Chapter 18
Economics of Water Resources

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Abstract Economic and social changes that have occurred in Chile in recent decades have affected water management in multiple ways. In particular, its adoption of an export-oriented growth strategy since the 1980s, based on developing natural-resource intensive activities in the primary sector has led to significant increases in water demand. Decoupling of economic growth from water demands is, thus, a priority so as to not limit future economic growth and social development. In this chapter an overview of the water sector in the national economy and growth is presented. Then the economic value of water resources is covered, analyzing its apparent productivity, as well as the water-energy-food nexus. Finally, some conclusions are presented.

Keywords Economy · Social · Water management · Export · Natural resources · Economic growth · Social development

18.1 Introduction

Economic and social changes that have occurred in Chile in recent decades have affected water management in multiple ways. In particular, its adoption of an export-oriented growth strategy since the 1980s, based on developing natural-resource intensive activities in the primary sector has led to significant increases in water demand. Decoupling of economic growth from water demands is, thus, a priority so as to not limit future economic growth and social development.

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The chapter is structured as follows. The next section presents an overview of the water sector in the national economy and growth as well as. Section 18.3 covers the economic value of water resources, analyzing its apparent productivity. The water-energy-food nexus is discussed in sect. 18.4. Finally, Section 18.5 concludes the chapter.

18.2 Overview of Water Management in Chile

18.2.1 Participation of the Water Sector in the National Economy and Development

Chile's economy has grown continuously over the past 30 years at a significantly higher rate than average world growth during the same period. GDP more than doubled in real terms in less than 30 years (Fig. 18.1).

Structural policies and policy reforms played a central role in Chile's growth. Chile implemented important structural reforms in many areas since the mid-1980s. The most important reforms included, liberalization of the capital accounts, reduction and harmonization of import tariffs, liberalization of foreign exchange markets, public sector restructuring and state-owned enterprise privatization, sector deregulation and adoption of social policies aimed at reducing poverty and improving equity (Schmidt-Hebbel 2006; Anríquez and Melo 2018).

Primary, secondary, and tertiary sector's growth has been relatively balanced. Between 1990 and 2015, the relative share of the primary sector (agriculture and livestock, fishing, and mining) slightly decreased from 12% to 11%, the secondary sector (manufacturing) decreased from 20% to 17%, while the tertiary sector

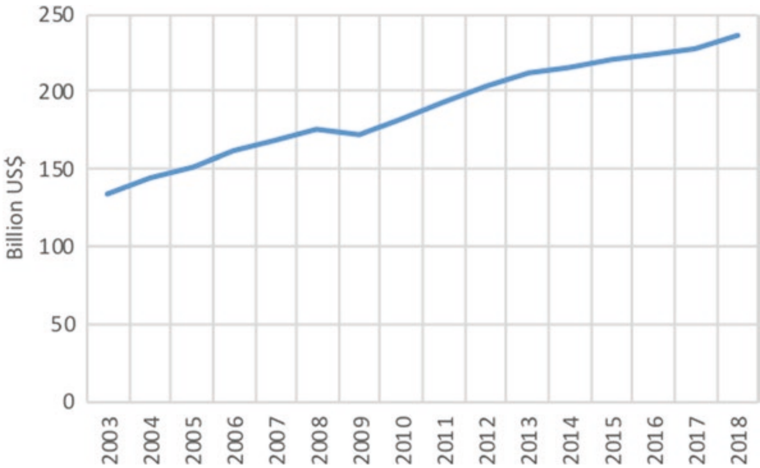

Fig. 18.1 GDP (Banco Central de Chile 2019)

(services and others) remained stable at a 68% of GDP (Schmidt-Hebbel 2006; Banco Central de Chile 2019).

The explanation for Chile's different sectoral growth is mainly its adoption of an export-oriented growth strategy since the 1980s, based on developing natural-resource intensive activities in the primary sector and in resource-processing manufacturing subsectors.

Due to this strategy, the share of mining (largely copper) in GDP declined from 7.3% in 1988 to 5.4% in 2018, the share of fisheries remained stable, at approximately 1.2% of GDP, while agriculture and livestock has declined between 1988 and 2018, from 4.6% to 3.0% (Banco Central de Chile 2019; ODEPA 2019a).

Associated to Chile's economic growth, total consumptive water use has increased. Sectoral water consumption trends are diverse responding to sectoral economic growth. The agricultural sector in Chile, the largest water user, increased its water consumption 31% between 1997 and 2007. This trend is expected to continue in the future since the declaration of the goal for Chile to become a world agricultural and food production power in the twenty-first century, requires at least a 36% increase in the total area under irrigation. Even though per capita water consumption of potable water in the urban sector decreased 20% between 2003 and 2017 (SISS 2017), its total volume increased 25% during the same period, due to significant increase in urban population. During the same period, total water consumption in the mining sector has nearly doubled. Raw and desalinated sea water use in copper mining doubled during the period spanning 2010–2015, representing in 2015 14% of all water consumed by this sector (Acosta 2018).

Decoupling of economic growth from water demands in Chile has not been an automatic by-product of growth in national incomes and requires dedicated policies to improve water allocation between competing uses so as to not limit future economic growth (Fig. 18.2).

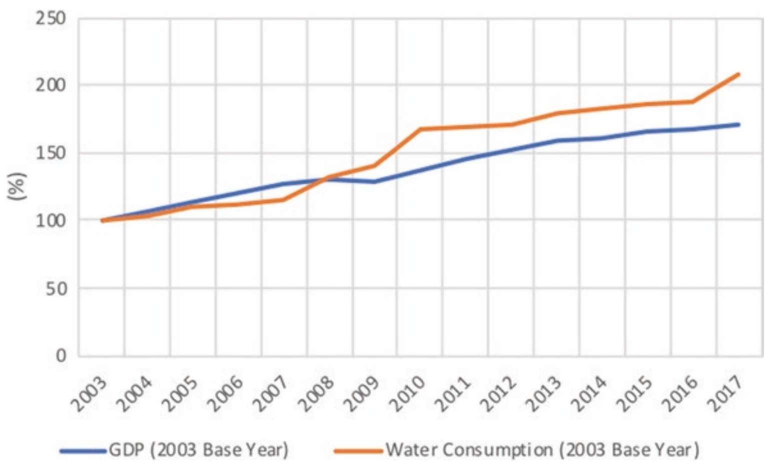

Fig. 18.2 Economic and consumptive water growth (Banco Central de Chile 2019; DGA 2016)

In recent times, groundwater has increasingly become a significant water supply source. Granted groundwater rights flow increased 224.4% between 2001 and 2017, while surface water rights flows grew 160%. The importance of groundwater as a water source is particularly evident in the north. In the future this trend is expected to grow as a consequence of the increased water use due to increased economic growth, together with population growth, urbanization, water quality deterioration, as well as projected climate change impacts on the availability of surface water.

The rapid development of groundwater use has generated a number of problems threatening the sustainability of water resources. Groundwater levels have been declining in a number of regions, revealing that aquifers have been exploited beyond sustainable limits (World Bank 2011). Groundwater over-allocation has increased water conflicts. At first, conflicts concerning groundwater were typically in the North and Center Macroregions of the country. However, the intensification of its use has expanded the territorial extent of such conflicts (Rivera et al. 2016; Herrera et al. 2019). For the period 1981–2000, problems related to property protection and the environment were the major drivers of conflicts; in the period 2001–2008, regularization of water rights stands out as an important cause of disputes; and during the period 2009–2014, overexploitation of groundwater due to surface water scarcity and poor DGA control on groundwater wells were the most frequent causes of conflicts (Herrera et al. 2019). Everything presumes that the number and complexity of water related conflicts will continue to expand.

Water rights markets in Chile have also enabled Chile's economic growth by facilitating the reallocation of water use from lower to higher value users and providing access to water resources at a lower cost than alternative sources such as investment in water infrastructure and desalination (Hearne 2018). Water rights markets are mainly driven by relative water scarcity due to economic growth, especially of water intensive sectors.

The volume of water reallocated by water markets has grown overtime throughout the nation and, thus, water markets have matured (Hearne and Donoso 2014; Hearne 2018). Coquimbo and Araucanía regions present the highest number of water rights transactions, followed by the Maule and Metropolitan regions (Cristi et al. 2014). Some of these market transactions may be for all of a seller's total water rights (WR), and thus not marginal. However, there are many transactions for relatively small quantities of water. The large percentage of small value transactions challenges the argument that high transactions costs limit market trading (Hearne 2018).

The majority of transactions have been between agricultural users, with resulting efficiency gains. Intersectoral transfers of water have been relatively infrequent. The O'Higgins and Metropolitan regions present the highest valuation of flow rates with an average of US$23,600/l/s and US$16,400/l/s, respectively (Cristi et al. 2014). However, water rights transaction prices are highly variable. This wide range of prices reveals that markets are imperfect and subject to individual bargaining power of buyers and sellers (Donoso et al. 2014).

18.2.2 Water Use and Efficiency per Sector Over Time

Consumptive water use in Chile is dominated by irrigation, representing 82%, followed by industrial, mining and potable water supply, which account for 8%, 3% and 7% of total water consumptive water use, respectively (Fig. 18.3).

Irrigation surface has increased in response to public policies launched in the mid-1980s (Martin and Saavedra 2018), reaching approximately, 1,100,000 ha (ODEPA 2019b). The introduction of efficient irrigation systems in Chile during the past 15 years has led to a significant increase in the proportion of irrigated land with efficient irrigation technology. Average irrigation efficiency increased by 17% between 1997 and 2007, rising from 48.6% to 56.9% (Martin and Saavedra 2018; Donoso 2017). At present, 30% of Chile's total irrigated surface is equipped with efficient irrigation technologies such as drip and sprinkler systems.

Thus, agricultural growth has been achieved, in part, by intensification of production, constant land use transition from agricultural use in import competing crops into higher value export crops (fruits and nuts), accompanied by a marginal expansion of agricultural land, and increases in water use efficiency (Donoso 2018).

Nevertheless, water use efficiency (WUE), defined from an economic perspective as the economic return per unit of water used for crop production, is on average low. Molinos-Senante et al. (2016) finds that average WUE score is 0.450 for farmers in the Limary basin, even when irrigation efficiency is 69% in that basin. Thus, as de Oliveira et al. (2009) points out, there is a considerable possibility of reducing water consumption in the Limary basin, without affecting production levels.

However, inadequate agricultural water use is salinizing, waterlogging, and eroding agricultural lands and polluting water. Chile has about 35% of their irrigated lands affected by salinity (Ringler et al. 2010), most of which are concentrated in the northern macroregion.

Although mining is the productive sector that consumes the least amount of water, in some arid areas of Northern Chile it is a relevant user ranking first or second followed by the agricultural sector. In arid northern regions, water withdrawal

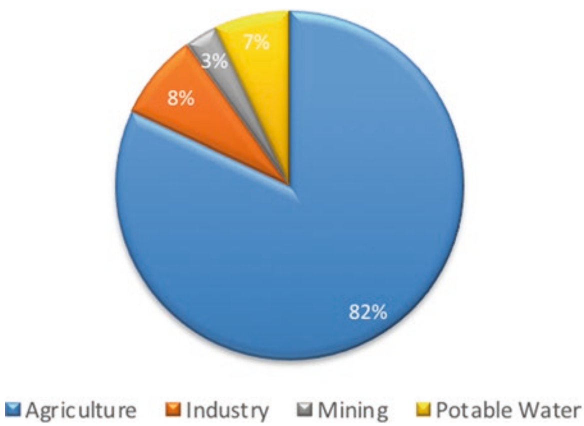

Fig. 18.3 Consumptive water use by economic sector (DGA 2016)

from mining is mainly from aquifers (Acosta 2018). Mining has significantly increased their water use efficiency from 2m^3/ton of treated ore in the 80s to 0.532m^3/ton of treated ore in 2015 (Peña et al. 2011; Acosta 2018). The main driver has been the increased value of water due to increasing copper production and the absence of alternative low-cost water supplies. New water demands owing to new mining developments that have not been able to be met by efficiency improvements, have been mainly supplied with desalinated water. The increase in raw and desalinated seawater use between 2010 and 2015 has doubled, reaching in 2015 approximately 14% of the total water used (Acosta 2018). It is estimated that this tendency will continue in the near future (Cochilco 2016).

The industrial sector has also increased water use efficiency. For example, the pulp industry reduced its water consumption from 130m^3/ton in the 80s to 40m^3/ton in 2012 (Peña et al. 2011).

On the other hand, domestic water use efficiency has not improved in the past years. Technical water use efficiency in urban water supply is rather low, due to high levels of non-revenue water, of which 74% corresponded to water losses (Molinos-Senante et al. 2018). In spite that the Chilean water regulator establishes that the maximum percentage of non-revenue water should be 20%, most water companies in Chile exhibit larger percentages. The majority of Chilean water supply companies (61%) present a percentage of non-revenue water above 30%, while only 26% present a percentage below the regulator's target of 20% (SISS 2017).

18.3 Economic Value of Water Resources: National and Sectoral Water Productivity

Water productivity is defined as the ratio between an output linked to a water use and its water consumption. It provides a description of how well water resources are made productive (i.e. generating value) in their different uses. Economic water productivity, measured in monetary units per unit volume ($/m^3), provides a tool to attribute value and productivity to all water uses and users within a hydrological domain. An indicator of economic water productivity is the apparent water productivity, estimated by the ratio of GDP to water consumption. Table 18.1 presents the estimates of Chile's apparent water productivity.

Table 18.1 Apparent water productivity (Banco Central de Chile 2019; DGA 2016)

Economic sector	Water consumption (MM m^3/year)	GDP (MM $/year)	Water productivity ($/m^3)
Agricultural and forestry	16,611	8720	0.52
Industry	1383	39,487	28.55
Mining	630	27,666	43.89
Country	20,353	281,249	13.82

Chile's economic water productivity is \$13.82/m^3/year, significantly higher than Latinamerica and the Carribean's (LAC) average of \$6.6/m^3/year (World Bank 2019; Mekonnen and Hoekstra 2011). The industrial sector's apparent water productivity is \$28.55/m^3, about half of the economic value of water in the mining sector, whose apparent water productivity is \$43.89/m^3.

Agriculture represents the lowest economic water productivity of Chile, which is lower than the sector's average economic water productivity in LAC of \$1.01/m^3 (World Bank 2019; Mekonnen and Hoekstra 2011). Economic water productivity within the sector varies between \$0.2/m^3 for cereal and \$0.85/m^3 for fruit production (Banco Central de Chile 2019; DGA 2016; Donoso et al. 2016). These results explain, in part, the significant reduction in the land devoted to cereals and increases in land devoted to fruits, which led to a reduction of agriculture's water footprint (Donoso et al. 2016).

18.4 Food-Water-Energy Nexus (FWE) in Chile

18.4.1 Current Situation of the FEW Nexus in Chile

Food-Water-Energy are critical resources that are to a great extent linked to one another, meaning that changes in any one in particular can affect one or both of the other areas. As the case with water demand, energy consumption is also coupled to economic growth in Chile (Fig. 18.4); thus, water and energy demands for urban water supply, mining, and export-oriented agriculture will continue to grow as the economy grows, unless dedicated policies are implemented to decouple this relationship.

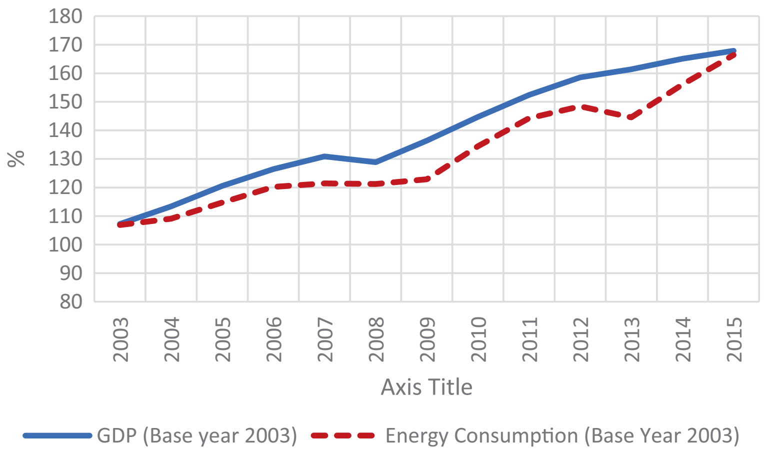

Fig. 18.4 Economic and energy consumption growth (Banco Central de Chile 2019; CNE 2017)

18.4.2 Drivers and Challenges of the FEW Nexus

Vicuña et al. (2011) estimates that mining will generate additional demands for fresh water to satisfy production expansion projects and future investments. This generates higher energy demands not only for desalinization but also for pumping water from the coastal zone towards the projects that are located at high altitudes above sea level. Cochilco (2017a) estimates a 2.7% yearly average growth in energy consumption between 2017 and 2018 for the mining sector. Non-conventional renewable energies can be coupled to seawater desalination plants, so as to produce a more sustainable water supply.

Urban water consumption has also increased due to the increase in the urban population and the non-reduction of water losses. This trend is expected to continue where water and energy consumption is projected to increase 10% and 15%, respectively (Vicuña 2011).

The total area under irrigation is projected to increase by at least 36% by 2020 (Martin and Saavedra 2018). Additionally, Chile has achieved an average irrigation efficiency of 57% (Donoso 2017). This is due to an 85.1% increase in higher efficiency technological irrigation methods and a 298.2% increase in the area in which micro-irrigation was used (Martin and Saavedra 2018). However, modernization of irrigation has increased energy consumption. Recognizing this, the Ministry of Agriculture promotes the use of non-conventional renewable energies in the agricultural sector (Ministerio de Energía 2016).

The FEW nexus is getting more entwined product of global climate change. Climate change projections show that temperatures will increase, and rainfall will decline in most of Chile (MMA 2016), causing changes in streamflow patterns. Snow driven basins in the north and center of the country will tend to be driven by a mix of rainfall and snow (Vicuña et al. 2011). This will further increase competition for water resources and increase groundwater pumping to meet demands. Thus, increased water scarcity due to projected climate change impacts for Chile will be a significant driver for FEW nexus.

Therefore, Chile faces increasing pressure on water resources and energy, incentivizing the need to look for alternative water and energy sources, particularly in water-scarce areas with large inter-sectoral competition for water. The national energy strategy for Chile (Ministerio de Energía 2012) for 2012–30 recognizes this and places special emphasis on increasing energy efficiency and the participation of non-conventional renewable energy sources. Since 2014, more than 40% of the generation projects that have been built each year correspond to non-conventional renewable energy sources.

Historically, Chile has opted for a policy of water resources supply management to cope with the growing scarcity. The State's policy on water management has focused on alternatives and new technologies aimed at improving the availability of the resource. To this end, three pillars have been proposed: (i) regulate the flows through investment in major reservoirs, (ii) implement artificial recharge projects for aquifers, and (iii) invest in desalination.

18.4.2.1 Projection of Large Hydraulic Infrastructure

The Direction of Public Works (Dirección de Obras Hidaúlicas – DOH) has developed an investment plan to increase the storage capacity in reservoirs (DOH 2016). The plan considers an investment of MM$5700 for the construction of 25 reservoirs between 2015 and 2025. This would increase actual storage by 70%, passing from 4200 MM m^3 to 7200 MM m^3 (DOH 2016).

Four of these are projected for the north, three for the center-north, fifteen for the central zone and three for the center-south. As for capacities, eight of them will exceed 100 Hm^3 and only one 500 Hm^3.

Additionally, together with the National Irrigation Commission (Comisión Nacional de Riego – CNR) the DOH projects the construction of 20 small reservoirs, with a storage capacity of less than 50 thousand m^3, so as to mitigate the drought situation in rural areas of the country, focused mainly towards vulnerable agricultural sectors. This plan considers an investment of MM$450 (Delegado Presidencial para los recursos hídricos 2014).

18.4.2.2 Projection of Non-conventional Water Supplies

(a) **Desalinization**

In the northern regions, the option to satisfy increased water demand from the mining sector, is through desalination plants. It is estimated that consumption of desalinated water for mining operations will increase from 2.9 m^3/s in 2016 to 11.2 m^3/s in 2028 (Cochilco 2017b). Thus, more than 150 MM m^3/year are being considered in desalination plants. An example of this is the launch of the EWS (Escondida Water Supply) project, BHP Billiton's second desalination plant in Puerto Coloso, with a capacity of processing 80,000 m^3/year, which once completed, will be the largest plant of its kind in Latin America and Europe.

Chile's National Drought Strategy also considers investing MM$265 in desalinization plants to supply human consumption in areas with structural water shortages such as Copiapó and La Ligua-Petorca (Delegado Presidencial para los recursos hídricos 2014).

(b) **Water Reuse**

Currently, Chile is the most advanced country in wastewater treatment in Latin America, treating 99.93% of its urban sewer water. This translates into a total annual discharge of 1200 MM m^3/year of treated wastewater of which 240 MM m^3/year are discharged into the sea through emissaries. The DGA has estimated that reusing the water discharged through emissaries would cover 10% of Chile's water deficit (DGA 2016). Hence, reuse of treated wastewaters is a promising water source for Chile. However, conflicts over use rights and the lack of a regulatory framework are hindering its potential.

The reuse of treated water has been developed up to now in an informal way and without the support of a regulatory, institutional and financial framework that orders, promotes and controls this complementary water source. Although it is possible to detect certain informal or indirect cases of treated wastewater reuse in Chile, they are isolated practices. Actual reuse is very low, approximately 1% of its potential, focused only on irrigation (SISS 2017). In order to advance in the use of this valuable resource, Chile must adapt its regulatory-institutional-financial framework.

However, as in other countries, increasing its use also requires considering an array of factors such as social attitudes toward treated wastewater, quality of agricultural produce, chemical quality of the water, and health, among others.

18.5 Conclusions

As a result of its structural economic and policy reforms, since Chile's return to democracy in 1990, real per capita GDP per capita increased in real terms over 100%. In response to this accelerated growth, given that water consumption is coupled to economic growth, water demands during the same period grew significantly. Due to the growth in water consumption, several basins in the north and central regions are overexploited presenting important water stress situations leading to economic vulnerability. Thus, water and energy will become critical limiting factors for future growth.

Chile has opted for a policy of water resources supply management to cope with the growing scarcity. However, this policy on its own is unsustainable, given that as water availability increases so does water consumption, leading once again to water scarcity.

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