resilience of the production system.

The conventional technified system demonstrates its strength mainly in direct monetary benefits, generating an operational cash flow that evolves from USD 3,401 to USD 4,289 per hectare during the period analyzed, with a growth of 20.8% in 10 years. This performance is based on significant water savings, with a 50% reduction compared to traditional irrigation, from 18,000-20,000 m^3 to 6,000-8,000 m^3 per hectare. Yields remain stable at around 26,000 kg/ha under normal conditions, facilitated by precise nutrient and pest control that ensures product quality.

The agroecological system exhibits superior financial performance, with an operating cash flow that grows from USD 4,750 to USD 5,578 per hectare, resulting in an NPV 36.5% higher than the conventional system (USD 34,084 versus USD 24,895). This economic advantage is built on the elimination of agrochemical and synthetic fertilizer costs, lower energy consumption, and a remarkable stability in yields under water stress conditions. In addition, productive diversification, which includes medicinal herbs and honey production, generates significant complementary income.

The non-monetary benefits of the agroecological system are particularly notable in environmental terms. It is estimated, according to the information gathered, that there is a reduction in water consumption due to better soil retention, an annual increase in organic matter, and an increase in the biodiversity of beneficial species.

The ecosystem services generated by the agroecological system are diverse and significant. In terms of provisioning, in addition to the sustainable production of pisca grapes, complementary products are generated and local genetic resources are conserved. Regulatory services include natural pest control (with natural biological fences), improved natural pollination, microclimate regulation and greater resilience to extreme events. Cultural services include the preservation of traditional knowledge, the potential for sustainable tourism and the strengthening of territorial identity. Support services are manifested in the improvement of nutrient cycles and the formation of fertile soil.

The time dimension is very relevant. It would be expected that in the short term (1-3 years), the conventional system shows immediate benefits in water savings, while the agroecological system should require a transition period. In the medium term (4-7 years), the agroecological system begins to show advantages in terms of resilience and ecosystem benefits become more evident. In the long term (8-10 years), the agroecological system demonstrates better overall economic performance, with an accumulation of ecosystem benefits that generates greater resilience and less dependence on external inputs.

In a final dimension, the positive externalities of the agroecological system also impact the territory as a whole. The conservation of local biodiversity, the improvement in the valley's ecosystem services, the preservation of traditional knowledge and the strengthening of cultural identity represent benefits that transcend the individual level of each producer. In addition, the contribution to climate change adaptation positions this system as a key strategy for the future sustainability of the Elqui Valley.

7.5 Cost-Benefit Analysis.

Given the advance of aridification, it is imminent that grapevine growers must have technified irrigation to manage the irrigation of their farms, which is why a scenario is considered with the technological solution (which is the first most popular solution in the area) and a second one that is complemented with agroecology and nature-based solutions.

7.5.1 Economic analysis of the technified system

The financial economic analysis of the system with technified irrigation has been developed considering a 10-year evaluation horizon (2024-2033), with an initial investment of USD 8,300 per hectare and using a discount rate of 8%. The study is based on an average production of 26,000 kg/ha and a sales price of USD 0.235/kg with a projection based on historical data, parameters that reflect current market conditions and documented production capacities in the Elqui Valley.

The system's income shows a consistent positive progression, evolving from USD 6,101/ha in the first year to reach USD 7,524/ha in the tenth year, which represents a growth rate of 19.5%. This increase is based on three main factors: stabilization of production thanks to better water control, a projected increase in market prices, and a sustained improvement in product quality due to technical management.

The cost structure of the system is divided into two main categories. Variable costs, which represent 92% of the total, are composed of labor (USD 2,901/ha, 60%), machinery (USD 320/ha, 7%), inputs (USD 1,412/ha, 27%) and contingencies (USD 232/ha, 4%). Fixed costs, which constitute the remaining 8%, include administration (USD 53/ha), insurance (USD 21/ha) and vine replacement (USD 320/ha), totaling USD 395/ha.

Operating cash flow shows a sustained upward trend throughout the evaluation period. Starting at USD 3,401/ha in the first year, it reaches USD 3,454/ha in the fifth year and culminates at USD 4,289/ha in the tenth year, showing a total growth of 20.8% during the period analyzed.

In terms of profitability, the project shows a Net Present Value (NPV) of USD 24,895. This positive result indicates that the project not only recovers the initial investment and generates the minimum required returns of 8%, but also produces a significant surplus that confirms its financial viability. Profitability is mainly based on the 50% savings in water consumption, stable production, precise control of inputs, and the sustained increase in sales prices.

A particularly favorable aspect of the project is its financing structure, where INDAP contributes 90% of the initial investment and the producer only has to contribute the remaining 10%. This distribution significantly reduces the financial risk for the cooperative and improves the initial viability of the project.

However, the analysis also identifies critical points that require attention. Profitability shows sensitivity to key variables such as sales price, yield per hectare, energy cost and water availability. In addition, specific risks related to energy dependence, system maintenance costs, vulnerability to technical failures and the need for specialized knowledge for its operation are identified.

The system's financial strengths include the generation of predictable cash flows, controlled costs, stable production and INDAP's significant institutional support. These factors contribute to the financial sustainability of the project and reduce its overall risk.

The analysis concludes that the technified irrigation system is financially viable, capable of generating sufficient returns to recover the initial investment, cover operational costs, generate a significant surplus and maintain a sustainable operation. However, it is important to note that this analysis focuses mainly on direct financial aspects and does not fully incorporate considerations such as environmental costs, ecosystem services, long-term resilience and vulnerability to climate change, factors that could influence the sustainability of the system over a longer horizon. The detail of the calculation can be reviewed in Table 1 below.

INGRESOS										
Venta de uva	USD	6.100,9	5.981,4	5.847,9	6.035,0	6.228,1	6.427,4	6.633,1	6.845,4	
Arriendo imputado	USD	2.559,8	2.559,8	2.559,8	2.559,8	2.559,8	2.559,8	2.559,8	2.559,8	
INGRESO TOTAL		8.660,8	8.541,2	8.407,7	8.594,9	8.788,0	8.987,3	9.193,0	9.405,2	

COSTOS VARIABLES										
Mano de Obra										
Poda y amarra	USD/ha	799,9	818,3	828,2	838,1	848,2	858,3	868,6	879,1	88
Mantención parrón	USD/ha	128,0	130,9	132,5	134,1	135,7	137,3	139,0	140,7	14
Riego	USD/ha	384,0	392,8	397,5	402,3	407,1	412,0	416,9	422,0	42
Aplicaciones fitosanitarias	USD/ha	256,0	261,9	265,0	268,2	271,4	274,7	278,0	281,3	28
Cosecha	USD/ha	1.333,2	1.363,9	1.380,3	1.396,8	1.413,6	1.430,6	1.447,7	1.465,1	1.
Subtotal Jornadas Hombre	USD/ha	2.901,1	2.967,9	3.003,5	3.039,5	3.076,0	3.112,9	3.150,3	3.188,1	3.
Maquinaria										
Máq aplicación agroquímicos	USD/ha	256,0	259,8	262,4	265,0	267,7	270,4	273,1	275,8	27
Acarreo interno cosecha	USD/ha	64,0	65,0	65,6	66,3	66,9	67,6	68,3	69,0	69
Subtotal Costo Maquinaria	$/Há	320,0	324,8	328,0	331,3	334,6	338,0	341,3	344,8	34
Insumos										
Cintas amarre	USD/ha	14,9	15,1	15,2	15,4	15,5	15,7	15,9	16,0	16
Agua	USD/ha	57,9	58,5	59,1	59,7	60,3	60,9	61,5	62,1	62
Electricidad	USD/ha	321,0	324,3	327,5	330,8	334,1	337,4	340,8	344,2	34
Fertilizantes										
Fostato Diamonico	USD/ha	88,8	88,8	88,8	88,8	88,8	88,8	88,8	88,8	88
Urea	USD/ha	173,3	173,3	173,3	173,3	173,3	173,3	173,3	173,3	17
Acido Sulfurico	USD/ha	29,3	29,3	29,3	29,3	29,3	29,3	29,3	29,3	29
Nitrato de Potasio	USD/ha	98,8	98,8	98,8	98,8	98,8	98,8	98,8	98,8	98
Compost	USD/ha	522,6	522,6	522,6	522,6	522,6	522,6	522,6	522,6	52
Fungicidas										
Systhane	USD/ha	52,9	52,9	52,9	52,9	52,9	52,9	52,9	52,9	52
Insecticidas										

Troya 4 EC	USD/ha	28,6	28,6	28,6	28,6	28,6	28,6	28,6	28,6	28
Herbicidas										
Rango- 480 SL	USD/ha	23,8	23,8	23,8	23,8	23,8	23,8	23,8	23,8	23
Subtotal Insumos	usd/ha	1.412,1	1.416,0	1.420,0	1.424,0	1.428,1	1.432,2	1.436,3	1.440,5	1.
Sub total costos variables	USD/ha	4.633,2	4.708,7	4.751,5	4.794,9	4.838,7	4.883,1	4.927,9	4.973,3	5.
Imprevistos (5% Sub total c. variables)	5%	231,7	235,4	237,6	239,7	241,9	244,2	246,4	248,7	25
Total Costos Variables	USD/ha	4.864,9	4.944,1	4.989,1	5.034,6	5.080,6	5.127,2	5.174,3	5.222,0	5.
COSTOS FIJOS										
Administración	USD	53,3	53,3	53,3	53,3	53,3	53,3	53,3	53,3	53
Seguros	USD	21,3	21,3	21,3	21,3	21,3	21,3	21,3	21,3	21
Reposición de parras	USD	320,0	321,6	323,5	325,8	328,4	331,4	334,7	338,4	34
Total Costos fijos	USD	394,6	396,2	398,2	400,4	403,1	406,0	409,3	413,0	41
UTILIDAD ANTES DE IMPUESTOS	USD	3.401,3	3.200,8	3.020,5	3.159,8	3.304,3	3.454,0	3.609,3	3.770,2	3.
UTILIDAD DESPUÉS DE IMPUESSTOS	USD	3.401,3	3.200,8	3.020,5	3.159,8	3.304,3	3.454,0	3.609,3	3.770,2	3.
FLUJO CAJA OPERACIONAL	USD	3.401,3	3.200,8	3.020,5	3.159,8	3.304,3	3.454,0	3.609,3	3.770,2	3.
FLUJO DE CAJA PROYECTO	**USD**	**3.401,3**	**3.200,8**	**3.020,5**	**3.159,8**	**3.304,3**	**3.454,0**	**3.609,3**	**3.770,2**	
Tasa de descuento	8%									

7.5.2 Economic analysis of the technical system complemented with the agroecological system

The economic and financial analysis of the technical system complemented with the agroecological system has been developed under the same temporal and methodological parameters as the conventional system, considering an evaluation horizon of 10 years (2024-2034) and a discount rate of 8%. However, it presents significant differences in both its cost structure and its financial results.

The system's income shows a more pronounced positive progression than the conventional system, evolving from USD 6,101/ha in the first year to reach USD 7,524/ha in the tenth year, with a growth of 19.5%. This process, although not considered monetarily, also contemplates complementary income from associated products such as medicinal herbs and honey, which diversify the sources of income and reduce the economic vulnerability of

The cost structure presents a notably different distribution from the conventional system. Variable costs represent 90% of the total, with a composition that reflects the nature of the agroecological system: labor constitutes 75% of the costs (an increase with respect to the conventional system due to more intensive management), while machinery represents only 6% and inputs are significantly reduced to 5% of total costs, being replaced by biodynamic preparations and seeds for cover crops.

Operating cash flow shows a more favorable increasing trend than the conventional system, starting at USD 4,750/ha in the first year, reaching USD 4,732/ha in the fifth year and culminating at USD 5,578/ha in the tenth year. This growth of 13.6% during the period analyzed, although percentage-wise lower than the conventional system, starts from a higher base and results in higher total flows.

In terms of profitability, the project shows a Net Present Value (NPV) of USD 34,084, 36.5% higher than the NPV of the conventional system. This superior result is mainly explained by::

● Elimination of agrochemical and fertilizer costs

Significant reduction in energy costs

Increased yield stability under stress conditions

The operational cost structure shows a significant reduction in several items:

● Elimination of chemical fertilizer costs.

● 50% reduction in energy costs

● 40% reduction in machinery use

● Substitution of external inputs for in-house preparations.

However, these savings are partially offset by a 15% increase in labor costs, necessary for the more intensive management required by the agroecological system. Nevertheless, this higher labor cost contributes to the generation of local employment and the maintenance of traditional knowledge.

Critical points of the analysis include:

● Increased demand for specific knowledge and management.

Initial period of system adaptation

● Need to maintain functional biodiversity

● Increased requirement for skilled labor.

The financial strengths of the agroecological system are particularly notable in:

● Less dependence on external inputs.

● Greater resilience to market fluctuations

● Diversification of income sources (additional income from productive diversification)

● Lower long-term operating costs

Greater adaptability and resilience to climate change.

The analysis concludes that the agroecological system is not only financially viable, but also outperforms the conventional system in terms of profitability, with a NPV 36.5% higher. This financial superiority is combined with additional non-monetized benefits such as ecosystem services, greater climate resilience and contribution to local biodiversity. The lower initial investment and lower operating costs make the system particularly attractive to smallholders, although it requires a greater commitment to intensive management and ecosystem knowledge.

It is important to note that this favorable financial analysis occurs even without considering the monetary value of the ecosystem services generated, suggesting that the real profitability of the system could be even higher if these additional benefits were included in the valuation. The details of the calculation can be reviewed in Table 2 below.

INGRESOS								
Venta de uva	USD	6100,9	5981,4	5847,9	6035,0	6228,1	6427,4	60
Arriendo imputado	USD	2559,8	2559,8	2559,8	2559,8	2559,8	2559,8	25
INGRESO TOTAL		8660,8	8541,2	8407,7	8594,9	8788,0	8987,3	91

Costos Variables								
Mano de Obra								
Poda y amarra	USD/ha	799,9	818,3	828,2	838,1	848,2	858,3	868,6
Mantención parrón	USD/ha	128,0	130,9	132,5	134,1	135,7	137,3	139,0
Riego	USD/ha	384,0	392,8	397,5	402,3	407,1	412,0	416,9
Aplicaciones fitosanitarias	USD/ha	281,6	261,9	265,0	268,2	271,4	274,7	278,0
Cosecha	USD/ha	1.333,2	1.363,9	1.380,3	1.396,8	1.413,6	1.430,6	1.447
Subtotal Jornadas Hombre	USD/ha	2.926,7	2.967,9	3.003,5	3.039,5	3.076,0	3.112,9	3.150
Maquinaria								
Máq aplicación agroquímicos	USD/ha	153,6	259,8	262,4	265,0	267,7	270,4	273,1
Acarreo interno cosecha	USD/ha	64,0	65,0	65,6	66,3	66,9	67,6	68,3
Subtotal Costo Maquinaria	$/Há	217,6	324,8	328,0	331,3	334,6	338,0	341,3
Insumos								
Cintas amarre	USD/ha	14,9	15,1	15,2	15,4	15,5	15,7	15,9
Agua	USD/ha	29,0	29,2	29,5	29,8	30,1	30,4	30,7
Electricidad	USD/ha	160,5	162,1	163,7	165,4	167,0	168,7	170,4
Fertilizantes								

Fostato Diamonico	USD/ha	-	-	-	-	-	-	-
Urea	USD/ha	-	-	-	-	-	-	-
Acido Sulfurico	USD/ha	-	-	-	-	-	-	-
Nitrato de Potasio	USD/ha	-	-	-	-	-	-	-
Compost	USD/ha	-	-	-	-	-	-	-
Fungicidas								
Systhane	USD/ha	-	-	-	-	-	-	-
Insecticidas								
Troya 4 EC	USD/ha	-	-	-	-	-	-	-
Herbicidas								
Rango- 480 SL	USD/ha	-	-	-	-	-	-	-
Subtotal Insumos	usd/ha	204,4	206,5	208,5	210,6	212,7	214,8	217,0
Sub total costos variables	USD/ha	3.348,7	3.499,1	3.540,0	3.581,4	3.623,3	3.665,7	3.708
Imprevistos (5% Sub total costos variables)	5%	167,4	175,0	177,0	179,1	181,2	183,3	185,4
Total Costos Variables	USD/ha	3.516,2	3.674,1	3.717,0	3.760,5	3.804,5	3.849,0	3.894

COSTOS FIJOS								
Administración	USD	53,3	53,3	53,3	53,3	53,3	53,3	53,3
Seguros	USD	21,3	21,3	21,3	21,3	21,3	21,3	21,3
Reposición de parras	USD	320,0	321,6	323,5	325,8	328,4	331,4	334,7
Total Costos Fijos	USD	394,6	396,2	398,2	400,4	403,1	406,0	409,3

UTILIDAD ANTES DE IMPUESTOS	USD	4.750,0	4.470,9	4.292,5	4.433,9	4.580,4	4.732,3	4.889
UTILIDAD DESPUÉS DE IMPUESSTOS	USD	4.750,0	4.470,9	4.292,5	4.433,9	4.580,4	4.732,3	4.889
FLUJO CAJA OPERACIONAL	USD	4.750,0	4.470,9	4.292,5	4.433,9	4.580,4	4.732,3	4.889
FLUJO DE CAJA PROYECTO	**USD**	**4.750,0**	**4.470,9**	**4.292,5**	**4.433,9**	**4.580,4**	**4.732,3**	**4.**

TASA DE DESCUENTO 8%

VAN USD	**34.083,8**

VAN ($)	**31.955.638**

7. Other actions and solutions of interest reviewed outside the case study.

Recovery and conservation of wetlands in high Andean plains of Tarapacá

In Chile, to address the impacts of drought and water scarcity in high Andean wetlands, a series of activities were implemented to return the biota and physical conditions of the site to their original condition. These included water decontamination techniques, groundwater recharge, revegetation, elimination of exotic species, removal of infrastructure, and reintroduction of native species to restore biodiversity, among others. These measures provided a constant supply of water, prevention and regulation of the effects of floods and droughts by retaining excess water, prevention and control of erosion, nutrient and toxic capture, atmospheric carbon sinks, provision of food and other natural resources for economic sustenance and satisfaction of needs. Source: Water Scenarios 2030 (2019).

Development of biostimulant prototypes to mitigate environmental stresses with different types of microorganisms, (Osses, Rómulo, 2024, CRIDESAT, Universidad de Atacama).

Research and Development in reuse technologies. CAPEL has also been participating in research and development projects to improve water use efficiency and explore new ways to reuse wastewater. This includes the evaluation of more advanced effluent treatment technologies for use in agriculture or industrial processing. Investment in advanced reuse technologies could further improve efficiency in pisco production, allowing for a closed water cycle that minimizes waste and improves long-term sustainability.

In the Peruvian Andes region, regenerative agricultural practices that restore soil health, increase biodiversity and are resilient to drought have been promoted using techniques such as agroforestry and intercropping.

Less exposure to the sun slows the accumulation of sugars in the grapes, which improves the balance between alcohol content and acidity in fermentation. According to La Svolta, this makes it possible to produce high quality wines without the need for corrective interventions.

Agrivoltaica installation in Italy. The project is called Vigna Agrivoltaica di Comunità and has 7,770 double-junction thin-film solar panels. Together they have a total power output of 970 kW. The shade cast by the solar panels has been delaying the La Svolta harvest by three to four weeks compared to the surrounding vineyards. For both white and red grapes. The agrivoltaic system improved the plants' water stress, protected the grapes from weather excesses and reduced wind speed by half, compared to the open field.The winery conducted technical studies that show a reduction in water consumption for irrigation of up to 20% and an increase in land yields between 20% and 60%.(https://www.xataka.com/energia/bodega-italiana-instalo-paneles-solares-sus-vinedos-descubrio-algo-inesperado-mejoran-calidad-vino?utm_source=whatsapp_AMP&utm_medium=social&utm_campaign=botoneramobile_AMP).

Payments for Ecosystem Services in the town of Mashue, Los Ríos Region, Chile.

An innovative Payments for Ecosystem Services (PES) initiative is being developed in the town of Mashue, led by the Rural Drinking Water Committee (CAPR).This program, which already had a base model, is being updated and strengthened thanks to the support of the "Economic Instruments for Biodiversity Conservation" project, implemented by the Ministry of the Environment in collaboration with UNDP and financed by the GEF.The distinctive feature of this initiative is its community management, where the community itself, through the CAPR, leads the implementation and administration of the system.

The program is structured through several components that operate in an integrated manner to improve ecosystem health and ensure the provision of water ecosystem services. These components include a watershed restoration program, environmental education activities, soil restoration initiatives, a hydrological monitoring system, and the implementation of agroecological practices at the farm level. Each of these elements is designed to contribute to ecosystem sustainability and community well-being.

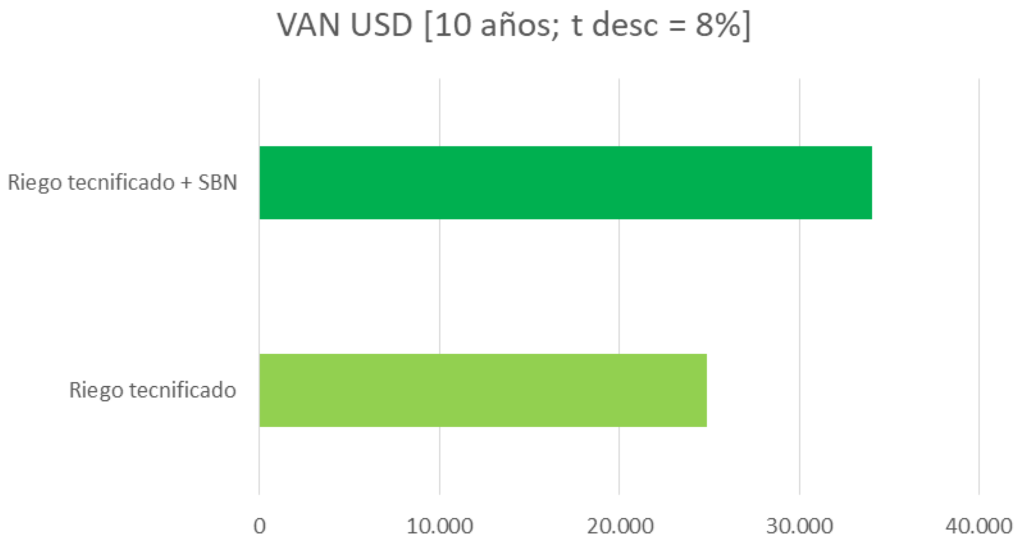
The central focus of the program is on the protection and restoration of native forests, recognizing their crucial role in the provision of water ecosystem services. This emphasis reflects a deep understanding of the interconnection between forest health and water availability and quality, seeking to generate benefits for both the ecosystem and the local community that depends on these resources.

The long-term vision of the program is ambitious and multifaceted. It seeks not only to ensure water supply for future generations, but also to develop a model that can be replicated in other localities and eventually become a national public policy. This experience in Mashue is laying the groundwork to demonstrate how local communities can effectively lead the conservation of their natural resources through innovative economic instruments.

8. Conclusions and recommendations

The Elqui River basin, in northern Chile, is currently facing one of the most severe water crises in its history, characterized by extreme drought and an accelerated process of aridification. The data are overwhelming: a 32% reduction in its flows during 2023 and reservoirs operating at only 18% of their capacity. This scenario has dramatically impacted the production of pisca grapes in the CAPEL Cooperative, which has seen its production volumes reduced from 200,000 tons in 2000 to barely 50,000 tons in 2024, demonstrating the vulnerability of the traditional production system to climate change.

Faced with this reality, producers have developed two main adaptation strategies. Irrigation technification, adopted by 70% of the cooperative members, and the implementation of agroecological systems with nature-based solutions (in a complementary manner). The economic analysis carried out shows that the agroecological system complemented with technified irrigation is not only viable, but also more profitable, presenting a Net Present Value (NPV) 36.5% higher than the purely technified system (USD 34,084 versus USD 24,895).



Agroecological systems have been shown to generate important additional benefits that, although not monetized in traditional economic analysis, since they must incorporate attributes not usually internalized in conventional project evaluation, are fundamental for ecosystem sustainability. These benefits include increased biodiversity, improved water retention in the soil, natural pest control, preservation of traditional knowledge and strengthening of territorial identity. These ecosystem services contribute significantly to the resilience of the production system as a whole.

From the data and information gathered, it is possible to infer that the extreme drought that has been affecting the territories of the Elqui and Limarí valleys has affected the quantity and quality of the pisca grapes produced, and therefore, the sales and value per kilo of grapes, as well as the working and living conditions of Capel's cooperative members.

Although it is true that the cooperative members have managed to develop resilience conditions to face the situation generated by the drought, these conditions have not been put to good use in an organized and timely manner. This could be due to the fact that their capacities have not been formed or trained to mitigate or solve in a sustainable way, the systemic effects of aridification caused in the different links of the production value chain by climate change, making it difficult to anticipate alternative solutions, applying their ancestral knowledge and learning from their productive experiences, in the way of agroecological or biodynamic systems.

It is important to note that the CAPEL Cooperative, as an institution, has been attentive and generating responses to control the effects of climate and drought in the valley. However, it has been possible to observe that taking charge of this extreme phenomenon, which is permanent, requires responses not only in the short term, but also in the medium and long term, with a strategic vision, necessary to work in a coordinated manner and with greater participation of all the cooperative members.

The solutions for the application, use and management of water have been rather in continuity with techniques that benefit the improvement of pisca grape production and the reduction of diseases in the vines, which, in the short term, are solutions to increase the volume of grapes produced, which is of high interest to achieve greater income for the cooperative members. However, this type of production can, in the medium and long term, generate situations of reduction and future disappearance of the native flora, complicating the rich biodiversity existing in the valley.

It was possible to perceive that there is no daily and permanent relationship between the different actors of the ecosystem that are linked to the issue of drought and climate change. In order to face this extreme situation of lack of water for irrigation, grape growers require new public resources, institutional contributions that provide targeted solutions, innovations and R&D from companies and universities, but within the framework of a plan that includes the entire value chain of the pisciculture industry.

From the point of view of economic sustainability, the agroecological system demonstrates a greater capacity to adapt to drought conditions. This is reflected in a lower dependence on external inputs (reduction to 5% of total costs versus 27% in the conventional system), lower operating costs in the long term, greater income diversification and better adaptability to climate change. This economic resilience is particularly relevant in the current context of climate uncertainty and water scarcity, allowing an operational cash flow that grows from USD 4,750/ha to USD 5,578/ha in ten years.

o capitalize on these experiences and promote a transition to more resilient systems, it is recommended that policies be implemented to encourage the adoption of mixed systems that combine technification with agroecological practices. It is essential to strengthen research on nature-based solutions, develop valuation frameworks for ecosystem services so that these can be incorporated into decision-making, and create support mechanisms for the preservation and transmission of traditional knowledge. This can be expressed in the concurrence of both public and private initiatives. From the public dimension, it is crucial to establish public policies that facilitate the transition to these more sustainable systems. On the private side, it is crucial to design and implement strategies that internalize the sustainability of agricultural practices enriched in terms of internalization of new criteria for the evaluation of investment projects or operational continuity, ideally extrapolated to other areas of the country affected by the drought.

Education and training in the generation of innovative solutions that link different types of knowledge of agricultural production, favoring those that are already installed in the producers themselves, becomes one of the key elements to make sustained progress in production systems based on nature that, in their processes, systematically integrate the challenges of climate change and those arising from drought, improving the quality of the savers, and strengthening the processes of knowledge transfer between cooperative members.

In this regard, it is necessary to work on cultural aspects to facilitate their productive practices from what they are and do, with an organization that favors agroecological modes of production, in consideration of the good use of edaphoclimatic resources, for the benefit of the sustainability of the production of grapevines and pisca grapes.

It is important to mention the need to form and generate nodes for the transfer of uses and adaptive practices among the cooperative members, who can share their productive experiences among themselves, taking into account their experiences and knowledge of the different localities, generating collaborative practices of production and management of water use, measuring their results in each activity and process, as well as their results.

It is necessary to generate a comprehensive database of the cooperative members, their land, production and learning, in order to categorize the different variables involved, in different cases, in the production of pisca grapes and thus develop a strategic plan to analyze the most sustainable type of production system for production and the cooperative member, in consideration of climate change and the current conditions of extreme drought.

The generation of a program for the sustainability of the pisca grape, through agreements with science, through centers and universities, mainly regional, and foreign entities, to seek alternative solutions designed for this fruit product, with the dimensions and variables that affect its production. In this regard, the contribution of CEAZA, INIA, CIREN, among other institutions, acting jointly, which have the availability of space technologies, specialists and others, to strengthen access to useful data, is seen as an opportunity.

The case of the CAPEL Cooperative in the Elqui Valley demonstrates that it is possible to develop productive systems that are both economically viable and environmentally sustainable, even under extreme drought conditions. The key lies in adopting an integrated approach that effectively combines technological innovation with traditional knowledge and nature-based solutions, thus creating a production model that is more resilient and adapted to the challenges of climate change. This model will also make it possible not only to make a given production activity viable, but also to harmonize it with its environment, especially in terms of ecosystem protection.

Beyond the economic and environmental analysis, it is essential to recognize that the production of pisca grapes in the Elqui Valley represents an invaluable cultural heritage, protected since 1931 by its appellation of origin. This centuries-old tradition has not only shaped the identity of the valley and its inhabitants, but has also generated a unique knowledge of pisco production that has been passed down from generation to generation. The loss of this productive activity due to the water crisis would not only have economic consequences, but would also mean the disappearance of an intangible cultural heritage. Therefore, the development of resilient production systems is not only an economic and environmental necessity, but also a way to preserve a tradition that has defined the identity of the Elqui Valley for generations.

The combination of modern technology with traditional agroecological practices thus represents an integral strategy to ensure the continuity of this cultural heritage in a context of climate change. It is hoped that this research will contribute to deepen the analyses carried out and ideally to configure collaborative strategies that allow the internalization of the necessary attributes of sustainability, especially designed for climate adaptation, in the different productive sectors of Chile and the rest of the world.