The economic impact of climate driven changes in water availability in Switzerland*

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Abstract

The broad objective of this study is to estimate the economic impact of changes in water availability due to climate change in Switzerland with a 2050 time horizon. To do so, the sectoral structure of the computable general equilibrium model GEMINI-E3 is being extended. Raw water resources are introduced as a production factor into the model and a drinking water distribution sector is specified for Switzerland to allow for a precise analysis of the economic consequences of restricted water supply. Predictions of water availability in 2050 are taken from a hydrological model and alternative climate change scenarios are considered. Simulations show possible restrictions in water resource availability to increase raw water prices substantially compared to the baseline. Sectors most affected are the water distribution and agricultural sectors that use irrigation. However, the global economic impact for Switzerland is rather small due to the low price of raw water in Switzerland and its small value in the benchmark scenario. Finally, the simulation of scenarios featuring alternative levels of endogenous adaptive capacity of the economy reveals the possible economic impact of adaptation to climate change.

Keywords : water ; CGE ; climate change ; adaptation

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1 Introduction

Switzerland is already and will continue to be affected by climate change. In its fourth assessment report, the IPCC indeed predicts a temperature increase of approximately 2 degrees during winter and 2.5 degrees during summer until 2050 compared to 1990 levels (IPCC [23], IPCC [22] and OcCC [26]). By then, precipitation levels are estimated to increase by about 8 percent during winter and decrease by 15 percent in summer. These changes are bound to affect the hydrological cycle and alter water supply in multiple ways, thus highlighting the importance of understanding the hydrological consequences of climate change and their impact on the Swiss economy.

The broad objective of this study is to estimate the economic consequences of possible changes in water availability in Switzerland with a 2050 time horizon. Particular attention is devoted to the evolution of water prices and the impact of alternative levels of endogenous adaptive capacity. To reach these objectives, this study employs GEMINI-E3, a computable general equilibrium (CGE) model particularly designed for the analysis of climate change and energy policies. The sectoral structure of the model is being extended in order to assess the economic impact of climate change on particularly sensitive sectors and to study the role of specific adaptation measures for alleviating climate change costs. To measure the consequences of changes in water availability, raw water resources are introduced as a production factor into GEMINI-E3. Further, a drinking water distribution sector is specified for Switzerland to allow for a precise analysis of the economic consequences of restricted water supply.

The structure of the paper is the following. Section 2 presents the context of the study and a review of the literature. Section 3 defines the CGE model and explains how raw water resources are introduced into GEMINI-E3. Section 4 describes the baseline scenario and section 5 presents the impact of climate change on water availability in Switzerland. Section 6 discusses the simulated scenarios and results and finally, section 7 concludes.

2 Context and literature review

Swiss water utilities are capturing about 980 million cubic meters of water a year (SGWA [32]). Most of this is groundwater or spring water, that account for 40 percent each of water captured, while the remaining 20 percent are surface water. The majority of this water is distributed to households and artisanry, while a lesser share of about 20 percent goes to industry. About 15 percent of the water extracted is lost by the utilities.

Water consumption in Switzerland however is not limited to water distributed by drinking water utilities. Indeed, both industry and agriculture are capturing an important share of their water themselves (Freiburghaus [16]). Approximately 75 percent of the water used by Swiss industries was extracted directly in 2006, a share that does not account for cooling water needed by power plants. The chemical sector has the highest water consumption among all industrial sectors, followed by waste disposal and consumption goods. Agriculture also extracts a substantial share of the water it uses itself, mainly for irrigation. However, the share of water used for irrigation in the total water consumption of the Swiss economy is quite small.

A growing community of researchers is investigating the physical impact of climate change on water resources in Switzerland and its economic consequences. While there are studies that forecast the physical consequences (WSL [37]), most analysis of the economic impacts remains descriptive (see for example IPCC [22], IPCC [23] and OcCC [26]). Conflicts among different uses of the resource is named as a potential future challenge, but a quantitative analysis of the consequences of changes in availability of water resources on the Swiss economy is still missing.

Water is used not only by households for drinking, cooking and washing, but also by agriculture for irrigation and numerous other sectors as an input in their production processes. Changes in water availability and the allocation of the resources can thus potentially impact multiple industries. Consequently, CGE models are more and more often applied to evaluate the economic effects of climate change and of a whole range of water policy measures both at a local and global scale. Different studies analyse the consequences of a modification of the availability of water resources and the economic impact of various policies implemented to make the best possible use of the increasingly scarce resource.

Globally, a range of studies use GTAP-W, a global CGE model in which water resources have been modelled. Berrittella et al. [4] investigate the role of water resources and water scarcity in international trade. They analyse the impact of reduced groundwater availability. Berrittella et al. [5] study water taxation policies and their worldwide effects on production and trade patterns. Calzadilla et al. [9] are interested in the impact of more sustainable water use for irrigation. Another paper using GTAP-W considers the consequences of climate change on global agriculture (Calzadilla et al. [8]) and a further study adds the analysis of the consequences of trade liberalization to climate change issues (Calzadilla et al. [10]). In the GTAP-W model, raw water is introduced as a production factor for irrigating agricultural sectors and water distribution only.

Other authors apply the CGE framework locally within one country or region but no such analysis has yet been designed for Switzerland. These studies mostly concentrate on the impact of the implementation of policies like pricing, resource allocation or the introduction of water markets. For example, Roe et al. [28] model the effects of policy interventions and external shocks on the water sector in Morocco. Also focussing on Morocco, Diao and Roe [11] study irrigation and the economic impact of a better allocation of water resources. The consequences of taxes on water in South Africa are studied by Letsoalo et al. [24] and van Heerden et al. [34]. Gomez et al. [17] consider the impact of the introduction of water markets on the economy of the Balearic islands. The modelling of the effects of water reallocation in Nevada is performed by Seung et al. [31] and the assessment of the optimal water allocation in the Maipo river basin by Rosegrant et al. [29]. Goodman [20] compares the economic impact of a proposed increase in reservoir storage to temporary water transfers as a response to projected water shortages in the Arkansas water basin.

But some studies also look at the future economic impact of restricted water availability, be it a consequence of population and economic growth or climate change. In an application of CGE modelling in the San Joaquin Valley, Berck et al. [2] analyse the impact of removing water in 10 percent increments. Water is solely used in agriculture. Watson and Davies [35] examine the implications of economic and population growth on fixed water supply in the South Platte River Basin. In their model, municipal water suppliers and agriculture are the only sectors to use raw water, while other industries employ drinking water. Other applications include Feng et al. [13], a study that investigates the impact of relaxing water constraints in China by allowing for transfers. In a research project on the impact of climate change in the Seine estuary, Briand [7] examines the impact of changes in the availability of water resources on the economy of the estuary.

3 The GEMINI-E3 model

3.1 Overview of GEMINI-E3

This study uses a modified version of GEMINI-E3, a computable general equilibrium model [1] that is specifically designed for the analysis of climate change and energy policies. This model originally comprises 28 regions, including Switzerland, and 18 different sectors. The model is a global one, as the future evolution of the Swiss economy obviously depends on the world economy. The model is built on the GTAP-6 database, that offers a description of the economy in 2001 and is completed by complementary information from OECD national accounts, IEA energy balances and energy prices/taxes and IMF Statistics. The sectoral structure of the model is being extended for Switzerland in order to assess the economic impact of climate change on particularly sensitive sectors like tourism, agriculture and water distribution. In this study, a drinking water distribution sector is specified to allow for a precise analysis of the economic consequences of restricted water supply. This is done for Switzerland only, as water is a local good and is not imported to or exported from Switzerland.

The new structure used in this study comprises 28 sectors and is presented in table 1, while the geographical structure is presented in table 2.

1. For further information about GEMINI-E3, please visit the web site `http://gemini-e3.epfl.ch/`.

Table 1 – Industrial classification

1	Coal	15	Paper products publishing
2	Oil	16	Transport nec
3	Gas	17	Sea Transport
4	Petroleum Products	18	Air Transport
5	Electricity	19	Consuming goods
6	Crop	20	Equipment goods
7	Milk	21	Winter overnight tourism
8	Animal product	22	One-day winter tourism
9	Vegetables	23	Other forms of tourism
10	Other agricultural products	24	Insurance and pension funding
11	Forestry	25	Health and social work
12	Mineral product	26	Services
13	Chemical	27	Dwelling
14	Metal and Metal products	28	Water

Table 2 – Regions

CHE	Switzerland
EUR	European Union (EU25)
USA	United States of America
OEC	Other developed countries
BRI	Brazil, Russia, India and China
ROW	Rest of the world

The model uses the walrasian perfect competition paradigm to simulate all relevant macroeconomic and microeconomic markets. It is recursive dynamic and endogenous real rates of interest determined by equilibrium between savings and investment link time periods. National and regional models are linked by endogenous real exchange rates resulting from constraints on foreign trade deficits or surpluses [3]. Nested Constant Elasticity of Substitution (CES) functions describe the production technologies of the industries. The model computes the demand for each sector on the basis of household consumption, government consumption, exports, investment, and intermediate uses. According to the Armington assumption [1], domestic and foreign goods are no perfect substitutes.

The economy in the modified version of the model counts seven primary factors : capital, labour, land, fossil energy resources, raw water for irrigation, raw water for other uses and natural snow. Land is used in agriculture only, while the winter tourism sectors are the only ones to employ natural snow. Labour is mobile domestically but not internationally, while the mobility of capital is restricted. Investments are mobile, but once attributed to a sector, the capital cannot be employed in another industry. Land is not mobile and the same goes for fossil energy resources, while on the other hand raw water for irrigation and raw water for other uses are mobile. They are however distinct goods, so raw irrigation water cannot be taken for other uses and vice versa.

The representative consumer maximises a nested CES utility function, described in figure 1. Households consume only drinking and no raw water.

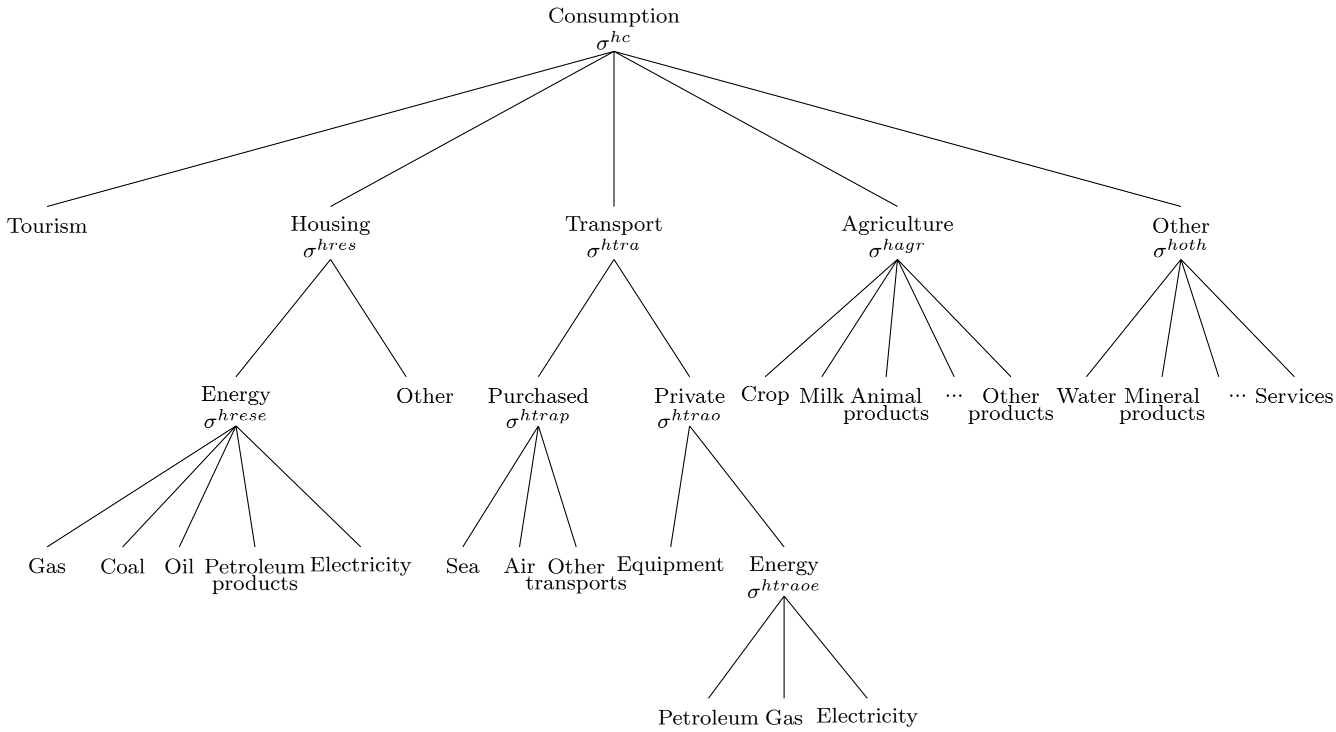

Figure 1 – Nested structure of household consumption

3.2 Modelling raw water resources and the water distribution sector

To be able to analyse the economic impact of a possible variation in water availability in Switzerland, GEMINI-E3 needs to explicitly account for water used by the different sectors and to model the water distribution sector. Hence the new version of GEMINI-E3 distinguishes two kinds of water : industries may use raw water resources directly in production processes, or they may alternatively employ drinking water, which is the output of the drinking water distribution sector.

3.2.1 Raw water resources

Raw water resources are introduced in the Social Accounting Matrix (SAM). Raw water quantities used by industry and services sectors originate from a study about the water consumption of the Swiss economy by Freiburghaus [16]. A study by Weber and Schild [36] provides data on water use for irrigation, whereas for milk and animal products, water volumes are calculated based on information about water consumption by animal unit, the percentage of water extracted directly by farmers (Freiburghaus [16]) and the number of animals in Switzerland (BLW [6] and Muller [25]). Figure 2 shows the water distribution sector to be the biggest raw water consumer, followed by the chemical industry and services. Among agricultural sectors, fruits and vegetables are the biggest consumers of raw water.

In Switzerland, raw water tariffs are defined at the cantonal or municipal level and are very heterogeneous both in terms of tariff structure and rate. Moreover, the country lacks a central

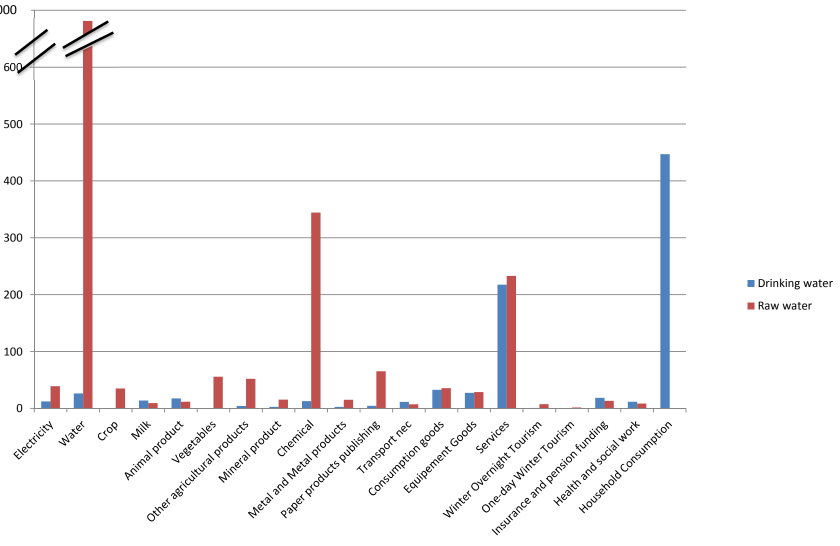

Figure 2 – Water use in Switzerland in 2001, in million cubic meters

database that would inform about the tariffs applied in the communes and cantons. However, water tariffs are generally speaking very low. This study follows Finger and Schmid [14] and employs raw water tariffs from the canton of Zurich, that equal 0.01 USD_{2010} per cubic meter of raw water. The value of initial raw water endowments is subtracted from the sectors' capital endowments.

Raw water extraction does not only use raw water resources but further requires other production factors. In our study, these are capital (pumping equipment, network, etc.) and energy. Energy and capital cost for the extraction of one cubic meter of water are estimated from the cost structure of the water distribution sector as represented in the SAM. However, drinking water distribution extracts the water, distributes and sells it to its customers, while in our calculation of capital expenses we are only interested in costs related to water extraction. The shares of investment that go into the network versus the water stations (about 76 and 24 percent respectively ([32])) serve as distribution key to allocate expenses to water extraction and distribution. This results in energy expenses of about 0.02 USD_{2010} per cubic meter of extracted water while capital cost amount to approximately 0.16 USD_{2010} per cubic meter.

Finally, raw water resources are separated into two distinct blocs, irrigation water and water for other uses. Indeed, climate change impacts differ considerably depending on the season. For instance runoff is predicted to increase from October to April but to decrease from May to September. To include seasonal impacts in an annual model like GEMINI-E3, irrigation water that is used seasonally is considered separately. Indeed, the three plant producing sectors of the model (crops ; vegetable, fruit and nuts ; other agricultural products) are assumed to need water mainly from the beginning of spring to the beginning of autumn, which corresponds to the main growing season of the plants. Hence our model contains two distinct raw water resources, water for irrigation and water for other uses that are impacted differently by climate change.

3.2.2 The drinking water sector

Drinking water distribution is the biggest raw water consumer in Switzerland. It capture raw water and transforms it into drinking water, a distinct good that is consumed by households and serves various production sectors as an input. Initially, there is no drinking water distribution sector in GEMINI-E3. To include it in the analysis, consumption of different inputs by the drinking water distribution are taken from the GTAP 6 database, while drinking water consumptions by industrial and service sectors come from Freiburghaus [16] and by households from SGWA [32]. The mean drinking water price for 2001 (1.20 USD_{2010} per cubic meter of water) is taken as price of water. Households are by far the biggest drinking water consumers, followed by services, consumption and equipment goods. Among agricultural sectors, milk and animal products use the most drinking water.

3.2.3 Production structures

Figure 3 illustrates the production structure of the drinking water distribution sector modelled in GEMINI-E3 with a CES production function. The sector uses capital, labour, energy, materials and raw water to produce and distribute drinking water. In the model calibration, particular attention goes to the definition of the elasticities of substitution between the different inputs. Elasticities are taken from the literature and are summarised in table 3. Intuition commands the substitution elasticity between water and other inputs in drinking water distribution σ to be rather low. Some studies even use a zero elasticity of substitution, reducing to a Leontief production function for this particular nest (see for example Gomez et al. [17]). However in this study, σ equals 0.025, allowing for adaptation strategies like the reduction of network losses, even though the elasticity is very low and substitution possibilities are thus fairly restricted. Water losses are used to calibrate the model at this point. The elasticity of substitution is chosen to allow adaptation but at the same time ensure that water losses do not reach unrealistically low or even negative levels.

Not only drinking water distribution, but also numerous other industrial and service sectors use water as an input. The new production structure of these sectors distinguishes water as an input and allows them to choose between employing drinking water and extracting water themselves. Indeed, the industry extracts about 75 per cent of the water it uses, while only 25 per cent come from drinking water distribution. Moreover, the industrial sectors seem to have substituted drinking water by own water adduction during the last 30 years (Freiburghaus [16]).

With the new production structure shown in figure 4, the use of different types of water (industrial, produced with raw water, capital and energy, or drinking) and the possibility to substitute one by the other are accounted for. Sectors get to choose among employing drinking water or extracting the water themselves, an important possibility as the tariffs of drinking and raw water differ a lot.

Again, elasticities of substitution are given in table 3. First of all, the literature shows real substitution possibilities between water, be it industrial or drinking, and other inputs. Indeed, production processes can be modified in order to be less water intensive, and water recycling systems can be implemented. This study uses an elasticity of 0.3, a value that equals the elasticity of substitution between water and capital proposed by Gomez et al. [17] and is well compatible with Goodman [20], who is testing for elasticities of 0.1, 0.25 and 0.5 between water and other

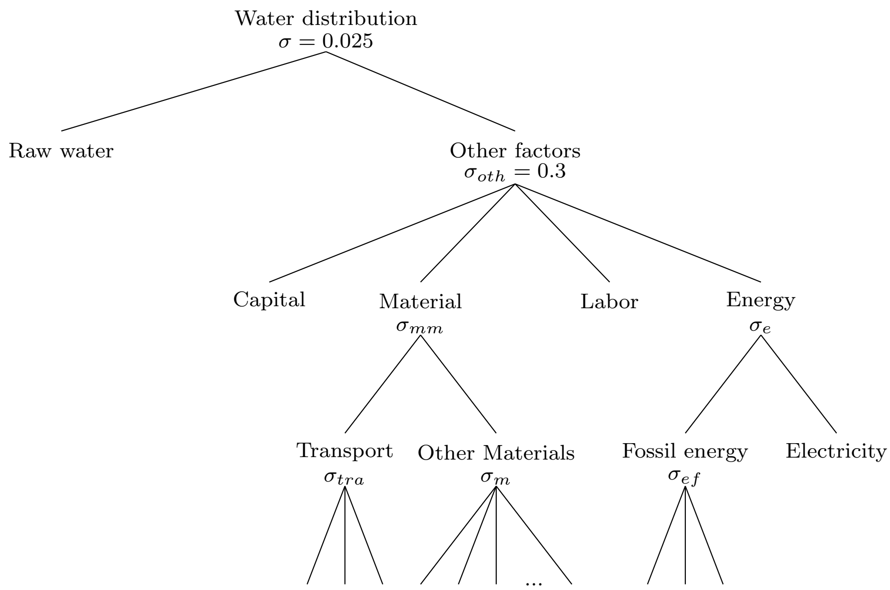

Figure 3 – Production structure of the water distribution sector

inputs and finds a value of 0.1 to be too low, as it induces too high prices. This substitution possibility allows sectors to adapt to climate change by using more or less water intensive production procedures.

Next, elasticities of substitution between industrial and drinking water σ_w have to be defined. Not many studies analyse the possibility to substitute drinking water by water extracted directly by firms. Reynaud [27] has carried out a study for France on this topic. According to this study, possibilities to substitute drinking water by industrial water and vice versa appear to be generally rather limited. More specifically, the substitutability between raw water and drinking water is lower if the raw water does not need to be treated. However, results by Freiburghaus [16] indicate the possible substitution of drinking water by autonomous raw water extraction in Switzerland during the last 30 years. To allow the model to capture these possibilities, we employ positive yet low elasticities. We hence adopt elasticities equal to 0.3 in agreement with Reynaud [27] for those sectors that treat a significant share of the raw water they extract. These are the metallurgical sector, the chemical sector and consumption goods (Reynaud [27]). The other sectors use mostly non-treated water, that has a lower substitutability with drinking water, and thus an elasticity of 0.1 is attributed to them.

Finally, figure 5 describes the production structure of the agricultural sectors. It is similar to the one of industrial and service sectors, except for the use of land as a production factor that is specific to the agricultural sectors. Indeed, land is combined with irrigation to form an irrigation-land aggregate. Land is immobile between agricultural sectors to reflect quality differences in land. An elasticity of substitution of σ_{agr} equal to 0.2, close to the 0.24 employed in agricultural sectors by Berrittella et al. [4] is chosen between the irrigation-land aggregate and other production factors. The next nest describes the possibilities to substitute land and irrigation with an elasticity σ_{lw} equal to 0.3 in vegetable production. In milk and animal production, it is however impossible to substitute land for water and the elasticity equals zero. Water and land are used in fixed proportions, a modelling also found for example in Seung et al. [30]. The remaining production structure reflects the possibility to use either drinking water or to extract its own raw water and is identical to the structure used in service and industrial sectors. However, as explai-

Table 3 – Elasticities

Household consumption		
Nest "Other"	σ_{hoth}	0.2
All sectors		
Capital, Material, Labor, Energy	σ_{oth}	0.3
Water distribution, Industry - Services		
Raw water - Other factors	σ ; σ_{wother}	0.025
Water - Other factors	σ_{ind}	0.3
Industrial water - Drinking water		
Metal, Chemical, Consumption goods	σ_w	0.3
Other industry and services	σ_w	0.1
Energy - Capital	σ_{wcapen}	0.3
Agricultural sectors		
Irrigation-Land aggregate - Other factors	σ_{agr}	0.2
Irrigation - Land		
Vegetable production	σ_{lw}	0.3
Animal production	σ_{lw}	0
Irrigation water - Drinking water	σ_w	0.1

ned previously raw water for irrigation and raw water for other uses are distinct resources and not mobile, although raw water for irrigation is mobile among vegetable producing agricultural sectors and raw water for other uses is mobile between all other sectors.

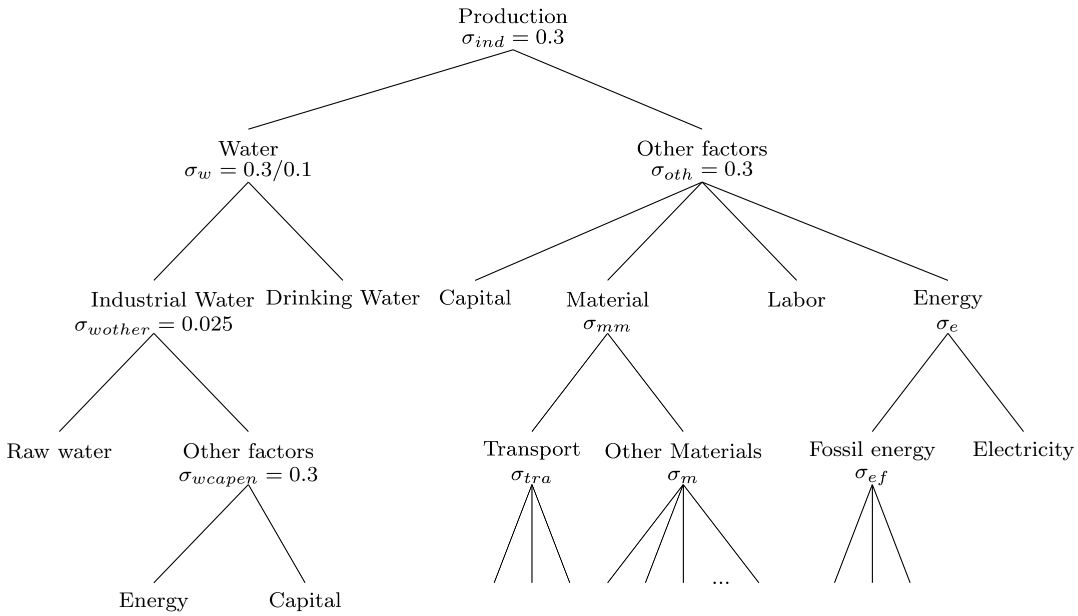

Figure 4 – Production structure of industrial and service sectors that use water as an input .

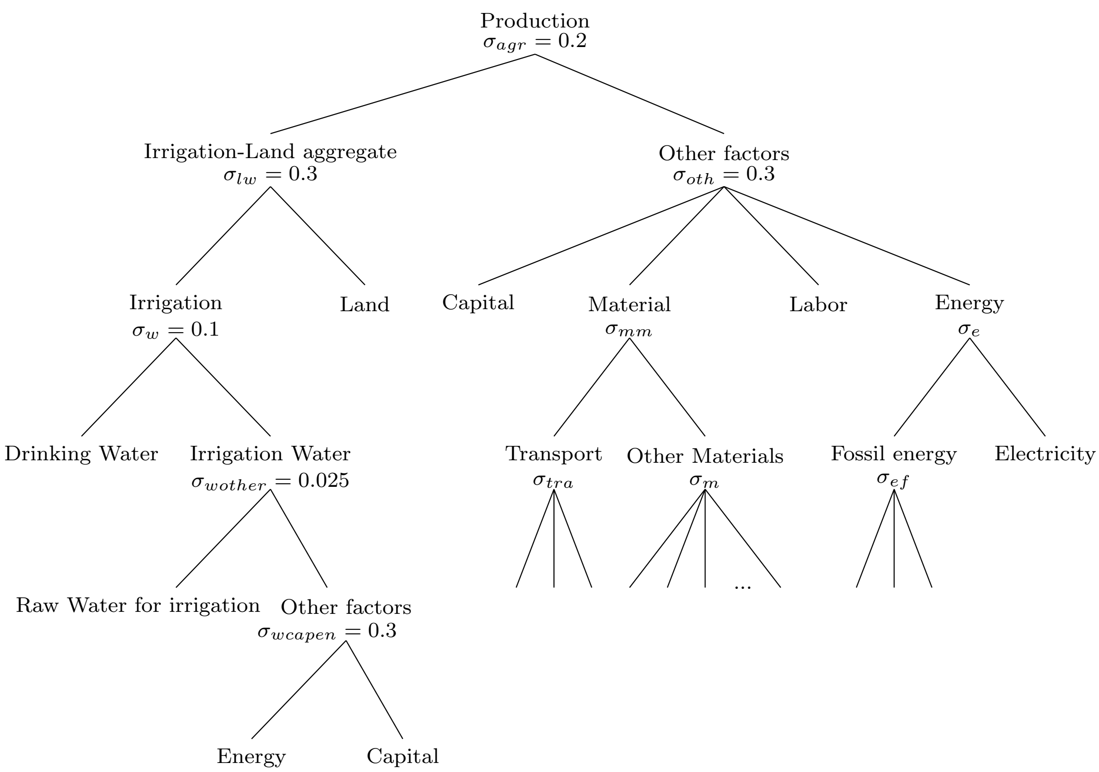

Figure 5 – Production structure of agricultural sectors

4 The baseline scenario

To simulate the evolution of the economy until 2050, the model uses predictions of GDP and population growth as well as energy prices. Future GDP growth rates are from The Swiss State Secretariat for Economic Affairs (SECO) for Switzerland and the US Department of Energy (Energy Information Administration) published in the *2011 International Energy Outlook*[12] for all other countries. As shown in table 4, Swiss economic growth is predicted to be 1.7 percent until 2020 before slowing to about 0.8 percent until 2050, while the world economy will grow at 2.8 percent until 2030 and at 2.6 percent from then on.

Table 4 – GDP growth rate (% per year)

	2010-2020	2020-2030	2030-2040	2040-2050
Switzerland	1.7%	0.8%	0.9%	0.8%
European Union	1.5%	1.8%	1.7%	1.7%
United States	2.3%	2.7%	2.5%	2.4%
Other OECD	1.3%	1.1%	1.1%	1.0%
BRIC	6.3%	4.5%	3.6%	3.6%
ROW	3.9%	3.6%	3.3%	3.3%
World	2.8%	2.8%	2.6%	2.6%

Table 5 presents population forecasts, taken from the World population prospect (United Nations Department of Economic and Social Affairs, Population Division 191 [33]). According to the forecast, the Swiss population will reach 8.4 million in 2050, and thus have increased by 15 percent compared to its 2001 level.

Table 5 – Population prospects, in millions

	2001	2009	2015	2020	2025	2030	2040	2050
Switzerland	7.3	7.5	7.7	7.8	8	8.1	8.3	8.4
European Union	453	464.6	468.9	470.5	470.8	470	465.3	457.4
United States	287.9	311.7	329	342.5	355	366.2	385.9	402.4
Other OECD	181.5	186.6	188.7	189.1	188.7	187.5	183.6	178.5
BRIC	2665.9	2884.4	3037.7	3152.9	3250.3	3324.6	3408.7	3429
ROW	2606.7	2973.3	3263.2	3504.3	3737.8	3961.3	4371.9	4715.5

For energy prices, the study employs the forecasts of the 2010 World Energy Outlook [21]. As reported in table 6, the predictions of the International Energy Agency stop in 2035, and in the model energy prices are supposed constant thereafter.

Table 6 – Energy prices in the baseline scenario ($ 2009)

	Unit	2000	2009	2015	2020	2025	2030	2040	2050
IEA Crude oil imports	Baril	34.3	60.4	94.0	110.0	120.0	130.0	135.0	135.0
Natural gas imports Europe	Mbtu	3.5	7.4	10.7	12.1	12.9	13.9	14.4	14.4
OECD Steam coal imports	Tonne	41.2	97.3	97.8	105.8	109.5	112.5	115.0	115.0

The evolutions of water prices are determined endogenously in the model according to the future evolution of the economy and the availability of raw water resources. However, technological progress that captures improvements in water use efficiency is exogenous. We use forecasts from the European Outlook on water use (Floerke and Alcamo [15]) that predict technological progress of 1 percent per year in the domestic and manufacturing sector, a rate we apply also to services and animal agricultural sectors. In irrigating agriculture, an annual technological progress of 0.5 percent is forecasted for Switzerland. Price evolutions largely reflect assumptions about economic growth in Switzerland, that is forecasted to slow down from 2020 on, as well as technological progress in the use of water resources. Prices for raw water for irrigation reach 0.03 USD_{2010} per cubic meter in the baseline in 2050, raw water for other uses is valued at 0.12 USD_{2010} per cubic meter and finally drinking water prices are approximately 1.21 USD_{2010} per cubic meter.

5 The impact of climate change on water availability

To evaluate the economic consequences of climate change particularly on the water distribution sector and water prices but also on the Swiss economy as a whole, one has to be able to evaluate the physical consequences of climate change on water resources. To do so, this study uses the results of the CCHydro project [37] that informs about possible evolutions of runoff and the water cycle from 2021 to 2100 for Switzerland for alternative climate-scenarios. It uses an innovative hydrological model to simulate the evolution of parameters like precipitation, evapotranspiration, runoff or groundwater levels.

The economic sectors represented in GEMINI-E3 use underground and surface water, consequently CCHydro simulations of runoff and groundwater level for 2050 are employed to impact raw water resources in the model. The variations of water resource availability in 2050 compared to the 1980-2009 reference period are calculated from the results of the CCHydro project that simulates projections for runoff and groundwater levels. From these projections, the evolutions of runoff and groundwater levels are combined proportionally to their use in the Swiss economy (hence 43 percent of surface versus 57 percent of underground water according to Freiburghaus [16] for industry and services and 92 percent of surface versus 8 percent of underground water for irrigation following Weber and Schild [36]).

Table 7 – Evolution of water resources until 2050 compared to 1980-2009 reference period

Climate scenarios	Annual variations	April - October
ETHZ HadCM3Q0 CLM	**-6.8%**	**-15.8%**
HC HadCM3Q0 HadRM3Q0	-4.6%	-15.2%
SMHI HadCM3Q3 RCA	**9.4%**	**-2.6%**
SMHI ECHAM RCA	3.7%	-7.1%
MPI ECHAM REMO	2.0%	-7.6%
KNMI ECHAM RACMO	4.9%	-4.2%
ICTP ECHAM REGCM	4.2%	-3.3%
DMI ECHAM HIRHAM	3.9%	-2.5%
SMHI BCM RCA	1.5%	-5.5%
CNRM ARPEGE ALADIN	-4.8%	-10.7%

Calculated on CCHydro data [37]

Table 7 reports the evolution of raw water resources in Switzerland annually and for the main irrigation period (April to October) simulated for 10 different ENSEMBLES climate scenarios. All are based on the A1B emission scenario. Annual predictions differ strongly among scenarios. Some predict a drop in runoff and groundwater level (the most pessimistic predicts a combined loss of about 7 percent) while others anticipate a rise in available resources of up to 9.5 percent for 2050. The annual evolution of water resources is thus very uncertain and a majority of climate scenarios predict the climate change driven impact on the resources to be low. This can be explained by the nature of climate change impacts on runoff which will increase from October to April but decrease from May to September. Irrigation water availability diminishes between 2.5 and 15.8 percent until 2050. As the evolution of available water resources both for irrigation and other uses is quite uncertain, different scenarios are used in this paper to simulate the economic impact of climate induced changes in water resource availability.

6 Simulated scenarios and results

This study simulates the following scenarios :

- Scenario 1 (ETHZ) : raw water availability follows CCHydro predictions for the ETHZ climate scenario,
- Scenario 2 (SMHI) : raw water availability follows CCHydro predictions for the SMHI climate scenario,
- Scenario 3 (-20) : availability of both raw water resources diminishes by 20 percent,
- Scenario 4 (low water extraction adaptation) : diminishes elasticities of substitution between raw water and other inputs to $\sigma = 0$ and $\sigma_{wother} = 0.01$,
- Scenario 5 (low industry adaptation) : diminishes the elasticity of substitution between industrial water and other inputs to $\sigma_{ind} = 0.1$,
- Scenario 6 (high industry adaptation) : increases the elasticity of substitution between industrial water and other inputs to $\sigma_{ind} = 0.5$,
- Scenario 7 (low agricultural adaptation) : diminishes the elasticity of substitution between irrigation and land to $\sigma_{lw} = 0.1$ in the plant growing sectors,
- Scenario 8 (high agricultural adaptation) : increases the elasticity of substitution between irrigation and land to $\sigma_{lw} = 0.5$ in the plant growing sectors,
- Scenario 9 (low substitutability of industrial/agricultural water and drinking water) : decreases the elasticity of substitution between industrial/agricultural water and drinking water to $\sigma_w = 0.1$ for metal, chemical and consumption goods and $\sigma_w = 0.001$ for other industry and services,
- Scenario 10 (high substitutability of industrial/agricultural water and drinking water) : increases the elasticity of substitution between industrial/agricultural water and drinking water to $\sigma_w = 0.5$ for metal, chemical and consumption goods and $\sigma_w = 0.3$ for other industry and services,
- Scenario 11 (low adaptation in household consumption) : decreases the elasticity of substitution between goods in the "Other" nest of the structure of household consumption to $\sigma_{hoth} = 0$,
- Scenario 12 (high adaptation in household consumption) : increases the elasticity of substitution between goods in the "Other" nest of the structure of household consumption to $\sigma_{hoth} = 0.4$.
- Scenario 13 (low adaptation): simultaneously decreases the elasticities of substitution as implemented in scenarios 5, 7, 9 and 11.

– Scenario 14 (high adaptation): simultaneously increases the elasticities of substitution as implemented in scenarios 6, 8, 10 and 12.

In scenarios 4 to 14, raw water availability follows CCHydro predictions for the ETHZ climate scenario.

6.1 The alternative climate scenarios

The first three scenarios concentrate on investigating the impact of three distinct variations in raw water availability. Scenarios 1 and 2 impose water use constraints that replicate the predicted evolution of raw water resources according to two ENSEMBLES based climate-scenarios. More specifically, the two most extreme CCHydro scenarios, ETHZ HadCM3Q0 CLM and SMHI HadCM3Q3 RCA, are chosen. The third restricts water by an arbitrary share of - 20 percent to simulate the consequence of a quite extreme constraint on water use.

The high uncertainty in climate predictions is reflected in economic forecasts. As shown in table 8, the surplus indicates a welfare loss of 39.5 million 2001 USD_{2010} compared to the baseline scenario for the ETHZ scenario while the SMHI scenario results in a gain of 20.6 million USD_{2010}. An important reduction of available water by 20 percent induces a welfare loss of 178.2 million USD_{2010}.

Raw water prices do vary very much and respond very sharply to changes in water availability, as shown in relative terms in table 8 and further highlighted in absolute terms in figure 6. Indeed prices of raw water for irrigation and of raw water for other uses are predicted to increase by 431.3 and 115.5 percent respectively compared to baseline levels in the ETHZ scenario to reach 0.16 and 0.26 USD_{2010} per cubic meter of water respectively. Simulating water constraints that follow the evolution of water availability in the SMHI scenario induces an increase in the price of raw water for irrigation by 50.3 percent and a drop in the price of raw water for other uses by 79.9 percent and leads to forecasted prices of 0.05 and 0.02 USD_{2010} per cubic meter of water. The higher relative increase in the price of raw water for irrigation than in the price of raw water for other uses results from the higher reduction of water availability during the growing season of plants than annually (as the SMHI scenario even predicts an increase in annual water resource availability). Prices vary by as much as 596.8 and 575 percent and reach 0.21 and 0.81 USD_{2010} per cubic meter of water if an extreme constraint of -20 percent is imposed on both types of raw water. Drinking water prices vary between +12.4 and -8.8 percent for the ETHZ and SMHI scenarios, with drinking water consumption going down by 3.2 percent and up by 2.6 percent respectively. In the -20 percent scenario, the relative drinking water price increase compared to the baseline scenario reaches 60.9 percent and drinking water consumption drops by 11.9 percent. These results also illustrate some substitution of raw water adduction by drinking water as the relative prices of industrial and irrigation water compared to drinking water increase as a consequence of constraints on the use of raw water resources. Indeed, the production prices of industrial and irrigation water (the combination of raw water with the capital and energy necessary to extract it) increase by 46.6 and 64.6 percent respectively in the ETHZ scenario, compared to a variation of + 12.4 percent in drinking water prices.

Globally, the economic consequences of these price variations remain rather limited because of the very low value of raw water in 2001 (0.01 USD_{2010} per cubic meter) as well as in the baseline scenario (0.03 for raw water for irrigation and 0.12 for raw water for other uses) and the small share of water expenses in the production cost of most sectors. This result confirms the conclusion of studies of authors like Briand [7], who finds a 60 percent decrease in available water resources in the Seine estuary to greatly increase the prices of water but to have only a

Table 8 – Simulation results with alternative climate scenarios, variations compared to the baseline

	Scenario 1	Scenario 2	Scenario 3
Climate scenario	ETHZ	SMHI	-20%
Production price of the raw resource			
Raw water	+115.5%	-79.9%	+575%
Raw water for irrigation	+431.3%	+50.3%	+596.8%
Production price of water			
Industrial water	+46.6%	-32.8%	+229.9%
Irrigation water	+64.6%	+7.7%	+88.9%
Drinking water	+12.4%	-8.8%	+60.9%
Drinking water consumption			
Total	-3.2%	+2.6%	-11.9%
Households	-2.3%	+1.9%	-9.1%
Welfare (mio USD_{2010})	-39.5	+20.6	-178.2
Welfare change (in % of household consumption)	-0.01%	+0.01%	-0.04%

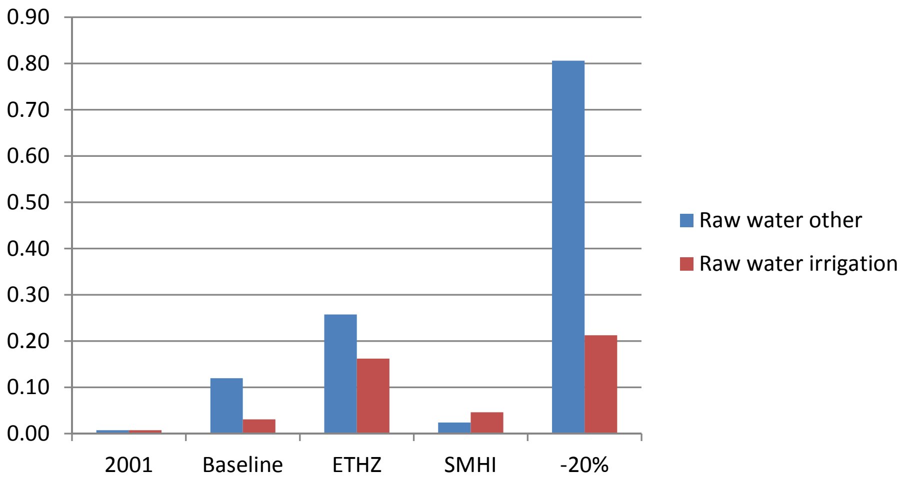

Figure 6 – Raw water prices in USD_{2010} per m^3

small impact on GDP. On the other hand, the studies of other authors suggest more important global consequences. Berck et al. [2] find a 20 percent reduction of water resources to cause a 0.75 percent drop in GDP in the San Joaquin valley. In their model, only agriculture uses water, but the weight of irrigating agricultural sectors is much higher in the San Joaquin economy than it is in Switzerland.

Sectors most affected by changes in raw water availability in Switzerland are after water distribution the chemical sector, agricultural sectors that use irrigation and the winter tourism sectors that need water for snowmaking. For example, production variations range from +0.4 to -2 percent in the chemical sector.

6.2 Endogenous adaptive capacity

Scenarios 4 to 14 investigate the impact of endogenous adaptive capacity by altering the substitution options among different inputs. For the scenarios to be comparable to each other, a price evolution similar to the one in the original baseline scenario is imposed on the baselines of subsequent scenarios with altered elasticities by modifying the constraints on available water. All scenarios use the ETHZ climate scenario, and simulation results of the scenarios 4 to 14 can be compared to the ones found in scenario 1. Scenario 4 ("low water distribution") reduces the possibility of replacing raw water by other inputs in water distribution σ from 0.025 to 0 and σ_{wother} from 0.025 to 0.01 in all other water employing sectors. The economic consequences are quite noticeable. First of all, prices for water are further inflated when compared to the first scenario : the price for raw water for irrigation now increases by 886.9 percent when compared to the baseline instead of the 431.3 percent observed in scenario 1 and raw water for irrigation goes up 180.8 instead of 115.5 percent. The price variation of drinking water increases from 12.4 to 18.3 percent in 2050 while industrial and irrigation water price changes respectively go from 46.6 to 53.1 percent and from 64.6 to 80.5 percent when a lower elasticity is chosen. Drinking water consumption reduces by 4.4 percent compared to 3.2 percent in scenario 1. Consequently, the substitution of raw water by drinking water is less pronounced with lower adaptation options. Total welfare loss increases from 39.5 to 45.2 million. Projected welfare gains from more adaptation highlight the potential of measures like the reduction of water losses through investments in capital. No scenarios are simulated with elasticities σ and σ_{wother} higher than 0.025, as this would reduce losses too much and thus not be justifiable technically.

Scenarios 5 ("low industrial adaptive capacity") and 6 ("high industrial adaptive capacity") analyse the possible consequences of altering the potential of non-agricultural sectors to replace industrial or drinking water use by other inputs, measured by σ_{ind}. The higher σ_{ind}, the easier it is to transform production processes to make them less water intensive. Changes in this elasticity are furthermost reflected in variations of the price of raw water for uses other than irrigation, that increases between 78.4 and 222.6 percent depending on the flexibility in substituting water by other factors. These changes are translated in drinking water as well as industrial water prices, that increase by 23.9 and 89.3 percent respectively compared to the baseline scenario if σ_{ind} equals 0.1 but only by 8.4 and 31.8 percent if σ_{ind} equals 0.5. Welfare losses amount to -46.4 million USD_{2010} in the "low industry adaptation scenario" and to -37.2 million in the "high industry adaptation scenario".

Changes in the possibility to substitute land and irrigation water mostly affect prices of raw water for agriculture, that increase much more in the low than in the high adaptation scenario. The economic impacts on other sectors are very restricted as raw water for irrigation is used in plant growing sectors only.

Table 9 – Simulation results, variations compared to the baseline

Scenarios	1	4	5	6	7	8	9	10	11	12	13	14
Climate scenario						ETHZ for all scenarios						
Production price of the raw resource												
Raw water	115.5%	180.8%	222.6%	78.4%	116.0%	115.4%	123.2%	104.1%	130.6%	102.9%	371.7%	68.5%
Raw water for irrigation	431.3%	886.9%	423.4%	434.2%	1630.7%	250.9%	448.4%	397.5%	429.7%	432.8%	1831.9%	242.7%
Production price of water												
Industrial water	46.6%	53.1%	89.3%	31.8%	46.8%	46.5%	49.3%	42.2%	52.7%	41.5%	149.4%	28.0%
Irrigation water	64.6%	80.5%	63.4%	65.0%	240.1%	37.9%	67.1%	59.6%	64.4%	64.8%	269.7%	36.6%
Drinking water	12.4%	18.3%	23.9%	8.4%	12.5%	12.4%	13.2%	11.2%	14.1%	11.0%	39.7%	7.3%
Drinking water consumption												
Total	-3.2%	-4.4%	-3.2%	-3.3%	-3.2%	-3.2%	-3.7%	-2.4%	-2.3%	-4.0%	-2.2%	-3.2%
Households	-2.3%	-3.3%	-4.2%	-1.6%	-2.3%	-2.3%	-2.5%	-2.1%	0.0%	-4.1%	0.0%	-2.8%
Welfare in mios USD$_{2010}$	-39.5	-45.2	-46.4	-37.2	-42.3	-39.2	-40.5	-38.0	-40.2	-39.1	-59.7	-35.8
Welfare change	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%	-0.01%

Scenarios 9 and 10 investigate the consequences of making the replacement of agricultural or industrial water by drinking water more difficult. As expected, restricting substitutability induces more important price increases for both raw water and drinking water. The reduction of drinking water consumption is more pronounced as it gets more difficult to replace agricultural and industrial water by drinking water. Global welfare impacts are rather robust to changes in substitutability between the different types of water, as they vary between -38 and -40.5 million. The adaptive capacity of households is under scrutiny in scenarios 11 and 12. Simulation results are very robust to changes in σ_{hoth}, highlighting the little global impact of allowing households to adjust their consumption more easily by reducing their water consumption.

The last two scenarios combine scenarios 5, 7, 9 and 11 (low adaptation, scenario 13) and scenarios 6, 8, 10 and 12 (high adaptation, scenario 14). Scenario 13 describes an economy for whom it is difficult to adapt to climate change. Possibilities to substitute industrial water by other factors, irrigation by land, drinking water by industrial or irrigation water and the capacity of households to adopt less water intensive lifestyles are limited. Scenario 14 simulates the parallel case but with high elasticities of substitution. In these scenarios, elasticities of substitution between raw water and other inputs σ and σ_{wother} keep their initial value of 0.025. Indeed a lower value restricts the model too much while a higher one results in negative losses.

Scenario 13 is characterized by important increases in the price of industrial water, irrigation water and drinking water of 149.4, 269.7 and 39.7% compared to the baseline, whereas much lower price variations of 28, 36.6 et 7.3 % are observed in scenario 14. Globally, welfare losses are 59.7 million de USD_{2010} in the low adaptation scenario and 35.8 million in the high adaptation scenario. The increase of adaptive capacity thus reduces welfare losses by approximately 40%.

Looking at scenarios 4 to 14, simulation results are most sensitive to the variation of σ and σ_{wother} as well as σ_{ind} and thus to substitution options between raw water and other factors in the production of drinking, industrial and agricultural water and to the difficulty of making production processes less water intensive. Restricting these substitution elasticities induces the highest welfare loss, implying that the degree of difficulty encountered in reducing water losses and reducing the water intensity of production may be key factors in determining the extent of welfare losses provoked by a decrease in water availability.

7 Conclusion

The future evolution of water resources is still quite uncertain which increases the importance of understanding the potential consequences of changes in the availability of this resource. This study adapts GEMINI-E3 by introducing raw water resources and a drinking water sector into this CGE model to analyse the consequences of climate-induced variations of raw water availability in Switzerland until 2050. Doing so, it creates a powerful tool to examine the effects of climate change or water policies.

The simulation of three alternative constraints on raw water resources leads to very important changes in prices of raw water resources in 2050 relative to the baseline. Compared to the high variations in water prices, global economic consequences remain relatively limited due to the low value of the resources both in 2001 and in 2050 in the baseline. Simulations highlight the importance of the capacity to reduce water losses and to transform production processes to decrease their water intensity in determining the extent of welfare losses provoked by a decrease in water availability. However, most of the uncertainty comes from the climate scenarios and not from the choice of the various elasticities of substitution.

This study aims at investigating the consequences of climate induced changes in water availability. It does not offer a global assessment of the impact of climate change as it does only partly consider changes in seasonality and does not integrate extreme events like floods and droughts. It is part of a larger project that assesses the economic impact of climate change on particularly sensitive sectors in Switzerland and more particularly the potential effect of adaptation. Aside from the water sector, applications include the tourism (Gonseth and Vielle [18]) and energy (Gonseth and Vielle [19]) sectors. The paper is work in progress and results are preliminary.

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