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Analysis of Chilean legal regime for brine obtained from desalination processes

Lorena Cornejo-Ponce[a,b,*], Claudia Moraga-Contreras[c], Patricia Vilca-Salinas[b]

[a]*Departamento de Ingeniería Mecánica, Facultad de Ingeniería, Universidad de Tarapacá, Avda. General Velásquez 1775, Arica, Chile, Tel. +(56) (58) 205075/(56) (58) 11 205406; email: lorenacp@academicos.uta.cl (L. Cornejo-Ponce)*
[b]*Laboratorio de Investigaciones Medioambientales de Zonas Áridas, LIMZA, Universidad de Tarapacá, Avda. General Velásquez 1775, Arica, Chile, email: patricia786vilca@yahoo.es (P. Vilca-Salinas)*
[c]*Escuela de Derecho, Facultad de Ciencias Sociales y Jurídicas, Universidad de Tarapacá, Cardenal Caro 348, Arica, Chile, email: cmoragac@uta.cl (C. Moraga-Contreras)*

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ABSTRACT

Seawater desalination plants provide an alternative solution to the problem of water scarcity although the process involved produces not only water, but also brine. The most practical and least expensive ways of disposing of the brine are to discharge it into the sea (41%) or sewers (31%). At the present time, there are no standards that specifically regulate the disposal of brine or the maximum concentration of sodium chloride, its main component and pollutant. Some countries such as Mexico and Chile have attempted to regulate some aspects of the desalination process; however, their draft laws do not include any indications regarding the discharge of salt residues or maximum permissible limits. This study analyzes the national legislative regimes in Chile and other countries that give rise to regulations governing the disposal of brine obtained from processes of desalination. It also proposes the establishment of a maximum limit for NaCl concentration, especially where brine is discharged into the sea or reused in sustainable energy processes.

Keywords: Brine; Desalination; Normative; Sustainable development

1. Introduction

Water is essential for human beings and their survival. Water scarcity is a global problem since, even though sources are available, they are often limited, of low quality (surface water) or contaminated (wastewater). According to the World Health Organization (WHO), 663 million people lack access to an improved source of water and 2.4 billion people lack access to improved sanitation [1], which causes 842,000 deaths/y from diarrhoea with children under 5 being worst affected [2].

Desalination technologies help meet the growing demand for water for different purposes, for example, human consumption, agriculture, or industrial use [3]. This process uses brackish or sea water as the input, which guarantees greater availability, especially when we consider that the sea is a practically inexhaustible source. It also alleviates water-scarcity problems in arid or semi-arid coastal regions [4,5].

Two outputs are obtained from desalination: distilled water and residual water, with the latter known as brine [6]. These outputs can have an effect on the environment if appropriate measures are not taken to reduce or mitigate contamination [7]. For example, producing 1,000 t/m^3/d of fresh water via desalination processes requires 2,832 t/m^3/d of oil per year (responsible for greenhouse gas emissions), brine to be discharged to the sea (with the consequent disruption of aquatic ecosystems) [8,9], and an increase in desalinated water production [7,10].

* Corresponding author.

Of all the different techniques used for desalination worldwide, reverse osmosis (RO) is the most common, used in 65% of cases, followed by multi-stage flash distillation (MSF), used in 21% of cases, multi-effect distillation in 7%, electrodialysis in 3%, and other techniques, accounting for 4% [11].

The amount of brine produced by the desalination process will depend on the type of technology used and the processes must be regulated and adapted, both from an environmental and legislative point of view [12].

In Chile, desalination plants date back to 1872, when the first solar desalination plant was built and installed in the office of the Las Salinas Nitrate Mine (Fig. 1) in the Atacama desert. By 1907 Chile had solar plants in the Domeyko and Sierra Gorda offices [13].

Despite using technology developed over a century ago and the fact that Chile has 8,000 km of coastline and 3,934,936 km of jurisdictional maritime space ideal for desalination plants [14], legislation to regulate both plants and their waste products is non-specific. This document contributes to the current literature by means of a bibliographic review of current Chilean regulations in terms of maximum discharge limits for brine produced by desalination technologies and which bodies these brines are discharged into. It aims to contribute to current policies regarding the sustainable development of this type of technology. In this context, the composition of the brine, its elimination and the resulting environmental impacts are reviewed and some alternative uses proposed in order to analyze the desalination processes in Chile and the possibility of improving sustainability by using solar energy. Finally, foreign regulatory systems in countries with higher concentrations of desalination plants are reviewed in order to compare them with those in Chile.

2. Methodology

The methodology used for this study was to research documents (mainly WoS indexed magazines and regulations) with the aim of identifying and reviewing laws or regulations governing the disposal of brine produced by desalination plants. Regulations were reviewed in countries across the world, for example, the United States, California, the Kingdom of Saudi Arabia, Spain, countries on the Mediterranean coast and Mexico. The Mexican regulations are of key importance, since the country has published a Draft of the Official Mexican Standard titled "PROY-NOM-013-CON AGUA/SEMARNAT-2015: que establece especificaciones y requisitos para las obras de toma y descarga que se deben cumplir en las plantas desalinizadoras o procesos que generen aguas de rechazo salobres o salinas" (to establish specifications and requirements for supply and discharge installations in desalination plants or processes that generate brackish or saline wastewater) [15]. We will also evaluate the suitability of some of the existing national regulations governing the discharge of waste liquids to different receiving bodies (underground water, sewers, sea, etc.).

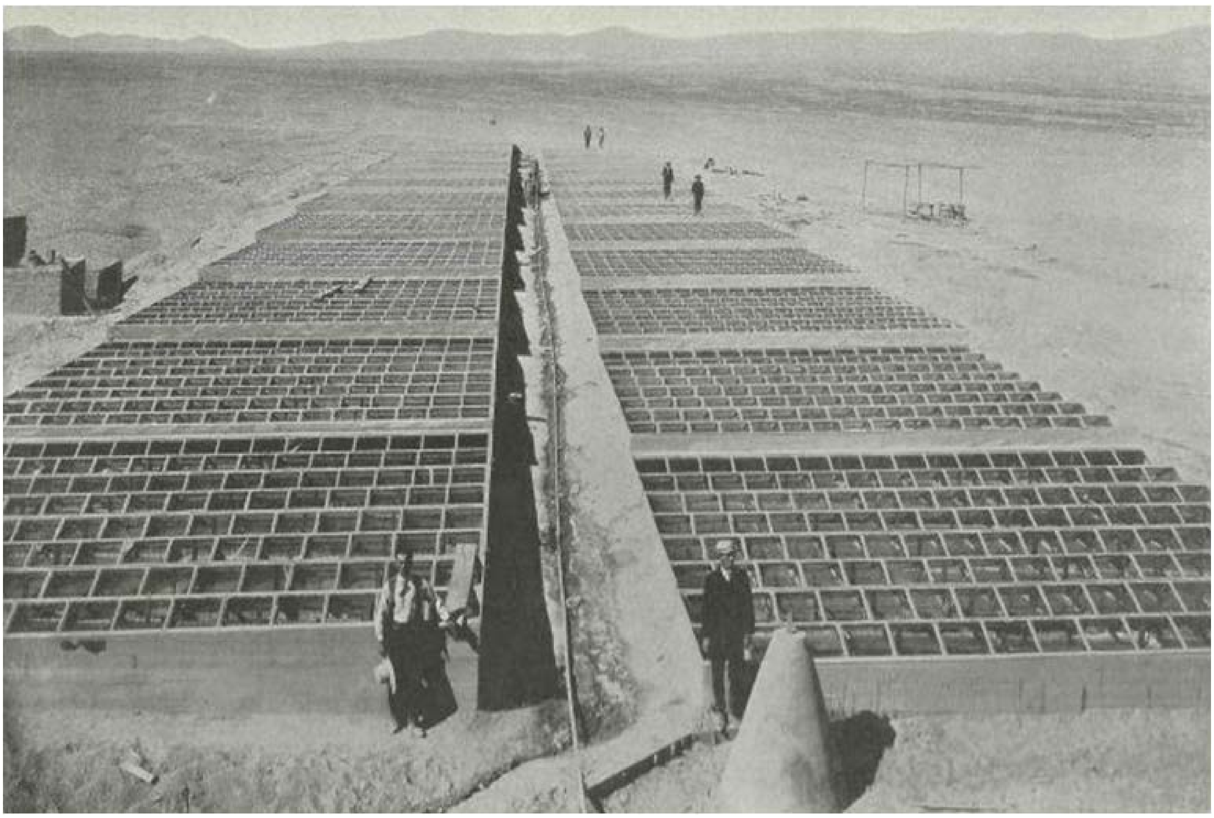

Fig. 1. World's first solar water desalination plant [13].

3. Brine

Brine is a product of the desalination process [16] that is usually more saline than seawater (1.5–2.5 times more than 35,000 mg/L) or brackish; in some cases, it has a temperature above the ambient temperature [17,18]. This high temperature is a result of thermal distillation processes where the treated water (sea or brackish) is put through "*n*" steps of consecutive evaporations. The unevaporated water is, therefore, concentrated at each step and brine is formed. After each step, the temperature of the steam generated is similar to the temperature of the remaining unevaporated brine. However, in the final step, the steam generated from the evaporation is condensed in a seawater-cooled condenser. The temperature of the brine at this step is usually 4°C–10°C higher than the temperature of the cooling water. This means that if the cooling water enters the condenser at 25°C, then the brine is extracted at 35°C [19,20]. Since the temperature of the brine is greater than the ambient temperature of the sea water, it can harm marine life in several ways [17]. For example, in the case of MSF distillation plants, which use seawater as feed water and are typical in the middle east (with salinity 40,000–45,000 mg/L and temperature up to 40°C) [7,21], brine is usually discharged with a salinity of 50,000 mg/L and a temperature between 10°C and 15°C higher than the receiving water. In the case of RO plants, brine is discharged with a higher salt concentration (65,000–85,000 mg/L) and a temperature similar to the receiving water [22,23].

The main constituents of brines are magnesium, sodium, potassium, calcium, chloride, sulfate, carbonates, and total dissolved solids, among other compounds [24].

Depending on the type of technology used, the environment can be affected in different ways as a result of the physical and chemical characteristics of the brine [23]. In the case of thermal technologies, temperatures are 1.37 and 1.82 times higher than the ambient temperature (22°C). This can have a harmful effect on marine life by altering the osmotic balance between marine species and their environment, which can cause cellular dehydration, decreased turgor pressure, and the long-term extinction of species [17].

Brine discharge has the potential to have a negative effect on the environment by degrading the physical, chemical, and biological characteristics of the receiving body [25], especially when discharged into the sea. For example, the discharge of brine from desalination plants into the Mediterranean Sea results in a water temperature of around 19°C in winter and 34°C in summer [26] with a density of 1,051 kg/m^3 [27], values that are greater than for the oceans [28]. It is worth mentioning that the magnitude of the effects produced by brine discharge will depend on the size and type of desalination plant [29].

3.1. Brine disposal alternatives

There are several alternatives for disposing of brine and the choice in each case will depend mainly on the location of the desalination plant, the type of plant and the costs associated with disposal [30,31].

When disposing of brine, treatment must be considered to mitigate or reduce the direct potential impact on the environment [32] and allow value to be given to the waste.

The topic of brine management is very important when analyzing the viability of a desalination plant since a large part of the budget is determined by the different factors that affect the final make-up of the brine [11,33], as shown in Fig. 2.

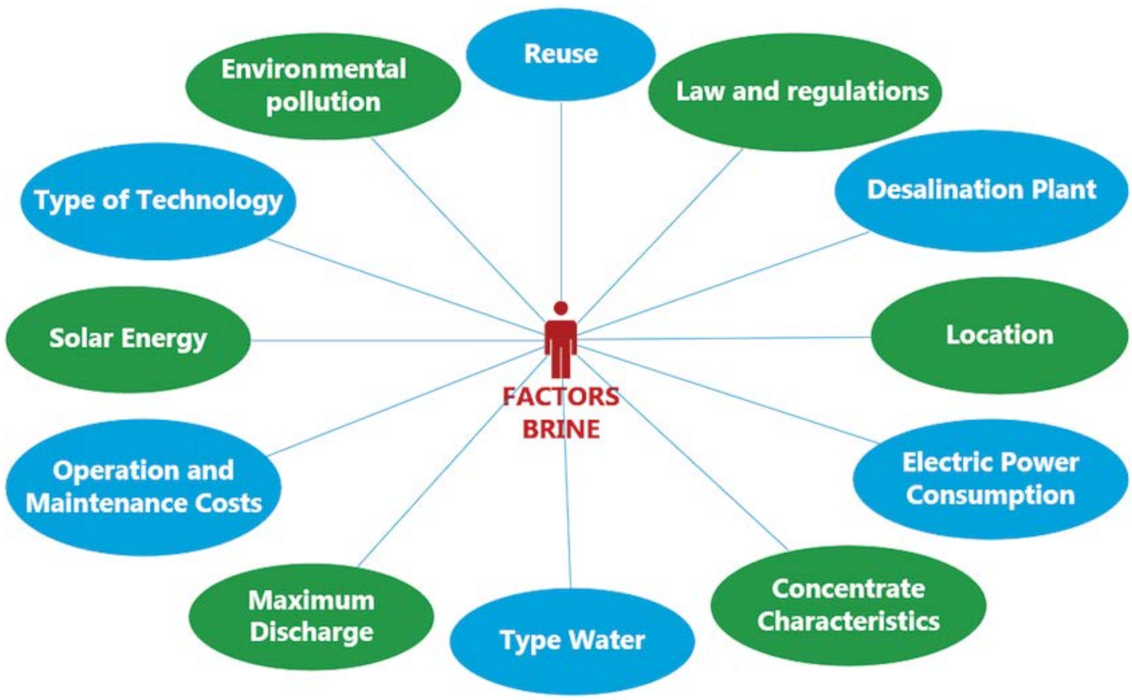

Fig. 2. Factors that affect the composition of brine (compiled by author).

Currently, the following options exist for eliminating brine:

- Deep well injection [30]
- Evaporation ponds [9]
- Discharge into surface water bodies [11]
- Disposal into municipal sewers [9]
- Concentration into solid salts, for example, harvesting of salt and on-site generation of sodium hypochlorite [6]
- Irrigation of plants that are tolerant to high salinity [30,31]
- Reusing the brine [6]
- Zero liquid discharge [22]
- Aquaculture farm [29]
- Application in soils [29]

Of the alternatives mentioned the most commonly used methods for eliminating brine are discharge into the sea (41%), disposal into sewers (31%), deep well injections (17%), and evaporation ponds (2%) [9].

It is estimated that for every 1 m^3 of fresh water produced, between 0.3 and 1 m^3 of brine is generated. In 2015, worldwide brine production from desalination processes was between 29.3×10^6 and 97.5×10^6 m^3/d [9] and in 2019 production is estimated to be approximately 142 million m^3/d [7]. In Chile, desalination plants produce 276,879 m^3/d of freshwater [34]. Therefore, according to the above estimate, they produce between 83,063 and 276,879 m^3/d of brine. This wastewater is generally discharged into the sea by means of submarine outlets or, to a lesser extent, released into sewers or rivers near the desalination plant [35–37].

3.2. Impacts and costs associated with brine discharge

It is important to note that there has been a considerable upturn in scientific literature looking at other aspects of desalination, such as economics and the environment. In relation to economic aspects, the number of publications increased from 400 in the year 2000 to around 5,000 in 2018. Publications related to environmental aspects have also increased significantly: there were 118 publications prior to the year 2000, with more than 2,000 publications since [7]. Accordingly, it is essential to keep these factors in mind when evaluating what type of desalination technology should be installed in any location.

The economic aspects should consider the total cost of desalinated water (i.e., costs related to capital, operation, and maintenance) depending on location of the desalination plant, quantity of treated water, components of the plant, supply water characteristics, and energy cost (electric or photovoltaic energy), among other factors [38]. The construction and operation and maintenance (O&M) of desalination plants involve high costs, as do brine treatment facilities [11,39]. Table 1 shows the capital, operation, and maintenance costs for different desalination technologies for a desalination plant with a capacity of 32,000 m^3/d [38].

In the case of brine, these costs vary depending on how it is disposed of, for example, if it is to be discharged into the sea, the infrastructure of the outlet depends on the environmental sensitivity of the discharge site and the volume and quality of the brine. The cost of a discharge outlet can range from 5% to 40% of the capital costs [40]. Table 2 shows some examples of final disposal costs for brines [17].

Table 1
Capital costs and operating costs associated with different desalination technologies [38]

Type Cost $US (millions)	MSF	MED	RO
Capital cost	51.4	48.3	42.4
Operation and maintenance cost	1.043	0.953	0.823

In terms of the environmental aspects that should be considered, the main problem in marine water bodies is the intake of sea organisms, which can disrupt marine ecosystems and, consequently, reduce numbers of fish and aquatic microorganisms [41–43]. This is directly related to the high salinity and temperature of the brine as well as the chemicals used in pre and post treatment (NaOCl, $FeCl_3$, and acids), corrosive metals used in pipelines (Fe, Ni, Mo, and Cr), and other elements that result from the process [44].

The geographical location of a desalination plant and its resulting infrastructure can alter the natural landscape, which can have an impact on tourism and the communities that live near the plant. Likewise, it may also limit or prohibit access to waters used for other competing uses, such as fishing and underwater sports, among others.

4. Desalination in Chile

In 2016, there were around 65 seawater desalination plants in Chile producing water intended for human consumption and sanitation, industrial processes, agriculture, and mining [45].

According to the Cadastre of Desalination Plants [34] produced by the Chilean Mining magazine, the total desalinated water capacity is 176,083 m^3/d. Of all the industrial sectors, mining has the highest demand of desalinated seawater production for mining represents 71% of capacity with the main plants in the sanitation sector representing 29%.

Fig. 3 shows the installation of desalination plants in Chile mainly concentrated in the Antofagasta and Atacama regions, this is due to the high demand for water in mining operations [46].

5. Regulatory framework

Although a regulatory framework to regulate environmental pollution caused by discharging liquid industrial

Table 2
Some final disposal costs for brines [17]

Disposal Brine	Cost (US $) of brine rejected
Surface water discharge	0.05–0.30 (m^3)
Deep-well injection	0.54–2.65 (m^3)
Evaporation ponds	3.28–10.04 (m^3)
Land application	0.74–1.95 (m^3)

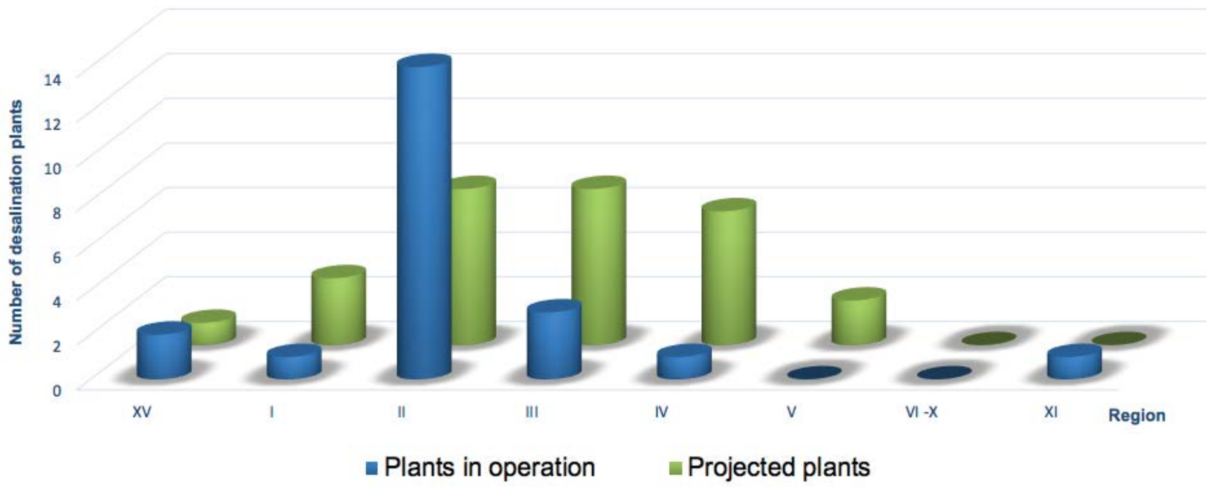

Fig. 3. Desalination plants in Chile, in operation and projected (compiled by author).

waste into inland or marine water bodies exists, it only briefly considers the desalination process and does not take into account brine disposal [47].

Various countries regulate the discharge from industrial processes or sewers to ground, surface, or marine water bodies. However, they do not make reference to maximum emission values for the main component of brine, NaCl [48,49]. A legal and institutional framework that deals with brine is essential in order to advance government policies aimed at minimizing environmental damage and seek alternative uses.

5.1. Some experiences from comparative law

Saudi Arabia is the largest producer of desalinated water in the world, accounting for approximately 30% of worldwide capacity [39]. Brine production in Saudi Arabia, the United Arab Emirates, Kuwait, and Qatar represents 55% of overall worldwide production [7]. This paper reviews the regulations governing the disposal of wastewater and looks at other countries such as the United States and Spain, which also have a large number of desalination plants. It should be noted that 17 coastal countries in the European Mediterranean Sea signed the Barcelona Convention BTelluric protocol in 1976 (modified in 1995) that regulates desalination plants (Table 3).

Of all the countries analyzed, only the United States and Saudi Arabia specify a limit for the discharge of liquid waste expressed in terms of salinity. Despite the fact that Mexico is not one of the leading producers of desalinated water, it is important to highlight that it published a draft standard in 2015, titled "PROY-NOM-013-CONAGUA/SEMARNAT-2015," that establishes specifications and requirements for supply and discharge installations in desalination plants or processes that generate brackish or saline wastewater. This deals with parameters such as turbidity, pH, total suspended solids, chemical oxygen demand, total nitrogen, total phosphorous, aluminum, copper, cadmium, and total chromium. However, it does not include chloride, sodium, or salt expressed as salinity [15].

The Clean Water Act (CWA) [50,51] is the primary legislation regarding the protection of the quality of surface water in the United States. It does not address groundwater regulation or matters related to the quantity of water. This regulatory framework considers it illegal to discharge any pollutant from a source into navigable waters unless a permit has been granted under the provisions of the CWA [52].

The United States Environmental Protection Agency's (EPA) National Pollutant Discharge Elimination System (NPDES) permit program regulates discharges from point sources. Point sources mean specific facilities such as pipes or ditches that flow into surface waters. Households that are connected to the municipal sewage system, those that use a septic below-ground discharge system and those that do not discharge into surface waters do not need an NPDES permit. However, industrial and municipal facilities, among others, must obtain permits if they discharge directly into surface waters.

The term pollutant is very broadly defined in the CWA as any type of industrial, municipal, and/or agricultural waste discharged into water, such as dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste.

Spain, on the other hand, does not have specific legislation that regulates either the concentration or physical–chemical parameters of brine discharges from processes of desalination [48].

The European Union Water Quality Directives, for their part, are limited to establishing maximum permitted limits for effluent discharge into receiving waters to avoid damaging water resources: they do not include maximum limits for the physical or chemical properties of brine. Desalination plants discharge brine into the Mediterranean Sea causing environmental pollution to marine ecosystems, especially in benthic communities such as *Posidonia oceanica* or *Cymodocea nodosa* [41].

Table 3
Environmental regulations for desalination plants in the countries with the highest desalinated water productivity [47]

Country/state	Applicable to	National regulation	Maximum limit
United States, California	All desalination facilities discharging brine into ocean waters, including facilities that commingle brine and wastewater	Water Quality Control Plan for the Ocean Waters of California, Effective April 7, 2016 Clean Water Act, National Pollutant Discharge Elimination System Permit Program, National Environmental Policy Act [50,51]	Discharges shall not exceed a daily maximum of 2.0 parts per thousand (ppt) above natural background salinity* (*Considering ocean water to have a salinity of approximately 35,000 mg/L)
Kingdom of Saudi Arabia	Comply with guidelines in the discharge permit	The Public Environmental Law (Royal Decree No. M/34, 2001) Guidelines for concentrations in discharge and at the edge of the mixing zone (size on a case by case basis) [75]	
	For Direct Discharge: Water desalination plants	General Environmental Regulations and Rules for Implementation Appendix 2.1: Guidelines for classification of industrial and development projects Key principles for environmental assessment of the project [76]	Only chlorine (residual) 0.5 mg/L
Spain	A. Wastewater treatment plants in any of the following cases: (i) Plant capacity exceeds 150,000 equivalent inhabitants (ii) When effluent discharge affects an aquatic environment that has been classified as sensitive (iii) In the case of rivers, when the location of effluent discharge is close to and upstream of intakes for human supply	Royal Decree 1302/1986, Group 8. Hydraulic engineering and water management projects [77]	
	Projects subject to environmental assessment with desalination facilities	Law 21/2013 [78]	Volume greater than 3,000 cm^3/d

Countries on the Mediterranean coast (France, Greece, Israel, Italy, Lebanon, Libya, Malta, Morocco, Monaco, Syria, Tunisia, and Turkey)	Agreement that limits the physical–chemical discharge rates (salt, chlorine, temperature, etc.) and requires an environmental impact study	Barcelona Convention BTelluric Protocol [42]	Does not state maximum permissible limit of salinity expressed as NaCl
		Annex I: A1; B Annex II: A13 "Substances that, even without being toxic, may be harmful to the marine environment or hinder any legitimate use of the sea as a consequence of the amounts discharged"	Does not state maximum permissible limit of salinity expressed as NaCl
Chile	Effluent standards	Environmental norms, established in Supreme Decree N° 90/00 [59]	
Mexico	Rejected water discharge works Discharging rejected water into the sea Infiltration or injection of rejected water into wells Discharging rejected water in maritime beaches Discharging into evaporation ponds Discharging water in lotic bodies	"Proy-NOM-013-CON Agua/ SEMARNAT-2015" to establish specifications and requirements for supply and discharge installations in desalination plants or processes that generate brackish or saline wastewater [15,29]	Does not state maximum permissible limit of salinity expressed as NaCl

Some of the European Union Directives on water quality are as follows:

- Directive 2006/11/EC, which relates to the discharge of dangerous substances into the aquatic environment, does not include the characteristic chemical components of the brine or special cleaning waters [53].
- Directives 91/271/EC and 98/15/EC, which relate to the quality of urban waste-water treatment, establish controls for the receiving environment for some parameters that are potentially significant in relation to discharges from desalination plants (BOD_5, suspended solids, etc.) However, values in general are greater that can be expected for brine [54].
- Directive 2006/113/EC, which relates to the quality of the waters for breeding shellfish, limits some parameters that are of interest in our case: pH, suspended solids, dissolved oxygen, etc., even salinity. However, the limits set are based on the effects on shellfish, and are not applicable to marine phanerogams or other susceptible species [55].
- Directive 2000/60/EC, which relates to a framework for water policy, includes salt concentration as a physical-chemical quality indicator but does not set any limit values.

It can be seen that although progress has been made in regulating water quality, there is still no legislation that sets critical limits for the chemical components or physical properties of brine with special regard to the habitats and species that can be found and are likely to be affected [56].

5.2. Chilean regulatory system

The regulations applicable to desalination plants, both in Chile and across the world, are mainly intended to regulate structure, water intake, effluent discharge, or criteria for drinking water quality and do not address the main problem: NaCl (brine) [47].

In order to construct and commission a desalination plant in Chile, one must consult the Environmental Impact Assessment System (Sistema de Evaluación de Impacto Ambiental), SEIA, whose function is to prevent the environmental impact of an activity or project regulated by Law No. 19,300 [57], article 10, item o) environmental sanitation projects, such as sewerage and drinking water systems, water treatment plants or plants for treating solid waste of household origin, landfills, submarine outlets, treatment systems, and disposal of liquid industrial waste (RILES) or solid industrial waste (RISES)." If a project or activity is submitted to the SEA and receives approval, it is issued with an Environmental Qualification Resolution (Resolución de Calificación Ambiental), RCA, which grants it permission to proceed.

Likewise, Decree 40/12 of the Ministry of the Environment [58] establishes that projects for liquid industrial waste treatment and/or disposal systems must be submitted for environmental evaluation when they meet at least one of the following conditions: effluents are used for irrigation, seepage, aspersion, and wetting of land or roads or the effluents treated have an average daily pollutant load equal to or

Table 4
Chilean regulations governing the quality of water and industrial waste

Normative or law		Inspection body		Maximum limit
Law No. 19,300 on Article 10 [57]	General foundations of the environment	Ministry of the Environment	Treatment and disposal systems for liquid or solid industrial waste	
Decree 40/12 [58]	Regulation of the environmental impact assessment system	Ministry of the environment	Establishes the provisions used: to govern the environmental impact assessment System and Community Participation in the environmental impact assessment process	
Supreme Decree No. 90 of 2000 [59]	Emissions standard for the regulation of pollutants associated with liquid waste discharge to marine and inland waters	Ministry General Secretariat of the Office of the President	Issuing body	Chloride (Cl^-) 400 mg/L Sodium (Na^+) does not state this parameter Temperature 20°C
			Discharge of liquid waste to river water bodies	Chloride (Cl^-) 400 mg/L Sodium (Na^+) does not state this parameter Temperature 35°C
			Discharge of liquid waste to lake water bodies	Chloride (Cl^-) does not state this parameter Sodium (Na^+) does not state this parameter Temperature 30°C
			Discharge of liquid waste to river water bodies considering the dilution capacity of receptor	Chloride (Cl^-) 2,000 mg/L Sodium (Na^+) does not report this parameter Temperature 40°C
			Discharge of liquid waste to marine water bodies within the coastal protection zone	Chloride (Cl^-) does not state this parameter Sodium (Na^+) does not state this parameter Temperature 30°C
			Discharge of liquid waste to marine water bodies outside the coastal protection zone	Chloride (Cl^-) does not state this parameter Sodium (Na^+) does not state this parameter Temperature does not state this parameter

Decree No. 46 of 2002 [62]	Emissions Standard for liquid waste to groundwater	Ministry General Secretariat of the Office of the President	Issuing body	Chloride (Cl^-) 400 mg/L Sodium (Na^+) does not report this parameter Temperature does not report this parameter
			Discharge liquid waste in conditions of medium vulnerability*	Chloride (Cl^-) 250 mg/L Sodium (Na^+) does not report this parameter Temperature does not report this parameter
			Discharge liquid waste in conditions of low vulnerability*	Chloride (Cl^-) 250 mg/L Sodium (Na^+) does not report this parameter Temperature does not report this parameter
Decree No. 609 of 1998 [63]	To establish Emissions Standard for the regularization of contaminants associated with discharging liquid industrial waste to sewer systems	Ministry of Public Works	Discharging effluent to sewage networks with sewage treatment plants	Chloride (Cl^-) does not report this parameter Sodium (Na^+) does not report this parameter Temperature 35°C
NCh 409/Of2005 [65]	Drinking water – Part 1 – requirements	National Institute for Standardization, INN	Quality of water intended for human consumption	Chloride (Cl^-) 400 mg/L Sodium (Na^+) does not report this parameter Temperature does not report this parameter
NCh1333.Of78 Mod.1987 [66]	Water quality requirements for different uses	National Institute for Standardization, INN	Water quality for irrigation and aquatic life	Chloride (Cl^-) 200 mg/L Sodium (Na^+) 35% Temperature 30°C
NCh 411/10. Of 2005 [67]	Standard for sampling wastewater	National Institute for Standardization, INN		Temperature

greater than the equivalent wastewater produced by a population of 100 people, in one or more of the parameters indicated in the respective standard for liquid waste discharge.

In similar, the standard conditions most commonly referred to companies that consult the SEIA to construct desalination plants in Chile is Supreme Decree No. 90 of 2000: Emissions Standard for the regulation of pollutants associated with liquid waste discharges to marine and inland surface water [59]. However, despite the long list of pollutants (total, volatile hydrocarbons, fixed hydrocarbons, BOD_5, arsenic, aluminum, boron, cadmium, cyanide, chlorides, copper, phenol number, hexavalent chromium, total chromium, tin, fluorine, phosphorous, iron, manganese, mercury, molybdenum, nickel, total nitrogen, Kjeldahl, nitrite and nitrate, pentachlorophenol, lead, SAAM, selenium, sulfates, sulfide, tetrachloroethene, toluene, trichloromethane, xylene, and zinc), and according to the maximum permitted concentrations for the discharge of liquid waste to marine waters inside and outside of coastal, river and lake protection zones, it only includes Chloride (Cl^-) and not Sodium (Na^+). In relation to temperature, this standard proposes a range of between 20°C and 40°C for the emitter and for river and lake bodies, but not for marine bodies.

According to Skewes Urtubia, 2019 [45], of all the desalination projects presented to the SEA in which it was not deemed necessary to submit the activity to the SEIA to carry out an Environmental Impact Assessment (EIA), most indicated that the brine returned to the sea had a minimal impact since it originates from the same location, has a low flow rate and low concentration, even stating that no treatment is required prior to being discharged to the marine receiving body [60]. As in the case of the "Seawater desalination modules, Windows No. 3" project, in which the Environmental Impact Statement indicates that the water rejected from the desalination plant will be disposed of via the RILES pipeline system into the sea and is part of the Applicable Environmental Legislation Compliance Plan, according to Supreme Decree No. 90 (2000) [61].

The disorganized and complex system of regulations that can be applied to desalination processes in Chile includes Decree 46 (2002) Emissions Standard of liquid waste to groundwater [62] and supreme Decree 609 of 1998, which approves the Emissions Standard for the regularization of contaminants associated with the discharge of liquid industrial waste to sewer systems [63]. Of these, only the first includes the parameter chloride (Cl^-) but does not include sodium (Na^+) and the second does not include either. Regarding temperature, only Decree 609 establishes a limit: 35°C.

The standards and standardized methods for drinking water and waste water issued by the National Institute for Standardization (Instituto Nacional de Normalización, INN) [64], consider it relevant to mention NCh 409/1:2005 as it establishes quality requirements for drinking water. However, it only establishes a maximum limit for chloride, not sodium or temperature [65]. NCh1333.Of78, on the other hand, establishes water quality requirements for different uses and establishes water quality criterion in terms of the physical, chemical, and biological aspects and according to the defined use. These criteria are intended to protect and preserve the quality of water intended for specific uses (water for human consumption, drinking water for animals, irrigation, recreation, and cosmetics and aquatic life). Polluting wastes discharged into bodies of water or streams cannot exceed the maximum limits for the elements and parameters established in the NCh1333.Of78 standard, taking into account the self-cleaning capacity ("natural process of purification of contaminated water that stabilizes dissolved or suspended organic matter by the action of dissolved oxygen in water, which has come from the atmosphere or photosynthesis helped by bacteria or other aquatic plants") and dilution ("residues of the procedure of removing water from a receiving stream to reduce the concentration of pollutants") of the receiving body, as in the case of rivers [66]. This regulation could be considered the most complete in relation to those previously described because it includes maximum permissible limits for chloride, sodium, and temperature.

Finally, the standard for wastewater sampling NCh 411/10: 2005 [67] describes that how the samples are collected, handled, and to standardize the methods for taking samples from these waters. However, it does not make reference to water from desalination plants. These criteria are intended to preserve the quality of the water meant for specific uses and protect it from degradation caused by contamination from any type of waste from any source.

Salinity is a parameter that describes the mass of salt dissolved in a given mass of solution. The only way to determine true salinity is by performing a complete chemical analysis [68]. Other indirect methods are often used, such as: conductivity, density, or sound velocity.

National and international standardized methods state that the maximum concentration allowed will depend on the use of the water, that is, irrigation, aquaculture, or recreation [66].

As can be seen in Table 4, none of the described standards have been created to regulate the desalination process, the final composition of brine, water governance, the ownership of desalinated waters, or many other matters that are relevant to promoting the use of seawater to solve a world-wide problem. This is especially relevant when considering the potential to develop this process in Chile by means of non-conventional renewable energy, in particular solar energy. We will now relate how draft bills have existed in Chile for more than 8 y but have not managed to obtain sufficient political support to tackle this complex process.

5.3. Legislative initiatives in Chile to promote desalination processes and their link with solar energy use

Some production processes require large amounts of energy and water, such as the mining industry in Chile. This situation had become a matter of concern for Chilean legislators on 2 November 2011, the date on which a bill was put before the National Congress, and later merged with another presented on 10 December 2013. These bills proposed modifying the mining code to compel mining companies with water extraction requirements in excess of 150 L per second to incorporate seawater desalination into their production processes. It also stipulated that the desalinated water would be regulated by a regulation created especially for this purpose. However, the consolidated text of both bills is still being processed [69,70].

On the other hand, and echoing the absence of public policy addressing the scarcity of water resources, which is directly related to rational use, a bill was presented on 15 January 2015 that empowered the State to create desalination plants [71], this bill has also failed to be passed into law.

Mining continuous to be one of the most important economic activities in Chile. It mainly takes place in the northern zone, which is characterized by limited availability of water resources, which in turn is the reason why desalination is a highly desirable alternative, "however, energy costs in Chile are still very high (0.12 US$/kWh), which means that not all mining projects or operations can use seawater (whether salty or desalinated) and in some cases even makes them unfeasible. On average, pumping cost per 1,000 m.a.s.l. varies between 1 and 1.5 US$, so moving a cubic metre of desalinated seawater to over 3,000 m.a.s.l. costs around 4–7 US$, which is more than four times (in some cases up to 10 times) the cost of extracting fresh water from the mountains. The value of fresh water is approximately 1.6 US$/$m^3$" [72], as implicitly acknowledged in the bill presented on 30 September 2015, the water-energy nexus. Said bill, modifies the Decree with Force of Law No. 340 [73], regarding Maritime Concessions to regulate the extraction of seawater and allows the development of agreed service areas (Art. 1). This allows complementary activities to be created in the Bidding Rules, making possible and optimizing a business model that will attract individuals to form part of this public-private association. The energy supply for this type of plant can be included as part of the installation requirements. Therefore, Chile has produced a bill that recognizes the importance of using bidding rules for maritime concessions to actively link – not only at the legislative level, but also at the administrative level – the use of seawater for desalination and the energy supply that this activity requires. Currently, this bill has been re-opened and is awaiting further processing.

The legal system regarding seawater is clear. Nevertheless, there is some discussion regarding its legal status in terms of the process performed in a desalination plant. In order to prevent these waters coming under the same regulation as surface water, which is currently heavily overexploited as a result of the right to exploit water, a bill was published on 25 January 2018 on the use of seawater for desalination. This argues that desalinated water is also a national asset for public use that can be used by the holder of the underlying maritime concession, although with limitations on the quantity and purpose with which said concession was conferred. As with the bills mentioned previously, this bill is being processed.

Although the bills described above exist to regulate various aspects of the desalination process in Chile, we believe that it is not helpful that an activity should have such widely scattered regulations since, ultimately, it means that the situation is not properly addressed. Likewise, we are concerned that none of the bills reviewed make reference to brine and its final destination, especially considering the adverse effects that can be generated by the mismanagement of this waste product.

The contradictory and insufficient nature of the Chilean regulatory system is evident in an area in which a swift and decisive response to the water governance crisis is urgently required.

Therefore, in accordance with the information set out above, the following proposals are put forward.

5.4. Proposal for Chilean regulations governing brine obtained from processes of desalination

Given the growing number of desalination plants in Chile, a regulatory system that considers the final composition of rejected water or Brine from the process expressed in terms of NaCl, or Na^+, Cl^-, or salinity should be urgently created. This system should at least consider a characterization of the rejected water or brine expressed in NaCl, (mg/L), or salinity (dimensionless) and temperature (°C). These are essential parameters and their maximum limits should be expressed as follows:

- Salinity, the concentration must be less than or equal to that of the receiving body. For example, if it is discharged into the sea, it must be less than the salinity of the sea (35 mg/L).
- Temperature, this parameter should be considered to be approximately 2°C higher than that of the receiving body (while respecting the temperature proposed in the Paris Agreement, 2016) [74].

Once the brine has been characterized, the alternative disposal solutions mentioned in section 3.1 (Brine disposal alternatives). should be evaluated and the natural content of the receiving body taken into account.

Finally, the system of standards should include using the brine obtained to develop new products.

6. Reflections and conclusion

The water crisis that plagues large populations worldwide requires decisive, organized, and urgent answers. As part of this response, this work advocates the implementation of a system to comprehensively regulate seawater desalination, from the construction and operation of plants, the extraction and treatment of seawater using renewable energy to the disposal of the resultant brine.

With regard to the integrated management of the saline waste produced by the desalination process, it is necessary to implement rules and public policies that guarantee the necessary balance of the economic–social–environmental system and ensure sustainability.

An analysis of regulations in various countries where desalination plants are increasingly constructed demonstrates that these regulations do not make specific reference to maximum limits of the main component of brine, that is, salinity or sodium chloride expressed as NaCl. Mexico is moving in the right direction by addressing alternative methods for disposing of brine in its proposed standard although it does not consider a maximum salinity concentration or temperature.

The two properties of brine that can cause environmental damage to the receiving body, especially the sea, are salinity and temperature. As such, this work considers fundamental that regulations in countries with desalination plants that include parameters and limits for these variables in order to prevent environmental impact.

This is a study that systematizes regulations, studies and data that, when looked at together, draw our attention to how attempts to tackle the current water crisis can trigger environmentally damaging processes if there is no regulatory system that allows the harmonization of the different stages of the desalination process, with special reference to brine disposal and sustainable development of the communities in which the desalination plants are located.

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