Economic Evaluation of Climatic Change Impacts on Water Resources at River Basin Scale: Insights from the Vergara River Basin – Chile.

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Abstract

This study presents the main results of the project "Economic Evaluation of Climatic Change Impacts on Water Resources at River Basin Scale". We evaluate the economic consequences of climate change at river basin scale using a hydro-economic model, which includes two water demand sectors: residential and agricultural. The main quantitative results are complemented with a qualitative social and vulnerability analysis. According to our results, climate change will have minor overall impacts on the basin economy with large distributional consequences. Moreover, subsistence agricultural communities, seem to be the most vulnerable groups to climate change.

Keywords: Welfare assessment, hydro-economic model, climate change, agriculture, residential water demand, river basin, integrated water resources management.

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1. Introduction

Water resources quantity and quality are likely to be affected by multiple stressors in the Latin-American region. Some of these stressors are associated with changes in climate patterns while others are related to human interventions in agriculture, land-use/land use change, construction/management of reservoirs, pollutant emissions, and water /wastewater treatment, among others (Bates et al, 2008). The expected changes in both demographic trends and climate patterns will exacerbate the challenges faced by policy makers to manage water resources.

In fact, the conclusions of the fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), suggests that climate change impacts on water resources will have uneven consequences across sectors and regions (Field et al 2014). Changes in precipitation, temperature, and increase of extreme weather events (floods and droughts), can seriously affect water supply for different users, among of which residential and agricultural sector may be relevant. The changes in water supply may have critical economic implications if these changes are expected to modify hydrological systems and production processes that have impacts on human welfare.

Given these facts -inevitability of climate change, impact on the supply and quality of water and its economic consequences-, policy makers need to count on some *"sophisticated simple"* tools that allow them not only to assess the impact of climate change on water availability (or quality) but also to evaluate possible economic instruments and adaptation strategies that facilitate an efficient use of scarce water resources.

There is consensus about the use of river basin scale as the proper spatial scale to analyze water resources management (UNCEP, 1998). One reason for using the river basin scale is due the externalities associated with water mobility, in which water users are linked through the hydrologic system. Thus, every decision regarding water consumption in one zone of the basin could have impacts on the other zones of the same basin. Hydro-economic models are able to represent water users' interactions within the basin combining hydrologic and socioeconomic information (Harau et al 2009). Their objective is to maximize the economic value of water use for the entire basin, for whatever definition of value policy makers are interested in. For instance, we could be interested in income, total production, consumer and producer surplus, etc. The maximization of these objective functions is subject to the hydrological, institutional, and environmental constraints (Brower & Hofkes, 2008; McKinney, Cai, Rosegrant, & Scott, 1999). Hydro-economic models have been widely used for the analysis of water resources (Blanco-Gutiérrez et al. 2013; Cai et al. 2008; Foster et al. 2014; Varela-Ortega et al. 2011; Ward and Pulido-Velazquez 2008), economic impacts of water variability (Graveline et al. 2014; Maneta et al. 2009a; Maneta et al. 2009b; Torres et al. 2012), water quality issues (Peña-Haro et al. 2010; Peña-Haro et al. 2011; Riegels et al. 2011), and economic impacts of climate change (Hurd and Coonrod 2012; Jiang and Grafton 2012; Varela-Ortega et al. 2013; Yang et al. 2013; You and Ringler 2010) among others.

2. Objective and research goals

This paper presents the results of the “Economic Evaluation of Climatic Change Impacts on Water Resources at River Basin Scale” project (eec2-water project) developed in Chile, Colombia, and Bolivia. The project is a combined effort between Universities, NGOs, and local government institutions, which aims at providing useful information for policy makers, increase awareness about climate change among stakeholders and fostering undergraduate and graduate students.

The main objective of this project is to provide an analytical tool that allows policy makers to identify the economic impacts of climate change on water availability at a basin scale taking into consideration the spatial allocation of users and to evaluate different policy strategies in order to minimize the economic impact of those changes.

To reach our goal we rely on a hydro-economic model, which links the physical impacts of climate change (decrease on water availability) with the economic responses of water users. The physical impacts on water supply are modeled using the SWAT hydrologic model for the basin, and the potential economic responses of distinct water users are analyzed using an appropriate combination of econometric and optimization methods.

This approach allows us to identify both the economic sectors and the population groups that will likely be affected by changes on water availability, as well as to identify policy alternatives that can be used to cope with climate change, and evaluate them using a cost effectiveness approach. Any potential change would have winners and losers, but some of the affected communities are not necessarily identified by the hydro-economic model due to their little share in the agricultural production or residential consumption. This is, for instance, the case of several agricultural communities oriented to subsistence agricultural production. Therefore, our hydro-economic analysis is accompained by the identification of the most vulnerable communities using participatory techniques.

3. Research Design

3.1 Study area

The Vergara river basin is located 600 km southward from Chile’s capital city– Santiago. In administrative terms, the Vergara basin spreads within two regions: Biobío and Araucanía. It is the largest sub-basin of the Biobío basin, one of the most important basins in the country (EULA 2004). The Vergara river basin has an extension of 4,260 km^2, including ten municipalities with a total population of almost 200,000 inhabitants and a large share of rural population (Table 1). Agricultural smallholders, forestry companies, and fruits exporters characterize the basin economy, whith the largest indigenous population (after Santiago). Besides, currently several municipalities within the basin are national hotspot regarding the indigenous rights acknowledge movement.

The Vergara river basin has two features that make it suitable for testing our methological framework: i) it presents some degree of conflicts among water users, which means that there is competition for the resource, and ii) the basin already had a hydrologic model calibrated and validated for climate change impact assessment[1]. Therefore, our efforts were devoted to design, estimate, and integrate the economic

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[1] For details about the hydrologic model see: Sterh et al., 2010.

water demands for urban households and farmers with the hydrologic model in a single and comprehensive framework.

[Table 1 around here]

The hydrologic cycle within the Vergara river basin is completely dependent on rainfall patterns and exhibits large seasonal variability (runoff peaks during July). Thus any decrease in the rain will drive a decrease in the water availability within the basin. The basin land use capability shows that 45% of the basin is seriously limited for field crops activities, and in those areas most of the land is devoted to forestry activities mainly due to slope characteristics, soil degradation, and soil quality. Current land use is dominated by forestry (64%), with a small share of agricultural activities (crops and fruits). Although agriculture is not the representative land use, it is the most relevant activity in socioeconomic terms with more than 14,000 smallholders under some government support program (INDAP, 2014)

Three users groups characterize water demand within the basin: residential, industrial, and agricultural. The basin has 59,000 residential water users (households) distributed within the ten municipalities, while the industrial water demand is dominated by paper mill industry accounting for more than 90% of the industrial water use. Other water users are diary and leather industries (Navarro, 2006). Regarding the agricultural sector, the most water-intensive activities are crops (maize, wheat, and sugar beet) and fruits, accounting for 38,000 ha under irrigation (INE, 2007). Regarding water resource policy, the basin is currently in its early stage to establish an institutional framework seeking to improve water resource management. This effort is critical, considering that currently the basin is under a severe water shortage.

3.2 Methodology

We used a four-step methodology in order to assess the welfare impacts of climate change at river basin scale. In general terms, the proposed methodology seeks to include all the aspects suggested by the water management literature combining a hydrologic model and socioeconomic analysis.

Figure 1 depicts the different steps of the project. First, we collected hydrological and land use data. This information allowed us to define the baseline for the basin, identifying the main stressors, climate change scenarios, main stakeholders and water use conflicts. The second step collected economic and social data needed to estimate water demand models for both agriculture and residential sectors. Within this step, we identified the most vulnerable water users to climate change using the vulnerability concept defined by the IPCC (Schneider et al, 2007). Based on secondary information, workshops, and key actors interviews we evaluated vulnerability to extreme weather events and vulnerability according to the systems at risk. In the third step we integrated the hydrologic and socioeconomic components, identifying excess of supply or demand under different climate change scenarios. This information allowed us identifying both the economic sectors and the population groups most affected by the changes on water availability. Finally, in the last step we identified policy alternatives that can be used to address climate change, and evaluate them using a cost effectiveness approach.

[Figure 1 around here]

The Vergara Hydro-economic Model (VHM) is a mathematical programming model designed to analyze water related issues considering two water users: residential and agriculture. The SWAT model represents the hydrologic characteristics of the basin, while the residential water demand and the agricultural water demand are modeled using econometrics and optimization techniques, respectively. Each of the VHM components are presented in the following sections.

At this stage this model does not captures the entire complexity of the interrelationships between the biophysical (ecology and hydrology), and socio-political (institutions) dimensions. Future models should address overlapping effects, feedback, surprise, irreversibility, and cross-scale interactions to understand the complex interrelations that influence water management decisions at the river basin level.

3.2.1 The SWAT Model

The Soil and Water Assessment Tool (SWAT, Arnold et al. 1998) was developed by the United States Department of Agriculture in the 1990s. It is a conceptual physically based hydrological & water quality model, designed to route water, sediments and contaminants from individual watersheds through the whole of the river basin systems (i.e. from meso-scale to macro-scale). It can be used to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils and land use and management conditions, over long periods of time. The model can be classified as semi-spatially distributed, as it uses a mixed vector- and raster based approach (this in contrast to the fully-distributed, raster based models). The basin is divided into sub-basins, and the input information is organized for each sub-basin into the following categories: climate, Hydrologic Response Units (HRUs), ponds/wetlands, groundwater, and the main reach draining each subwatershed. The hydrology of the watershed is conceptually divided into two major phases: (a) the land phase of the hydrologic cycle and (b) the routing phase. The water, sediment, nutrient and pesticide load to the main channel of any given subwatershed is controlled by the land phase. The routing phase then determines the movement of water, sediment and pollutants from the channel network to the basin outlet.

3.2.2 Residential Water Demand

The demand model is formulated as a Discrete Continuous Choice (DCC) model and an increasing block rate price (see Olmstead et al, 2007; Hewitt and Hanemann, 1995). While the discrete decision is related to the consumption block, the continuous decision refers to the demanded amount of water given the selected block. The model takes into account the probability that an individual chooses any of the blocks, and consumes a given quantity within that block. Additionally, it will consider the probability that an individual decides to consume at any of the thresholds or kink points defining the different blocks. Olmstead et al. (2007) show that the price elasticity of a DCC is a complex function of the parameters of the model, since the calculation has to consider a change in the whole price structure and includes a price effect and an income effect produced by a virtual subsidy implicit in the block rate structure.

3.2.3 Agricultural Water Demand

The agricultural water demand is computed as a derived demand through the use of the Agricultural Supply Model (ASM). The ASM is a mathematical programming model designed to analyze the agricultural sector with high geographical disaggregation. It includes the major agricultural activities within the area, and differentiates between water provision systems (rainfed and irrigated), among other features (Ponce et al, 2014).

The core of the ASM includes the behavior of the agricultural producers (supply), which is characterized by detailed information at the producer level in order to represent a system of outputs supply and inputs demand, which is the result of the assumed profit maximization behavior. The information is differentiated by activity and geographical area, including: area planted, yield, variable costs, and labor demand, which is used to compute total costs, gross margin, and net revenues. The information presented above is complemented with supply elasticities for each activity. The core model is optimized based on a series of endowment restrictions, such as: total land, irrigated land, and water availability.

3.2.4 Integrated Modeling Framework

The VHM is a spatially differentiated model in which each commune is the basic unit of analysis for both economic models, whose objective is to maximize the basin's total surplus: residential surplus plus agricultural surplus. The former is computed by aggregating at commune level the changes in the consumer surplus using a log-log expression for the residential water demand, while the latter is computed by aggregating at commune level the net agricultural income coming from the non-lineal agricultural supply model. The objective function, total surplus, is subject to geographical, resources endowment, and institutional constraints.

In a second stage, we induce a water supply shock in the SWAT model by using the SRES A2-2040 regionalized climate change scenarios (Nakicenovic et al, 2000). Finally, in a third stage the VHM compares water supply and demand by each user in each commune. In case that water supply cannot meet the commune demand (residential plus agricultural), the model re-allocates water across users, activities, and communes, allocating water to move to its most valuable use. Then, welfare impacts of climate change are computed as the difference between total surplus with and without the climate shock.

Model Structure

As it was established above, the objective of the integrated model is to maximize the total surplus, which is composed by household surplus associated to water demand, plus farmer's surplus.

The specification for the residential water demand is presented in equation [1], while the consumer and the farmer' surplus are defined in equations 2 and 3, respectively.

$$Ln\left(W_c^{\,d}\right) = \delta Z_c + \beta Ln(P^w) + \gamma Ln(\tilde{y}_c) + \eta + \varepsilon \qquad [1]$$

In [1], W_c^d is the water demand in commune c; Z_c is a matrix containing household characteristics and climate variables that are thought to shift demand in commune c; P^w is the marginal water price faced by the household; $\tilde{y}_c$ is the virtual income or monthly income adjusted by Nordin difference [Nordin, 1976]; η is specified to capture unobserved preference heterogeneity; ε captures the optimization error derived from the discrepancy between optimum and observed water consumption; and δ,β,γ are parameters to be estimated.

Using the parameters estimated in [1] is possible to compute the change in the consumer surplus under the new climate conditions (higher temperatures). This is represented by [2].

$$CS_c^0 = \frac{P_c^w * W_{cc}^d}{\vartheta_c + 1} \qquad [2]$$

In [2], CS_c^0 represents the consumer surplus *if* households could consume all the water needed under the new climate conditions. P_c^w represents the water marginal price in commune *c*, W_{cc}^d is the water demand in commune *c* under climate change scenario, and ϑ_c is the estimated price parameter for commune c. The impact of climate change on households' welfare will be the difference between CS_c^0 and the welfare associated to the water consumption that households actually have (equation [3]).

$$CS_c = CS_c^0 - \left[\frac{\left(eW_{cc}^d - W_c^d\right) * \left(P_c^{vw} - P_c^w\right)}{2}\right] \qquad [3]$$

In [3], eW_{cc}^d represents the actual water demand under climate change scenario in commneu c, W_c^d is the water demand in the baseline for commune c, while P_c^{vw} is the virtual water price in commune c.

$$FS = \sum_{c,a,s}\left(\left(y_{c,a,dry} * p_a - AC_{c,a,dry}\right) + \left(y_{c,a,irr} * p_a - AC_{c,a,irr}\right)X_{c,a,s}\right) \qquad [4]$$

In [4], $y_{c,a,s}$ is the yield (ton/h) in commune *c*, for irrigated activity *a* using system *s*: dry or irrigated. p_a denotes the market price for activity a, while $AC_{c,a,s}$ represents the average costs for activity *a*, in commune *c*, using system *s*.

The basin problem is to maximize the Total Surplus (TS), CS plus FS, subject to resources constraints as depicted below .

$$Max\colon TS = CS + FS \qquad [5]$$

$$AC_{r,a,s} = \alpha_{r,a,s} * \left(X_{r,a,s}\right)^{\beta_{r,a,s}} \qquad [6]$$

$$\sum_a \sum_s r_{i,r,a,s} * X_{r,a,s} \le b_{i,r} \qquad [7]$$

$$W_c^d + \sum_a IRRDEM_{c,a} \le W_c^s \qquad [8]$$

where expression [6] represents a cost function whose parameters α and β are derived from a profit-maximizing equilibrium using Positive Mathematical Programming (Blanco et al, 2008; Howitt et al, 2009), expression [7] represents resource constraints (total land, irrigated land). Finally, expression [8] is the water constraint in which the total water demand in commune c cannot be larger than their corresponding total supply.

4. Results

4.1 Welfare Impacts

The basin under analysis includes 10 communes and the agricultural sector is represented by 14 activities, aggregated in the following categories: Crops (7) and Fruits (7). Regarding the residential sector, we used basin averages parameters and mean values for number of rooms, number of inhabitants, income, price, and temperatures to predict the water demand at commune level.

The agricultural information used in the model (area, production, yield) is from the year 2007, and comes from the National Agricultural Census (INE, 2007), considering a disaggregation at communal level. The information about costs per commune, activities and watering systems (irrigated, rainfed), as well as labor intensity comes from an Agrarian Policies and Studies Bureau (ODEPA) study (ODEPA, 2010). Prices were taken from the Agrarian Policies and Studies Bureau website (ODEPA, 2010), while the elasticities used to calibrate the model were collected from previous studies (Quiroz et al., 1995;CAPRI Model, 2008; Foster et al., 2011).

Regarding climate change, the expected changes in water availability according to the A2-2040 SRES scenario imply, on average, a 21% river flow reduction, ranging from a -26% maximum reduction in Angol to -17% minimum reduction in Ercilla. The simulated temperature change is +2.9ºC for the whole basin. Under the climate change scenario, both water users (agriculture and households) should evaluate their water consumption decisions in order to allocate the water to its most valuable use, in terms of economic welfare.

Results suggest that water use will decrease 22%, on average, and for both users. Regarding the agricultural sector, the simulated changes will drive a 3.2% decrease in total agricultural land, with uneven consequences among activities and communes. Due to the decrease in water availability, farmers will change their practices by moving from irrigated crops to rainfed crops. Total irrigated land will decrease 22.8%, with Traiguen facing the largest decrease (-30%), and Negrete facing the largest increase in rainfed land (39%). Detailed changes in agricultural land by commune are shown in Table 2.

[Table 2 around here]

Considering the water restriction scenario, farmers will allocate water to its most valuable use across activities. That implies to allocate the lower amount of irrigated land to the most profitable activities. Although an average general decrease in irrigated land is expected, some croplands such as wheat can increase by 13% in Negrete. The largest decrease in irrigated land is faced by alfalfa in Curacutin (- 85%), Angol (-54%) and Collipulli (-50%), and common bean in Ercilla (-77%). On the other hand, for those activities in which it is possible to use rainfed and irrigated land (potatoes, and wheat), the switch from irrigated to rainfed holds for all most of the communes.

The changes on land allocation described above will reduce the total agricultural production by 11.5% at the basin scale, with large variability across activities and communes. For instance, the largest production increase is reported by wheat in Negrete (23%), while Curacautin faces the largest decrease in alfalfa production (-85%). Changes in agricultural production by crop type are shown in Figure 2.

[Figure 2 around here]

All the predicted changes will lead to a decrease in agricultural economic welfare of \$555 million (USD 1.1 million), equivalent to -2.6% of total agricultural income. All the changes in farmer´s economic welfare at commune level are shown in Table 3.

[Table 3 around here]

Regarding residential users, the estimated econometric model predicts that water demand will increase with the temperature increase. The estimated demand parameters and mean values for all variables are reported in Table 4.

[Table 4 around here]

The current and expected water demand at household level are presented in Table 5, assuming that farmers and household water demand are not linked through the SWAT model, and for the climate change scenario. As we used mean values, for all the communes the water demand at household level is the same 14.3 m^3/month, so the differences are associated to the different households number across communes.

[Table 5 around here]

By using this information, along with the estimated price parameter, it is possible to compute the consumer surplus for both cases, with and without climate change. Results are presented in Table 6.

[Table 6 around here]

According to the results, under the new climate scenario, less water and higher temperature, households could meet almost all their desired water demand. This is because water has more value for households than for farmers. For instance, total agricultural water use decrease 26%, while the water used by the household decrease 3%, showing the magnitude of the water transfer between users.

All the changes described above will have impacts on the total welfare, households and farmers, with a \$564 million decrease in total welfare (USD1.12 million). Among this figure, farmers will face the largest burden of climate change.

4.2 Vulnerability analysis

As it was established in the methodological section, the social vulnerability analysis to climate change was carried out using the vulnerability concept defined by the IPCC based on secondary information, workshops, and key actors interviews. By using this method we classified groups and vulnerable zones according to two criteria: vulnerability to extreme weather events and vulnerability according to the systems at risk.

Results show that the indigenous communities are the most vulnerable groups under every criterion. These communities include 2,000 households and 20,000 ha. For these communities the agricultural production is one of the most relevant issues regarding climate change vulnerability, mainly because their productive practices are not suitable for the expected climate conditions. It is expected that their high vulnerability will be exacerbated due to their poor living conditions, low literacy, migration to urban centers, and the social conflict regarding the indigenous acknowledge rights movement.

Another vulnerable group are the settlers communities located in the Nahuelbuta mountain range. In this case the vulnerability is associated to extreme weather events such as heavy snowfalls, wildfires, and persistent droughts. As for the indigenous communities, the settlers show high vulnerability, which is expected to increase due to their low adaptive capacity represented by poor living conditions, low literacy, and remote areas without access to urban markets.

Currently, for both groups the access to secure water sources is the most relevant issue. To solve this, municipalities within the basin should deliver water by trunk from October to May in order to meet human needs. This situation is becoming a serious fiscal burden for the municipalities finance balance, with a figure greater than US$1 million allocated to water delivery in the basin.

A spatial analysis of both economic and social vulnerability shows that those communes with largest social vulnerability are also the communes that face the largest economic impacts from climate change to the agricultural sector. For instance, the communes where the most vulnerable groups are located tend also to be those with the largest decrease in agricultural income, accounting for 37% of the total impact. The predicted changes in agricultural income will exacerbate the fragile situation of the smallholders located in those communes, increasing their vulnerability to climate change.

The policy implications of the results reported in this study are relevant as by using this approach policy makers could rank policy options regarding their cost-effectiveness. For instance, evaluating if the construction of new water infrastructure aimed at smoothing water availability within the year is more effective than increasing water use efficiency; the latter considering the water rebound effect (Berbel and Mateos, 2014). This approach is also useful for evaluating which are the distributional effects of a newly ban on forestry plantations, urban areas expansion, programs aimed to increase water use efficiency at household level, a new water allocations system (market versus governmental based), among others.

The results presented in this study are consistent with the mainstream literature in which climate change is expected to have negative impacts on human welfare. Most of the studies analyzing climate change impacts on the agricultural sector find small aggregated impacts with large distributional effects (Arent et al, 2014; Nelson et al, 2014). Then again, studies addressing climate change and households welfare found negative impacts (Yates et al, 2013). Moreover, our results are consistent with those reported in other studies using hydro-economic models in which water is allocated to its most valuable use (Maneta et al, 2009; Hurd and Coonrod, 2012; Varela-Ortega et al, 2011)

5. **Conclusions**

Based on the results, the major conclusion of this study is that the Vergara river basin economy is vulnerable to the change in water availability as a consequence of climate change. At the communal level, the model shows substantial re-allocation of water between farmers and households. On the other hand, the vulnerability analysis shows that the most vulnerable groups to climate change are located in the most affected communes. This situation suggests that the current vulnerability of those groups will increase in the coming decades.

Our proposed model is useful for policy makers since it allows for a complete and rigorous analyses of the climate change impacts on water availability and its spatial distribution, identifying the economic impacts of these changes in agricultural production and residential water demand. As the VHM is developed in modules (hydrologic, economic, and social), we are almost sure that the methodological tool developed as part of the eec2 project can be easily replicated in other basins in Chile and Latin America in general. The success of this replication seems to only be limited by the availability of data as we were able to experience in our replication of the methodology in Santa Cruz (Bolivia) and Manizales (Colombia). Regarding the policy relevance, as an anecdotic evidence of the policy implications of the approach used in this project, our research team has been invited by the Regional Government of the Araucanía Region through the Water Presidential Delegate to be part of the scientific support to a broad initiative to settle a "water dialog table" within the basin. The idea is that we could use our results to motivate different stakeholders to participate in this initiative, and use the VHM model to evaluate different public policies and adaptation strategies that can arise from this social dialog in terms of its economic and social impacts.

Due to lack of data, some issues could not be considered in this study, including: water markets, farm level economic performance, groundwater extraction (if any), and environmental related issues. Despite these drawbacks, and due to the modular approach, these issues could easily be included once the needed information becomes available. Still, despite the usefulness of the hydro-economic approach for policy evaluation, this method should be part of a more comprehensive approach in which the economic dimension is only one of the topics under consideration, together with other topics, such as social and cultural aspects. One step in this regard could be the use of the Robust Decision Making approach, in which climate risks and social and institutional constraints, not yet considered in this model, can be explicitly addressed.

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Table 1: Commune's Socioeconomic Characteristics

Commune	Population	% Urban Share
Mulchen	25,557	85%
Nacimiento	26,523	79%
Negrete	9,394	56%
Angol	50,804	86%
Collipulli	23,321	69%
Curacautin	16,508	75%
Ercilla	8,466	38%
Los Sauces	7,169	51%
Renaico	9,850	70%
Traiguen	17,164	82%
Total	194,756	76%

Source: INE, 2012

Table 2. Changes in Agricultural Land (%)

Commune	Rainfed	Irrigated
Mulchen	6%	-29%
Nacimiento	15%	-17%
Negrete	39%	-11%
Angol	3%	-25%
Collipulli	1%	-23%
Curacautin	0%	-16%
Ercilla	0%	-29%
Los_Sauces	0%	-24%
Renaico	1%	-20%
Traiguen	0%	-30%

Table 3. Changes in Farmer's Welfare (MM$)

Comune	Baseline	Climate Change
Mulchen	4,410.9	4,273.7
Nacimiento	549.6	528.7
Negrete	1,388.2	1,334.8
Angol	1,682.8	1,577.3
Collipulli	2,421.2	2,373.9
Curacautin	2,044.9	2,027.9
Ercilla	817.5	810.6
Los Sauces	325.4	325.0
Renaico	3,042.1	2,936.6
Traiguen	4,963.4	4,902.1
Total	***21,646.0***	***21,090.5***

Table 4. Residential Water Demand: Parameters and mean values

Variable	Parameter	Mean Value
Constant	-7.182	-
Mean Temperature	0.03	13.2
Rooms number	0.381	4.9
Household Inhabitants	1.276	4.4
Water Price	-0.458	825
Income	2.692	295,318

Table 5. Residential Water Demand (th m3/year/commune)

Commune	Households	Total Water Demand
Curacautin	3,103	535.2
Traiguen	3,535	609.7
Los Sauces	909	156.8

Angol	10,950	1,888.5
Ercilla	810	139.7
Collipulli	4,001	690.1
Mulchen	5,454	940.7
Renaico	1,719	296.5
Negrete	1,320	227.7
Nacimiento	5,221	900.5
Total	***37,022***	***6,385***

Table 6. Consumer Surplus (MM $)

Commune	Baseline	Climate Change
Mulchen	1,376.1	1,375.6
Nacimiento	1,903.9	1,903.2
Negrete	172.6	172.5
Angol	2,980.5	2,978.1
Collipulli	1,088.5	1,088.0
Curacautin	844.0	841.8
Ercilla	220.4	219.7
Los_Sauces	247.4	247.2
Renaico	467.9	467.7
Traiguen	962.2	961.4
Total	***10,263.5***	***10,255.3***

Figure 1. Methodology

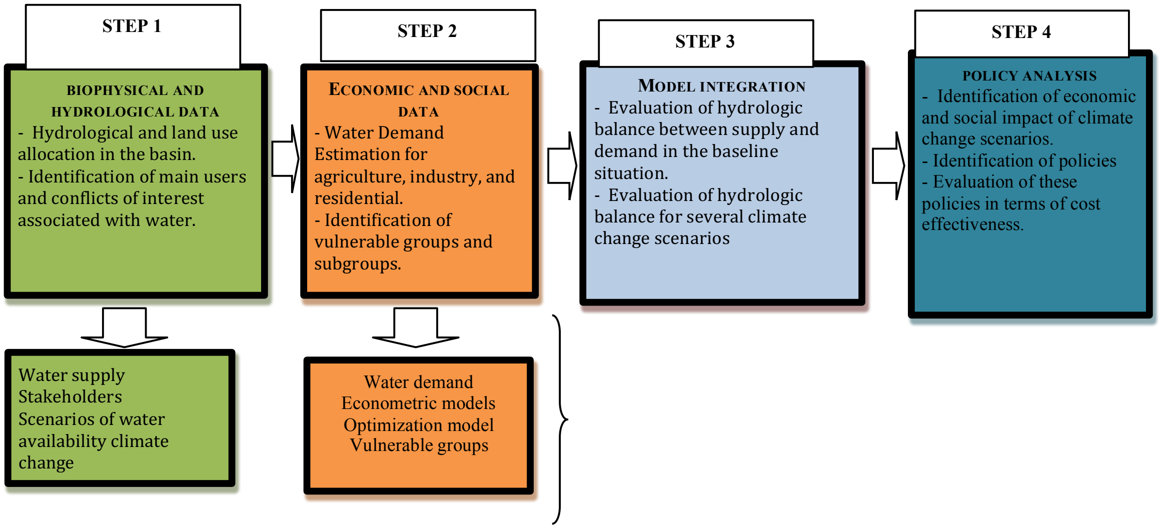

Figure 2. Changes in Agricultural Production (%)