28 February 2017

Assessing the impacts of climate change for Switzerland

Final report

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Commissioned by:
Federal Office for the Environment (FOEN)
Climate Division
CH‑3003 Bern

The FOEN is an agency of the Federal Department of the Environment, Transport, Energy and Communications (DETEC).

Contractor:

École Polytechnique Fédérale de Lausanne
Laboratory of Environmental and Urban Economics (LEURE)
Station 16
CH-1015 Lausanne
http://leure.epfl.ch

Authors: Frank Vöhringer, Marc Vielle, Boris Thurm, Wolfgang Knoke, Dario Stocker, Anita Frehner, Sophie Maire, Philippe Thalmann

FOEN support: Roland Hohmann

TABLE OF CONTENTS

TABLES

FIGURES

ABBREVIATIONS

A1B	intermediate greenhouse gas emissions scenario of SRES
A2	high greenhouse gas emissions growth scenario of SRES
BRIC	Brazil, Russia, India and China
CC	climate change
CDD	cooling degree days
CH2011	Swiss climate change scenarios published in 2011
CHF	Swiss francs
CGE	computable general equilibrium
CO_2	carbon dioxyde
EU	European Union
FSO	Federal Statistical Office
GDP	gross domestic product
GCM	general circulation model
FOEN	Federal Office for the Environment
HDD	heating degree days
HTM	Hamburg Tourism Model
IAM	integrated assessment model
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ODT	one-day winter tourism
OECD	Organisation for Economic Co-operation and Development
RCM	regional climate model
RCP	representative concentration pathways
RCP3PD	emissions scenario that reduces them by 50% by 2050 relative to 1990
ROW	rest of the world
SECO	State Secretariat for Economic Affairs
SRES	IPCC's Special Report on Emissions Scenarios of 2000
SSP	shared socioeconomic pathways
toe	tonne of oil equivalent
TWh	terawatt-hour
US	United States
WEO	World Energy Outlook
WBGT	Wet Bulb Globe Temperature
WOT	winter overnight tourism
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research

1. INTRODUCTION

1.1 Aim of the research program

This report summarizes the results of a research program that seeks to estimate the possible costs of climate change for Switzerland at the horizon of 2060. The main goal of this research program is to bundle, update and complete earlier assessments with a view to producing a full picture of the economic consequences of climate change impacts in Switzerland by 2060. Secondary goals are developments of the methodology, improvements of the simulations models, and updating of the SWIDCHI-Database, which provides a public inventory of literature on climate change impacts in Switzerland. Particular emphasis is put on examining uncertainties and the role and nature of adaptation, as well as identifying cross-sectoral and international effects that are transmitted via trade. The results should also be useful for the Federal Office for the Environment (FOEN) in developing the federal adaptation strategy and in preparing the consultation documents for the next revision of the CO_2 Act.

1.2 Background

For Switzerland as for other continental regions, climatologists expect a temperature increase much higher than the global average (Swiss Academies of Arts and Sciences 2016). Even up to 2011, Switzerland has experienced an increase by 1.7°C since the beginning of institutionalized temperature measurements in 1864, while the average on-land warming in the northern hemisphere amounted to 1.1°C (Perroud & Bader 2013). Under these circumstances, it is necessary to inquire about climatic effects in Switzerland and their economic magnitude. Understanding these effects is a prerequisite for developing adequate adaptation strategies, with the objective to reduce damages and to reap opportunities of climate change.

Despite this, there has been little research that would include attempts for monetization over a long period of time. One of the reasons is the complexity and heterogeneity of the subject: Many sectors are involved in very different ways, requiring different types of analyses. This includes e.g. areas as diverse as

- the assessment of hydrological changes and their effects on various sectors including electricity generation and agriculture,
- projections regarding the spread of vector-borne diseases,
- investigations on how high temperatures affect the human body, crops and other plants, and even biodiversity,
- the economic valuation of changes in human mortality, biodiversity and scenic beauty,
- the assessment of changes in energy demand for heating and cooling,
- the prediction of tourist flows in winter and summer seasons under changing climatic conditions,
- projections regarding the incidence of various natural hazards and an assessment of their consequences.

In general terms, climate change impacts to a given actor at a given place and time are functions of:

1) **Exposure**, defined by IPCC 2007a as the 'nature and degree to which a system is exposed to significant climatic variations';

2) **Sensitivity** of the system, 'the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli' (IPCC 2007a);
3) **Adaptive capacity**, the 'ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (IPCC 2007b).

Although IPCC 2007a defines the impact of climate change with adaptation as 'vulnerability', we prefer to use the clearer expression of 'impacts with adaptation' for this report.

Any meaningful statement with regard to economic effects needs to rely on a thorough understanding of the physical impacts of climate change and how these impacts will affect the availability of resources and the biological cycle. Uncertainties arise in natural sciences, in the social sphere and in economic valuation. The monetization of non-market goods, such as biodiversity or scenic beauty, is particularly challenging. Although valuation methods exist, they have usually not been applied to the areas and impact indicators that are relevant in this report. Another difficulty of projecting economic effects to the future is that economic activities are dynamic and will adapt to climate change in order to offset its negative effects, although the actual degree of adaptation is hard to predict. Research on adaptation to climate change is still a rather young discipline: As the original research focus in climate economics was on mitigation, large research programs on adaptation were only initiated in the 2000s.

1.3 State of the art

Although Meier 1998 made a first crude attempt to monetize the possible impacts of climate change in Switzerland, it was not before 2007 that the first considerable and encompassing estimation of the costs of climate changes for the Swiss economy was conducted by Ecoplan and Sigmaplan, commissioned by FOEN. The study focused on direct impacts of climate change in Switzerland, while another study (INFRAS/Ecologic/Rütter und Partner 2007) estimated the consequences for Switzerland of climate change impacts occurring in the rest of the world. These were the last all-encompassing economic assessments of the possible consequences of climate changes for Switzerland to date.

The Ecoplan/Sigmaplan 2007 study took uncertainty explicitly and quantitatively into account, using a Monte Carlo simulation approach. It estimated that there would be hardly any impacts by 2030 and moderate impacts until 2050 (0.15% of GDP), but that they would grow substantially until the end of the century, to reach 0.5% of GDP with a large margin of uncertainty, from 0.15% to 1.6%. The authors attributed 40% of that uncertainty to that of the climate scenarios and 60% to the translation of these scenarios into economic losses.

Important caveats of the analysis are the following:

- There was no valuation of impacts in several sectors including agriculture, summer tourism, landscapes (e.g. glaciers melting) and ecosystems. Due to lack of information from climate sciences, there was also no analysis for a number of natural hazards: hail, avalanches, storms, droughts, and forest fires.
- It is generally difficult to take into account large-scale catastrophic risks or the possibility that tipping points in the climate system might be triggered. Hence, such risks had to be ignored.

- There was no analysis of barriers for adaptation measures, which may have led to overly optimistic assumptions regarding the implementation of adaptation measures. For winter tourism, in contrast, no adaptation measures (e.g. artificial snowmaking) were taken into account.
- With the exception of winter tourism, impacts that would be transmitted through price changes and markets were neglected.

Since the 2007 studies, new climate scenarios were developed (CH2011) and new impact studies were published. The most important of these are:

- Swiss Confederation 2012a was a first global assessment of the challenges facing all policy fields (referred to as sectors) of Switzerland due to climate change impacts. The assessment of the impacts is qualitative, based on published results and expert statements. The report did not attempt to estimate the costs of climate change impacts, but to identify priorities for action. It was elaborated by ten federal offices and other units and designed as first part of the national adaptation strategy. The second part of the strategy is an action plan for the 2014-2019 period with 63 measures that the federal offices should take to seize the opportunities created by climate changes, to reduce risks and to increase the adaptive capacity of society, the economy and the environment (Swiss Confederation 2014).
- The CH2014-Impacts report presents research advancements for various sectors individually, such as tourism, agriculture and energy demand. They translate the climate scenarios CH2011 into quantitative impacts for the cryosphere, hydrology, biodiversity, forests, agriculture, energy use and health. Very few of these impacts are expressed in monetary terms.
- Comprehensive economic assessments of risks induced by climate change were completed in a series of cantons that were selected to be representative of a main geographical region of Switzerland. The selected cantons are Aargau, Uri, Basel-Stadt, Geneva, Graubünden, Ticino, Fribourg, and Jura.

Many economic sectors are affected by climate change, e.g. health, agriculture, forestry, water management, energy supply and demand, tourism, buildings and infrastructure. In recent years, many advances in assessing climate impacts have been made for each of these sectors. These advances are acknowledged in chapter 3.

1.4 Structure of the report

The remainder of the report is organized as follows: Chapter 2 describes the general methodology and sets priorities for model enhancement. Chapter 3 is organized by climate sensitive area: health, buildings and infrastructure, energy, water management, agriculture, and tourism. Within each sectoral sub-chapter, we present the existing literature as well as our modeling approach and input data. We show the results of the simulations of impacts in the respective area and discuss these results. Chapter 4 presents an overview of the main results and concludes.

2. METHODOLOGY

2.1 A sector-based top-down approach

Different approaches can be taken to analyze the impacts of climate change in an economic setting, which all have their advantages and shortcomings. Approaches can be descriptive, semi-quantitative (e.g. multi-criteria analysis), or quantitative (bottom-up, partial equilibrium, general equilibrium, macroeconomic / econometric models).

The cantonal case studies indicate that climate change (CC) impacts should not just be considered individually, but also in their interactions. A striking result of these studies (as was also emphasized in the latest IPCC assessment report) is that for individual sectors, socio-economic changes and uncertainties are often more important than climate uncertainties and impacts. These considerations call for an integrated assessment of CC impacts, combining as much as possible of the predicted climate modifications and as much as possible of expected socio-economic trends into a coherent model of the Swiss economy. Based on the analysis of existing research gaps, we choose to investigate the subject with the help of a general equilibrium framework and present options to model climate change impacts and adaptation within that framework.

The ability to compare results and educate each approach by another is of utmost importance. With this in mind, we opt for an approach which builds up information and model inputs sector by sector, such that, at least in principle, information from all kinds of studies can be integrated into the analysis. Of course, this is hardly possibly without any consistency issues, although we build our approach as much as possible on sources which use the same or similar scenarios as well as compatible methods. The need to combine sources with at times very different methodological backgrounds is a reflection of the state of affairs in the research on the impacts of climate change: After many years of using crude macroeconomic estimates, more detailed sector by sector approaches to determine economic impacts of climate change are still relatively new. At the same time, the field involves many sectors, individual impacts, determinants and uncertainties. As a consequence, the research field will remain lively and challenging for many years to come.

In the current project, we want to build on the existing literature, but take things further with a more comprehensive quantitative assessment. We use a general equilibrium approach, because intersectoral dependencies, feedbacks within the economy, and international impacts are crucial for the analysis of impacts of climate change in Switzerland. Yet, to keep the effects of the many impacts traceable, we simulate the economic impacts separately for six different impact areas: health, buildings and infrastructure, energy, water management, agriculture, and tourism. This includes the effects which the impacts in these areas exert on other sectors. In addition, we simulate all of the modeled impacts jointly to determine interaction effects as well as crude projections of potential overall economic impacts.

Indeed, due to the fact that sectors compete for factors of production and that the outputs of some sectors might serve as intermediate inputs for other sectors, the impact of climate change on one sector of the economy might have noticeable effects on related sectors. Also, domestic CC impacts could be small for some sectors. However, due to international trade, significant impacts of climate change in other countries could be transmitted to Switzerland and have non-negligible effects on the economy.

Computable General Equilibrium (CGE) models are based on neo-classical economic theory and model the whole economy and hence take into account feedback between the different economic agents. They are used widely for the analysis of climate change mitigation policies, both national and international (de Bruin et al. 2009; Aaheim & Schjolden 2004). They have also been used for some specific analyses of sectoral climate change impacts (Faust et al. 2012; Ciscar & Dowling 2014; Eboli et al. 2010).

CGE models have their disadvantages. Firstly, they are not forecasting models: They provide orders of magnitude, direction and distribution of effects rather than precise numerical results. We believe, however, that, due to the uncertain nature of climate change, this is adequate anyway. Secondly, CGE models require a lot of data. When analyzing OECD countries, input-output tables are usually available. For the analysis of climate change, however, we may sometimes lack data on specific impact valuation. As any other quantitative assessment, CGE models struggle with non-market effects of climate change. Their valuation is difficult and based mostly on stated preference methods (contingent valuation, conjoint analysis, or choice modeling) or revealed preference methods (travel cost, hedonic price, or other market price methods).

In what follows, we show how the impacts of climate change in Switzerland can be estimated with our multi-regional CGE model GEMINI-E3. We start by presenting the scenarios that we simulate.

2.2 Scenarios

2.2.1 Reference case

To simulate the evolution of the economy until 2050, GEMINI-E3 uses projections of population growth, gross domestic product (GDP) and energy prices, as well as assumptions on electricity generation.

2.2.1.1 Demography

We use the evolution of the Swiss population as defined by the A-00-2015 scenario from the Federal Statistical Office (FSO 2015). In this publication the population is projected up to 2045; we extrapolate the population up to 2060 assuming that its growth rate between 2045-2060 will be the same as the one projected for the period 2040-2045 (i.e. 0.27% per year). Table 1 gives the evolution of the Swiss population. In 2060, 10.6 million inhabitants are projected to live in Switzerland.

Table 1: Swiss population
('000, January 1st)

	2015	2030	2040	2050	2060
Swiss population	8’239	9’467	10’014	10’292	10’578

For the rest of the world, assumptions on population are based on the latest forecast by United Nations 2015. We use the "median-fertility variant". In 2060, the world population reaches 10.2 billion inhabitants. In comparison to the scenarios of the IPCC’s Special Report on Emissions Scenarios SRES (IPCC 2000), this number is higher than in scenario A1B (8.5 billion), but lower than in scenario A2 (12.1 billion).

2.2.1.2 GDP growth

For Switzerland, GDP growth is forecasted by the State Secretariat for Economic Affairs SECO by multiplying the labor force (coming from the demographic scenario) with a labor productivity increase of 0.9% per year. For the rest of the world, we apply a similar methodology. We use the GDP growth rates projected in the World Energy Outlook (WEO) 2015 of the International Energy Agency (IEA 2015) up to 2040. After 2040, we multiply the labor force by labor productivity based on what is retained by the IEA for the period 2013-2040. Table 2 shows the resulting GDP growth rates used in the reference scenario. These international growth rates are in between those of the SRES scenarios A2 (low growth) and A1B (high growth).

Table 2: Annual GDP growth rate
(%)

		2014-2020	2020-2030	2030-2040	2040-2050	2050-2060
CH	Switzerland	1.7	1.3	1.1	0.9	0.8
EU	European Union	1.8	1.7	1.5	1.4	1.3
USA	USA	2.5	2.0	2.0	2.0	1.9
OECD	Canada, Japan, Norway, Australia, New Zealand	1.8	1.7	1.5	1.3	1.2
BRIC	Brazil, Russia, India, China	6.1	4.2	3.6	3.3	3.1
ROW	Rest of the World	3.2	4.9	4.1	3.4	2.9
World	World	3.0	3.0	2.7	2.5	2.4

2.2.1.3 World energy prices

Assumptions concerning energy prices are drawn from the World Energy Outlook 2015 of the International Energy Agency (IEA 2015). The scenarios presented in this report assume, for the sake of simplification, that no stringent climate policy is implemented. Therefore, we retain the IEA scenario called "Current Policies Scenario". The predictions of the IEA stop in 2040. After that, we assume that energy prices will continue to grow at the same rate of the last decade. Table 3 shows the energy prices used in the reference scenario. The oil price and the price of imported gas in Europe are assumed to reach 198 US$/barrel and 16.7 US$/Mbtu in 2060, respectively.

Table 3: Fossil fuel import prices
(US$ of 2014 per unit, WEO´s 2015 Current Policies Scenario)

	2014	2020	2030	2040	2050	2060
IEA crude oil imports (barrel)	97.0	83.0	130.0	150.0	172.2	197.7
Natural gas EU imports (MBtu)	9.3	8.1	12.5	13.8	15.2	16.7

2.2.1.4 Electricity generation

In May 2011, the Federal Government decided, after the devastating earthquake in Japan and the nuclear disaster at Fukushima, to gradually decommission all nuclear power plants. The strategy is to decommission the five nuclear power plants when they reach the end of their service life and not to replace them with new ones. However, the Swiss Government does not fix the end of their lifetime. The operator of the Mühleberg power plant already decided to cease all electrical generation in 2019. For the four remaining power plants we decided to use a maximum lifetime of 60 years, although their actual lifetime may be shorter. Table 4 shows the assumed operating lives of the 5 existing nuclear power plants that have been introduced in GEMINI-E3.

Table 4: Operating life of Swiss nuclear power plants

Nuclear power plant	Operating life
Beznau I (365 MWe)	1969-2029
Beznau II (365 MWe)	1971-2031
Mühleberg (373 MWe)	1972-2019
Gösgen (985 MWe)	1979-2039
Leibstadt (1190 MWe)	1984-2044

2.2.2 Climate scenarios

For the sake of comparability, we base our analysis on the three scenarios used in CH2011 and CH2014-Impacts: A1B, A2 and RCP3PD. Figure 1 shows the assumed global greenhouse gas emissions pathways and the corresponding projected mean temperature changes for Switzerland (average of 2070-2099 relative to the average of 1980-2009) as presented in CH2011.

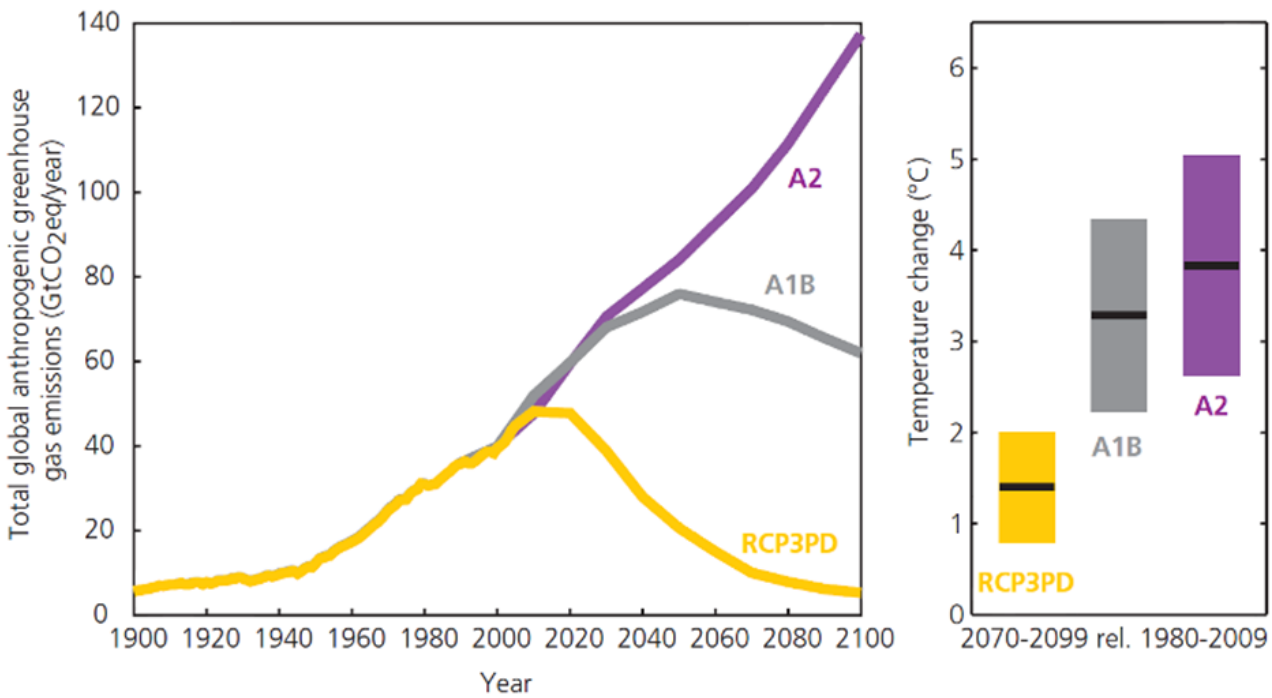


Figure 1: Pathways of past and future anthropogenic greenhouse gas emissions and projected annual mean warming for Switzerland for the 30-year average centered at 2085
(Source: CH2011)

A1B and A2 are alternative non-intervention scenarios which were originally developed for the IPCC's Special Report on Emissions Scenarios (IPCC 2000). A2 assumes high population growth and continued use of fossil fuels. In contrast, the A1B scenario assumes rapid economic growth and high technical progress. This reduces the dependence on fossil fuel and slows down population growth in the second half of the century. For 2060, the year which this analysis mainly considers, temperature differences between A2 and A1B are very small.

The RCP3PD scenario originates from the more recent Representative Concentration Pathways (RCP) family of scenarios, which were used for the simulations of the IPCC's 5th Assessment Report (IPCC 2013). RCP3PD is an ambitious climate mitigation scenario, which has a 2/3 likelihood of limiting global warming to 2°C above the preindustrial level.

To allow for a meaningful CGE analysis, the basic socioeconomic assumptions in GEMINI-E3 are not modified between scenarios and remain in accordance with the reference case described in section 2.2.1 above. This can be viewed as an inconsistency with the IPCC's SRES approach, but it is necessary to avoid that differences in results arise mainly because of differences in socioeconomic assumptions rather than due to that impacts of climate change which we are interested in.

For each of the three scenarios, we simulate impacts for a range of climate outcomes which include – next to the medium projected climate – the upper and the lower end of the range. In CH2011, the upper and lower values formally correspond to the 95% confidence interval generated by the climate model simulations. However, the interpretation in CH2014-Impacts is different: "This range captures true climate uncertainty incompletely, due to the limited number of climate models used and incomplete coverage of the relevant processes in the climate system and their respective scientific uncertainties. Based on expert judgment informed by the current state of climate science, CH2011 recommends the following interpretation of the climate uncertainty range: the expected chance that actual observed values will fall between the upper and the lower values is two in three for temperatures, and one in two for precipitation."

Please refer to CH2011 for further information on the scenarios and the corresponding changes in climate.

2.3 Modeling approach

2.3.1 The Model GEMINI-E3

The GEMINI-E3[1] model, is a multi-sectoral multi-regional recursive-dynamic general equilibrium model (Bernard et al. 2008). It has been used widely for the analysis of energy and climate-related issues, including: an assessment of the impact of a warming climate on energy consumption in buildings for Switzerland (CH2014-Impacts 2014), as well as an analysis of the impact of climate change on heating and cooling on a global level (Labriet et al. 2013). Coupled with a geographical information system, GEMINI-E3 has helped assess economic impacts of sea level rise (Joshi et al. 2013). It has also been further developed to analyse the impact of climate change in Switzerland for the water, tourism, energy and agriculture sectors (Faust et al. 2012 and 2015; Gonseth et al. 2015). We build on this know-how, and improve it, to assess the impacts of climate change in Switzerland.

1 General Equilibrium Model of International-National Interactions between Economy, Energy and the Environment. A detailed description of the model can be found on the model webpage http://gemini-e3.epfl.ch.

GEMINI-E3 is built on the energy disaggregated input-output table of Nathani et al. 2011 for Switzerland, and on the GTAP-8 dataset for the other regions of the world. The disaggregation of sectors (Table 5) and countries (Table 2) can be chosen to best suit the required analysis, provided that sufficient data are available.

Table 5: Sector classification in GEMINI-E3

1	Coal	12	Land transport
2	Oil	13	Water transport
3	Natural gas	14	Air transport
4	Petroleum products	15	Insurance
5	Electricity	16	Health
6	District heating	17	Other services
7	Grains and oil seeds	18	Winter overnight tourism
8	Other crops	19	One-day winter tourism
9	Livestock	20	Other forms of tourism
10	Forestry	21	Water
11	Industry		

2.3.2 Modeling issues in the context of climate change impacts

This section addresses general issues with modeling climate change impacts in a CGE framework. For descriptions of the specific modeling approaches that we have taken in the different sectors, please consult chapter 3.

2.3.2.1 Impacts of climate change

From an economic point of view, climate change can impact sectors in different ways. The productivity of natural resources necessary for production could be affected, as for example in the agriculture, forestry, winter tourism, or energy sectors. The final demand could be modified, e.g. for the tourism, health and energy services. Finally, climate change can also lead to losses of capital due to natural hazards, or a change in total labor or labor productivity.

The way climate change impacts have to be modeled in GEMINI-E3 differs from one sector to another and depends on:

1) The way the given sector is impacted by climate change; whether it is mainly through natural resources' or factors' productivity, changes in demand and/or loss of capital or labor;
2) The extent to which information and data are available for the modeling.

Depending on the above, different modeling options can be contemplated:

- To model a natural resource such as temperature, precipitation or snow cover as a factor in the production function, which is modified by climate change. The effect is felt through a substitution in factors of production and a possible reduction of output.
- To exogenously modify a sector's output and/or demand.
- To introduce an exogenous productivity shock on capital or labor.
- To apply a generic sectoral damage function.

Climate change impacts also household welfare, for example through the loss of scenic beauty, mortality risks, changes in health quality and other notions entering a broad definition of well-being. These notions are difficult to monetize and hence do not often enter welfare functions of CGE models, which are often based mostly on consumption of market goods and services, for which data is readily available in input-output tables.

2.3.2.2 Adaptation

Adaptation measures are numerous and can be undertaken by either public or private actors or both. Chapter 17 of the Fifth IPCC report (Chambwera et al. 2014) provides the following characterization of adaptation measures and actors to which they are usually linked:

- "Altered patterns of enterprise management, facility investment, enterprise choice, or resource use (mainly private)
- Direct capital investments in public infrastructure (e.g., dams and water management—mainly public)
- Technology development through research (e.g., development of crop varieties—private and public)
- Creation and dissemination of adaptation information (through extension or other communication vehicles—mainly public)
- Human capital enhancement (e.g., investment in education— private and public)
- Redesign or development of adaptation institutions (e.g., altered forms of insurance—private and public)
- Changes in norms and regulations to facilitate autonomous actions (e.g., altered building codes, technical standards, regulation of grids/networks/utilities, environmental regulations—mainly public)
- Changes in individual behaviour (private, with possible public incentives)
- Emergency response procedures and crisis management (mainly public)."

Autonomous (private) adaptation can be a very efficient form of adaptation. However, it is important to investigate whether private adaptation will reduce impacts of climate change to an optimum level, or whether anticipatory public adaptation is necessary, and to what degree. Public intervention is furthermore needed to reduce barriers to adaptation and to care for equity.

The Swiss economy is composed of many sectors, which all have their peculiarities and may be very different in terms of exposure, sensitivity, and adaptation options. Contrary to mitigation, where the principal solution lies in burning less fossil fuel (the most important exceptions being land use change and forestry as well as carbon capture and storage), adaptation to climate change takes many forms depending on the sectors and actors it relates to. Indeed, adaptation in the health sector is quite distinct to adaptation in the energy sector, for example. This makes the representation of adaptation within a modeling framework challenging.

Also, contrary to mitigation, adaptation is a long-term issue. In some instances, adaptation can be built into the economic development of sectors, for example by taking into account climate change in the replacement of capital. In these situations, differentiating/isolating adaptation to climate change from normal (adaptive) evolution is a difficult task. Moreover, if adaptation is fully integrated in the sector's development, it might not incur much additional cost.

A core issue is how to identify the net benefit of adaptation; more specifically, how to define a scenario 'without' adaptation to be compared with a scenario including adaptation. It would not be realistic to remove all adaptation. Indeed, in everyday life, we adapt to changing environments even without climate change. Removing all adaptation capacities from the agents would amount to unrealistic 'dumb farmer' assumptions[2] and lead to the overestimation of the impacts of climate change (OECD 2004).

As per their assumptions on representative agents' behaviour, CGE models naturally include price-induced (endogenous/private) adaptation (Aaheim et al. 2012). For example, if the price of a given good increases, agents will, to a certain extent, substitute away from that good. As this process is completely endogenous and central to the working of markets, it is impossible to 'turn it off' entirely in an economic model. That makes it very difficult to estimate all the benefits of adaptation to climate change, because it is nearly impossible to estimate the damages without any adaptation whatsoever. It would be possible to prevent all substitutions in the model, but this would also prevent 'normal life' adaptation to normal economic changes and thus massively overestimate the costs of climate change without adaptation.

2.3.2.3 International effects

International effects might be important and possibly have a greater impact on the Swiss economy than domestic effects of climate change, as Faust et al. 2012 have shown in the case of winter tourism. It is therefore worthwhile to model international effects as exhaustively as possible. The most obvious approach is to assume, for the other countries, changes in factor productivity or sectoral outputs through exogenous constraints. This requires sufficient data on the likely impacts of climate change for all important countries. The Swiss economy is affected by what happens abroad through terms of trade effects.

2.3.2.4 Uncertainty

Uncertainty is inherent to climate science. It is actually present in every field (natural sciences, economics, etc.) and applies to exposure, sensitivity, and adaptive capacity. With uncertainty at every stage, there arises the question of how the uncertainties combine along the chain of effects. They need not simply 'add up'. The question of how to deal with uncertainties in a CGE framework is complex. Two standard approaches are Monte Carlo simulations and scenario comparisons spanning the full uncertainty range ('low', 'middle' and 'high' scenario).

Following the approach taken in CH2014-Impacts, we build on the ranges of results for each scenario presented in CH2011. There, the upper and lower values correspond to the 95% confidence interval generated by the climate model simulations, but following the current state of climate science, these ranges need to be interpreted with more caution (CH2014-Impacts). The expected likelihood that the observed values will fall within the range between the upper and the lower values might be two thirds for temperatures and 50% for precipitation.

---

[2] The 'dumb farmer' cultivates the same crop even after climate conditions are no longer suitable. This is a metaphor for any agent impacted by climate change who would not change his production or consumption patterns in order to mitigate the consequences of climate change.

Impacts presented in this report come with additional uncertainties from the socioeconomic sphere. This reduces further the likelihood that the actual impacts will fall into the presented range. We do not presume to be able to quantify this effect. Certainly, readers should keep in mind that "upper" and "lower" corresponds to the climate-related values presented in CH2011 and CH2014, but do not mark upper and lower bounds for the possible impacts of climate change.

2.3.3 Priorities for model enhancement

Much still remains to be done when it comes to modeling the impacts of climate change. For this project, we have had to set priorities with respect to the areas where we are able to enhance modeling approaches. Among many options, we have selected matters which, according to other studies or previous own research, could be expected to be important in terms of impacts and feasible in terms of data availability and within the limitations of our modeling approach.

The following is a short overview. The actual modeling approaches are described in chapter 3.

GEMINI-E3 has the important advantage to be a world trade model. This is ideal to simulate **impacts of international price changes** on Switzerland. These are potentially strong effects which are neglected in other climate impact studies on Switzerland, with the exception of the input output approach of INFRAS et al. 2007. We have identified two main areas where international price effects could have sizable impacts on Switzerland: **agriculture** and **electricity** trade. The challenge is to simulate the price impacts in the different world regions.

We have previously worked on the climate change impacts on winter tourism (Faust et al. 2012, Gonseth & Vielle 2012a, Gonseth 2013, Matasci et al. 2013). In all of these works, impacts on **summer tourism** were neglected, although these impacts are potentially large. We have thus decided to adapt the model structure such that impacts on summer tourism can be simulated. This is another topic where international interdependence is important. We had to find ways to simulate impacts on tourism in the different regions of the model and to consider the interaction between these impacts and changed international tourism flows.

There is the concern that more frequent and possibly stronger extreme events increase damages through **natural hazards**. As climate change is more a story of increased risk rather than of average changes, this concern may well be relevant. On the other hand, climate model uncertainties and the tremendous natural variability imply that at present climate scientists cannot confirm quantitative assessments which would significantly deviate from impacts without climate change. This seems to call for neglecting the impacts of natural hazards in the economic modeling of climate change. However, such impacts can still be considered using a scenario approach. It informs about what impacts can be expected when we assume a certain increase in frequencies of extreme events. We have thus decided to implement scenario approaches for storms and floods and to modify the model such that it is able to represent the related damages.

Some of the other areas do not require structural changes to the model as compared to prior analyses. They do however require updates of data inputs. These areas include **winter tourism, energy demand for heating and cooling, water management for irrigation**, and the impact of hot summer days on **labor productivity**.

3. CLIMATE-SENSITIVE AREAS

3.1 Health

3.1.1 Literature-based assessment

3.1.1.1 Exposure

A major part of climate change (CC) impacts on health comes along with extreme weather events, such as heat waves, droughts and floods. Changes in the prevalence of extremely cold periods can also have an effect. Other impacts originate from the gradual changes in climate, such as the rise in average temperature and changes in precipitation and other weather patterns. These gradual changes influence, for example, labor productivity, accidents, and the size and distribution of natural habitats for plants and animals that can be relevant to human health.

According to the literature, heat waves constitute the highest risk to human health in Switzerland (OcCC/ProClim 2007, Ecoplan/Sigmaplan 2007). Extremely high temperatures affect human health primarily via cardiovascular diseases and respiratory health problems. The summer of 2003 in Switzerland, which has been described as the warmest summer in at least 250 years, led to a rise in mortality of about 1000 additional mostly elderly persons (Grize et al. 2005). During the heat wave in summer 2015, about 800 mostly elderly people died due to heat stress (FOEN 2016).

Floods and droughts are serious threats to life, too, and in addition may lead to psychological distress among those who are affected by such a considerable menace to their existence. On the other hand, also very low temperatures and related weather events such as freezing and icing, as well as prolonged snowfall and avalanches involve deadly risks.

Food security can be an issue: In the presence of insufficient cooling capacities and a lack of experience with food preparation under the conditions of higher summer temperatures, the risk of infections and diarrhoea increases.

An important impact of rising temperatures are infectious diseases and vector-borne diseases which spread to regions where they were not known before. In Switzerland, the incidence of the tick-borne encephalitis is probably the most prominent issue in this respect. However, predictions are uncertain, since ticks like to settle in an environment where summers are warm and winters are mild, but retreat when it gets too hot and too dry (FOPH/FOEN 2007). Another potential risk lies in the growing spread of the tiger mosquito, an efficient vector of at least 22 arboviruses, dengue, chikungunya and west nile being the most prominent among them. Distribution is expected to increase in the future, because today large parts of central and Mediterranean Europe are a suitable habitat for the species already (ECDC 2012). Climate change facilitates this process (Petrini et al. 2012), but is only one contributing factor besides more important influences such as international trade and travel habits.

Because of rising average temperatures, pollen production in some plants might change as well as the geographic distribution and the growth periods of allergenic species in general. This concerns the health of all those who are particularly sensitive, and it may increase the prevalence of asthma.

Air pollution is another factor for human health which changes with the climate. Sunshine duration is a major determinant for tropospheric ozone formation, also known as summer smog. Tropospheric ozone aggravates respiratory diseases and can cause immediate respiratory problems. Other air pollutants, notably particulate matter, accumulate especially during periods of inversion, which are expected to increase.

3.1.1.2 Sensitivity

The vulnerability to extreme heat waves depends on the age structure of the population, because very high temperatures can cause a substantial rise in mortality particularly among elderly people (Grize et al. 2005). The case studies for the cantons Zürich and Basel-Stadt (Econcept 2013, INFRAS/Egli Engineering 2014) add the share of urban areas to the picture, since the main reason for health problems during heatwaves is the lack of night-time relief (IfW 2007), and this is more common in cities where there is only little open and green space (heat island effect). Furthermore, many people who died during the summer 2003 lived in residential homes for the elderly which were not sufficiently air-conditioned. Hence, the degree of air-conditioning in those facilities is an important indicator for the sensitivity to climate change impacts on health. This applies to impacts on labor productivity as well, with air-conditioning in the workplace being one effective – although energy-consuming – option for adaptation.

The potential for damages originating from vector-borne diseases is intensified by various global trends which favor the spread of pathogens and vectors (Sutherst 2004). Worth mentioning here are population growth, urbanization, global trade and travel, particularly between climate zones, and movements of refugees. Growing trade with livestock and animal feed increases the risk of animal diseases and thus, the danger of a spread of pathogens to humans.

Since all health problems might at some stage require a visit to a doctor or hospital, the general state of the health care system is fundamental. As a high income country, Switzerland should be prepared whenever extreme weather events and related health problems occur. On the other hand, the high death toll of the 2003 heat wave indicates some scope for improvement. The case study for canton Basel-Stadt (INFRAS/Egli Engineering 2014a) points to the already prevailing scarcity of medical doctors in Switzerland.

3.1.1.3 Impacts without adaptation

Despite the large number of described factors that can possibly contribute to health impacts of climate change, the available studies refrain from a quantitative assessment for most of them. Primarily, this is due to the high level of uncertainty that is associated with the task of projecting their influence into the future. For many determinants, there is a lack of unambiguous quantitative evidence even for today, e.g. concerning the interrelation between allergies and respiratory diseases. The case studies for the cantons face as an additional difficulty the need to disaggregate existing national data to their regional level.

INFRAS/Egli Engineering 2014a (case study Basel-Stadt) choose a comprehensive approach by integrating a large amount of influences and taking up the task of economic valuation. A fully quantitative analysis is conducted for the rise of mortality and the productivity loss during heatwaves only, but many other determinants, which are first explored only qualitatively, are also monetized. However, specific margins of uncertainty remain for each factor, represented on a 4-point scale. The synthesis of all negative and positive impacts of the rise of average temperature, when estimated in monetary terms, add up to an incremental (largely immaterial) cost of 532 to 1´164 million CHF in 2060 for the canton as a whole (depending on the climate scenario). The examined health determinants contribute as much to this impact as the increase of sensitivity incorporated in a socioeconomic scenario. Thus calculated, health impacts represent in this study the highest damage cost of all investigated sectors. This is also confirmed by the case studies for the cantons Aargau and Uri.

3.1.1.4 Adaptation

Since heat waves constitute the biggest threat to human health in the course of climate change, suggestions for adequate adaptation concentrate largely on measures to reduce temperatures inside buildings. Possible action includes detailed consideration of heat management in architecture and retrofitting of existing buildings with sufficient air-conditioning. However, the latter needs to take into account requirements of low energy consumption. CO_2 mitigation measures which aim to increase the cost of energy use might conflict with health issues here. Residences for elderly people and hospitals have to be improved first.

Education and other forms of information are other important measures to reduce health impacts in the future. The high mortality during the heat wave of 2003 induced several campaigns intended to provide the public with suitable instructions (e.g. FOPH/FOEN 2007). The high mortality in summer 2015 implies that it is not clear whether these measures were successful in all regions. In the future, the need for education will comprise information on new diseases, new insects and probably safer ways of food conservation. Another field are leisure-time activities that could become more dangerous if the incidence of avalanches increases, which is, however, not yet predictable from current data. A current research project at the University of Basel investigates the consequences of the 2003 heat wave, e.g. political measures that have been taken since then and their likely effectiveness in reducing the death toll of a similar event in the future (Urbinello & Röösli 2014).

A special way of adaptation occurs without involvement of any political or private stakeholder: the adaptation of the human body itself to a warmer climate. In this field, solid findings are scarce and more research has to be done to understand how fast and effective such adaptation would be. It can be reasonably assumed, however, that the potential of this form of adaptation is rather low (Hanna and Tait 2015). For example, Aström et al. 2013 discover a non-existent influence of adaptation on heat-related mortality in a 30-year period in Stockholm, Sweden.

3.1.1.5 Impacts with adaptation

Only the Ecoplan/Sigmaplan 2007 study calculates human health impacts with adaptation. It provides quantitative estimates for two indicators: additional mortality and loss of productivity of the workforce during heatwaves. For the period to 2050, no substantial impacts are predicted. This sharply contrasts with the findings of the much more recent cantonal case studies, which regard health effects as important. Apart from the fact that these latter studies use the newer CH-2011 climate scenarios, incorporate more indicators and apply different algorithms for mortality and productivity loss, the difference may result from adaptation. Ecoplan/Sigmaplan 2007 assume full air-conditioning for all indoor workplaces and an improvement of air-conditioning in residential buildings. In addition, that study assumes that emissions of precursors of tropospheric ozone are substantially reduced.

3.1.2 Modeling and data

3.1.2.1 Impacts, adaptation measures and effects to be included in GEMINI-E3

Data availability and the challenge of monetization are the key issues when including health effects in a CGE analysis. This may be the reason for the fact that by today there is no CGE-based impact study on Switzerland which tries to accomplish this. Table 6 shows studies from the international literature which apply CGE models and incorporate health impacts.

Considering data availability for Switzerland, the integration of three health impacts in our model is considered as feasible. Each of them can be attributed to very high temperatures during summer months:

- Excess mortality from cardiovascular and respiratory diseases due to heat stress,
- loss of productivity of the workforce due to heat stress, and
- increased health expenditure through hospitalizations for respiratory diseases due to heat stress.

Table 6: International literature that incorporates health impacts into CGE models for impact assessment

Source	Model	Country / World region	Time horizon	Included health impacts
Jorgenson et al. 2004	IGEM	USA	2050, 2100	cardiovascular and respiratory diseases, ozone exposure
Bosello et al. 2006	GTAP-E	World (8 regions)	2050	cardiovascular and respiratory diseases, diarrhoea, malaria, dengue fever and schistosomiasis
Eboli et al. 2010	ICES	World (8 regions)	2100	infectious diseases, cardiovascular and respiratory diseases
Reilly et al. 2012	MIT IGSM	World (16 regions)	2020-2100	respiratory diseases due to ozone pollution
Bosello et al. 2012	ICES	World (14 regions)	2050	heat stress
Ciscar et al. 2014	GEM E3 (comparative static)	Europe (5 regions)	2071-2100	heat stress, respiratory & cardiovascular diseases, renal failure, food and water-borne diseases
OECD 2015	ENV Linkages, AD DICE (for post-2060)	World (25 regions)	2060, post-2060 (more stylized)	heat stress, cold stress, vector-borne diseases (malaria, schistosomiasis and dengue), diarrhoea, cardiovascular and respiratory diseases

3.1.2.2 Knowledge base and data sources

To estimate climate-induced changes in mortality and morbidity, empirical exposure-response functions are needed as input. These functions depict statistical relationships between a specific human health impact and climate change variables, e.g. maximum temperature. Data from Switzerland is the first choice here, but the small amount of national data available in this field means that in some instances results for other countries or larger regions need to be adopted. For each individual case, the advantage of broadening our model analysis has to be weighed carefully against the probable increase of inaccuracy.

3.1.2.2.1 Mortality

The relationship between mortality and temperature has been analyzed in various studies which differ widely in methodology and reach quite heterogeneous conclusions (e.g. Franchini & Mannucci 2015; Curriero et al. 2002; Yu et al. 2012). Data on the empirical correlation between hot days and mortality and morbidity for European regions is available from the PESETA II project and is based on pooled estimates from various epidemiological studies (Paci et al. 2014). A distinction must be made between single hot days and extended periods of extreme temperatures. Heat waves increase mortality and morbidity risks above the overall summertime burden of heat (as shown in Anderson & Bell 2009 and Hajat et al. 2006). Therefore, the correlations described below cannot capture heat wave effects as observed in Switzerland in 2003 and 2015. In addition, the climate scenarios do not cover extreme events, which led to the conclusion that the two types of impacts should better be analyzed separately (see section 3.1.3 and the box on heat waves at its end).

A caveat of our exposure-response functions is of the same kind as the main restriction of Paci et al. 2014: It is based on an epidemiological meta-study which uses apparent temperature as indicator (see Baccini et al. 2008). That concept includes relative humidity and wind speed in order to get a more realistic picture of the impact of temperatures on human beings. By using maximum temperature as a proxy for apparent temperature, an underestimation of future impacts is likely in relatively humid regions, which include most of Europe.

3.1.2.2.2 Productivity

Regarding productivity loss on hot days, we follow the pragmatic approach of the cantonal risk studies, which defined a single temperature threshold and a uniform depreciation of physical and mental capacity on days with maximum temperature above the threshold (see INFRAS/Egli Engineering 2014a and 2014b). This approach builds upon findings from IfW 2007 and Bux 2006. The IfW 2007 study sees mental and physical impairment starting at 26°C, whereas Bux 2006 estimates a loss of productivity between 3% and 12% at temperatures between 26°C and 36°C.

3.1.2.2.3 Health expenditures

The international literature on the relation between climate change and health expenditures is rather scarce (see overview in CH2014-Impacts and Bosello et al. 2006). A recent contribution for Switzerland is the CH2014-Impacts study. Looking at disaggregated data with a high spatial resolution, interrelations with weather data are calculated and applied to the climate scenarios A1B, A2 and RCP3PD. The CH2014-Impacts study estimates correlations of varying significance between pharmaceutical sales, doctor visits and hospitalizations and daily mean temperature in periods of different length between 1998 and 2012. Additional warm days lead to increases of 0.3% to 0.5%, but because of restrictions imposed to secure sensitive health data, no operational relations can be derived from there.

Similar to mortality, we base our exposure-response functions on Paci et al. 2014 who show a linear relation between daily maximum temperature above certain thresholds and hospital admissions due to respiratory diseases. The hospital admissions can be monetized with health statistics data from Switzerland. The need of further research in this field is illustrated by the fact that a relation between high temperatures and hospital admissions due to cardiovascular diseases is not found to be significant so far, although it exists for mortality (Paci et al. 2014).

3.1.2.3 Model assumptions and parameters

3.1.2.3.1 Climate scenarios

For the assessment of climate change impacts with the previously described data, we need projections of daily maximum temperature. The CH2011 climate scenarios provide projections of temperature and precipitation. We restrict our analysis of the impacts of climate change on human health to the potential relation of maximum daily temperature and health effects. The CH2011 scenarios are designed relative to the reference period 1980-2009, for three emission trajectories (RCP3PD, A1B, and A2) and for three 30-year projection periods centered around 2035, 2060, and 2085. Since the initial publication in 2011, the scenarios were complemented with various extension series covering additional projections, mainly to close gaps the first series left with regard to temporal resolution, regional resolution and GHG scenarios (Bosshard et al. 2015; Fischer et al. 2015 and 2016). For our model analysis, we need the data to cover daily maximum temperature in Switzerland as a whole for all three scenarios RCP3PD, A1B, and A2 and the period 2010-2060. None of the publications above fulfill these requirements entirely. Thus, we had to treat the available data to fit our spatial and temporal resolution.

Adjusting spatial resolution to model requirements

The datasets with a temporal resolution of daily maximum temperature are provided on a regional or local level only – just like all the other scenarios. There are no values for the country as a whole. Three different datasets are available:

a. By assessment of a probabilistically generated joint multi-model projection: all three scenarios A1B, A2, RCP3PD (upper/medium/lower) and five regions which cover Switzerland completely.
b. Based on 10 individual combinations of a global climate model with a high-resolution regional climate model (RCM; so-called GCM-RCM model chains): all three scenarios A1B, A2, RCP3PD and 188 stations with the results of the 10 models displayed individually.
c. Based on 20 individual GCM-RCM model chains: gridded daily change signal for temperature and precipitation in Switzerland. All three scenarios A1B, A2, RCP3PD (upper/medium/lower) are covered with a grid size of about 2x2 km.

All scenarios consist of daily change signals and need to be combined with observations from the reference period 1980-2009. The resulting values represent the expected future climate for a given scenario period. Historical meteorological measurement data can be obtained from MeteoSwiss. Available gridded data covers the whole country, but since health impacts can only occur in inhabited areas, this is not a meaningful data set for health impacts. The data portal IDAweb[3] from MeteoSwiss provides values from meteoro-

[3] https://gate.meteoswiss.ch/idaweb

logical measuring stations in Switzerland, whereby a continuous coverage of the reference period is available from 69 stations.

MeteoSwiss offers three different selections of stations suitable to represent the Swiss climate. The largest set consists of 24 stations, but includes municipalities in high altitudes with a rather small population. Data from these high altitude stations reduces the average of daily maximum temperature to an extent which is inappropriate for the aim of our study. The other sets comprise 12 and 8 stations, respectively. We take the second largest set of 12 stations to account for variability and cut out three stations at altitudes higher than 1000 meters above sea level: Davos (1594 m), La Chaux-de-Fonds (1018 m) and Samedan (1709 m). To account for this, we weighted the results of the exposure-response functions with the share of the Swiss population living in municipalities with center-coordinates of below 1000 meters above sea level (97% in 2015[4]). The nine stations representing Switzerland in our study are: Basel/Binningen, Bern/Zollikofen, Genève-Cointrin, Locarno/Monti, Luzern, Neuchâtel, Sion, St. Gallen, Zürich/Fluntern.

The historical data for each day must be combined with the delta change signal from the climate scenarios in order to obtain future temperatures. Daily data of the average maximum temperature of the above 9 stations is taken from dataset b. It displays the results of 10 GCM-RCM model chains. For each day, the values for upper/medium/lower are selected individually, whereby 'medium' represents the average value of the 10 delta signals.

Adjusting temporal resolution to model requirements

The three scenario periods cover 30 years each, but none of these corresponds with the required timescale 2010-2060. The scenarios represent the expected future climate for a given scenario period as a whole and should generally not be used for other periods. However, in order to match the model time horizon, we had to combine as a first step the two 30-year scenario periods centering around 2035 and 2060. This resulted in an incongruent time series with an interrupted continuity at the turn of the year 2044/2045. Both problems were tackled by adjusting the daily change signals of all years except 2060. The adjustment factors were calculated with the aid of the only continuous time series from the CH2011 scenarios (Fischer et al. 2015). The dataset covers thirteen consecutively shifted future periods (shifted by 5 years) for 2010-2039, 2015-2044, until 2070-2099. Unfortunately, it displays no daily data, but seasonal means of delta signals for daily maximum temperature for the evaluation points 2020, 2025, …, 2085. The spatial resolution is regional, i.e. five regions covering Switzerland as a whole (West, East, South, West of the Alps, East of the Alps). We determined the required Swiss values as average of the regions, whereby the two Alpine regions were omitted for the same reason that we cut out meteorological stations at high altitudes from the historical data. The continuous dataset includes results from 10 individual model chains from which the values for upper/medium/lower were derived also in the same manner as for the historical data.

The adjustment factors for the daily change signals of the total of 9 climate scenarios (A1B, A2, RCP3PD with upper/medium/lower) were calculated in order to match the trajectory path of yearly means with the continuous dataset. The years between the evaluation points were interpolated linearly. Since the spatial resolution differs, only the trajectory paths are the same after the modification, not the absolute values at the evaluation points as would be the case with identical spatial resolutions.

[4] Own calculation with data from the Federal Statistical Office (FSO).

3.1.2.3.2 Mortality

The data from Paci et al. 2014 displays linear relationships between the number of days with daily maximum temperature above a certain threshold and the increase in mortality. The thresholds are differentiated by two European regions (North Continental, Mediterranean) and two settlement patterns (urban, rural), while for the %-changes of mortality a distinction is made between the two regions, three age brackets (0-64, 65-74, 75+) and two diseases (cardiovascular and respiratory).

This dataset provides a reasonably useful opportunity to adapt the findings to Switzerland. The cantons Ticino and Valais were assigned to the Mediterranean region, the rest of Switzerland to the North Continental region. The share of population in urban and rural settlements were obtained from the population statistics of the Federal Statistical Office (FSO).

For each day with a maximum temperature 1°C above the threshold, the %-changes from Table 7 were applied to age specific causes of death from cardiovascular and respiratory diseases per day. This data was taken from FSO (5 year average 2014-2010). The different affectedness of men and women by the two diseases has been taken into account. These figures were held constant throughout the time horizon of the model. However, the distinction of three age groups in Table 7 was used to incorporate demographic change and the rising vulnerability to heat-related mortality in the future because of an aging population in Switzerland. The medium demographic scenario 2010-2060 from FSO 2010 was used to include projected changes in size and relative share of the two groups of men and women. The impact of climate change is calculated by applying the data from Table 7 to the historic temperature series in the reference scenario and deducting the result from the mortality which is associated with the projections from the climate scenarios.

Table 7: Exposure-response functions for temperature related mortality
(temperature threshold = 24.09°C; source: Paci et al. 2014 and own calculations)

Percentage increase in number of cases per 1°C increase above threshold per age group	
0-64	
Cardiovascular disease	0.95
Respiratory disease	2.77
65-74	
Cardiovascular disease	1.33
Respiratory disease	3.58
75+	
Cardiovascular disease	2.34
Respiratory disease	6.08

3.1.2.3.3 Productivity

Following the Cantonal case studies, we reduce the range of temperature thresholds to a single value and set the productivity loss on a day with maximum temperature of 30°C or higher at 7%. This does not take into account how long or how far above the threshold temperature rises, which may lead to an underestimation of the impact. On the other hand, we do not consider any depreciation in physical or mental capacity in the temperature range from 26°C and 30°C, which points in the opposite direction. We assume that economic activity is distributed evenly over the 365 days of a year and that every member of the workforce is affected in the same manner independent of the location of the workplace (indoor/outdoor) or effects of air-conditioning.

The impact of climate change is calculated by deducting the number of hot days in the reference scenario from the respective numbers in the climate scenarios. This method omits any (additional) impact on a day with a temperature of e.g. 30°C in the reference case raising with climate change up to e.g. 36°C. This is due to the fact that there is no reliable data about the possible increase of productivity loss on such a day, although it seems reasonable to assume it. From this perspective, the results on productivity loss could be underestimated.

3.1.2.3.4 Health expenditures

The data from Paci et al. 2014 on temperature-related hospital admissions due to respiratory diseases is organized similarly to the data on mortality. For adaptation to Switzerland, an identical procedure is being followed. The resulting exposure-response functions are depicted in Table 8.

Table 8: Exposure-response function for temperature-related hospital admissions
(temperature threshold, i.e. daily maximum temperature = 27.25°C;
source: Paci et al. 2014 and own calculations)

Percentage increase in number of cases per 1°C increase above threshold per age group and day	
0-64	
Respiratory disease	2.77
65-74	
Respiratory disease	3.58
75+	
Respiratory disease	6.08

Data on annual hospital admissions by diagnosis and age are available from FSO. Again, a differentiation between men and women is taken into account and held constant at the average of the 5-year period of 2010-2014. Since we expected a rather low effect of climate change on hospital admissions, we refrain from incorporating demographic change. The monetization is made with the cost of a hospitalization in Switzerland for respiratory diseases per day in the benchmark year 2008, differentiated by two age groups (0-64: 951 CHF, 65+: 1’249 CHF; source: FSO and own calculations).

The CC impact on health expenditures as measured by the indicator ‘hospital admissions due to respiratory diseases’ is very low. In 2060, the annual number of additional hospitalizations which can be attributed to a temperature rise because of climate change is less than 400 in the age group 65+. This causes additional health expenditures of about 4 mio CHF, which is below 0.006% of total health expenditure in 2060. Considering this, we do not include this impact in the model simulations.

These results are in line e.g. with the comprehensive OECD 2015 study. That study includes vector-borne diseases (malaria, schistosomiasis and dengue), diarrhoea, cardiovascular and respiratory diseases, whereas the assessment for cardiovascular diseases comprises both cold and heat stress. Additional demand for health services is very small in regions other than developing countries. In Canada and large EU countries such as Germany and France, the effect of climate change is even negative, because of the dominant role of cardiovascular diseases. They are favorably affected by warmer winters, which leads to a reduction of overall health care costs.

3.1.3 Results

3.1.3.1 Mortality

Table 9 shows the additional premature deaths which can be attributed to climate change in 2060. For the A1B and A2 scenarios, about 650 premature deaths are estimated for the medium case, whereas the upper extremes with 928 (A1B) and 877 (A2) reach the level of excess mortality caused by the heat waves of 2003 and 2015. It has to be emphasized that, as previously specified, these figures show the number of premature deaths caused by the two diseases on days with maximum temperature above certain thresholds. Although they do not cover heat wave effects, which arise during a period of consecutive days with high temperatures, in the high emissions scenarios excess mortality reaches a level in 2060 which today is touched only by exceptional heat waves.

Table 9: CC impacts in terms of premature deaths due to cardiovascular and respiratory diseases
(in 2060)

	RCP3PD			A1B			A2		
	Lower	**Medium**	**Upper**	**Lower**	**Medium**	**Upper**	**Lower**	**Medium**	**Upper**
Premature deaths	213	380	533	403	662	928	337	641	877

3.1.3.2 Productivity

Table 10 depicts the results of the CGE simulations with respect to productivity loss on hot days, the latter defined as days with a maximum temperature of 30°C and above. It shows that high temperatures are going to have tangible effects on the economy in the course of climate change. In the RCP3PD scenario, the decrease of household consumption due to productivity loss is still relatively small, ranging from 0.09% at the lower bound to 0.23% at the upper bound. However, at the upper ends of the A1B and A2 scenarios, it reaches more than 0.4% of household consumption. As mentioned above, these figures are to be seen against the background that the impact of climate change may actually be higher, because on days with temperatures already above the threshold in the reference scenario, no further depreciation of physical or mental capacity is taken into account if climate change leads to much higher temperatures.

Table 10: Climate change welfare impacts due to productivity loss
(% of household consumption in 2060)

	RCP3PD			A1B			A2		
	Lower	Medium	Upper	Lower	Medium	Upper	Lower	Medium	Upper
Benefit	-0.09	-0.17	-0.23	-0.17	-0.31	-0.41	-0.14	-0.31	-0.42

Heat waves

The integration of impacts of heat waves into the model simulations faces several methodological complexities centering around monetization and uncertainties regarding the future incidence of heat waves. Data for a rural and an urban area in Austria is delivered by Moshammer et al. 2006 and Moshammer et al. 2007. These analyses investigate the impact of heat waves on mortality and use 'Kyselý days' as definition for heat waves (= a consecutive period of at least three days with a daily maximum of at least 30 degrees). Paci et al. 2014 also estimate a 'heatwave' effect on mortality and morbidity. However, an important caveat is that the CH2011 climate scenarios are not suitable to project extreme weather events like the heat wave of 2003, which on the other hand are accountable for a high portion of total excess mortality. A possible solution would be the extrapolation of the impacts from 2003 with the climate scenarios by defining the respective probabilities for the occurrence of an identical extreme event in the future (the probability of an event *i* is inverse value of the return period of *i*). The advantage of this approach is that the matter of monetization is easier to resolve in the case of a historic event. The data availability for a single historic event can be expected to be better than for more universal exposure-response functions. For example, briefly before the finalization of the report, a comprehensive analysis of the 2015 heat wave has been published (FOEN 2016). Our research concluded in three health related impacts: mortality, productivity and health expenditures.

Mortality

The most important impact of the heat wave of 2003 is a mortality rate of about 1'000 premature deaths (Grize et al. 2005).

Productivity

We already simulated productivity loss on hot days in the model by using a simplified approach (-7% of overall productivity on each day with a maximum temperature above 30°C). However, analyzing a single extreme event provided the opportunity for a more elaborated concept. The most common indicator in the international literature is the Wet Bulb Globe Temperature (WBGT). It is a heat exposure index (unit = °C) based on physiological models of the body's response to heat. It is created from three measurement values: the natural wet bulb temperature (measured with a wetted thermometer exposed to wind and heat radiation), the black globe temperature (measured inside a 150 mm diameter black globe), and the air temperature, commonly referred to as ambient temperature, which is measured with a standard thermometer shaded from direct heat radiation (Lemke & Kjellstrom 2012). Based on health standards for workers, Costa et al. 2016 present several exposure-response functions and differentiate for work intensity and indoor vs. outdoor workplaces (see Table 11). It is possible to display the effect of a heat wave with this data, because gradually rising outdoor and indoor temperatures result in a growing productivity loss.

Table 11: Worker productivity at different work intensities
(US standards for non-acclimatized workers, NIOSH; source: Costa et al. 2016)

Worker productivity (per hour)	Light work (intensity: 180W) WBGT °C	Moderate work (intensity: 295W) WBGT °C	Heavy work (intensity: 415W) WBGT °C
100%	27.5	25.0	22.5
75%	29.0	26.5	26.5
50%	30.0	28.0	28.0
25%	31.0	29.0	29.0

WBGT is not a common measurement value at meteorological stations. However, there exist some algorithms which approximate WBGT with standard data, but biases remain which are hard to determine because of non-linear relations (amongst other reasons; see Lemke & Kjellstrom 2012). We choose the algorithm by Liljegren et al. 2008 which uses air temperature, wind speed, solar radiation and relative humidity to calculate WBGT. Data from MeteoSwiss allows for an analysis on an hourly basis for the work-time (8-12 and 13-17 hours) and for the three months June-August 2003 at the 9 stations representing Switzerland in our study. Table 12 shows losses projected onto the full year:

Table 12: Productivity loss due to heat stress in Switzerland 2003
(in %)

Outdor (non-acclimatized workers)			Indoor (non-acclimatized workers)		
Light work (intensity: 180W)	Moderate work (intensity: 295W)	Heavy work (intensity: 415W)	Light work (intensity: 180W)	Moderate work (intensity: 295W)	Heavy work (intensity: 415W)
0.03	1.01	2.10	0.0	0.0	0.0

There is no simple explanation for the low level of impacts, which seems to contradict intuition. In the first half of August – the core of the hot summer of 2003 –, WBGT in the hottest hours of the day is far below air temperature, because relative humidity is between 30 and 40% and reduces WBGT. Solar radiation which has the opposite effect, is included in outdoor WBGT, but excluded in indoor WBGT.

In order to bypass potential imprecisions of the approach, we decide to go back to the simplified function of a general productivity loss of 7% at an ambient temperature of 30°C and above. However, other than with the climate scenarios, we could base our analysis of the historic event in 2003 on hourly data, thus avoiding the simplification of assigning the whole day to the maximum temperature. Similar to above, we include only working hours. For the year 2003, we estimate the overall productivity loss at 0.28% for outdoor workers and 0.03% for indoor workers.

Health expenditures

Paci et al. 2004 present exposure-response functions for hospital admissions which encompass a heat wave-effect. We already used this source in section 3.1.2.3.4. The temperature threshold is the same as without heat wave-effect, but the percentage changes on days with temperatures above the threshold are much higher. Apart from respiratory diseases, the functions include also renal failure.

We apply the meteorological data from the summer of 2003 and add the population forecast for the year 2060 in order to integrate the increasing vulnerability to heat wave stress in an ageing society. This results in about 2'500 additional hospitalizations in 2060 from a heat wave like 2003. This equals to additional health expenditures of 15-20 mio. CHF.

Return period

Regarding the return period, the minimum requirement for the integration of the impact of the summer of 2003 into our simulations is an estimation for the year 2060 for any of the climate scenarios. Figures for the other scenarios could be obtained by assuming a linear relation of the incidence of heat waves and maximum temperature and by applying the temperature signal from the CH2011 scenarios to scale the return period to A2, A1B and RCP3PD.

However, the international literature on return periods of heat waves and the possible rise in the course of climate change is rather scarce. Existing information is flawed by high uncertainties, differing definitions, time horizons and climate scenarios, and partly contradicting results.

For Switzerland, estimations from MeteoSwiss project (FOEN 2016) the return period of a heat event of at least 7 consecutive days with a maximum temperature of 30°C and above at four Swiss meteorological stations (Basel, Geneva, Lugano, Zurich). For the A1B scenario in the year 2055, the mean of the four cities is rated at one such event per year. However, the benefit of this result is limited by the fact that the heat wave of August 2003 was much longer than 7 days (14 days).

Christidis et al. 2014 estimate return periods for the summer of 2003 in Europe, defined as a temperature anomaly of +2.3°C relative to 1961-1990. An important caveat is that the study defines the European region from 30-50°N, with 50°N crossing the middle of Germany and 30°N crossing Northern Africa (the city of Cairo). Applying this to Switzerland most likely overstates the results, but it remains unclear how far. However, the projections of the study point in the same direction as the data from MeteoSwiss: a heat wave like 2003 is more or less a common event in the forthcoming climate of 2060. For the high emissions scenario RCP8.5, Christidis et al. 2014 expect 2003 being more of a cold event instead of an extreme heat event.

The conclusion from these findings has to be that **the monetized impacts for the 2003 heat event are a far too low estimation for an extreme heat event in 2060**. This leads us to abandoning the intention of including extreme heat events in our simulations. For the latter, it would be necessary to define an extreme heat event for 2060 and know the return periods of this event under the different climate scenarios. Also, we would need to be able to estimate expected damages for this extreme event. These are eminently **important tasks for future research** which can, however, not be performed within the scope of this report. Certainly, the impact of an extreme heat event in 2060 will be far above the level that was experienced in 2003. This will be challenging particularly with respect to mortality.

3.2 Buildings and infrastructure

3.2.1 Literature-based assessment

3.2.1.1 Exposure

Climate change impacts on buildings and infrastructure predominantly originate from the growing incidence of extreme weather events such as heavy and/or prolonged precipitation, hail, and windstorms. However, projections of the changes in frequency or magnitude of these events are especially difficult, because of competing physical mechanisms and a weak statistical basis (for windstorms, see e.g. Schwierz et al. 2010). Hence, the CH2011 scenarios do not include extreme events, but some qualitative conclusions are drawn: heavy precipitations are expected to become more frequent in the winter, whereas the same prediction for windstorms is less robust according to existing data. Changes in the incidence of hail are not being projected, since the spatial scale of these events is too small (CH2011).

Floods and/or heavy rainfall can cause damages to basement floors and ground floors of buildings, and to houses located at slope positions or in basins. A changing seasonal pattern of river runoff will likely increase the risk of floods during winter (CH2014-Impacts). Intense snowfall is a potential hazard particularly to large buildings with flat roofs, but occurrence is expected to decrease because of a receding snow line. However, the incidence of avalanches might grow at least in higher altitudes, but projections at local scales are still rather uncertain. Avalanches as well as landslides and rockfall pose a threat to buildings and infrastructure within reach. The same applies to bedload in watercourses, which can damage buildings and infrastructure close to rivers and streams. The thawing of the permafrost raises the risk of mudslides and rockfall especially during heatwaves.

One area of marked infrastructure damages from natural hazards concerns the rail system, because it cannot provide alternate routes during blockage as easily as the road network (OcCC/ProClim 2007). Increased precipitation and strong winds during winter cause service disruptions mainly through falling trees, landslides and rockfall. Track buckling, which requires a reduction of train speed, can arise from very high temperatures during summer.

3.2.1.2 Sensitivity

Future trends in population growth and employment as well as spatial development are major determinants of the vulnerability of buildings and infrastructure to climate change (OcCC/Proclim 2007). Population growth often leads to the expansion of settlements into areas that are more exposed to flood risks. In this context, the study for the canton Basel-Stadt (INFRAS/Egli Engineering 2014a) points to the growing use of basements in cities.

The more commuters are travelling between home and workplace each day, the higher the requirements with regard to the functioning of the rail and road networks. Capital accumulation, rising prices for real estate and increasing construction costs for buildings and other infrastructure lead to higher impacts from natural hazards even without the influence of climate change. Repercussions from CO_2 mitigation measures occur when retrofitting and insulation enhance the value of houses, but also when buildings are equipped with components such as solar energy modules which are vulnerable to strong winds or hail.

Topographical characteristics contribute to the sensitivity towards natural hazards, too. Avalanches, mudslides, rockfall and bedload are risks that are particularly prevalent in the mountainous parts of Switzerland. In many cases, these incidents appear in areas that are sparsely populated, which reduces impacts.

3.2.1.3 Impacts without adaptation

Estimating the specific impacts of CC on buildings and infrastructure is a particularly challenging task, because damages are primarily due to natural hazards, the evolution of which in the course of climate change is still highly uncertain. Furthermore, the scope of extreme weather events such as violent storms, hail, and heavy rainfall is often geographically limited. Hence, the bulk of the impact studies confine analysis in this field to the investigation of sensitivities (e.g. INFRAS/Egli Engineering 2014a and 2014b). Ecoplan/Sigmaplan 2007, however, follow a quantitative approach for the risks of floods by picking a typical event: They estimate the change in return periods of the event until 2050 and extrapolate the impacts to the country level under the assumption of economic growth. According to a case study from Tyrol (Austria), which incorporates land use and economic development into an analysis of CC impacts through flood risks by 2030, the impact of climate change is rather small, whereas urbanization and economic development constitute a substantial factor (Thieken et al. 2014). Schwierz et al. 2010 couple regional climate models with an operational insurance loss model, thus combining meteorological and insurance aspects of storms (e.g. vulnerability affected by spatial settlement patterns). The study considers climate change by employing the A2 emissions scenario for the period 2071-2100. For Switzerland, Schwierz et al. 2010 project a rise in annual expected losses of 1-year storm events of about 19% (see further discussion in section 3.2.2.1.1 below).

3.2.1.4 Adaptation

Climate change adaptation in the field of buildings and infrastructure is hard to distinguish from protection against natural hazards in general, because protective measures are often guided by the requirements of extreme events. This means that in many cases, the measures that need to be taken are also going to tackle additional risks that arise from climate change. Adaptation essentially means reducing vulnerability to risks. Large scale operations designed to reduce the incidence of natural hazards, such as flood protection facilities, embankments, safety nets or catching fences against avalanches and rockfall are important elements in this respect. However, they represent only a small part of the possible measures. The Swiss adaptation strategy specifies numerous activities that aim to improve identification and monitoring of possible perils (Swiss Confederation 2014): Intensifying research on the origin of hazards, improving forecasts of extreme weather events, creating hazard maps that include the influence of climate change, implementing new policies that promote the consideration of natural hazards in urban and regional planning, monitoring of particularly endangered areas, and installing warning systems (e.g. for floods or windstorms) are the most important activities. Another set of measures is intended to enhance precaution and handling of natural perils and comprises e.g. information and education of the public in order to improve self-responsibility and to broaden the knowledge of rescue organizations.

3.2.1.5 Impacts with adaptation

The study for the canton Basel-Stadt (INFRAS/Egli Engineering 2014a) highlights the difficulty of distinguishing CC impacts with and without adaptation when it comes to natural hazards. In the city of Basel, a flood of the Birsig, a tributary of the Rhine, may cause a damage of CHF 500 million in the case of a 100-year event. It is very likely that authorities will take appropriate measures to reduce this substantial threat and that these will also cover possible impacts of climate change without being attributable to climate change adaptation. As a general rule, not only construction costs, but also the maintenance costs of adaptation infrastructure need to be taken into account. While attributing construction costs to climate change is difficult, because CC does not necessarily drive the need for protection against natural hazards, climate change may still raise operational demands for constructions and therefore cause higher maintenance expenses.

The Ecoplan/Sigmaplan 2007 report proposes estimates for CC impacts through floods with and without adaptation, but adaptation costs are estimated rather roughly. Adaptation reduces the expected damage in 2050 by 30% to 60%. A flood model calculation by Swiss Re (Hausmann et al. 2012) points at possible adverse effect of adaptation: enhanced flood protection could attract more settlements and urbanization into the protected areas, with the effect that the occurrence of an extreme event that exceeds the protection level could lead to higher damages than without adaptation.

3.2.2 Modeling and data

The findings of the regional case studies indicate a large variety of climate change impacts on buildings and infrastructure (INFRAS/Egli Engineering 2014a and 2014b). They also show the difficulties of monetization and of attribution to climate change, specifically in the case of storms. Since extreme weather events cannot be projected with the CH2011 climate scenarios, we restrict our analysis to damages from floods and storms and include both impacts in the form of sensitivity analyses. Other types of impacts on buildings and infrastructure are expected to be rather low, as the case studies also indicate. The availability of suitable data for damage estimation and monetization is generally limited.

3.2.2.1 Knowledge base and data sources

3.2.2.1.1 Storms

We use the storm 'Lothar' of 1999 as blueprint for our sensitivity analysis. The Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) carried out a comprehensive study on the damages of 'Lothar', which is frequently classified as 'storm of the century' (WSL/BUWAL 2001). The compiled damages are to be assigned to the model sectors.

The future incidence of storm events in Europe (especially Switzerland) and even their attribution to climate change is still rather unclear (Karremann et al. 2014). The aforementioned study on the European level by Schwierz et al. 2010 includes results for Switzerland. Due to the high uncertainty associated with projections of storm incidence, the results are to be interpreted with caution. In addition, the underlying period 2071-2100 stretches further into the future than our study, and only the high emissions scenario A2 is analyzed. On the European level, the expected loss of a 100-year storm event is calculated at 104% above the reference period, with an uncertainty range from 54% to 154%. For Switzerland, only an estimation of the 1-year loss (annual expected loss) is available. With 19%, it is below the European average of 44%, indicating a possibly lower vulnerability of the country. There is, however, a wide uncertainty range from 50% to even below zero.

3.2.2.1.2 Floods

The sensitivity analysis of the flood risk in Switzerland is based on the flood event of August 2005. It affected the complete northern rim of the Alps from the river Sarine in the West to the Alpenrhein in the East. Considering the severity of the damage, it is often described as the most exceptional flood event in the history of Switzerland. However, this statement has to be seen in relative terms. In the 19th century several floods occurred which came close to the 2005 event, depending on the conversion rate of the monetized damages (Bezzola & Hegg 2007). The same study assembled a detailed enumeration of the damages from the flood of 2005, which can be used for our sensitivity analysis.

Similar to storms, the future incidence of flood events in Switzerland in the course of climate change remains indistinct. A correlation of historical data between temperature rise and precipitation in Switzerland is found to be significant in winter and summer in CH2011. Spring and autumn show weaker and often insignificant correlations. On the other hand, Mani & Caduff 2012 estimate %-changes of a 50-year heavy precipitation event in the A1B scenario in 2060. They divide Switzerland into three regions and find in winter, spring and summer only small increases in the range of 0-4% in the Swiss plateau/Jura and the pre-Alpine/Alpine region and even small decreases in the South. This is different in autumn, when the 50-year event is expected to result in a precipitation level 12% above the current level in the Swiss plateau, plus 7% in the pre-Alps and plus 6% in the South. The CCHydro study (FOEN 2012a) includes no estimations of extreme events.

3.2.2.2 Model assumptions and parameters

3.2.2.2.1 Storms

For the implementation in GEMINI-E3, we estimate the expected annual cost of event *i* at year *t* for sector *j* as:

$$Cost_t^{i,j} = Cost_{2008}^{i,j} \times \frac{gdp_t}{gdp_{2008}} \times \frac{1}{return\ period_t^i}$$

where $cost_{2008}$ represents the cost for sector *j* which event *i* would have caused had it occurred in 2008; *gdp* is the GDP in prices of 2008 (the benchmark year of the GEMINI-E3 model) and *return period* the return period of event *i* for the year *t*. One over the return period provides an estimation of the probability of occurrence of event *i* in year *t*. This cost is translated into a corresponding production loss through a decrease of technical progress of inputs used for production.

Table 13 depicts the detailed damages from storm Lothar. All figures are inflated to mio. CHF of 2008 with GDP growth in current prices. An exception was made for the forestry sector. These damages were trended with the timber wood price index (source for both: FSO 2016). Furthermore, the growth of the forested area by 3.2% between 1999 and 2008 is taken into account (source: Worldbank 2016). Table 14 shows the allocation of the cost elements to the sectors of the model.

Table 13: Damages from storm 'Lothar' (1999) if it had occurred in the base year 2008
(source: WSL/BUWAL 2001 and own calculations)

Sector			mio. CHF 1999	mio. CHF 2008
Forest	Setup cost and salvage cost minus wood sales		220	276
	Wood storage and timber yards		40	50
	Loss of value due to lower wood sales		150	188
	Rectification of consequential damages (bark beetle)		150	188
	Reforestation of storm-afflicted areas		150	188
	Repair of infrastructure		50	63
	Total		760	954
Individual trees and fruit trees	Damage to individual trees (parks, recreation areas)		32	44
	Damage to fruit trees		6	9
	Total		38	52
Buildings			600	823
Movable objects			127	174
Transport	Streets	Clearing operations / repair	6	9
		Damage to motor vehicles	55	75
	SBB	Clearing operations / repair	5	7
	Other rail companies	Clearing operations / repair	9	12
		Cost of replacement buses	2	2
		Loss of revenue	3	3
	Urban transport	Clearing operations / repair	1	1
	Mountain railways	Clearing operations / repair	8	10
		Loss of revenue	39	54
	Shipping	Damage to ports and banks	22	30
		Damage to vessels	17	23
	Aviation	Damage to airports	3	4
		Damage to aircrafts	1	1
		Loss of revenue	1	1
	Total		170	233
Electricity	Clearing operations / repair		57	78
Communication	Swisscom	Damage to fixed-line network	12	16
		Damage to mobile network	0	0
	Total		12	17
Other economic sectors	Operational interruption		17	23
Total			1'781	2'355

Table 14: Cost allocation of an exemplary storm event in GEMINI-E3 classification
(million CHF)

Sector	Damage from exemplary storm
01 Coal	
02 Oil	
03 Natural gas	
04 Petroleum products	
05 Electricity	78
06 District heating	
07 Grains and oil seeds	
08 Other crops	9
09 Livestock	
10 Forestry	954
11 Industry	
12 Land transport	174
13 Water transport	53
14 Air transport	6
15 Insurance	
16 Health	
17 Services	1'082
18 Winter overnight tourism	
19 One-day winter tourism	
20 Other forms of tourism	
21 Water	
Total	**2'355**

The return period of storm 'Lothar' is hard to assess, because meteorological data such as peaks in wind gusts are not sufficient to explain the enormous damage (WSL/BUWAL 2001). With regard to caused damage, 'Lothar' can roughly be classified as a 100-year event (Munich Re 2002), although in Switzerland three storms of this category occurred in the 20th century (1967, 1990, 1999; Indermühle et al. 2005). As described above, a reliable assessment of the influence of climate change on the incidence of storms is not possible. For our analysis, we follow a pragmatic approach for sensitivity purposes only and assume that the return period of storm events is increasing during this century and set the return period at 50 years in 2060.

3.2.2.2.2 Floods

The damages from the flood of August 2005 are shown in Table 15. The figures were inflated with the growth of GDP in current prices to CHF of 2008. Possible influences on the vulnerability to flood events such as settlement patterns are simply assumed to be constant for the time horizon of the model.

Table 15: Damages caused by the flood of 21st/22nd of August 2005 in Switzerland
(million CHF; source: WSL flood damage database, Bezzola & Hegg 2007 and own calculations)

Sector		2005	2008*
Physical properties	Residential buildings	831	978
	Industry, commerce, hotels	705	830
	Farm buildings	14	16
	Public buildings and infrastructure	26	31
	Protection structures	191	225
	Other	3	4
	Non assignable physical properties	872	1'027
	Total	**2'643**	**3'111**
Transport and infrastucture	Highways and national roads	5	6
	Main roads	80	94
	Other roads	94	111
	Railways	73	86
	Transport facilities, poles	4	4
	Cables, pipelines	26	31
	Non assignable damage to transport infrastructure	18	21
	Total	**299**	**352**
Forest		2	2
Agriculture		34	40
Total		**2'978**	**3'505**

* Inflated from 2005 to 2008 with nominal GDP.

The implementation into GEMINI-E3 follows the same approach as for the storm event. The expected annual cost of the event *i* at the year *t* for the sector *j* is estimated as:

$$Cost_t^{i,j} = Cost_{2008}^{i,j} \times \frac{gdp_t}{gdp_{2008}} \times \frac{1}{return\ period_t^i}$$

with $cost_{2008}$ representing the cost for sector *j* which event *i* would have caused had it occurred in 2008; *gdp* standing for the GDP in prices of 2008, and *return period* for the return period of event *i* for the year *t*. The allocation of the costs to the respective sectors of GEMINI-E3 is shown in Table 16.

Measured by areal precipitation of a period of 2 days at the northern rim of the Alps, the return period of the heavy rainfall which led to the flood of 2005 is estimated at 77 years (90% confidence interval: 30 to 500 years) (Bezzola & Hegg 2007). We make the simplifying assumption that the return period of 77 years is also applicable to the whole country and set the return period for the sensitivity analysis at 38.5 years (i.e. 77/2).

Table 16: Cost allocation of an exemplary flood event in GEMINI-E3 classification
(million CHF of 2008)

	Damage from exemplary flood event
01 Coal	
02 Oil	
03 Natural gas	4
04 Petroleum products	5
05 Electricity	26
06 District heating	1
07 Grains and oil seeds	7
08 Other crops	14
09 Livestock	48
10 Forestry	4
11 Industry	1'129
12 Land transport	373
13 Water transport	1
14 Air transport	8
15 Insurance	37
16 Health	50
17 Services	1'767
18 Winter overnight tourism	3
19 One-day winter tourism	0
20 Other forms of tourism	25
21 Water	2
Total	**3'505**

3.2.3 Results

3.2.3.1 Storms

Table 17 shows the results of the simulations in GEMINI-E3 pictured as loss of production per sector and welfare cost for the year 2060 from the assumed change of the return period of a storm event characterized by the dimensions described above. The impacts are based on the simulation of sectoral damages of the exemplary event, divided by the return period of the event in the reference and sensitivity cases respectively, complemented by general equilibrium effects. Furthermore, in GEMINI-E3, the loss of capital due to an extreme event such as the exemplary storm increases the Swiss interest rate, which penalizes sectors with high capital intensity.

The high vulnerability of the forest sector with respect to storm damages is obvious and demonstrated by a production loss of about 0.61%. Compared to that, all other sectors are only marginally affected, with fluvial transport being one of the sectors confronted with slightly more significant losses (-0.5%). The overall effect on welfare is -0.01 % in 2060.

Table 17: Impacts of an assumed change of the return period of an exemplary storm or flood event
(% change of production per sector w.r.t. reference scenario in 2060)

	Storm	Flood
Natural gas	-0.00	-0.06
Petroleum products	-0.01	-0.03
Electricity	-0.00	-0.03
District heating	0.00	-0.09
Grains and oil seeds	-0.01	-0.04
Other crops	-0.02	-0.05
Livestock	-0.01	-0.06
Forestry	-0.61	-0.05
Industry	-0.01	-0.07
Land transport	-0.01	-0.06
Water transport	-0.05	-0.01
Air transport	-0.00	-0.01
Insurance	0.00	-0.09
Health	-0.01	-0.02
Services	-0.00	-0.02
Winter overnight tourism	-0.00	0.00
One-day winter tourism	-0.01	-0.02
Other forms of tourism	-0.00	0.00
Water	-0.01	-0.03
Total	**-0.01**	**-0.04**
Welfare	**-0.01**	**-0.03**

3.2.3.2 Floods

The impact of the exemplary flood event is higher than the effect of the storm event (Table 17). Although the employed flood event is larger in damages than the storm event, this has to be interpreted with caution, especially in light of the high uncertainties associated with the estimation of the return periods. The assumed return period of the flood event of 38.5 years is 11.5 years shorter than our assumption in the case of storms, which is another reason for the resulting difference in the impacts. Both effects contribute to a higher overall welfare loss (0.03%) in our sensitivity due to floods. Significant (production) losses are reported for the insurance sector (0.09%) and district heating (0.09%). All other sectors are less severely affected, e.g. industry (0.07%), natural gas (0.06%) or land transport (0.06%).

3.3 Energy

3.3.1 Literature-based assessment of energy demand

3.3.1.1 Exposure

For energy demand, the literature focuses on the effects of climate change for energy demand for heating as well as for cooling, due to the expected increase in average temperatures in winter and summer.

3.3.1.2 Sensitivity

Today, approximately one third of Switzerland’s total final energy use is directed towards space heating, while around 2.5% are used for space cooling and ventilation (Kemmler et al. 2015). The vast majority of heating energy is provided by oil and natural gas (approximately three quarters). Therefore, Switzerland is heavily dependent on fossil fuel imports and exposed to their world market prices.

3.3.1.3 Impacts without adaptation

Since far more energy is consumed for heating than for cooling, overall energy expenditure is projected to decrease with rising average temperatures. The magnitude of this effect depends on the climate scenario and on the assumed sensitivity of energy demand for cooling to increases in summer temperatures.

Seven cantonal case studies for Aargau, Basel-Stadt, Uri, Geneva, Graubünden, Ticino and Fribourg (Ernst Basler + Partner et al. 2013, INFRAS/Egli Engineering 2014a and 2014b, INFRAS et al. 2015, Bergwelten 21/GRF Davos 2015, IFEC et al. 2016, Ernst Basler + Partner/CSD Ingenieurs 2015) agree that climate change will lower energy demand for heating. For projections into the future, heating degree days (HDD) produced by MeteoSwiss are used. Heating energy demand is essentially proportional to this indicator (and similarly cooling degree days CDD for cooling energy demand). The Basel-Stadt case study, an example for an urban area, estimates a decrease by 12% to 30% depending on the climate scenario. A different case study, for the largely rural and mountainous Canton of Uri, offers similar values (the lower bound is 15%). For the Canton of Aargau, which represents a typical canton in the Swiss plateau, the projections are slightly lower (10% to 22%).

The reports expect that energy demand for cooling will increase significantly. The Basel-Stadt case study estimates an increase by 55% to 140%. Similar numbers can be found in the Aargau case study. The Canton of Fribourg spans both the Swiss plateau and the pre-Alpine region. The case study conducted for this canton finds that the relative increase in cooling energy demand is significantly higher in the pre-Alpine region (+140% in low scenario to +420% in high scenario) than in the Swiss plateau part of the canton (+48% to 127%). However, this strong difference in relative change is owed to the fact that the level of CDD is much higher under the current climate in the Swiss Plateau region (178 CDD compared to 31 CDD in the pre-Alpine region). While the projected increases seem large, today’s energy demand and cost of space cooling are on a low level, and therefore the increase is expected to be outweighed by the decreasing energy demand for heating.

The cantonal case studies do not take rebound effects into account (increasing demand due to lower overall costs) nor increasing energy efficiency in new constructions and renovations.

3.3.1.4 Adaptation

The adaptation measures on the energy demand side include improvements in the energy efficiency of buildings. For example, the Confederation and Cantons are currently supporting the energetic refurbishment of houses (Buildings Programme). Better energy efficiency of buildings helps to ensure that energy savings that originate from a climate change induced drop in HDDs will not be diluted by rebound effects (part of the possible energy saving is lost e.g. through higher room temperatures or more frequent ventilation induced by lower energy costs).

A critical question will be whether air conditioning will be allowed more easily in residential buildings as summers get warmer and to what extent it would penetrate the housing stock – from which it is essentially banned today – as well as other types of buildings that are not yet equipped with cooling systems. In anticipation of increasing room cooling penetration, energy efficiency and labeling requirements have been introduced in Switzerland in accordance with EU regulation (Energieverordnung). Aebischer et al. 2007 estimate that half of the surfaces in the services sector that are not cooled under a scenario without climate change in 2035 would be cooled under a scenario with 2°C warming in the summer, and that half of the surfaces that are partially cooled would become fully cooled. Gonseth et al. 2015 extrapolate these estimates to conclude that 50% of surfaces in the services sector would be fully cooled by 2060 and 35% partially. In the housing sector, the share of cooled surfaces could increase from 0.6% in 2000 to 2% in 2060.

3.3.1.5 Impacts with adaptation

Winkler et al. 2014 present in the CH2014-Impacts report an examination of CC impacts on the energy demand side on a national level. A contribution of the study is that it takes into account rebound effects and projections for the development of the Swiss economy as well as increasing energy efficiency (which is assumed to be independent of climate change). Despite the different approach, the main result of these CGE simulations is consistent with the findings of the cantonal case studies: The savings in heating demand are projected to overcompensate the increasing demand for cooling, such that total energy savings are expected in the interval of 0.04% to 0.23% of energy consumption for space conditioning.

Gonseth et al. 2015 use the same CGE approach, but a more careful and detailed representation of rebound effects and scenarios on the penetration of space cooling. They project that the welfare gain from the net reduction in energy demand for heating and cooling compared to a reference scenario amounts to 0.16% of consumption. That gain would be divided by two by a 20% penetration rate of air conditioning, not counting the comfort and health benefits of space conditioning.

3.3.2 Literature-based assessment of energy supply

3.3.2.1 Exposure

On the energy supply side, the literature focuses on the effects of CC on hydropower production through a change in water flow regimes. Changes in runoff regimes are caused by changes in precipitation schemes as well as by temperature changes that affect melt water runoff from glaciers and snow cover. Furthermore, extreme weather events such as droughts and floods are relevant to hydropower production.

In hot summer periods, low water levels and high water temperatures can affect the cooling of thermal power plants, such as nuclear or natural gas-fired power stations. However, it is yet unsure whether there are going to be any thermal power plants in Switzerland in 2060.

3.3.2.2 Sensitivity

Hydropower is currently the most important source of electricity in Switzerland: approximately 60% of Switzerland's electricity is generated by hydropower plants today. Thereof, 4.4% are produced by pump storage plants, and the rest is delivered to equal parts by run-of-river and regular storage plants.

The Swiss nuclear power plants will be shut down over the next few decades and not replaced. The strategies for replacement sources of electricity are subject to political debate. Most scenarios include demand reductions, more wind power and photovoltaics, a small increase in hydropower capacity, and possibly natural gas plants (Prognos 2012). Hydropower is likely to strengthen its already important role for Swiss electricity generation.

Electricity supply for Switzerland does, however, not only depend on domestic production. The Swiss electricity sector is closely integrated with those of its neighbouring countries. This integration reduces vulnerability of electricity supply to extreme weather conditions in Switzerland, as it enables the purchase of electricity on European markets to make up for domestic shortfalls. At the same time, it also establishes a vulnerability to supply shortages and stability problems in the European grid. Due to the very different generation technologies used in our large neighbouring countries (currently, coal and nuclear are most prominent there), such imported risks arise from extreme weather conditions, not from changes in hydrological regimes.

3.3.2.3 Impacts without adaptation

With regard to domestic electricity generation, the effects on the hydrological cycle are examined in the CCHydro report (FOEN 2012a) and more specifically in the report on the effects of CC on hydropower production (SGHL/CHy 2011). While these reports investigate physical effects even at a scale of catchments, they have in common that they do not – or only in a very limited manner – quantify the economic effects.

Economic valuations are presented by the cantonal case studies, which quantify the expected hydropower production change in 2060 with mixed results. The Aargau case study, for example, projects the expected economic impact on hydropower production due to a changed precipitation regime to be small in comparison to the impacts on the energy demand side. Assuming that its electricity generation will increase proportionally to the increasing flow of the Argovian rivers, hydropower production is projected to rise by

0.4% to 2.4% (in the weak and the strong climate change scenarios respectively). Additional costs for maintenance and infrastructure damage from natural hazards are also expected to be rather small.

Fribourg on the other hand, expects precipitation and hydropower production to decrease by 2.5% (weak scenario) to 4.9% (strong scenario). Even stronger decreases are projected for the Canton Ticino. This case study concludes that hydropower might drop by 4.2% (weak scenario) to 6.8% (strong scenario). In Geneva, no influence is expected from climate change on hydroelectric facilities. Graubünden expects very heterogenous effects: While glacier-fed areas are positively affected, other locations might experience little or even negative impact.

In the Uri case study, the authors assume that annual average precipitation is the measure that determines hydropower production. Since it is projected not to change significantly for the case of Uri, no change to hydropower production is expected. This connection is, in general, less clear than one would expect, because

- heavy precipitation reduces run-of-river hydropower electricity generation,
- taking reservoir capacity limits into account, shifts in seasonal precipitation and runoff patterns could increase annual generation from existing plants with reservoirs, and
- the changing precipitation patterns are partly overlaid with retreating glaciers with a temporarily increasing melt water discharge (CH2014-Impacts).

While not considering these two potentially influential effects, the Uri case study reflects the mountainous topography of the canton by analysing the possible increase in natural hazards:

- damages from mudslides are expected to increase slightly;
- damages from floods in Uri are expected to increase by 5% to 20%, depending on the climate scenario.

The Basel-Stadt case study points out that the increasing occurrence of heat spells might lead more frequently to events where river water is too warm for cooling purposes, which would affect thermal power plants (incl. gas combined cycle power plants), if they are built to replace decommissioned nuclear power plants. Indeed, their demand for cooling water might not always be satisfied during summer months, considering also that cooling water extraction underlies strict regulation.

In summary, while some seasonal shifts in runoff patterns may occur, the overall effect on hydropower production is expected to be smaller than the natural variation until 2050. More work is needed to make the few available valuations more comprehensive: In the existing analyses, electricity prices are assumed to be constant and market and international effects are ignored. Further important aspects are not or only qualitatively included in these studies. For example, as mentioned above, a temporary change in glacier melt water might have significant short-term effects on hydropower production in Uri as well as in other cantons.

3.3.2.4 Adaptation

Possible direct adaptation measures in hydropower supply include raising dam heights and adding intermediate reservoirs for pumped storage (Gaudard 2014). However, these measures must be balanced against the protection of natural spaces and landscapes.

Indirect adaptation mainly includes shifting to other energy sources for electricity production and electricity imports. Other modes of cooling need to be considered in long-term planning of thermal plants, or warmer water temperatures need to be taken into account in the location decisions for such facilities.

3.3.2.5 Impacts with adaptation

Gonseth & Vielle 2012b use a computable general equilibrium (CGE) modeling approach to project impacts including endogenous adaptation. They simulate an annual runoff change of -2.2%[5], based on the mean of four different climate scenarios. Under the assumption that hydropower production is proportional to runoff, a production decrease of 816 GWh is projected. In the respective scenario, increased electricity generation from other renewable energy sources and natural gas compensates for this.

3.3.3 Modeling and data

3.3.3.1 Direct effects on energy demand

Next to the international price effects (see section 3.3.3.3), the change in heating and cooling energy demand is incorporated into GEMINI-E3. This is achieved with the help of the methodology used in Gonseth et al. 2015. In brief, the heating degree day (HDD) and cooling degree day (CDD) methods sum up differences between the outside temperature and a given interior target temperature to approximate energy demand for that particular year. More specifically, HDDs are calculated as follows:

$$HDD(\theta_i, \theta_{th}) = \sum_{k=1}^{365} m_k \cdot (\theta_i - \theta_{e,k}),$$

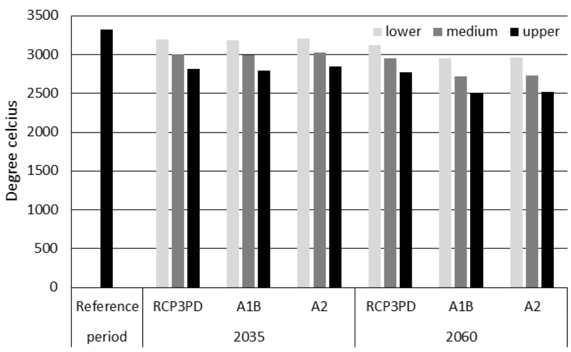
with θ_i being the target heating temperature and $\theta_{e,k}$ being the average outside temperature of day k. However, heating is only necessary if the outside temperature is below a certain threshold temperature, θ_{th}. In order to only sum up days with an outside temperature under the threshold, the parameter m_k turns from 1 to 0 if $\theta_{e,k} > \theta_{th}$. The specific parameters used in this study are the threshold temperature $\theta_{th} = 12°C$ and $\theta_i = 20°C$, as established by Christenson et al. 2006 and Kirchner et al. 2010. Finally, energy demand for heating is assumed to develop proportionally to changes in HDD.

The same method with inverse logic can also be applied for cooling energy demand and CDD. Cooling is only required if outside temperature rises above the chosen threshold of 18.3°C. With the help of a linear relation, the summed up CDD are then converted to specific electricity demand per surface, D_{spec}. Consequently, future cooling energy demand depends on the development of the total commercial and residential area. A special challenge with cooling energy demand is that the currently low levels of penetration of cooling technology in Switzerland are likely to increase amid climate change. To incorporate this effect, the estimation of the future share of cooled space by Aebischer et al. 2007 is used. Putting the pieces together, total electricity demand from cooling, E, for 2060 is projected using the following equation:

[5] However, the more recent CH-2014-Impacts report suggests that the average annual runoff is likely not to decrease significantly.

$$E = D_{spec} \cdot Surface \cdot \left(\alpha^{full} + \frac{\alpha^{part}}{4} \right),$$

where α^{full} and α^{part} correspond to the percentage of fully and partly cooled surfaces respectively.



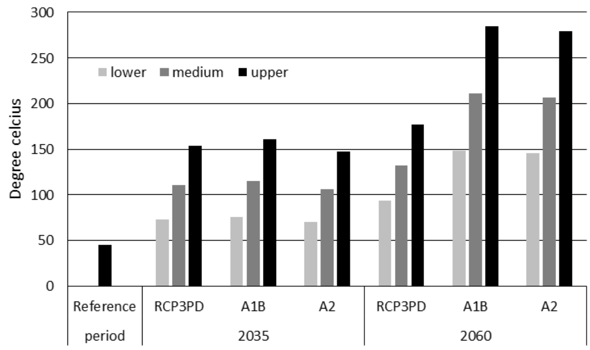
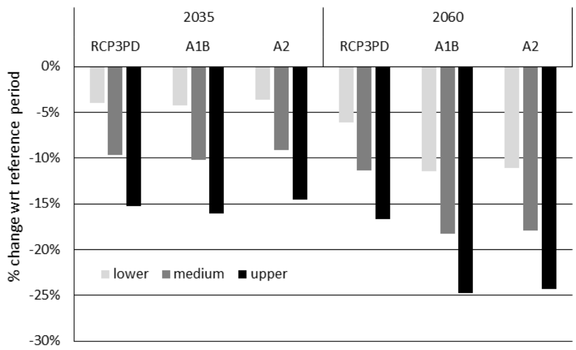


Figure 2: HDD with θ_{th} = 12°C (left) and CDD with θ_{bp} = 18.3°C (right) in ˚C



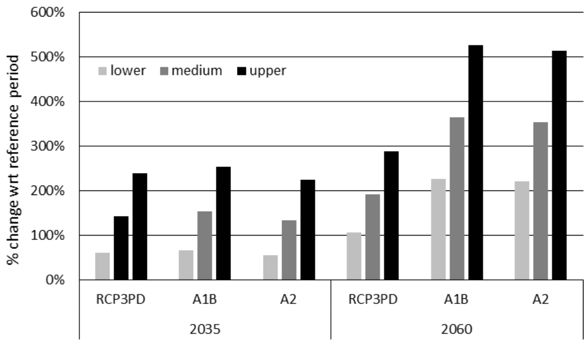


Figure 3: Changes of HDD with θ_{th} = 12°C (left) and CDD with θ_{bp} = 18.3°C (right)
(% deviation from reference scenario)

Figure 2 and Figure 3 show the evolution of the HDD and the CDD indicators for the years 2035 and 2060 (Figure 2 in absolute numbers, Figure 3 in % changes with respect to the reference period 1980-2009).

In the reference period, the annual value of HDD is equal to 3´328. In 2060, the HDD is projected to decrease by between 6.1% and 24.7% relative to the reference period, depending on the climatic scenario. The scenarios A1B and A2 give similar results, because the respective temperatures do not differ much in 2060. The RCP3PD scenario, which may limit global warming to 2°C, reduces the decrease of HDD by more than 40% with respect to the other two scenarios. Within the same climatic scenario, the HDD decrease is multiplied by more than a factor of 2 when we move from the lower estimate to the upper estimate.

In contrast to heating, space cooling needs will increase with climate change as indicated by the CDD changes. Note the different scaling of the CDD graphs compared to the HDD graphs. The percentage changes of CDD are much bigger in comparison to the HDD, which comes from the fact that in Switzerland the CDD for the reference period are quite low (see Figure 2). Within the same scenario, the climate uncertainty (represented by the lower, medium and upper estimates) significantly affects the percentage changes. For example, in scenario A1B, CDDs increase in 2060 within a range of 227% to 527%. In contrast to heating, the changes in cooling needs are not assumed to be proportional to the variations of CDD (see equation above).

3.3.3.2 Direct effects on energy supply

Switzerland's current main source of electricity is hydropower. The exact extent of the effect of a changing climate regime on hydropower generation in Switzerland is uncertain. As already mentioned in section 3.3.2, there might be a shift in seasonality. The effect on production potential aggregated over a year, however, is likely to range within the current natural variability.

The currently second most important source of electricity, nuclear power, might face a decreasing productivity due to less available cooling water during heat spells. Stronger than this direct effect of climate change, however, will be the political decisions taken to shape the future of the nuclear power sector. While the Swiss Parliament reached a consensus on the phasing out of nuclear power, no shut down dates were set.[6] Beyond that, the shape of the post-nuclear electricity system is also yet to be determined. Especially interesting and relevant from an economic point of view are the thereby implied policy schemes for new power plants. As the future Swiss electricity mix strongly depends on these decisions, it is hard to predict what number and what type of thermal power plants Switzerland will possess in the future. Hence, the level of the exposure of Swiss power plants to a decreased availability of cooling water is subject to great uncertainty.

To sum up, the Swiss electricity production sector is characterized by many unknowns not only regarding the physical effect of climate change, but also with regard to political matters. For that reason, and because the expected impact of these issues is rather low, they are omitted from modelling.

3.3.3.3 International price effects

As Switzerland is a landlocked country and possesses considerable capacity for international power exchange[7], development of electricity prices in the neighboring countries also affect Swiss prices and ultimately demand. For this reason, we incorporate the development of the electricity prices of Switzerland's European neighbors into GEMINI-E3. As input data, the results from the POLES model run by Dowling 2013 are used (see Table 18). It uses a partial equilibrium cost-based approach and states relative climate change cost impacts for individual European countries. Furthermore, the model is run under two climate scenarios[8] and with four different climate models. Incorporated into Dowling's 2013 model are both supply and demand side climate effects. On the supply side, the following climate change effects are modelled:

- Efficiency decrease of thermal power plants due to a lack of cooling water;
- Change in productivity of renewable generation systems (hydro, wind & photovoltaics) due to an altered climate regime.

---

6 Details can be found here: http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20130074

7 In 2014, Switzerland imported 37.4 TWh (65% of end use) and exported 42.9 TWh (75% of end use), with the largest part of imports coming from France and the largest outward flows directed to Italy (SFOE 2015).

8 A1B & E1, both of which are then compared to a reference scenario which corresponds to a model run without climate change.

On the demand side, the effect of the changing temperature regime on both heating and cooling energy demand is modeled in Dowling's 2013 study. The relative change resulting in the electricity production cost from all these effects in each country is then incorporated into GEMINI-E3's price signal for the electricity traded with other countries.

Dowling 2013 reports values for 2030 and 2050, for the A1B and the E1 climate change scenarios. The E1 climate scenario was created by the European ENSEMBLES project and is similar to RCP3PD. It represents a strong mitigation pathway, with the aim of keeping global warming below 2° C (Royer et al. 2009). Table 18 displays the values for 2050 from Dowling 2013, where the A1B values are the average of the runs of three different climate models. These 2050 values are taken as a basis to estimate the values for 2060 for the three scenarios simulated in this study (A1B, A2 and RCP3PD). To this end, the values are inflated or deflated linearly in temperature. For the target scenario RCP3PD, the E1 data from Dowling 2013 was used, while for the SRES target scenarios, Dowling's A1B data served as a source. This decision was driven by the assumptions underlying these scenarios. While E1 and RCP3PD are both strong mitigation scenarios, A1B and A2 are more akin to business-as-usual scenarios until mid-century. The implication is that price changes are driven by different mechanisms. In the case of strong mitigation, a change in the electricity mix towards more carbon neutral technologies results in a tendency for higher electricity prices. In a business as usual case, on the other hand, climate change impacts are more severe. This results in less heating energy demand, in particular for Germany, and in less efficient thermal power plants, due to a lack of cooling water.

Table 18: Climate change impact on European electricity prices in 2050
(% deviation from reference scenario in 2050; source: Dowling 2013; A1B data is the average of three different climate model runs; data for Austria acquired through personal communication)

	EU27	Germany	France	Italy	Austria
A1B	-0.67	-8.33	2.33	1.00	0.67
E1	3.00	4.00	7.00	1.00	-1.00

The target temperature values which are used to extrapolate the 2050 price change values from Dowling 2013 are derived from the climate multi-model ENSEMBLES output range for 2060, which is also used in the IPCC reports. For RCP3PD (assumed to be identical to RCP2.6, which served as basis for the following calculation), a 90% confidence interval of the whole ENSEMBLES range was taken, as is stated in the IPCC 2013 report (p. 23). For the older SRES scenario, no information on how the so-called likely range was derived is stated. Therefore, the distribution was reconstructed, with the target being the temperature range given in IPCC 2007b for the end of the 21st century. The resulting distribution was then applied to the 2060 values in order to find the triplet of values for the A1B and A2 scenarios.

The results of the extrapolation and the values which are finally applied to European electricity prices in the GEMINI-E3 model run are presented in Table 19.

Table 19: Climate change impact on European electricity prices
(% deviation from reference scenario in 2060; calculations on the basis of data from Dowling 2013)

	RCP3PD			A1B			A2		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
EU27	1.23	**3.08**	4.93	-0.49	**-0.79**	-1.22	-0.46	**-0.78**	-1.24
Germany	1.65	**4.11**	6.58	-6.14	**-9.83**	-15.23	-5.72	**-9.72**	-15.44
France	2.88	**7.20**	11.51	1.72	**2.75**	4.26	1.60	**2.72**	4.32
Italy	0.41	**1.03**	1.64	0.74	**1.18**	1.83	0.69	**1.17**	1.85
Austria	-0.41	**-1.03**	-1.64	0.49	**0.79**	1.22	0.46	**0.78**	1.24

3.3.4 Results

3.3.4.1 Impact of climate change on energy demand for heating

We first analyze the impacts of climate warming on energy consumption for heating. Table 20 shows the results for the different climate scenarios. With warmer climate, heating energy needs decrease. This implies a reduction in the total energy consumption between 0.85% and 3.53% depending on the climate scenario. The consumption of energy goods used for heating purposes in Switzerland decreases. That is the case for district heating and for fossil fuels (oil and natural gas). Therefore, CO_2 emissions decrease between 1.17% and 4.92%. In contrast, consumption of electricity increases by between 0.31% and 1.41%, depending on the scenario. At the aggregate level, the simulations yield significant welfare gains, mainly from a smaller energy bill for heating consumption.

The reduction in energy consumption could be much higher than shown in Table 20 if rebound effects could be prevented. In our simulations, rebound effects for households concerning heating are about 41% (industry: 42%, services: 35%), i.e. reductions in energy consumption are only about 59% of what they would be in the absence of rebound effects.

Table 20: Impact of climate change on heating
(% deviation from reference scenario in 2060)

	RCP3PD			A1B			A2		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
Energy consumption (toe)	-0.85	**-1.59**	-2.35	-1.60	**-2.58**	-3.53	-1.55	**-2.54**	-3.47
Petroleum products	-1.10	**-2.07**	-3.06	-2.07	**-3.37**	-4.62	-2.01	**-3.31**	-4.55
Natural gas	-1.51	**-2.84**	-4.19	-2.85	**-4.61**	-6.31	-2.76	**-4.53**	-6.21
Electricity	0.31	**0.60**	0.90	0.60	**1.00**	1.41	0.58	**0.98**	1.39
District heating	-2.26	**-4.25**	-6.28	-4.26	**-6.92**	-9.49	-4.13	**-6.79**	-9.33
CO_2 emissions	-1.17	**-2.20**	-3.26	-2.21	**-3.59**	-4.92	-2.14	**-3.52**	-4.84
Welfare	0.09	**0.18**	0.26	0.18	**0.29**	0.39	0.17	**0.28**	0.39

3.3.4.2 Impact of climate change on energy demand for cooling

In contrast to heating, space cooling needs will increase with climate change, as indicated by CDD increases reported in Figure 3. This implies an increase of electricity consumption of 1.5% to 4.1% in 2060 depending on the climate scenario as shown in Table 21. In GEMINI-E3, the resulting increase in Swiss electricity demand is partly satisfied by thermal power generation using natural gas, which results in an increase of overall natural gas consumption ranging between 0.6% and 1.7%. Petroleum products consumption decreases as households and firms spend a greater share of their budgets on cooling. The changes presented in Table 21 entail a welfare loss.

Table 21: Impact of climate change on cooling demand
(% deviation from reference scenario in 2060)

	RCP3PD			A1B			A2		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
Energy consumption (toe)	0.45	**0.57**	0.72	0.62	**0.83**	1.26	0.61	**0.82**	1.07
Petroleum products	-0.04	**-0.04**	-0.05	-0.04	**-0.05**	-0.07	-0.04	**-0.05**	-0.06
Natural gas	0.60	**0.77**	0.97	0.84	**1.13**	1.72	0.83	**1.11**	1.45
Electricity	1.49	**1.90**	2.37	2.07	**2.74**	4.13	2.04	**2.70**	3.50
District heating	-0.11	**-0.13**	-0.16	-0.14	**-0.18**	-0.25	-0.14	**-0.18**	-0.22
CO_2 emissions	0.08	**0.11**	0.14	0.12	**0.16**	0.26	0.12	**0.16**	0.22
Welfare	-0.02	**-0.03**	-0.04	-0.03	**-0.04**	-0.06	-0.03	**-0.04**	-0.05

There are rebound effects also for cooling, although they are smaller than for heating and they mitigate the increase in energy use. In our simulations, energy consumption for cooling, as shown in Table 21, increases 26% less than in the absence of rebound effects.

3.3.4.3 Net impact of climate change on energy demand for heating and cooling

In Switzerland, global warming can be expected to lead to a decrease in heating energy demand, which is partly countered by an increased energy demand for space cooling. The GEMINI-E3 simulations confirm this expectation and show that the net effect of climate change on these two demand categories is projected to cause an overall decrease in energy demand in 2060 under all three climate change scenarios (see Table 22). The effect is more pronounced for the two SRES scenarios A1B and A2 (-1.74% and -1.70% in the medium cases), which exhibit stronger warming than the RCP3PD scenario (-1.02% energy consumption). This implies not only that the decrease in energy demand for heating outweighs the increase in energy demand for cooling, but also that this gap widens as temperature increases.

The changing pattern of energy usage can also explain the shift in the energy mix. The decrease in petroleum products can be attributed to a lower demand of heating oil. The projection with the weakest climate change effect, RCP3PD lower, shows a decrease in petroleum product consumption of 1.13%, while the projection for A1B upper, which contains the strongest climate change signal, shows a decrease of 4.68%.

Table 22: CC impacts on heating and cooling demand
(% deviation from reference scenario in 2060)

	RCP3PD			A1B			A2		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
Energy consumption (toe)	-0.40	**-1.02**	-1.62	-0.97	**-1.74**	-2.42	-0.93	**-1.70**	-2.38
Petroleum products	-1.13	**-2.11**	-3.11	-2.12	**-3.42**	-4.68	-2.05	**-3.36**	-4.61
Natural gas	-0.90	**-2.06**	-3.19	-1.99	**-3.45**	-4.77	-1.92	**-3.39**	-4.70
Electricity	1.81	**2.51**	3.30	2.68	**3.78**	5.05	2.63	**3.71**	4.95
District heating	-2.37	**-4.39**	-6.44	-4.41	**-7.10**	-9.71	-4.27	**-6.97**	-9.55
CO_2 emissions	-1.09	**-2.10**	-3.11	-2.09	**-3.42**	-4.69	-2.02	**-3.35**	-4.61
Welfare	0.07	**0.15**	0.22	0.15	**0.25**	0.34	0.14	**0.24**	0.33

Electricity consumption, on the other hand, sees a relatively strong increase (1.81-4.95%), which is due to cooling increases being predominantly powered by electricity. By 2060, a considerable part of this additional electricity is assumed to be generated from natural gas, counteracting some of the CO_2 emission decreases caused by lower overall fossil fuel consumption.

In total, the lower net energy consumption involves a welfare gain in the order of 0.15% (RCP3PD medium) to 0.25% (A1B and A2, medium cases).

3.3.4.4 Impact of foreign electricity price changes

Table 23: Impacts of foreign electricity price changes on Switzerland
(% deviation from reference scenario in 2060)

	RCP3PD			A1B			A2		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
Electricity cons. Price	0.61	**1.52**	2.42	-0.09	**-0.14**	-0.22	-0.08	**-0.14**	-0.22
Electricity generation	0.13	**0.32**	0.51	-0.02	**-0.03**	-0.05	-0.02	**-0.03**	-0.05
CO_2 emissions	0.02	**0.04**	0.06	0.00	**0.00**	-0.01	0.00	**0.00**	-0.01
Welfare	-0.01	**-0.02**	-0.03	0.00	**0.00**	0.00	0.00	**0.00**	0.00

Although electricity price impacts are very considerable in some countries, e.g. due to costs of mitigation measures for scenario RCP3PD, impacts of these price changes on Switzerland are very small. The main reasons for this are the following:

- Import prices do not change much on average. Especially for A1B and A2, price increases in France are more than compensated by price decreases in Germany.
- International electricity trade very much increased in recent years. For Switzerland, imports and exports each almost match domestic electricity generation. Yet, net foreign trade in electricity is small. Depending on the future regulation of electricity markets, Swiss generation costs, which we assume to

remain unaffected by climate change, will continue to influence end user prices to a considerable extent, especially for households. In scenario RCP3PD, Swiss generation even gains importance. It increases by about 0.3%, because mitigation efforts abroad become a comparative disadvantage for foreign producers.

- While wholesale electricity prices are rather closely linked to generation costs, this is less true for end user prices, especially for households.
- Electricity consumption is a rather unimportant and decreasing share of household consumption. In 2060, it is projected to be about half a percent.

While the considerable changes in French and German electricity markets will be an issue for managers in the Swiss electricity sector, the effects on Swiss consumers are very small. Where they exist, they are mostly a consequence of foreign mitigation measures in the electricity sector (scenario RCP3PD), not of modified climatic conditions.

3.3.4.5 Total impact of aggregated effects on energy

Together, the impact of climate change through heating, cooling and foreign electricity prices leads to a welfare increase in all assessed scenarios (see Table 24).

Table 24: CC impacts on energy consumption
(% deviation from reference scenario in 2060)

	RCP3PD			**A1B**			**A2**		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
Energy consumption (toe)	-0.36	**-0.98**	-1.59	-0.84	**-1.54**	-2.14	-0.80	**-1.51**	-2.11
Petroleum products	-1.15	**-2.14**	-3.15	-2.12	**-3.42**	-4.68	-2.05	**-3.35**	-4.60
Natural gas	-0.76	**-1.70**	-2.63	-2.01	**-3.49**	-4.83	-1.94	**-3.42**	-4.75
Electricity	1.61	**2.01**	2.51	2.71	**3.83**	5.12	2.71	**3.83**	5.12
CO_2 emissions	-1.07	**-2.05**	-3.05	-2.09	**-3.42**	-4.69	-2.02	**-3.36**	-4.62
Welfare	0.06	**0.13**	0.19	0.15	**0.25**	0.34	0.14	**0.24**	0.34
Electricity cons. Price	0.84	**1.84**	2.85	0.24	**0.33**	0.41	0.24	**0.32**	0.40
Electricty generation	1.15	**1.74**	2.37	1.50	**2.11**	2.80	1.47	**2.07**	2.75

Domestic and international effects seem to simply add up, at least in terms of welfare changes. Under the RCP3PD scenario, an increase in welfare of 0.13% is projected, while the A1B and A2 scenarios project a welfare increase of 0.25% and 0.24%, respectively. The main driver for these differences can be found in the heating energy demand, which diminishes under a warmer climate. In the A1B and A2 scenarios, winters warm up more, hence welfare gains from reduced heating needs are larger. The decrease in the usage of petroleum products can also be attributed to decreasing heating energy needs. The considerable increase in electricity consumption is chiefly induced by a strong increase in cooling energy demand. A part of this additionally required electricity is generated within Switzerland, but especially in the A1B and A2 scenarios, a considerable part is covered by imports. A substantial difference can be found in the electricity consumer prices; the RCP3PD medium scenario projects an increase of 1.84%, while in the other two medium scenarios, the price only rises by 0.25% (A1B) and 0.24 (A2). The major reason behind this disparity is the global – and in particular the European – mitigation effort for the RCP3PD scenario, which leads to higher international electricity prices.

This shift in the demand pattern away from fossil fuels towards electricity, which in Switzerland is largely produced from low-carbon sources, also appears in CO_2 emissions; they are projected to drop by 1.07% (RCP3PD lower) to 4.69% (A1B upper) in 2060 relative to the reference scenario without climate change.

3.4 Water management

3.4.1 Literature-based assessment

For the scope of this report, water management is defined as the activities that are related to the preparation and treatment of drinking water and industrial water (used in irrigation, production and cooling), as well as to the disposal of waste water. Impacts caused by floods in other economic sectors are treated separately in the respective sections.

3.4.1.1 Exposure

Water management is concerned with maintaining security and quality of supply, preserving infrastructure, economic efficiency and protection of the water resource (FOEN 2014). From these goals, the exposure to climate change can be deduced: changes to runoff regimes that might affect the availability of drinking water and changing occurrence of extreme weather events (such as dry spells) and natural hazards (e.g. flooding) that might affect availability of drinking water or cause damage to water infrastructure. In addition to that, increasing temperatures potentially affect microbial activity; while this might deteriorate drinking water quality, it could facilitate waste water treatment.

3.4.1.2 Sensitivity

Today, water management in Switzerland is considered to be of very high quality (FOEN 2014). From a purely economic point of view, the water management sector is rather small in Switzerland; Ernst Basler + Partner 2009 estimated that annual costs for drinking water production and waste water management amount to approximately CHF 3.6 billion.

3.4.1.3 Impacts without adaptation

Studies agree that impacts on Swiss water management are uncertain, but likely to be low in absolute terms and – if tackled in time – manageable. Based on two different climate scenarios, the cantonal case studies offer an economic evaluation of some of the CC impacts on the water management sector by 2060. For instance, the Aargau case study estimates that an increase in flood events will increase maintenance costs in the water management sector by 10% to 50% depending on the climate scenario. On the other hand, increasing occurrence of dry spells might increase the operation costs for the provision of drinking water by up to 10% (in a strong climate scenario). The estimates of the Uri case study are on the same order of magnitude. Additionally, due to the mountainous topography of that canton, damages from mudslides to water management infrastructure are estimated to increase by 10% to 30%, again depending on the climate scenario. In Graubünden, it is expected that a shift in seasonality of precipitation will lead to a slight reduction of the risk of drinking water shortage. Currently, peak demand and lowest supply coincide in winter. A rising snow line will further add to an increasing water supply in winter. Dry spells are expected to put an additional burden on water, as such conditions are expected to make the preparation of drinking water more expensive (Bergwelten 21/GRF Davos 2015).

All these cost estimates are assumed to change in linear proportion to the occurrence of such events. This is a good approximation only when neglecting adaptation that is prompted by learning from damaging events. Some important effects such as climate change impacts on drinking water quality have not been estimated quantitatively.

3.4.1.4 Adaptation

While experts do not expect irresolvable issues from climate change in the water management sector, some adaptation is required to cope with the expected changes. Notably, the Basel-Stadt case study (INFRAS/Egli Engineering 2014a) points out that an increase in strong precipitation events might require expanding flood basins in waste water treatment facilities. FOEN 2014 finds that in order to increase adaptive capacity, the role of the federal administration, which currently is rather subordinate in water management, should be strengthened. Furthermore, in the answer to Postulate 10.3533 (17 June 2010) by National Councillor Hansjörg Walter (SVP/TG), the Federal Council deemed unnecessary to define national regulation regarding usage of water, but rather emphasized its supporting function for the cantons to tackle potential future water scarcity issues (FOEN 2012b).

3.4.1.5 Impacts with adaptation

Faust et al. 2015 examine economic impacts of climate change on a broadly defined water management sector for different degrees of adaptation. Using a CGE modeling approach, they find that the costs for the provision of drinking water will increase by 7% to 40%, depending on the scenario. Industrial water prices are projected to increase by 28% to 150%. This translates into welfare losses of CHF 35.8 to 59.7 million, depending on the degree of adaptation. From a macroeconomic point of view, these welfare changes are very small, which reflects both the small macroeconomic importance of the water management sector and the low water prices in the baseline.

3.4.2 Modeling and data

Total river runoff in Switzerland will experience only negligible changes, according to projections of the CH2014 report. However, seasonal patterns of water resources are projected to change, which is of interest for irrigation in plant production, i.e. crop farming and horticulture. In the following, we thus concentrate on climate-induced changes in summer river runoff used for plant production in Switzerland.

Supply of irrigation water is a water management issue and is treated as such in the current chapter. At the same time, changes in availability and costs of irrigation water also affect the agricultural sector to a considerable extent. We thus include the effects simulated in the current chapter also at the end of section 0 on agriculture, more precisely they are entailed in the combined simulations presented in section 3.5.3.2.

Water scarcity is an issue in only few agricultural areas of Switzerland. Regions where demand potentially reaches a critical share of river runoff supply are identified by Fuhrer & Calanca 2014, cf. Figure 4. Six regions historically exhibit a ratio of demand to supply of more than one (regions 31, 37, 20, 39, 32, and 34 in Figure 4). In addition, we consider two regions (regions 18 and 19) which, according to the same article, were critical in the summer of 2003.

Generally, with extreme events such as the heat wave and drought of the summer of 2003, water scarcity could become an issue in more than these eight regions, i.e. in almost all non-alpine areas of Switzerland. However, this section concentrates on average changes rather than extreme events, because we lack information on the return period of the 2003 drought event. As a dry spell even more than as a heat wave, 2003 was very exceptional, and severity and return periods of future extreme droughts are unknown. For more information on the difficulties of analyzing such exceptional events, please consult the box on heat waves at the end of section 3.1.2. This implies that the consequences of unusual dry spells are not considered, which admittedly results in an underestimation of climate change impacts on water supply.

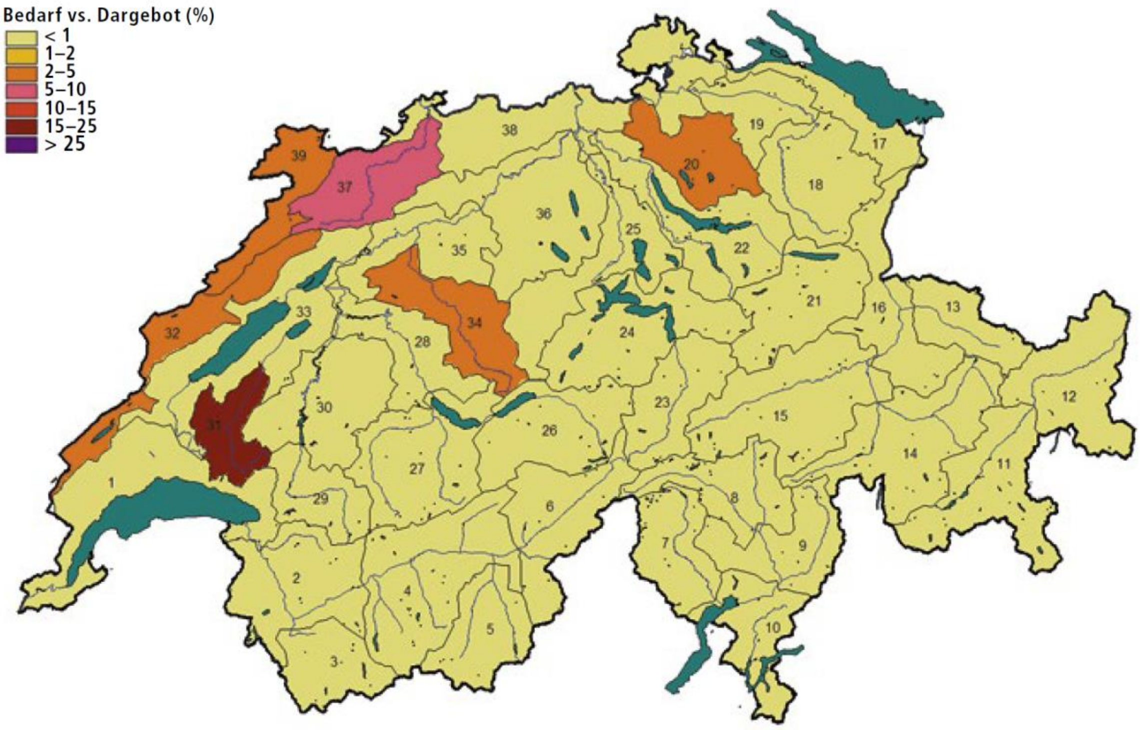


Figure 4: Distribution of the regional share of demand (Bedarf) vs. supply (Dargebot) for river runoff in the months June to August for 1981-2010
(source: Fuhrer & Calanca 2014)

Unfortunately, up-to-date runoff projections are available for six catchments only. Page 64 of the CH2014-Impacts report presents the respective projections for the three different emission scenarios RCP3PD, A1B, and A2 and two seasons (summer and winter). Of the six catchments, two directly correspond to the critical areas identified above: Emme (region 34) and Thur (regions 18 and 19). The remaining regions that were identified in Figure 4 are matched to the available runoff projections by using results of a similarity clustering conducted by Köplin et al. 2012, cf. Figure 5. In this analysis, different catchments have been clustered according to their projected climate change signals and hydrological responses.

The remaining five critical regions belong to cluster C1. Of the catchments for which runoff projections are available, only the Venoge belongs to cluster C1. Hence, we transfer summer runoff changes of the Venoge to the five remaining regions.

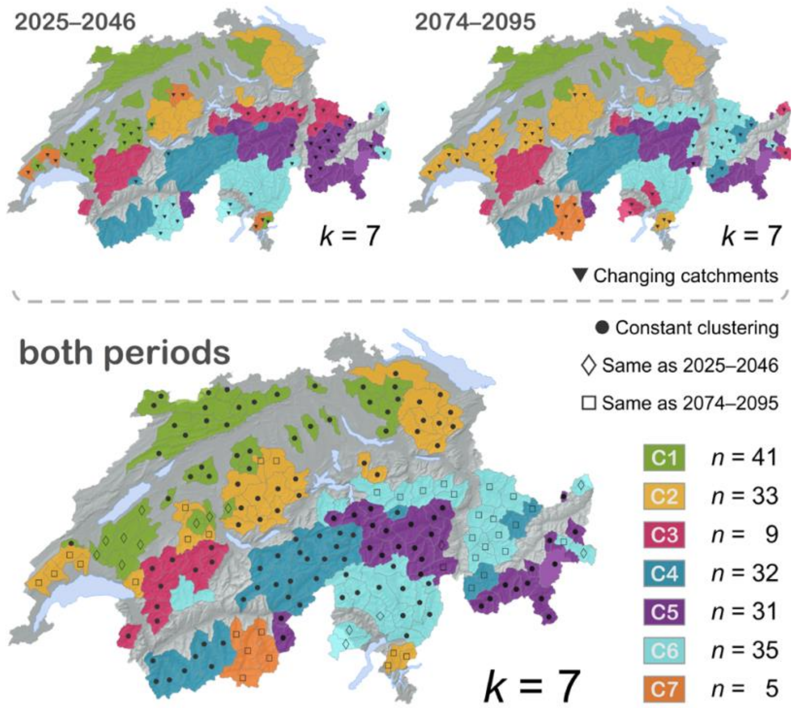


Figure 5: Cluster analysis for hydro-climatological change signals
(n = number of cluster members; source: Köplin et al. 2012)

For all eight critical regions and based on cantonal data, we estimate plant production as a share of total plant production in Switzerland of 2015. Summer runoff changes are applied only to the thus established affected shares of Swiss plant production. The weighted changes in the critical regions are aggregated to attain numbers for Switzerland as a whole. Given that the critical regions represent a share of only 21% in total plant production, the change in critical summer runoff is small relative to total summer runoff in Switzerland. In addition, we take into account that summer runoff only accounts for 60% of the total irrigation water resource, the remainder being groundwater. As a result, critical changes of the irrigation water resource are only small fractions of the total irrigation water resource for Switzerland (see Table 25).

Table 25: Critical changes of the irrigation water resource
(% deviation from total irrigation water resource in the reference scenario in 2060)

	RCP3PD	A1B	A2
Lower	-0.50 %	-2.62 %	-2.19 %
Medium	**-4.73 %**	**-6.49 %**	**-6.06 %**
Upper	-8.04 %	-10.89 %	-10.46 %

3.4.3 Results

With the input data presented above, it comes as no surprise that the macroeconomic impacts are extremely small. Welfare changes in terms of total consumption do not exceed 5.5 mio. CHF of 2008 (Table 26). This contrasts to the almost one hundred times larger decline of production in agriculture in 2003. Defining this loss as the deviation from a 5-year average, it summed up to 520 mio. CHF of 2003. For the most part, this can be attributed to the exceptional weather conditions of 2003 (FOAG 2004). A combination of high temperatures and low precipitation was essential here, in particular the very dry weather during springtime. Our much lower result for average changes indicates once more the importance of further research on future weather extremes under climate change.

In our analysis, even if price changes for raw irrigation water are large, impacts are humble, because price levels for raw water and the cost share in agricultural production are extremely low. Hence, the low welfare effect and the high price changes for raw water can both be explained by the fact that there is no need for agricultural producers to change their decisions, even if prices change. Moreover, the small macro-economic importance of plant production further limits the significance of the impacts.

Table 26: Impacts of changes in the irrigation water resource
(% deviation from reference scenario in 2060)

	RCP3PD			**A1B**			**A2**		
	Lower	**Medium**	Upper	Lower	**Medium**	Upper	Lower	**Medium**	Upper
Raw water prices	6.7	**73.7**	139.3	37.9	**107.0**	206.2	31.2	**98.5**	195.4
Raw water consumption									
Grains and oil seeds	-0.5	**-4.5**	-7.7	-2.5	**-6.2**	-10.5	-2.1	**-5.8**	-10.1
Other crops	-0.6	**-5.1**	-8.7	-2.8	**-7.0**	-11.7	-2.4	**-6.5**	-11.3
Production									
Grains and oil seeds	0.0	**-0.2**	-0.3	-0.1	**-0.2**	-0.4	-0.1	**-0.2**	-0.4
Other crops	0.0	**-0.1**	-0.1	0.0	**-0.1**	-0.2	0.0	**-0.1**	-0.2
Welfare	0.00	**0.00**	0.00	0.00	**0.00**	0.00	0.00	**0.00**	0.00

3.5 Agriculture, forestry, biodiversity

3.5.1 Literature-based assessment

3.5.1.1 Exposure

The living conditions of species are greatly influenced by climate parameters at the respective site. With a changing climate, new species may migrate into Swiss habitats, thus further changing living conditions in the affected ecosystems, while other species may partly be displaced or even become extinct. For agriculture and forestry, in contrast, the choice of cultivated species falls to farmers and forest officials and is part of adaptation to climate change (see section 3.5.1.4). The exposure of the three sectors agriculture, forestry and biodiversity to climate change in Switzerland is determined by an increase in mean temperature, changes in precipitation patterns and changes in weather extremes.

An increase in mean temperature causes an increase in the length of vegetation periods and thus potentially higher crop and timber yields, but also an increase in evapotranspiration and a higher water demand. Concerning forestry, an increase in mean temperature is likely to shift the timberline upwards. For an increase of 2°C, an upward shift of 300 meters of altitude is assumed. On the other hand, mild winters can lead to improved living conditions for pests, which in turn causes a reduction in yields.

For Switzerland, projected changes in precipitation patterns encompass a decrease in summer precipitation and an increase in winter precipitation (CH2011). These changes in precipitation patterns can cause changes in seasonal water availability. A decrease in summer precipitation can have negative effects on water availability, e.g. for irrigation, as analyzed in Section 3.4.2. Furthermore, drier conditions in summer are expected to cause negative effects on timber growth (Swiss Confederation 2012a). Also, the risk of forest fires is likely to increase.

Extreme weather events (such as summer warm spells) with potentially adverse effects on the three sectors examined here are likely to occur more frequently in the future (CH2011). Changes in weather extremes relevant for forestry are e.g. storms likely becoming stronger, which can cause damage to forest stands. Damaged forest stands are more vulnerable to pests, such as bark beetles. Bark beetles can therefore encounter improved living-conditions and cause destruction and reduced timber value. Moreover, changing climatic conditions can cause changes in site suitability for different plants.

Regarding the specific exposure of biodiversity, the projected increase in mean temperature of about 2 to 4.5°C (depending on region, season and emissions scenario) for Switzerland (CH2011) lies outside the variability of the last centuries, which makes it difficult to project responses of ecosystems. It is known, however, that climate change affects the natural range of species, site properties and the functioning of ecosystems (Swiss Confederation 2014). Next to the absolute change in average temperatures, a fast rate of change is problematic, because it can overstrain the natural ability of ecosystems and species to adapt.

3.5.1.2 Sensitivity

<u>Agriculture</u>

Agricultural production is exposed to a variety of changes originating from climatic conditions and, at the same time, from management practices. Thus, tracing impacts back to changing climatic conditions is a difficult matter (Swiss Academies of Arts and Sciences 2016). However, by applying model chains combining climate projections with crop models, the relation between climatic conditions and yields can be revealed, and the agricultural sector’s sensitivity resulting from a changing climate estimated (Rosenzweig et al. 2014).

In Switzerland, agriculture accounts for less than one percent of Swiss GDP, thus on a macroeconomic scale, the effects of a changing climate on this sector are of minor significance. On a sectoral level, however, a substantial impact could arise from international price effects. Impacts of climate change on agriculture vary regionally; world regions such as South America and parts of Asia are more exposed and more vulnerable to negative impacts of climate change than Switzerland, which is going to influence world market prices for certain agricultural commodities. As one third of Switzerland’s agricultural imports originate from these world regions, this could be significant for Switzerland, e.g. in the form of higher prices for agricultural imports (INFRAS et al. 2007) and thus shifts in agricultural terms of trade.

Forestry

About 30% of the surface of Switzerland is covered by forests. In the first part of the adaptation strategy (Swiss Confederation 2012a), the dimension of climate sensitive forest sites is estimated at 50’000 ha, which corresponds to roughly 3.6% of the total forest area in Switzerland. Thus, forests in these areas tend to suffer from overly dry conditions, which make it more difficult to grow timber. This is of economic importance on a sectoral level. However, the last decades witnessed a shift in forestry. On the one hand, wood production is no longer as profitable as it used to be and is therefore conducted less. On the other hand, forests are favoured as parts of protected areas and have increasingly been allocated to this purpose (Frehner 2005).

A main source of sensitivity in forestry is the length of planning periods. To optimize planning, responses of different tree species to changes in climatic circumstances need to be known well in advance. Switzerland’s forests consist inter alia of spruce, beech, pine, oak and linden. It is known that spruce is quite sensitive to an increase in temperature, and therefore its population is projected to decrease. The population of beech is expected to decrease in lower altitudes and increase in higher altitudes, while pine, oak and linden benefit from increasing temperatures (Kantonsforstamt Sankt Gallen 2008).

Biodiversity

The Federal Councils strategy on biodiversity in Switzerland (Swiss Confederation 2012b) proclaims the long-term goal to preserve diversity, resilience and ecosystem services. The uncertainty concerning ecosystem responses to climate change puts this goal in danger, which characterizes the sensitivity of this sector. The first part of the adaptation strategy (Swiss Confederation 2012a) identifies five areas of action for biodiversity management in Switzerland, which result directly from the sector’s sensitivity: reduction of the genetic pool of local species, changing site suitability for different species, increase of invasive species, danger for connections between biotopes, and potential challenges for ecosystem services.

3.5.1.3 Impacts without adaptation

Agriculture

The studies examined for this report agree on a rather high probability for positive impacts of climate change on Swiss agriculture. The Federal Council’s adaptation strategy (Swiss Confederation 2012a) identifies six areas associated with impacts of a changing climate on this sector: site suitability, heavy rainfalls, drought, heat stress, pests, and price volatility.

Site suitability for grain maize and winter wheat has been analyzed by Holzkämper et al. 2015: An increase in suitable sites for grain maize and a decrease in suitable sites for winter wheat resulted. The authors note that these findings may assist short-term adaptation to climate change planning, but at the same time emphasize that more research in this area is needed to gain more knowledge about the CC impacts on site suitability in Switzerland. Further research related to site suitability was presented in the CH2014-Impacts report, where the climatic suitability for viticulture was assessed: An increase in mean temperature in spring and summer would allow to grow a larger variety of grapes, especially in Northern Switzerland. This was deduced using the Huglin index, which suggests an increase in climatic suitability for viticulture in Switzerland.

Droughts are related to water availability, which is modelled in Section 3.4.2.

Heat stress is e.g. analyzed in the CH2014-Impacts report for cattle, by projecting the temperature-humidity index THI for the three emission scenarios RCP3PD, A1B, and A2. Results suggest that in the future, the performance of dairy cows is likely to suffer under heat stress. Considering the scale of Swiss milk production (550'000 cows producing over 4 million tonnes of milk yearly)[9], this result might well be of economic importance. However, in order to quantify the economic impact, projections for milk production in each emissions scenario are needed, which calls for further research in this area.

Regarding pests, the third study in the CH2014-Impacts report focuses on pest management for apple production. It projects a substantially increased risk of apple pests for the emission scenarios A1B and A2 for 2085. Also here, further research is necessary to enable an economic assessment of this effect.

The last area identified in the Federal Council's adaptation strategy is related to price volatility. As noted above, CC induced international price effects for agricultural commodities could be of economic importance. Several studies offer a suitable quantitative basis for this issue (Nelson et al. 2014, Wiebe et al. 2015).

The cantonal case study on Aargau (Ernst Basler + Partner et al. 2013) defines three indicators to quantify impacts of climate change. With these indicators, a rough magnitude for direct benefits and costs is derived: Two emission scenarios are used, 2060-weak and 2060-strong, which correspond to RCP2.6 (median values) and A1B (combination of temperature and precipitation extreme values). The scenario 2060-weak projects an average increase in yields of 4% per year, while the scenario 2060-strong projects an average decrease in yields of 6% per year. These are considered to be rough estimates. The study accounts for direct impacts of climate change only, including financial losses due to natural hazards (e.g. estimated as hail insurance payments). International and other price effects are not considered. Yet, price effects could be especially important both for consumers and sectoral competitiveness.

The cantonal case study on Uri (INFRAS/Egli Engineering 2014b) defines hazards affecting agriculture and derives expected changes in production costs and yields for each of them. These changes are calculated using a linear projection of today's production costs and yields. According to the authors, the consequences

9 https://www.bfs.admin.ch/bfs/de/home/statistiken/kataloge-datenbanken/publikationen.assetdetail.871-1600.html

of non-linear relations are covered by the uncertainty range. The study suggests that for Uri, net reduction in costs of 0.6 million CHF per year for the scenario 2060-weak and 1 million CHF per year for the scenario 2060-strong are expected. Again, these are rough estimates.

The cantonal case study on Graubünden (Bergwelten 21/GRF Davos 2015) takes a similar approach. Expected changes in revenue are derived using a linear projection of today's values, depending on four climatic hazards: changes in mean temperature, frost, drought, and floods. Notable is that droughts are projected to have the most severe negative impact on agricultural production, varying from -0.04 to -0.1 Mio. CHF compared to today's production. Also for forestry, droughts are projected to cause losses of the same magnitude. On the other hand, changes in mean temperature are projected to have mainly positive effects on forestry, and countervailing effects on agriculture.

Further, the cantonal case study on Fribourg (Ernst Basler + Partner/CSD Ingenieurs 2015) estimates a yield increase of 14% due to higher mean temperatures and changes in precipitation patterns. Regarding forestry, this case study finds the negative impacts to be predominant, caused by improved living conditions for pests and extreme events. Positive effects can be expected from the prolonged vegetation periods. The case study for the Canton Ticino (IFEC et al. 2016) finds the impacts on agriculture to be moderate, and for forestry, moderate – or slightly negative – as well. For the Canton Geneva, INFRAS et al. 2015 estimate benefits of a changing climate of up to 62 Mio. CHF for agriculture in the year 2060.

Forestry

The CH2014-Impacts report examines inter alia forest dynamics, growth of Norway spruce and changing infestation potential by bark beetles. Concerning forest dynamics, the authors expect only minor changes until 2050. Until the end of the century, however, they project major changes for some emission scenarios. Growth of Norway spruce is projected to be strongly reduced if mean temperature increases by 2 to 3°C (depending on the region) and if precipitation is less than 600 mm during growing season. Both these states are likely for 2 out of 3 analyzed emission scenarios. Furthermore, forests will become more susceptible to bark beetle attacks under warmer and drier conditions. The report presents important insights into different aspects of Swiss forestry under climate change, both qualitatively and quantitatively. However, no economic effects have been quantified.

Biodiversity

Impacts on biodiversity are analysed qualitatively in several publications. Ecoplan/Sigmaplan 2007 indicate species loss due to a lack of adaptive capacity and immigration of foreign plant and animal species from warmer regions. These two processes can cause Swiss biodiversity to become more similar to that of southern regions. The cantonal case study on Aargau takes into consideration that species distribution is likely to change, and also here native and moisture-loving species are projected to decrease. The study furthermore identifies insects as 'winners of climate change', because warmer climates favor reproduction of certain insects. The cantonal case study on Uri provides further insights for biodiversity of the alpine altitudinal belt. For this region, strong negative effects are expected.

The case study on Basel-Stadt is concerned with urban biodiversity. For this region, an important insight is that the impact of socioeconomic factors is likely to be much larger than the impact of climate change. This insight could be relevant for some other regions as well. The cantonal case study on Fribourg finds that the impacts on wetlands and aquatic systems are likely to be most severe and result in a decrease of species diversity. Similar results are found in the case study on Ticino, additionally proposing negative impacts on cold loving species of the alpine belt.

The cantonal case study on Graubünden presents an approach of economic evaluation using linear projections for the year 2060 of today's costs and benefits of the impacts of different climatic hazards on changes in gene variety, changes in species, and changes in habitats.

The CH2014-impacts report analyzes prevalence of birds and vascular plants quantitatively. The results are in line with the findings discussed qualitatively in the cantonal case studies. In addition, it is found that low-elevation cantons will be among the most highly impacted by climate-driven changes in species distribution.

3.5.1.4 Adaptation

Agriculture

Farmers need to react constantly to weather conditions as well as changes in the market environment. With the notable exception of viticulture and fruit trees, crops can be changed within rather short periods. Change is thus an inherent aspect of the agricultural system. Adaptation to climate change will be entangled in this change, and it will have to occur over time frames that are rather long by the standards of the agricultural sector. This will make it difficult to clearly distinguish adaptation to climate change from other developments in the sector. It is thus unrealistic to consider any scenario without adaption for the agricultural sector. As a consequence, a distinction between impacts with and without adaptation becomes meaningless to a certain extent.

Research suggests different approaches to optimize production in Switzerland in the presence of climate change. One approach is concerned with early consideration of future climatic circumstances in the selection and cultivation of crops and livestock (Swiss Confederation 2014). A second approach suggests changes in pest management, as analyzed in CH2014-Impacts for apple production. A third approach highlights the importance of responding to higher frequencies of periods of water scarcity by a careful allocation of resources. Water-saving production systems and better forms of water usage can be promoted (Swiss Confederation 2014).

Forestry

Concerning forestry, the Federal Council's strategy for adaptation to climate change in Switzerland (Swiss Confederation 2014) lists three fields of adaptation:

- early regeneration of protective forests (where need for action exists),
- improvement of resilience and adaptive capacity in climate sensitive areas,
- improvement of resilience and adaptive capacity in regeneration areas.

To improve the resilience and adaptive capacity of forests, measures such as an adequate choice of tree species and tree care are recommended. Better knowledge about resilience and adaptive capacity is derived from research and monitoring programs of forest development. Corresponding to this, 'Forests and Climate Change' is an important research program. It is concerned with impacts of a changing climate on forests and forestry and investigates adaptation measures to ensure forest services.

Biodiversity

With respect to biodiversity, the strategy for adaptation (Swiss Confederation 2014) describes fields of adaptation such as risk management for particularly affected populations (e.g. with respect to water availability), standards for green and open spaces, protection and regeneration of peat and organic soils, and early identification of invasive alien species. Further, the SCNAT 2008 presents recommendations for action to optimize synergies and minimize conflicts between biodiversity and climate.

3.5.1.5 Impacts with adaptation

Agriculture

Swiss Confederation 2014 identifies three approaches for adaptation in agriculture: adjustment of crop and livestock choice, changes in pest management, and allocating resources under water scarcity. Regarding the first adaptation measure, impact studies which explicitly assume that choices are made optimally are still limited in number. Calanca et al. 2005 state that yield increases of C3-plants (e.g. wheat) resp. C4-plants (e.g. maize) could amount up to 30 % resp. 10 %. These results suggest that there is potential to increase total yields when adjusting the crop choice optimally. However, an encompassing quantification which takes this adaptation measure fully into account is still missing. Further, also for the second type of adaptation measures, changes in pest management, studies quantifying impacts given the application of this measure are not yet available for Switzerland.

The third approach to adaptation, allocating resources under water scarcity, has been analyzed by Lehmann et al. 2013 and Faust et al. 2015. Lehmann et al. 2013 take optimal irrigation and nitrogen fertilization for winterwheat and grain maize production under climate change as given and find negative impacts between 7% and 25% for the farmer's certainty equivalent (emission scenario A1B, year 2050). Faust et al. 2015 analyze, inter alia, the impact of changes in water availability on Swiss agriculture using a CGE modelling approach for different degrees of sector-specific adaptation. Raw water is therefore introduced as a production factor for irrigation in agriculture. The production price of raw water for irrigation is simulated to increase by 1631% and 251% depending on how easily agriculture can replace water by other inputs, which results in a welfare losses of 42.3 and 39.2 million USD respectively. The absolute level of these welfare losses is unimpressive. The remarkable variation between degrees of adaptation results from differences in the elasticity of substitution between land and irrigation water. Faust et al. 2015 therefore emphasize the importance to reduce water losses and, especially important for agriculture, to implement water-saving production systems that minimize the water intensity of production processes.

Concluding, impacts with adaptation for the sector agriculture have not been fully quantified so far, and therefore, an all-encompassing conclusion cannot be given. While positive effects can be expected with regard to crop suitability given optimal crop choice, negative effects are expected due to water scarcity, even with optimal irrigation patterns.

Forestry

For the forestry sector, a clear distinction between impacts with and without adaptation is also difficult. Despite this, the cantonal case studies for Aargau and Uri offer some insights concerning impacts with adaptation. In the cantonal case study for Aargau, it is assumed that measures ensuring tree species distribution suitable for future climatic conditions are incorporated. With this assumption, an economic quantification is carried out based on the three indicators yields, production costs and financial losses (e.g. through storm damages). Slightly positive economic effects result. A caveat of the analysis is that it assumes constant timber prices. In the cantonal case study for Uri, some impacts were qualitatively discussed and forced timber harvesting due to storms was quantitatively analyzed. The range of costs occurring as a result of forced harvesting is estimated between 600'000 CHF and 1'350'000 CHF per year.

Biodiversity

Biodiversity presents challenges with respect to differentiating between impacts with and without adaptation as well. These challenges mainly arise due to the large uncertainties mentioned above and the fact that valuation of biodiversity is a difficult task. Possibly due to these circumstances, we have not yet found any monetized estimates of clearly distinguished impacts with adaptation nor any valuation approaches for biodiversity in Switzerland.

To sum up, the three sectors presented in this section are projected to experience a variety of impacts caused by a changing climate due to their direct exposure to climatic conditions. Several of these impacts are considered to be substantial on a sectoral level, however, on a macroeconomic scale, relatively small. Furthermore, the data availability of quantified impacts is still limited.

3.5.2 Modeling and data

3.5.2.1 Impacts, adaptation measures and effects to be included in GEMINI-E3

Mostly for reasons of limited data availability for domestic impacts and an ambition to extend the analysis to cross-border influences, the focus for an implementation of agriculture in GEMINI-E3 is on international effects which can be expressed in changes in world market prices for agricultural commodities. For Switzerland, an increase in world market prices can lead to increasing prices for imports of agricultural imports and to an increase in competitiveness of agricultural commodities produced within Switzerland. -Impacts on forestry and biodiversity are not pursued further in the following analysis.

3.5.2.2 Knowledge base and data sources

Following the preceding argumentation, price deviations of agricultural commodities for both time scopes 2030 and 2060 for the three emission scenarios (RCP3PD, A1B, A2) are used as input for the CGE model. Several studies offer information about price deviations. Nelson et al. 2014 calculate price deviations of coarse grains, rice, oil seeds, sugar, and wheat for the emission scenario RCP8.5 in 2050. Rosenzweig et al. 2014 conduct a model intercomparison of the effects of all four RCP scenarios on maize, wheat, rice, and oil seeds, does however not model price effects. Wiebe et al. 2015 combine multiple climate and economic models to estimate the global and regional impacts of climate change on agricultural yields and prices, which makes it the only study reviewed that models different emission scenarios as well as price impacts for several crops. Thus, we use the price impacts derived in that study as data basis. The study's base year is 2005. Projections for four socioeconomic and climate scenarios are modelled: no climate change, SSP1-RCP4.5, SSP2-RCP6.0, and SSP3-RCP8.5. Prices are reported for 2030 and 2050, and the percent deviations for the different emission scenarios are calculated with no climate change values in 2030 and 2050 respectively as basis.

3.5.2.3 Model assumptions and parameters

To derive input data that is in line with the previous analysis in terms of emission scenarios and temporal scope, some data treatment is necessary. For the temporal scope 2030, price deviations from RCP6.0 are taken for all three emission scenarios, since this is the best estimate with respect to temperature change.

Price deviations for scenario RCP3PD in 2060 are derived by applying the following transformation rule to the projections with RCP4.5:

$$\Delta P_{2060}(RCP3PD) = \Delta P_{2030}(RCP4.5) + (\Delta P_{2050}(RCP4.5) - \Delta P_{2030}(RCP4.5)) / 2$$

Thus, we take the projection of RCP4.5 for 2040, derived by interpolation as indicator for the projection with emission scenario RCP3PD in 2060. This transformation can be justified by the fact that according to IPCC 2013, RCP4.5 implies approximately the same temperature change in 2040 as RCP3PD in 2060. This simplification builds again upon the assumption that the impacts on prices are mainly linearly correlated with temperature increases. Further, as an estimation for price deviations in scenarios A1B and A2 in 2060, a linear function is derived from temperature change and price deviations of RCP6.0 in 2050 and applied to temperature change in A1B and A2.

We choose Faust et al. 2012 as a reference study for the implementation into GEMINI-E3, including its sectoral structure, i.e. how agriculture is represented in GEMINI-E3. Faust et al. (2012) describe in a first step the general structure of agriculture in the GTAP data base. In a second step, weights of the structural elements for the Swiss economy are taken into account, and based on this, a modified structure of the definitive sub-sectors for the representation of agriculture in GEMINI-E3 is chosen.

Two main criteria are used to aggregate GTAP agricultural sectors to agricultural sub-sectors in GEMINI-E3 (see Table 27 and
Table 28): First, each sub-sector must be economically relevant. Second, we gather in the same sub-sectors the agricultural activities that will face similar climate change impacts according to existing studies.

We particularly focus on the crops with the largest expected changes. Concretely, we define a section ‘grains and oilseeds’, which includes wheat, coarse grains, rice, and oilseeds. Of these, wheat accounts for the largest part of agricultural imports, i.e. 10 % of total import[10]. We choose this aggregation also, because substitution between wheat, coarse grains, rice, and oilseeds are possible, but the group ‘grains and oilseeds’ as a whole is not easy to substitute away from.

For Switzerland, also fruit and vegetables are an important branch in agriculture[11], however no studies dealing with CC impacts on these could be found. Thus, fruits and vegetables become part of the “Other crops” sector, together with the GTAP sectors 6, 7 and 8. Further, the GTAP sectors 9, 10, 11, 12, and 14 are aggregated to ‘animal products and fishing’, and GTAP sector 13 remains forestry.

10 http://www.bfs.admin.ch/bfs/portal/en/index/news/publikationen.html?publicationID=7039

11 cf. ibid.

Table 27: Agricultural sectors in GTAP database

1	Paddy Rice	8	Crops n.e.c.
2	Wheat	9	Cattle, sheep, goats, horses
3	Cereal grain n.e.c.	10	Animal products n.e.c.
4	Vegetables, fruit, nuts	11	Raw milk
5	Oil seeds	12	Wool, silk-worm cocoons
6	Sugar cane, sugar beet	13	Forestry
7	Plant-based fibers	14	Fishing

Table 28: Agricultural sectors in GEMINI-E3

Sectors in GEMINI-E3		GTAP Sectors
7	Grains and oil seeds	1+2+3+5
8	Other crops	4+6+7+8
9	Animal	9+10+11+12+14
10	Forestry	13

Wiebe et al. 2015 model impacts on the crops coarse grains, rice, wheat, oilseeds, and sugar, with the first four being aggregated to the group 'grains and oil seeds'. The spatial aggregation is as follow:

- EU: Europe
- OECD: Canada, Australia, New Zealand
- USA: USA
- BRIC: Brazil, Former Soviet Union, India, China
- ROW: Middle East and North Africa, Other Latin America, South Asia, Southeast Asia, Sub-Saharan Africa

Thus, the regional classification matches GEMINI-E3's quite well (see Table 2). The price information for grains and oilseeds is given as percent deviations from no-climate change values for 2030 and 2060 for the above mentioned regions. 15 model runs were done by Wiebe et al. 2015 (3 climate models combined with 5 economic models); we take the lowest / highest value for lower / upper and the mean of the 15 model runs. The projections for 2060 that are used as input to GEMINI-E3 are displayed in Table 29.

In the RCP3PD medium scenario (i.e. modified RCP4.5), only moderate changes in both crop yields and prices are projected. The average price increase of grains and oilseeds over all regions in 2060 is 7%. When we include the full range for RCP3PD, the data varies from a 4% decline in prices (BRIC, lower) to an increase of 30% (OECD, upper). Second, in scenarios A1B medium and A2 medium (based on Wiebe et al. 2015 RCP6.0), yields are projected to decrease by 7% (median across crops, regions, and models relative to the baseline value in 2050), which causes an increase in prices of 12% on average. The increase in prices is most pronounced in the BRIC region with 16%, and least in the USA with 7%. The EU region lies slightly above the average price deviation. Again, including upper values increases the range of results for all regions, with price increases between 24% and 37%.

Table 29: Price deviations for grains and oil seeds
(% deviation from reference scenario in 2060; source: Wiebe et al. 2015)

	EU	OECD	USA	BRIC	ROW
RCP3PD					
medium	7.07	7.75	6.01	5.81	6.86
lower	1.28	-0.98	0.87	-3.58	0.33
upper	16.10	29.59	13.90	14.78	15.78
A1B					
medium	13.44	11.19	7.24	15.78	13.35
lower	2.69	0.62	0.80	4.83	4.27
upper	31.56	36.33	23.69	30.84	30.59
A2					
medium	13.30	11.07	7.17	15.61	13.21
lower	2.51	0.58	0.75	4.50	3.99
upper	32.00	36.84	24.01	30.84	31.02

3.5.3 Results

Results of the simulations for the sector agriculture are presented in two parts: first, considering the price effects only, and second, by combining price effects with changes in water runoff as elaborated in the water management section 0.

3.5.3.1 Price effects

The price changes presented above originate from productivity changes for grains and oilseeds production in the different world regions. As a consequence of these productivity changes, grains and oilseeds production declines in most regions (see Figure 6). On a global average, the decline is 3.4% for the A1B scenario. We concentrate on price effects of yield changes abroad, given also that quantitative information on yield changes for Switzerland is incomplete. For Switzerland, direct impacts on production are thus assumed to be zero in the context of this simulation. Still, production in Switzerland increases by about 4% for A1B and A2. This is due to the comparative productivity improvement that is implied by productivity reductions abroad.

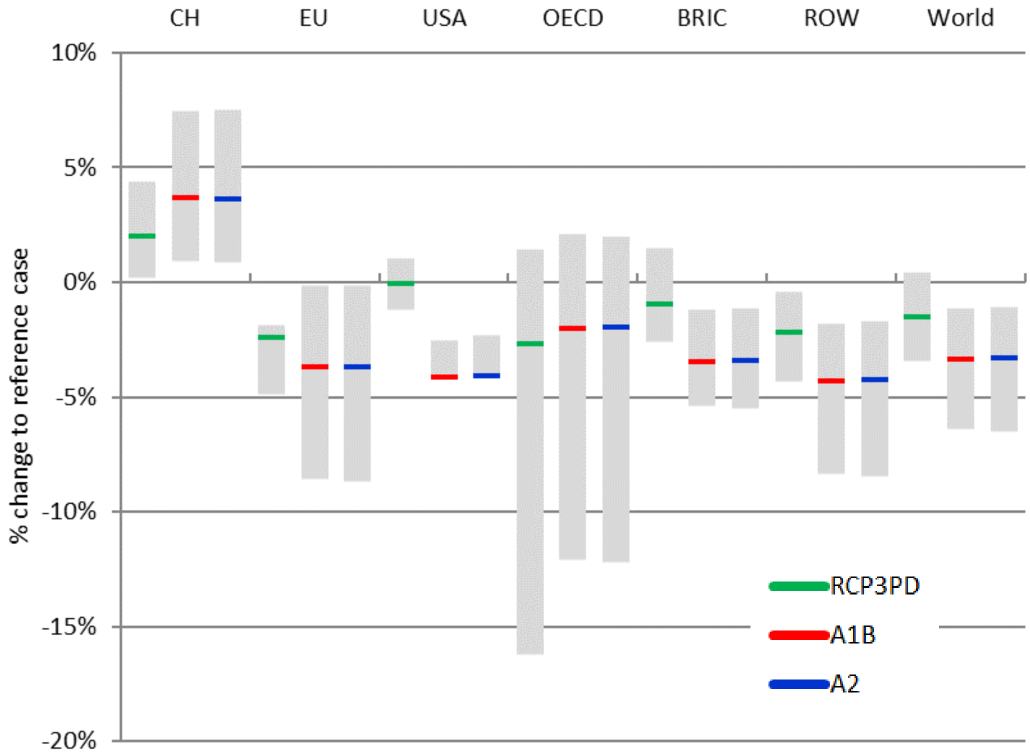


Figure 6: Production of grains and oilseeds under the three scenarios
(% deviation from reference scenario)

The changes in prices und quantities translate into welfare changes which are considerable at least for some parts of the world (see Figure 7). For example, the welfare reductions for BRIC and ROW countries are about 0.4% and 0.5% respectively in the A1B and A2 scenarios. The comparison of results across regions reflects the fact that developing and emerging economies rely to a much higher percentage on agriculture, including grains and oilseeds production, than industrialized countries. The projected welfare losses for Switzerland are 0.02% for A1B and A2 (up to 0.05% in the upper range, 0.01% for RCP3PD medium). They are the consequence not only of higher prices for imported grains and food products, but also of reduced export opportunities for goods and services other than grains under lower foreign purchasing power. When global consumption falls by a quarter percent or so (half a percent in the upper range), this affects Switzerland in many ways. Moreover, the effects simulated in this section are due to agricultural impacts only, while the total decline of foreign purchasing power may be much higher under unfavorable climate scenarios.

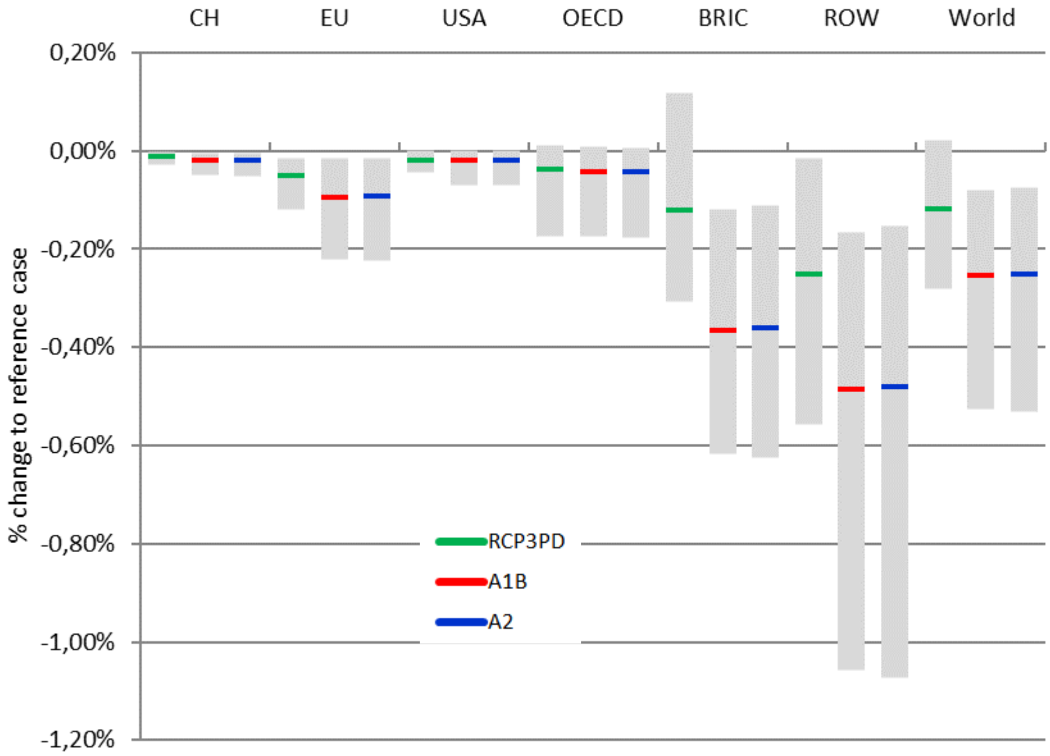


Figure 7: Regional welfare changes due to impacts on agriculture under the three scenarios
(% deviation from reference scenario)

3.5.3.2 Combined effects

The combination of price effects as taken from Wiebe et al. 2015 and the effects on water runoff, cf. section 0, results in production and welfare deviations only marginally different from those with price effects only. Compared to the previous section 3.5.3.1, the projected welfare loss for Switzerland for the scenario A1B medium remains at 0.02% (see Figure 9). This is to be expected, given that in section 0, the welfare impacts of runoff changes for irrigation are very small. However, Switzerland´s increased competitiveness for grains is somewhat reduced when we take into account the effects of increased irrigation water scarcity (see Figure 8).

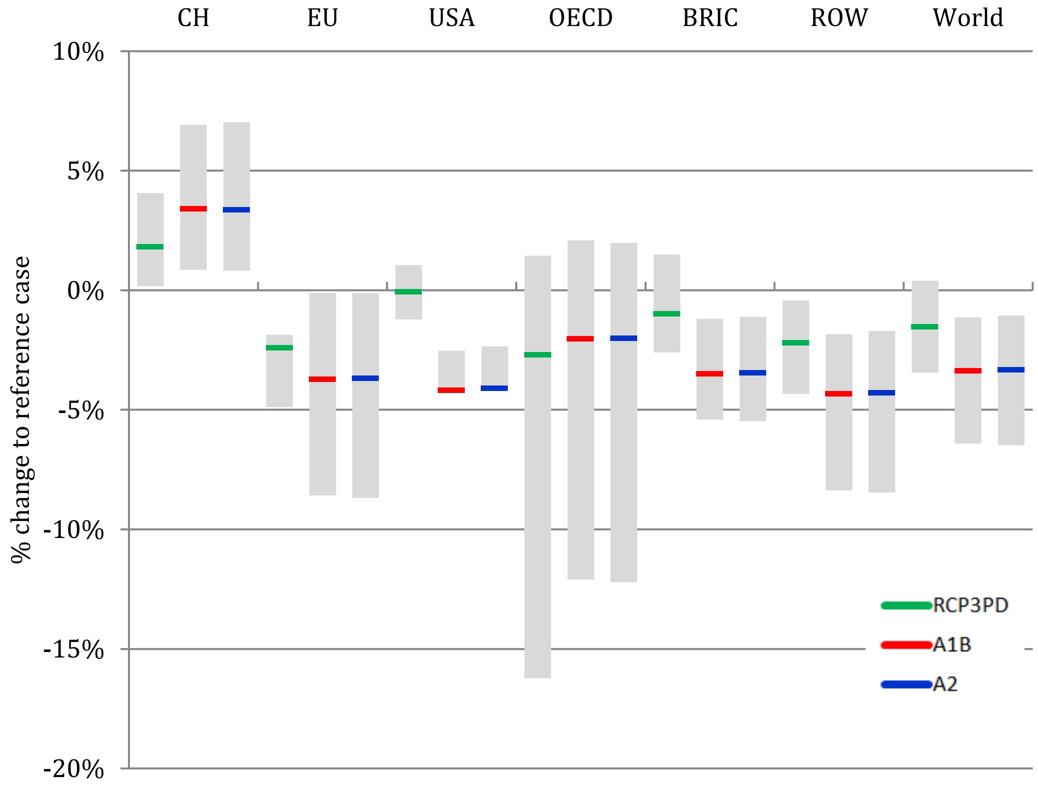


Figure 8: Production of grains and oilseeds under the three scenarios (combined effects)
(% deviation from reference scenario)

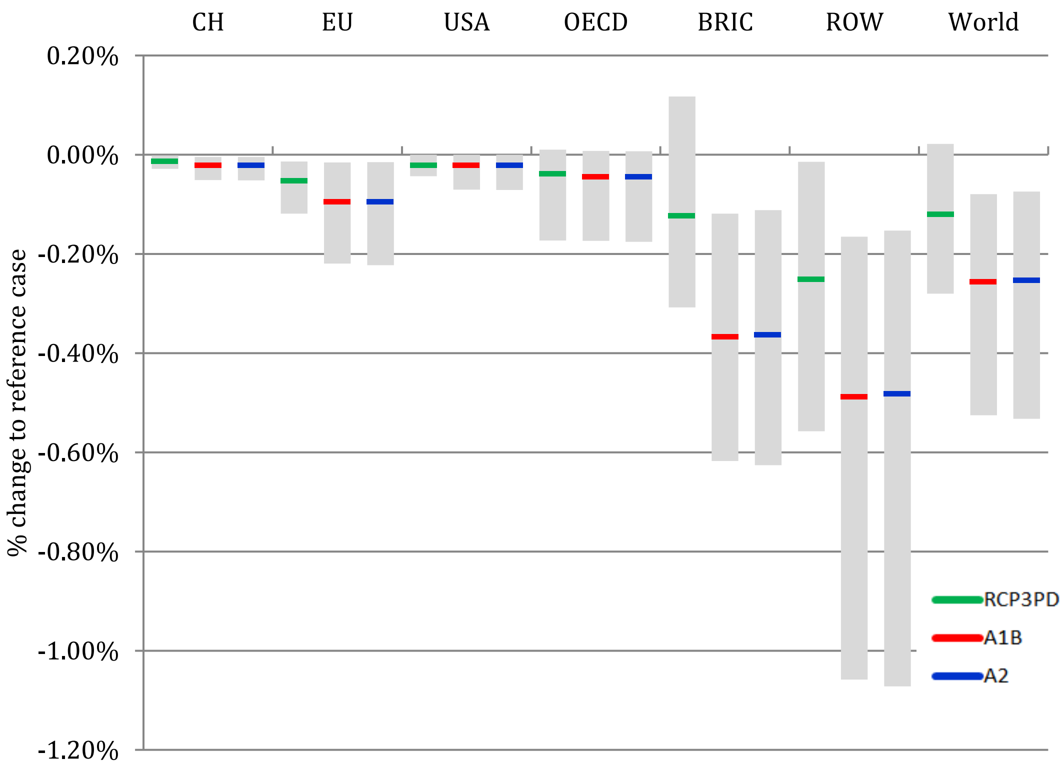


Figure 9: Regional welfare changes due to impacts on agriculture under the three scenarios (combined effects)
(% deviation from reference scenario)

3.6 Tourism

3.6.1 Literature-based assessment

3.6.1.1 Exposure

The tourism industry is highly dependent on weather and climate. Regarding climate change, winter tourism seems particularly affected. The increase in temperatures will decrease the annual mean snow depth by about 50% in 2060, and the number of snow-reliable ski areas could decrease by 29% in case of high greenhouse gas emissions and without snowmaking. Moreover, around 70% of the glacier ice volume is projected to melt by 2060 in climate scenario A1B (CH2014-Impacts). It will be more difficult to operate glacier ski runs because of changes in glacial routes and an increase in natural hazard (rockfalls) due to permafrost melting (NELAK 2013). On the other hand, tourism in general could benefit from a longer summer season. The emergence of new lakes in the alpine regions, the development of new via ferratas and trails due to glacier retreat and an improvement of the thermal comfort could make Switzerland more attractive (Matasci 2010; NELAK 2013). Tourism flows are also influenced by biodiversity and scenic beauty (Macagno et al. 2009). Glacier melting, new lakes, desertification, an upward move of the vegetation belt or even a change in forest ecosystems will modify landscapes, have an impact on scenic beauty, and hence on tourism.

3.6.1.2 Sensitivity

Tourism represents a significant part of the Swiss economy, accounting for about 3% of GDP and employing 4.4% of the total workforce in 2005, with high regional disparity (Baumann & Schiess 2008). In Graubünden, for instance, tourism accounts for around 3.3 billion Swiss CHF per year, just over 30% of GDP, and 30% of employment (Bergwelten 21/GRF Davos 2015). In Valais, it represented about 25% of GDP and 30% of employment in 2007 (Serquet & Rebetez 2011). Many ski resorts are going to face serious challenges, including a shorter business season (CH2014-Impacts). Koenig & Abegg 1997 estimated that 85% of all Swiss ski slopes are snow-reliable under current climate conditions, while this number would drop to 63% with a 2°C temperature rise. Several studies highlight the greater vulnerability of lower ski areas (Koenig & Abegg 1997, CH2014-Impacts, Müller & Weber 2007, Gonseth 2013, Abegg et al. 2013). Higher ski resorts might take advantage of the lack of snow in lower areas and thus increase their market share. Overall, winter tourism could even benefit from climate change. Indeed, since Switzerland has more snow-reliable ski fields than its neighbouring countries, international tourist flows may increase in Swiss ski resorts (Faust et al. 2012).

3.6.1.3 Impacts without adaptation

Meier 1998 assessed the economic impacts of climate change for tourism in Switzerland using several studies and estimated the cost for alpine tourism between CHF 1.8 and 2.3 billion in 2050, including between CHF 1.6 and 2.1 billion for winter tourism alone. This was derived from the simple assumption that value added would drop by 30%. Müller & Weber 2007 analyzed the consequences of climate change in Bernese Oberland, projecting an annual revenue loss of CHF 200 million during winter, and a gain of CHF 80 million during summer. The Ecoplan/Sigmaplan 2007 study uses a general equilibrium model to assess climate change costs for the tourism sector. The damages are expected to be low in 2050, with a loss of about CHF 120 million or 0.05% of GDP. However, uncertainties are high and increase over time. In 2100, the loss is estimated between 0% and 0.95% of GDP. Recent cantonal studies have provided new information about the cost of climate change at the cantonal level. For example in Graubünden, the reduction of snow cover could result in considerable losses for winter tourism, between CHF 12 and 25 million in 2060. On the other hand, frequent heat waves could benefit summer tourism, with an expected gain between CHF 1 and 5 million in 2060. Since the lowlands are too hot during heat waves, tourists seek refuge at higher altitudes (Bergwelten 21/GRF Davos 2015). The projected cost and gain are even stronger in Ticino. The change in precipitation regime could cost between CHF 24 and 97 million, while heat waves could generate a gain between CHF 11 and 45 million in 2060 (IFEC et al. 2016).

3.6.1.4 Adaptation

A wide range of adaptation measures exists in the ski industry. It includes e.g. artificial snowmaking, slope development and operational practices, ski conglomerates, revenue diversification, marketing incentives, government subsidies, weather insurance, and improved weather forecasting (Scott & McBoyle 2007). Gonseth 2013 has shown that higher snowmaking investments lower the sensitivity of skier visits to the natural snow conditions. Since the level of snowmaking coverage is low on average, it provides a significant opportunity for the Swiss ski industry to reduce its vulnerability to climate change. However, snowmaking requires important amounts of water and energy, and its economic and technical viability is not ensured in a future warmer climate.

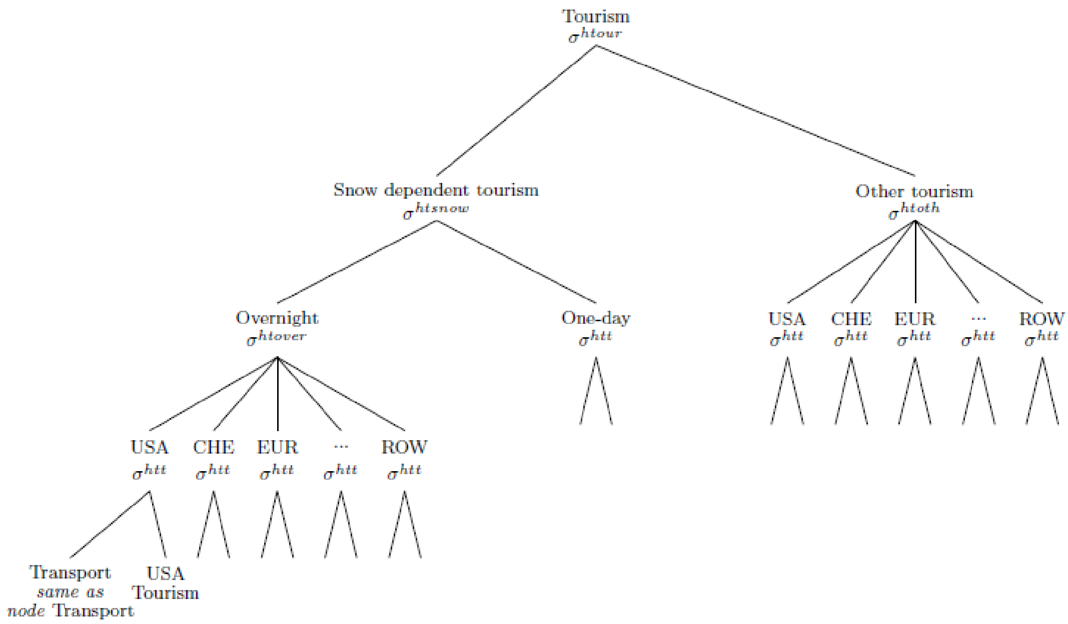
Another adaptation measure in alpine regions is the promotion of summer tourism. Although economic and social feasibility barriers are important impediments to adaptation, the process can be facilitated with better information, good governance and possibly financial support (Matasci et al. 2014).

3.6.1.5 Impacts with adaptation

Adaptation significantly reduces the costs of climate change for the Swiss tourism industry. Müller & Weber 2007 estimate that adaptation measures could save about 50 million CHF annually in the Bernese Oberland. The Faust et al. 2012 study on modeling adaptation in a CGE model shows that climate change has a positive impact for Swiss tourism if adaptation and, more importantly, stronger climate change impacts in competing foreign destinations, are taken into account. A welfare gain of 83 million CHF in 2050 is estimated. Adaptation enables to save 137 million CHF and costs 7.9 million CHF for lower ski areas and 56.8 million CHF for higher ski areas, including respectively 4 million CHF and 39 million CHF for artificial snowmaking.

3.6.2 Modeling and data

Faust et al. 2012 performed a detailed study of the climate change impacts on winter tourism using GEMINI-E3. They disaggregated total tourism into three sectors: “winter overnight tourism”, “one-day winter tourism” and “other forms of tourism”. We build on their work, keeping the same representation. The tourism consumption function is shown in Figure 10. We assume that consumers can substitute one type of tourism by another, subject to an elasticity of substitution.



Elasticities of substitution		
Snow dependent and other tourism	σ^{htour}	0.7
Overnight and one-day tourism	σ^{hsnowr}	0.5
Domestic and foreign tourism (overnight)	σ^{htover}	3
Domestic and foreign tourism (other tourism)	σ^{htoth}	3
Transport and other touristic demand	σ^{htt}	0.2

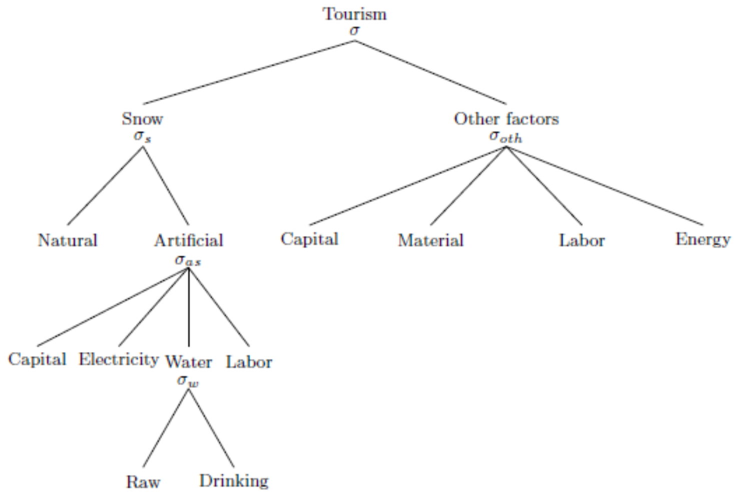
Figure 10: Nested CES tourism consumption function and elasticities of substitution in GEMINI-E3

Few scientific publications assess the climate change impacts on scenic beauty in Switzerland. Consequently, we do not study these impacts due to a lack of data and difficulties to include them in a CGE framework.

3.6.2.1 Winter tourism

The “winter overnight tourism” sector represents skiers spending one or several nights in a ski resort. A consumer can take a ski trip in any of the regions included in GEMINI-E3. The “one-day winter tourism” sector represents skiers spending only one day in a ski resort. In the model, only Swiss agents consume this good, because the respective consumption of foreign residents is almost negligible. The winter tourism sectors are calibrated based on the Swiss Tourism Satellite Account 2008.

The production function of the winter tourism sectors is presented in Figure 11. To adapt to the decrease in natural snow endowment, the sectors can either produce more artificial snow or substitute other production factors. This represents the sectors capacity to exploit ski resorts with less snow, by investing in ski slopes operation and maintenance and in the modernization of transport facility. We assume that these adaptation measures will still be available until 2060.



Elasticities of substitution		
Snow and other factors	Σ	0.1
Natural and artificial snow (overnight)	σ_s	0.9
Natural and artificial snow (one-day)	σ_s	0.45
Among inputs used to produce artificial snow	σ_{as}	0.3
Raw and drinking water	σ_w	0.5

Figure 11: Nested CES winter tourism production function and elasticities of substitution in GEMINI-E3

The “one-day winter tourism” sector is more vulnerable to a snow decrease than “the overnight tourism” sector. Indeed, one-day skiers mainly go to close to home ski resorts, which are located at lower altitudes and have a limited adaptation capacity (Faust et al. 2012). This greater vulnerability is represented in GEMINI-E3 through a lower elasticity of substitution between natural and artificial snow for the “one-day winter tourism” sector.

Winter tourism sectors use natural snow as a production factor. We calculate the variation in snow endowment using the variable “Fractional Snow Cover” from ENSEMBLES[12] and CORDEX projects[13]. These projects provide results of Regional Climate Models (RCM) simulations, respectively for IPCC SRES and RCP scenarios. We get monthly data until 2100 at a regional scale from 4 RCMs for the A1B scenario (C4I, DMI, KNMI, SMHI) and 2 RCMS for the RCP3PD scenario (KNMI, SMHI). We extract data for Switzerland, Germany, Austria, France and Italy and aggregate them to GEMINI-E3 regions (Switzerland and Europe). To do that, each point of the grid is weighted according to the length of ski runs (weights calculated by Faust et al. 2012). For Switzerland, we also distinguish between one-day and overnight tourists. While overnight skiers prefer higher altitude remote regions, one-day skiers mainly go to ski resorts that are close to cities, as illustrated in Figure 12 and Figure 13. We assume that the regional weights are constant in time, i.e. we do not consider adaptation measures such as closing, expanding or opening ski resorts.

12 http://ensembles-eu.metoffice.com/data.html

13 http://www.cordex.org/

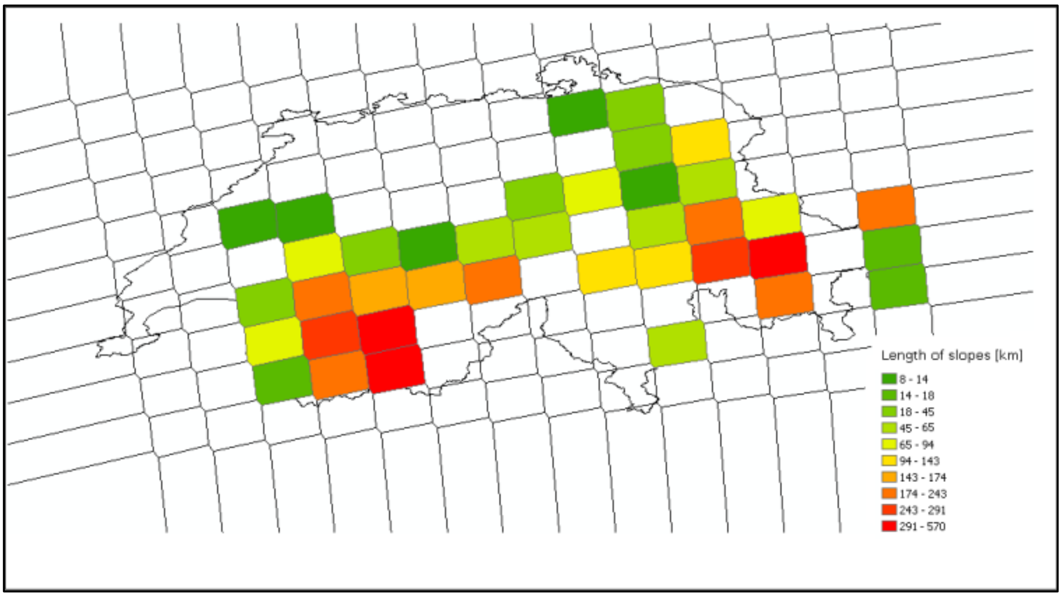


Figure 12: Regional weights used in the winter overnight tourism sector
(source: Faust et al. 2012)

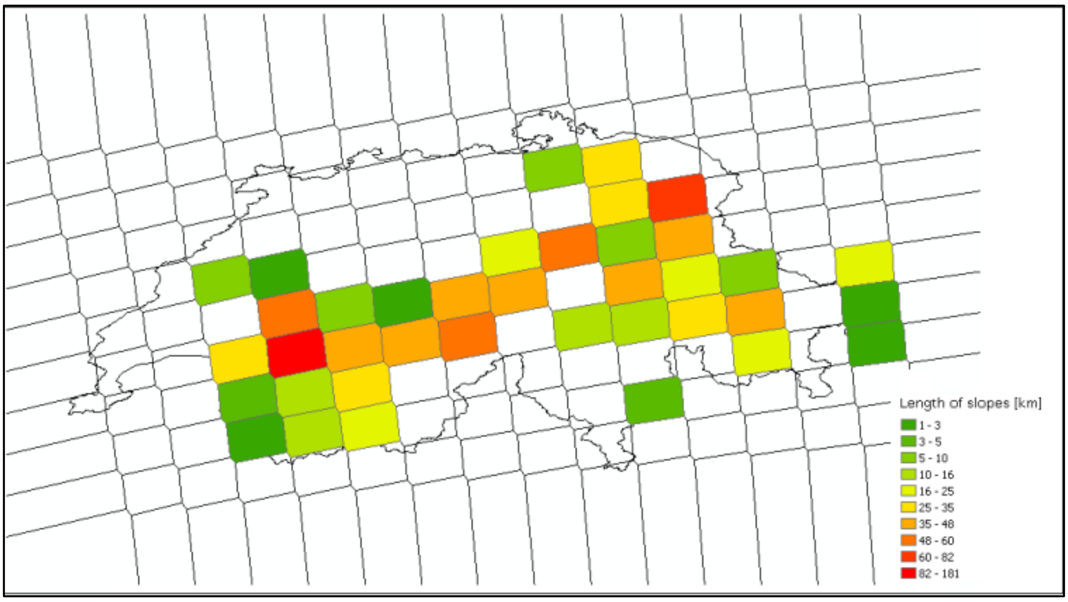


Figure 13: Regional weights used in the one-day winter tourism sector
(source: Faust et al. 2012)

Then, we aggregate monthly snow cover into annual data, giving weights to winter season months based on the distribution of ski lift revenue (Faust et al. 2012). We assume that these weights remain constant.

Table 30: Monthly weights in the winter tourism sector
(source: Faust et al. 2012)

November	December	January	February	March	April
0.03	0.17	0.25	0.35	0.15	0.05

Once the regional and time aggregation are done, we get the annual fractional snow cover for Switzerland (winter overnight and one-day tourism) and Europe for each RCM and scenario. Next, we calculate the snow cover variations compared to the reference year 2010. For example, for winter overnight tourism (WOT) in Switzerland, for model C4I and scenario A1B, we have:

$$\%\,Var\;FNS(CH\;WOT, A1B\;C4I, Year) = \frac{FNS(CH\;WOT, A1B\;C4I, Year) - FNS(CH\;WOT, A1B\;C4I, 2010)}{FNS(CH\;WOT, A1B\;C4I, 2010)}$$

where *FNS* stands for the fractional snow cover. The results for 2030, 2050, 2070 and 2090 are presented in the following figures.

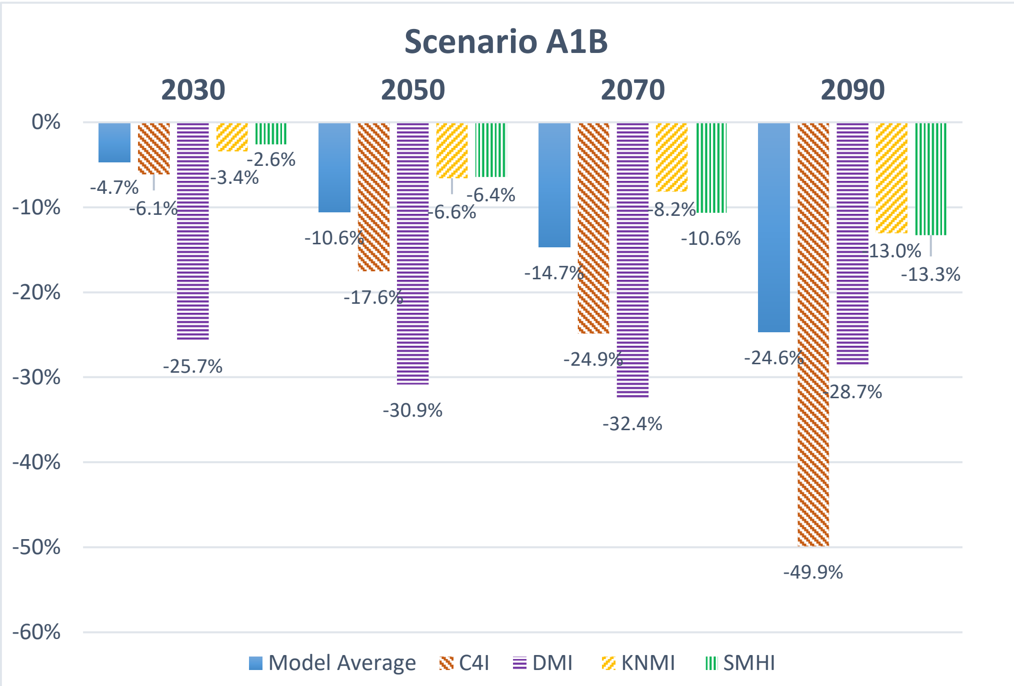


Figure 14: Snow cover variation of the Swiss winter overnight tourism sector with respect to 2010 under the A1B scenario

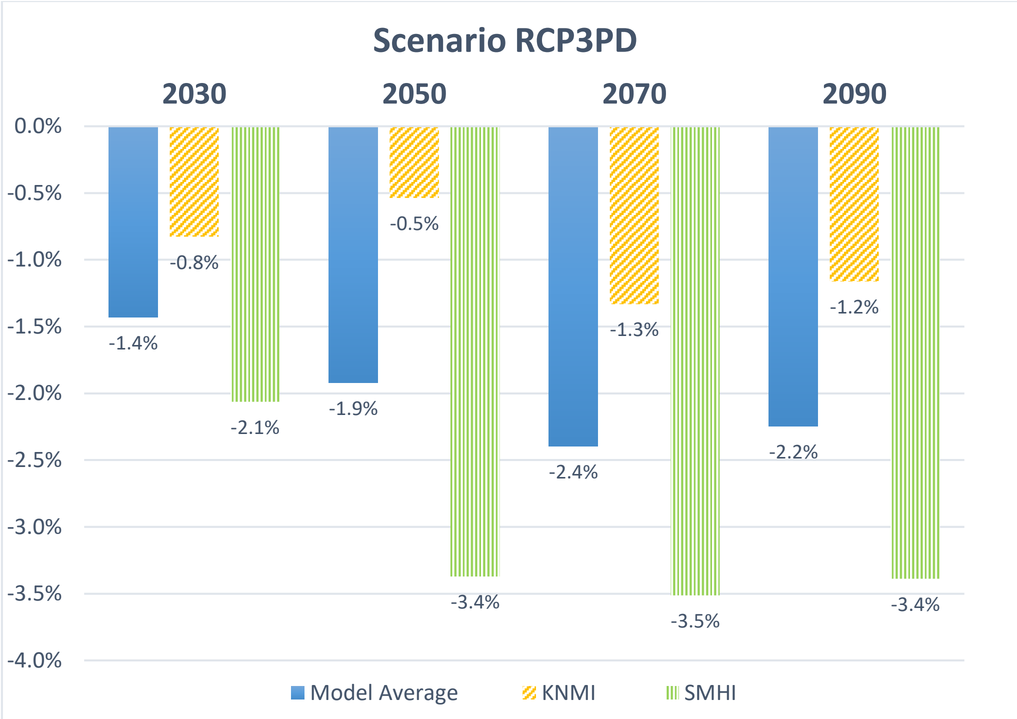


Figure 15: Snow cover variation of the Swiss winter overnight tourism sector compared to 2010 under the RCP3PD Scenario

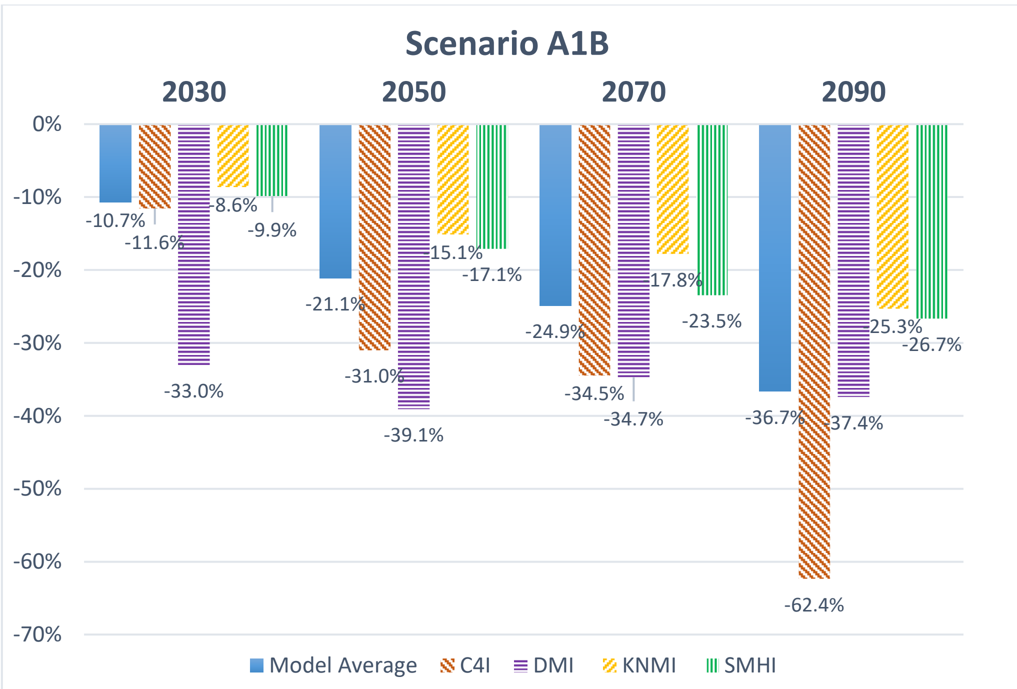


Figure 16: Snow cover variation of the Swiss one-day winter tourism sector with respect to 2010 under the A1B scenario

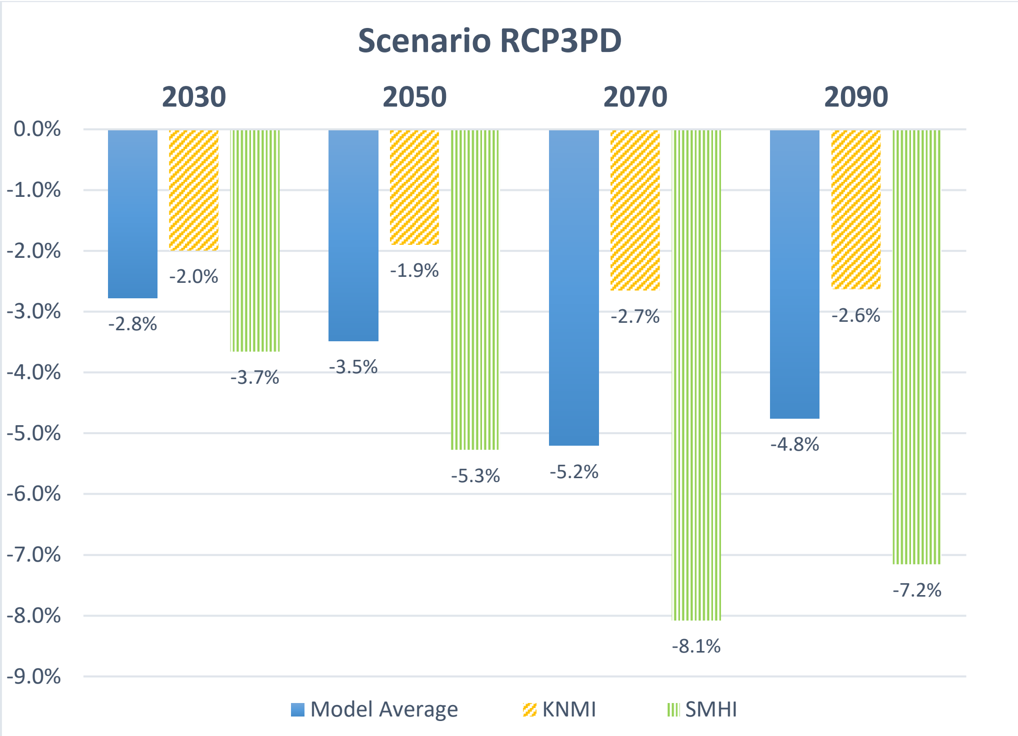


Figure 17: Snow cover variation of the Swiss one-day winter tourism sector with respect to 2010 under the RCP3PD scenario

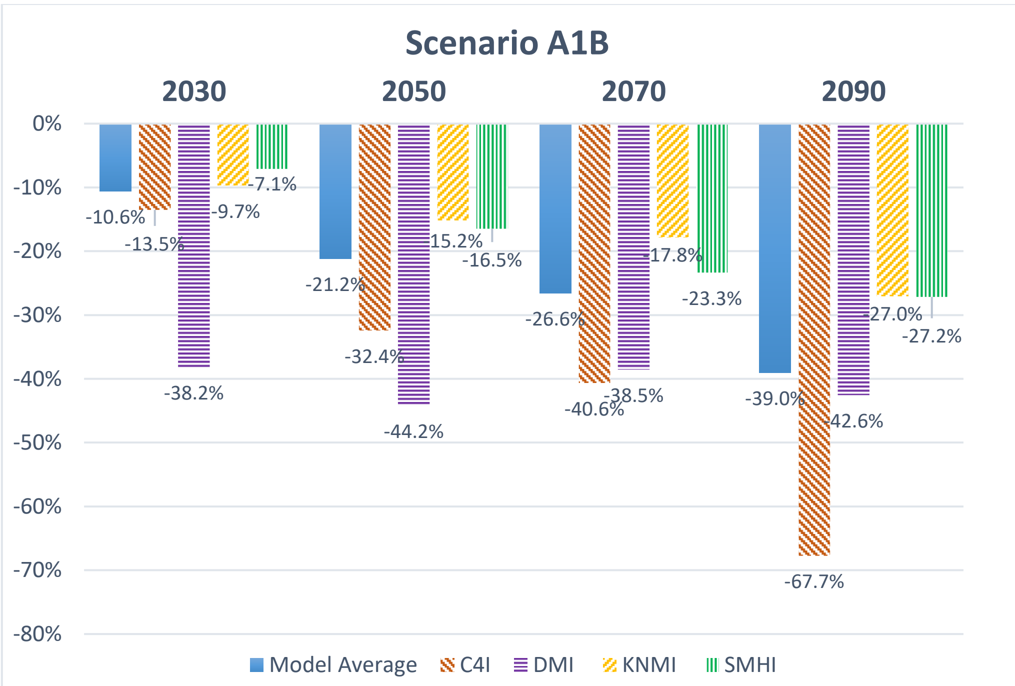


Figure 18: Snow cover variation in Europe (excluding CH) with respect to 2010 under the A1B scenario

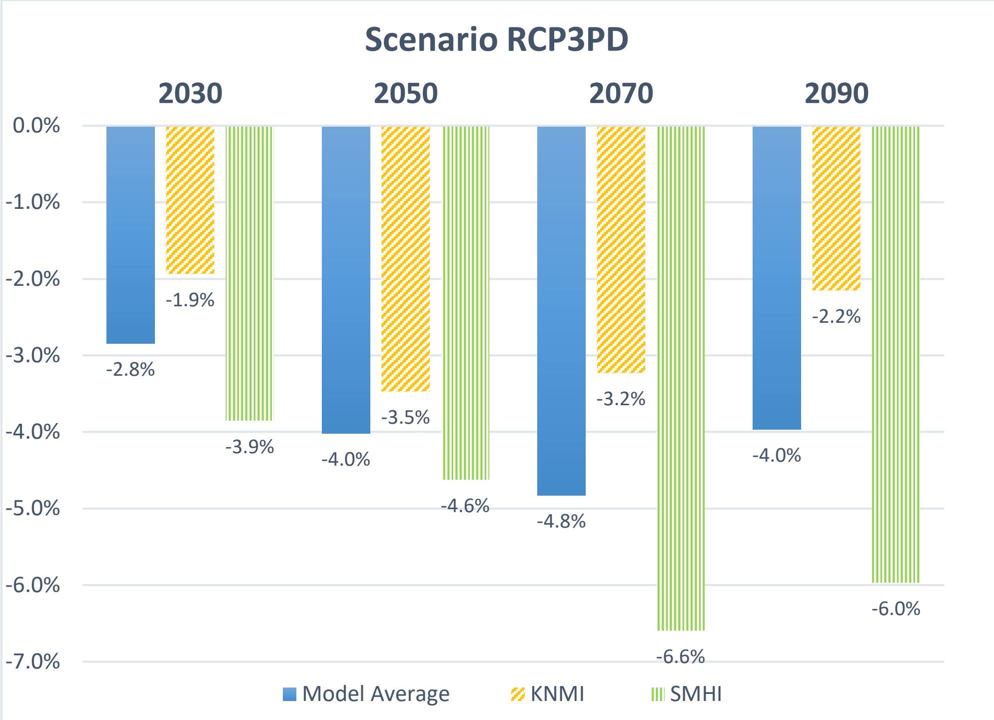


Figure 19: Snow cover variation in Europe (excluding CH) with respect to 2010 under the RCP3PD scenario

The natural snow resource is given an economic value based on results obtained in Gonseth 2013. He analyzes the marginal effects of snow conditions on skiers visits and hotel overnight stays at the ski resort level. We use econometric estimates of these effects to extrapolate, for the two Swiss winter tourism segments, the seasonal profit that is generated on average under natural snow conditions. We mainly use data provided by the Swiss Federal Statistical Office (FSO 2008). More information about the methods and data used are available in Faust et al. 2012 and Gonseth 2013.

3.6.2.2 Summer tourism

As Faust et al. 2012 show that international effects might have a greater impact on winter tourism than domestic effects of climate change, we expand their analysis to investigate the international effects on summer tourism.

Model for deriving input data to GEMINI-E3: In order to model the variations in tourism flows, we use the Hamburg Tourism Model (HTM) developed by Hamilton et al. 2005[14]. The purpose of the model is to understand how the current pattern of tourism flows may change under scenarios of future population growth, economic growth and climate change. It includes 207 countries, but does not look at any country in detail. For each country, the model calculates the international arrivals and departures and the domestic tourists flows. Results from the model have already been implemented successfully in CGE models to analyze scenarios of climate change and climate policies (Berrittella et al. 2006, Bosello et al. 2012).

[14] A detailed description of the model, related publications as well as the model code are available from the authors.

Calibration of the HTM: The model is calibrated against the international arrivals and departures data of 1995 contained in the World Resources Database (WRI 2000). Domestic data are derived from the Euromonitor 2002 database and other sources such as national statistical offices. All data are annual. Since summer tourism dominates winter tourism in most countries, the HTM is calibrated on summer tourism. More information about the model, the source and the limitations of the dataset is available in Hamilton et al. 2005 and Bigano et al. 2007.

Scenarios to be simulated in the HTM: To be consistent and to simplify comparison with previous climate assessments performed in Switzerland such as CH2011 and CH2014-Impacts, we model the IPCC scenarios SRES A1B and A2, and RCP3PD. The time horizon of our study is 2060, but the simulation of the tourism flows cover the period 1950-2100.

Socioeconomic changes: In the HTM, population and economic growth affect tourism flows. For the SRES scenarios A2 and A1B (Nakicenovic et al. 2000), data is obtained from the IPCC Data Distribution Center[15]. A range of Integrated Assessment Models (IAM) has been used to produce quantitative socioeconomic data. In accordance with IPCC recommendations, scenario A1B is taken from the integrated assessment model simulation, and scenario A2 is taken from the ASF model simulation. During the first phase of the fifth IPCC assessment, climate and socioeconomic scenarios were conjointly developed. RCP describes representative greenhouse gas concentration pathways, and Shared Socio-economic Pathways (SSP) illustrates economic, technical and population change scenarios. Socioeconomic data for the RCP3PD scenario is obtained from the SSP database[16]. We select SSP scenarios 1 and 2, describing a future sustainable world for the former and a pursuance of the current trend for the latter. Data for economic growth is taken from the OECD GDP V9, and data for the population is taken from the IIASA-WiC Population V9.

Climate change: In the HTM, the climatic variable of interest is the global mean temperature. Then, the temperature is downscaled to national means using the COSMIC model. Climate change data for the SRES scenarios A1B and A2 is taken from the IPCC Data Distribution Center[17]. Global mean temperature has been simulated by 14 General Circulation Models (GCM). Simulation of global mean temperature for the RCP3PD scenario is obtained from the CMIP5 data archive[18]. In this case, we use the results of 32 GCMs.

Uncertainties: Uncertainties exist at each step of the simulation. To deal with uncertainties regarding climate and socioeconomic changes, we use 4 scenarios (A1B, A2, RCP3D-SSP1, RCP3D-SSP2) that represent different futures. To address climate model uncertainty, we follow the same methodology as CH2011, deriving the 2.5th, the 50th and the 97.5th percentiles of the GCMs results, characterizing lower, medium and upper values for each scenario. To derive the medium scenario, we take the average of all GCMs simulations, i.e. we attribute an equal weight to all models regardless of their performance. The lower scenario is equal to the medium minus 1.96 standard deviation, and the upper scenario is the medium plus 1.96 standard deviation. This range captures true climate uncertainty incompletely. Results should not be interpreted as a prediction with 95% probability confidence. Rather, it represents possible ranges of future climate evolution which are consistent with the data available, but may change as more uncertainty sources are included.

---

15 http://sedac.ipcc-data.org/ddc/sres/index.html

16 https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

17 http://www.ipcc-data.org/sim/gcm_global/index.html

18 http://cmip-pcmdi.llnl.gov/cmip5/index.html

Figure 20 sums up the scenarios, data and models used for the simulations with the HTM.

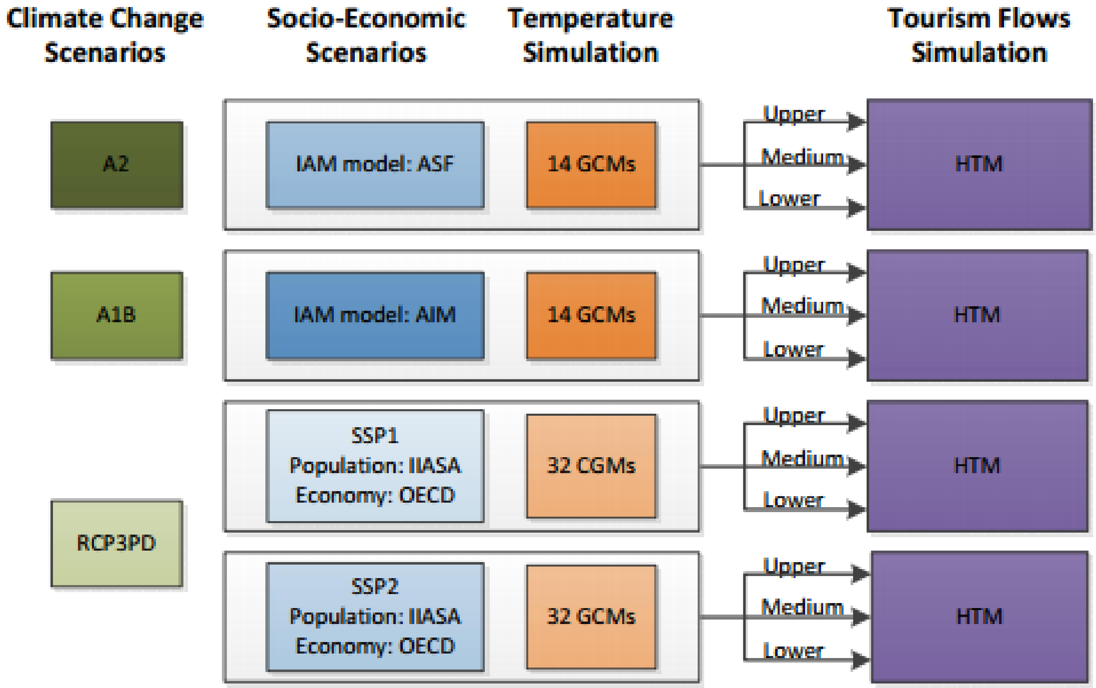


Figure 20: Simulations with the Hamburg Tourism Model

HTM Results and Implementation in GEMINI-E3: For each scenario, tourism flows (domestic, departures and arrivals) for all countries are simulated and then aggregated to GEMINI-E3 regions. In the HTM, the total number of tourists depends on the world population and GDP. On the other hand, temperature affects countries' attractiveness and its changes only cause a reallocation of tourism flows between countries.

Since we focus on climate change effects, we want to remove the socioeconomic scenario effects (increase of population and GDP) to allow for meaningful comparisons between climate change scenarios A1B, A2 and RCP3PD. To do this, we keep global flows constant when implementing tourism flows variations in GEMINI-E3 and calculate the variations of tourists with respect to the same scenario without climate change under this assumption. For example, let *CH(A1B Medium, Year)* be domestic tourism in Switzerland for the scenario A1B Medium in a given year, we have:

$$\%\,Variation\ CH(A1B\ Medium, Year) = \frac{CH(A1B\ Medium, Year) - CH(A1B\ Without\ CC, Year)}{CH(A1B\ Without\ CC, Year)}$$

For each simulation year and scenario, we get a matrix of results (see for instance Table 31).

Table 31: Changes in tourism flows
(% deviation from reference scenario in 2060, scenario A1B with HTM)

Destination	Origin	CH	EU	USA	OECD	BRIC	ROW
CH		18.1	-0.1	-14.8	-26.6	14.6	14.3
EU		-4.6	5.4	-23.1	-33.5	3.7	3.1
USA		-1.5	-7.4	14.0	-53.1	7.1	6.8
OECD		55.4	45.6	41.0	25.4	58.8	62.2
BRIC		10.1	4.6	-14.6	-16.0	2.2	13.3
ROW		-15.1	-20.0	-31.8	-37.4	-7.6	-5.2

Each cell (line i, column j) indicates the percentage change in the number of tourists arriving in region i from region j; or equivalently, departing from region j to region i. For example, the number of European tourists visiting Switzerland decreases by 0.1% because of temperature increase in the A1B Medium scenario in 2060. Diagonal cells correspond to changes in domestic tourism.

The results of the simulations with the HTM are then used as input data for GEMINI-E3. The destination flows in GEMINI-E3 are modified according to the variations calculated with the HTM. We assume that the results of the HTM simulations correspond to the "other forms of tourism" sector. We aggregate in this sector summer tourism, cultural tourism and all the other forms of tourism except for snow-dependent winter tourism.

HTM caveats:

- Data are weak, too coarse geographically and temporally. Different types of travel are grouped together, although they are not homogeneous. Since the model uses data at the national level, a representative climate and income are assumed for each country. This implies a distortion, particularly for large and diverse countries such as the USA and China. Similarly, data are annual, and seasonality is not accounted for.
- Temperature is assumed to be the only important climate variable, because many climate parameters are strongly correlated to temperature, and temperature is the only climate variable with reliable data and future projections with a large spatial coverage. For example, precipitation has a high spatial variability.
- Future drivers are uncertain, such as disposable income, time budget and travel costs.
- Stochastic events such as natural disasters, terrorism or sport events change short-term predictions even though their effect on long-term trends is much smaller.

3.6.3 Results

3.6.3.1 Winter tourism

We simulate two climate scenarios, RCP3PD and A1B. For each of them we assume three snow variations outside Europe:

- In a first case, we assume that ski resort outside Europe would not be impacted by climate change. This represents the worst case for winter tourism sectors in Europe;
- In the second case, non-European ski resorts are affected by climate change. The assumed reductions in snow resources (respectively -4% in RCP3PD scenario and -20% in A1B scenario) are similar to the ones computed for the EU;
- In the last case, reduced snow resources are equal to 50% of the variation used in the previous case.

Moreover, for scenario A1B we simulate two cases, namely with and without changes in artificial snow-making, to show the impacts of technical adaptation measures. Climate change will put additional constraints on artificial snow, since its production requires cold temperature, water and energy. The scenario without snowmaking represents, however, a kind of worst case scenario with a disputably assumed absence of a particular form of technical adaptation.

The outcomes obtained with GEMINI-E3 for the six scenarios are given in Table 32. We first discuss scenario A1B where we assume that snow resources outside Europe would be impacted by climate change to a similar extent as computed for the EU. The producer price increases by 5.1% for one-day winter tourism (ODT) and by 1.6% for winter overnight tourism (WOT). The two price increases are not similar due to the fact that the climate change impacts on the snow resource vary across segments (-21.8% for ODT and -12.5% for WOT). The difference also arises, because adaptation capacities on the supply and demand sides are different in the two segments. Due to these price variations, production decreases by 2.8% in ODT, but increases by 0.6% in WOT. Indeed, Swiss WOT benefits from relative competitiveness improvements, as the impacts of climate change on winter tourism are more significant outside Switzerland. Therefore, Swiss exports (foreign tourists visiting Switzerland) increase and Swiss imports (Swiss tourists abroad) decrease. This induces some welfare improvement, which is however limited (+0.01%). Low altitude Swiss ski resorts are, however, negatively impacted.

When we assume that ski resort stations outside Europe suffer less from climate change, this penalizes Swiss WOT. Production now decreases by 0.6% in the worst case, and the welfare improvement vanishes.

If snowmaking stays constant, the impacts are more severe. In the scenario with snow change outside Europe, the producer price increases by 9.1% for the ODT sector and by 6.4% for the WOT sector. Ski resorts cannot substitute natural snow by relatively cheap artificial snow. They need more capital, labor and energy to maintain and modernize ski slopes. This results in a decrease in production of 5.4% for the ODT sector and of 2.5% for the WOT sector. Despite this, welfare slightly improves due to gains from terms of trade: The EU is more affected than Switzerland by climate change. Since snow endowment decreases by 23.4% in the EU and by only 12.5% in Switzerland in the WOT sector, the price of skiing in the EU increases much more than in Switzerland. Thus, Swiss imports decrease much more than Swiss exports. Moreover, revenue from exports grows, because the increasing producer prices more than compensate for the loss of demand (decrease in domestic consumption and exports). Switzerland has a comparative advantage with respect to the EU, since its ski resorts are located at a higher altitude.

Comparing these results to the above scenario with adaptation, the latter scenario enables the EU to compensate its decrease in natural snow by investing into artificial snow, mitigating the Swiss comparative advantage. Thus, the positive welfare effect in Switzerland is lower in the scenario with adaptation.

In the RCP3PD scenario, the decrease in snow endowment is very limited. Therefore, the economic impacts on Swiss Winter tourism are very low. WOT production change ranges between -0.1% to 0.0% and ODT production decreases by 0.4%. Welfare remains essentially unchanged with respect to the baseline scenario.

Table 32: Impacts of climate change for the Swiss winter tourism sector and welfare
(% deviation from reference scenario in 2060)

	RCP3PD with adaptation			A1B with adaptation			A1B without adaptation		
	No snow change outside Europe	50% snow change outside Europe	Snow change outside Europe	No snow change outside Europe	50% snow change outside Europe	Snow change outside Europe	No snow change outside Europe	50% snow change outside Europe	Snow change outside Europe
Variations in snow endowment for winter overnight tourism									
CH	-2.0	-2.0	-2.0	-12.5	-12.5	-12.5	-12.5	-12.5	-12.5
EU	-3.4	-3.4	-3.4	-23.4	-23.4	-23.4	-23.4	-23.4	-23.4
OECD	0.0	-2.0	-4.0	0.0	-10.0	-20.0	0.0	-10.0	-20.0
USA	0.0	-2.0	-4.0	0.0	-10.0	-20.0	0.0	-10.0	-20.0
BRIC	0.0	-2.0	-4.0	0.0	-10.0	-20.0	0.0	-10.0	-20.0
ROW	0.0	-2.0	-4.0	0.0	-10.0	-20.0	0.0	-10.0	-20.0
Variations in snow endowment for one-day winter tourism									
CH	-4.0	-4.0	-4.0	-21.8	-21.8	-21.8	-21.8	-21.8	-21.8
Swiss winter overnight tourism									
Production	-0.1	0.0	0.03	-0.6	-0.1	0.6	-3.1	-2.8	-2.5
Consumption	-0.2	-0.2	-0.2	-1.1	-1.2	-1.2	-3.5	-3.8	-4.2
Exports	-0.1	0.0	0.2	-0.2	0.8	2.3	-2.9	-2.2	-1.2
Imports	-0.4	-0.4	-0.4	-3.6	-3.6	-3.7	-7.9	-8.3	-9.0
Artificial snow	1.1	1.3	1.4	8.4	9.2	10.5	0.0	0.0	0.0
Producer price	0.2	0.2	0.2	1.5	1.5	1.6	5.2	5.7	6.4
Swiss one-day winter tourism									
Production	-0.4	-0.4	-0.4	-2.8	-2.8	-2.8	-5.3	-5.4	-5.4
Consumption	-0.4	-0.4	-0.4	-2.8	-2.8	-2.8	-5.3	-5.4	-5.4
Artificial snow	1.0	1.0	1.0	7.2	7.2	7.2	0.0	0.0	0.0
Producer price	0.7	0.7	0.7	5.1	5.1	5.1	9.3	9.2	9.1
Welfare	**-0.00**	**0.00**	**0.00**	**-0.00**	**0.00**	**0.01**	**0.02**	**0.02**	**0.03**

In short, even if welfare impacts are slightly positive, the situation is mixed among segments. Production of the one-day winter tourism sector decreases in all scenarios, highlighting the greater vulnerability of ski resorts located at low altitudes, since they suffer from a greater natural snow loss. Higher ski resorts benefit from their comparative advantage with respect to lower altitude resorts in Switzerland and in the EU. However, their vulnerability also increases, because the decrease in natural snow raises their production costs.

The results are sensitive to our modeling approach and assumptions. First, we treat the changes in natural snow endowment and temperature as deterministic, using the average change simulated by several models; But uncertainties are high, as highlighted by the high disparities between model results. Moreover, due to our CGE approach, the decrease in natural snow endowment only increases the production cost of winter tourism exponentially. This means that there is no ultimate restriction on the supply side, and producers substitute missing natural snow with other production factors, for example increasing the share of artificial snowmaking. However, the preparation of ski slopes might be impractical in a warmer climate. Also, the fractional snow cover used in our simulations does not factor in snow quality. Higher temperature will lower snow quality which could decrease people's willingness to ski. This effect could be reinforced by the lack of snow in cities or the concentration of skiers in a few high altitude ski resorts. By using the fractional snow cover, we also assume that the minimum depth to ski is uniform, although it depends on soil types and on slopes (Serquet & Rebetez 2013). Finally, we use an econometric model to assess the economic impacts of snow cover changes, and assume that the estimated relation will be the same in 2060. However, the lack of snow in cities or the concentration of skiers in high altitude resorts could decrease people's inclination to ski.

3.6.3.2 Summer tourism

The results presented below correspond to the simulations in GEMINI-E3 for scenarios A1B, A2 and RCP3PD.[19] International tourism flows change according to the new temperature pattern. Cooler countries like Canada, Norway or Russia become more attractive. Thus, regions OECD and BRIC get more arrivals. For example in 2060 in scenario A1B, OECD arrivals increase by 18% to 54% and BRIC arrivals increase by 3.1% to 8.4%.

On the other hand, temperature increase reduces international tourism flows, i.e. total departures and arrivals decrease while domestic tourism increases. In 2060 in scenario A2, international tourism trade decreases by 4.8% to 9.4%. On aggregate, the Swiss tourism sector benefits from this effect. Indeed, even if international tourists spend less in Switzerland, Swiss tourists also spend less outside Switzerland and more at home. For example in 2060 in scenario A2, arrivals decrease by 1.9% to 5.2% (Figure 21) while departures decrease by 9.6% to 18.9% (Figure 22).

[19] Since we focus on climate change impacts relative to the reference case without temperature increase, socio-economic effects are removed, and scenarios RCP3PD-SSP1 and RCP3PD-SSP2 yield similar results. We show results for RCP3PD-SSP1. For conciseness, results for scenario RCP3PD-SSP2 are not shown.

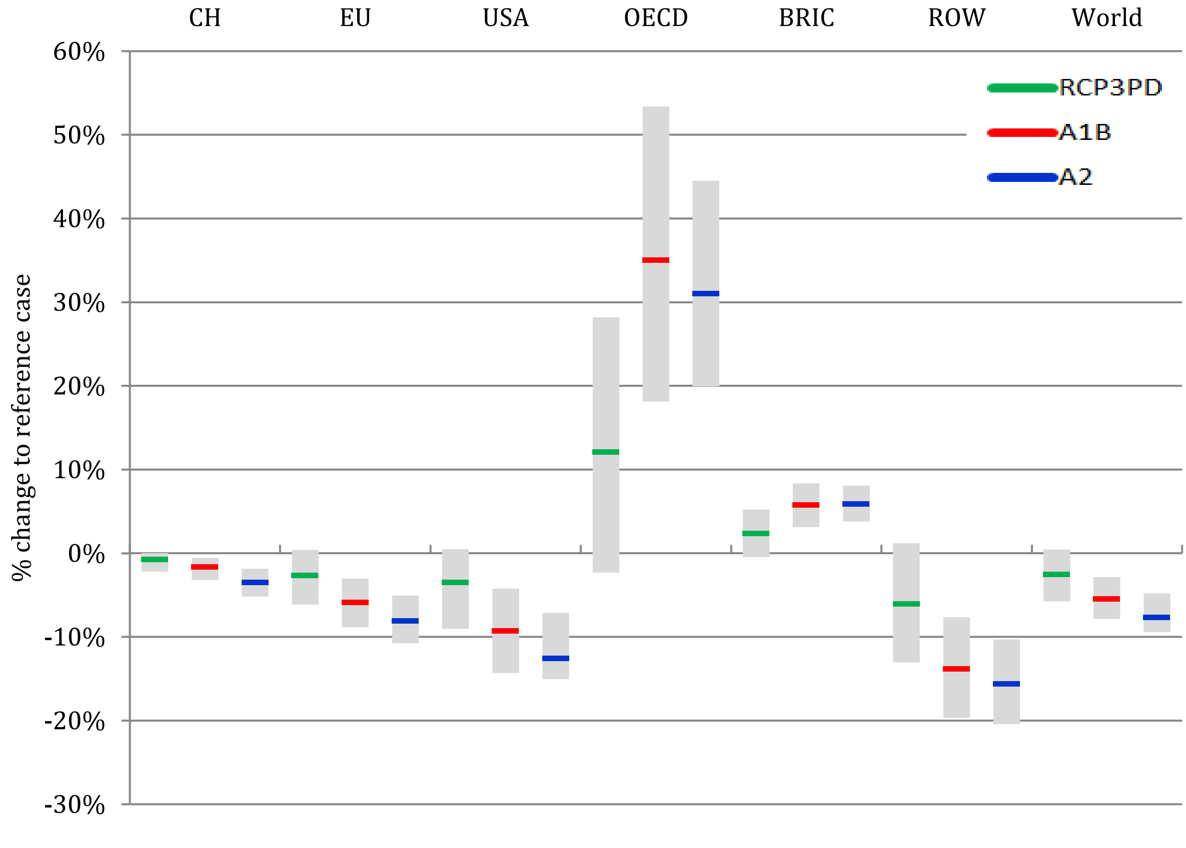


Figure 21: International touristic arrivals in 2060
(% deviation from reference scenario in 2060)

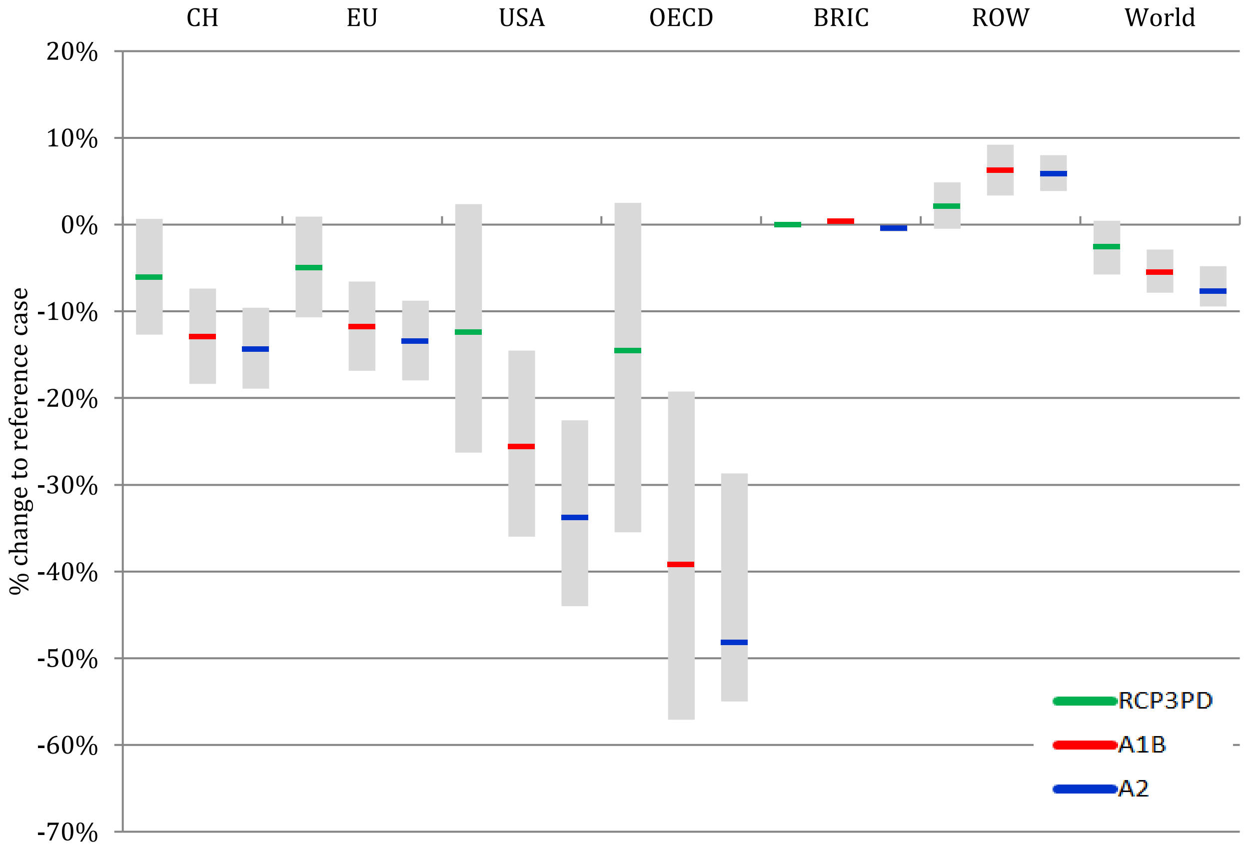


Figure 22: International touristic departures in 2060
(% deviation from reference scenario in 2060)

The reallocation of tourism flows translates into welfare changes. The main winner is the OECD region, because the increase in arrivals and the reduction of departures greatly improve the regional trade balance in tourism. In 2060, Switzerland is better off in all scenarios except RCP3D Lower. Switzerland benefits from larger increases in temperature, although to a lesser extent than GEMINI-E3's OECD region. One explanation is that more tourists will enjoy cooler mountain areas at the expense of hot city or seaside destinations. Moreover, the summer tourism season in alpine areas could expand to spring and autumn. Thus, the decrease in arrivals is more than compensated for by the decrease in departures and the increase in domestic tourism. The projected welfare gain is moderate and goes up to 0.21% in scenario A1B. Worldwide, climate change has a negative impact on tourism, lowering welfare by 0.04% to 0.09% in scenario A2 due to the decrease in international trade. For most regions, smaller temperature increases are preferable to larger ones.

Figure 23: Scenario impacts on summer tourism, regional welfare in 2060
(% deviation from reference scenario in 2060)

The results presented above must be read with care. The main limitations of the HTM have been presented in section 3.6.2. We now underline the consequences of these and other limitations on the results. First, tourism flows not only depend on climate, but also on population and GDP. We use a reference socio-economic scenario to focus on climate change effects, but this could seem inconsistent since carbon emissions are strongly linked with population and GDP growth. On the other hand, tourists could also get used to higher temperature, making summer tourism flows more robust to climate change. Large uncertainties also arise from the influence of changes in precipitation. Thus, our simulations should not be interpreted as predictions. They indicate a possible future and are useful to understand how climate change could impact tourism and the direction of the effects.

The HTM uses a representative temperature for each country. Switzerland's tourism sector benefits from a lower average annual temperature in comparison with other regions. All the simulated scenarios show a positive impact of climate change on total summer tourism in Switzerland, but the situation might be more nuanced inside the country. Indeed, it is likely that summer tourism will increase in cold Alpine regions, but it is unclear what will happen in cities. Serquet & Rebetez 2011 for example found a significant correlation between tourism in mountain resorts and hot temperature at lower elevation, especially in alpine resorts located near cities. These results suggest i.a. that ski resorts could adapt to climate change diversifying and developing their summer tourism offer.

3.6.3.3 Aggregate impact of climate change on tourism

To get an overall view of the combined climate change effects on winter and summer tourism, we simulate two more scenarios, RCP3PD medium and A1B medium, both of them with variations of snow endowment in all regions and with adaptation (change in artificial snowmaking).

Table 33: Impacts of climate change for the Swiss tourism sectors and welfare
(% deviation from reference scenario in 2060; results for the summation of separate summer and winter simulations indicated in brackets)

	RCP3PD medium snow variations in all regions, with adaptation	**A1B medium snow variations in all regions, with adaptation**
Swiss other tourism		
Production	1.4 (1.4)	3.0 (3.0)
Consumption	0.2 (0.1)	0.4 (0.3)
Exports	-0.8 (-0.7)	-1.7 (-1.6)
Imports	-6.0 (-6.0)	-12.8 (-12.9)
Swiss winter overnight tourism		
Production	-0.2 (0.03)	0.3 (0.6)
Consumption	-0.2 (-0.2)	-1.2 (-1.2)
Exports	-0.1 (0.2)	1.7 (2.3)
Imports	0.0 (-0.4)	-2.9 (-3.7)
Artificial snow	1.1 (1.4)	10.0 (10.5)
Producer price	0.2 (0.2)	1.5 (1.6)
Swiss one-day winter tourism		
Production	-0.4 (-0.4)	-2.8 (-2.8)
Consumption	-0.4 (-0.4)	-2.8 (-2.8)
Artificial snow	1.0 (1.0)	7.2 (7.2)
Producer price	0.6 (0.7)	5.0 (5.1)
Welfare	**0.08**	**0.17**

The results of the GEMINI-E3 simulations are shown in Table 33. There are some interesting deviations from simply summing over the separate results of winter and summer tourism simulations, due to general equilibrium effects: Swiss imports of winter tourism decrease less; On the other hand, exports of winter tourism increase less in A1B and turn negative in RCP3PD. This is due to two contradictory effects: climatic attractiveness vs. exchange rates. Switzerland becomes more attractive when Europe is affected by climate change. Thus, demand and supply of Swiss tourism increase, generating additional income for Swiss households, and the supply of tourism elsewhere in Europe decreases. This modifies the exchanges rates: the Swiss Franc becomes relatively stronger to the Euro. Consequently, Swiss households spend a greater share of their income in Europe and Swiss imports decrease less. European households consume less in Switzerland, so Swiss winter tourism exports increase less.

4. CONCLUSIONS

This report presents a comprehensive overview of economic impacts of climate change in Switzerland to be expected in 2060. Next to a thorough appraisal of the existing literature, we have further enhanced the monetary quantification of the impacts of climate change on Switzerland in the context of computable general equilibrium (CGE) analysis. Earlier modeling exercises were updated to the latest climate scenarios and socioeconomic data, e.g. concerning impacts on labor productivity, winter tourism, irrigation for crop cultivation, space heating and cooling. Even more importantly, we added effects which previously had not been included in macroeconomic analyses for Switzerland. In particular, we focused on certain economic cross-border effects: international tourism flows, electricity prices, and agricultural terms of trade.

Despite these achievements, the report also reveals how much still needs to be done to attain a reasonably complete and reliable quantitative picture of economic impacts of climate change in Switzerland. In fact, many impacts have not yet been quantified in a satisfactory way, and some of them could be very significant. These omissions concern, among other things, disastrous extreme events such as heat waves and droughts, which are expected to become more frequent and severe.

We report the current state of research, but need to restrict our simulations to impacts for which adequate data are available. Also, we concentrate in the simulations on a selection of impacts which can be assumed to be important according to existing literature.

Table 34 presents an overview of economically relevant influences of climate change in Switzerland. Simulated impacts are colored in red and green (for net negative/positive impacts). Impacts colored in orange where not simulated due to methodological and data constraints or (in light orange) low economic relevance. Most importantly, there is at this time an insufficient basis for quantifying the impacts of extreme weather events in 2060 across all sectors. Among other impacts, we also refrain from quantitative statements concerning ecosystems and biodiversity. Not only are economic impacts poorly known; the methods for monetization are also particularly contested.

In the following, we summarize our findings for the different sectors before we arrive at final conclusions.

Impacts on **human health** are among the most serious of climate change impacts in Switzerland, with summer heat being the main cause. A usual 2060 summer under climate change (scenarios A1B and A2) is expected to cause about 650 additional deaths due to cardiovascular and respiratory diseases (based on Paci et al. 2014). Additional risks related to vector-borne diseases could add to this. Other heat-related health issues include increased tropospheric ozone formation and influences on the prevalence of allergens.

Heat also affects labor productivity. Following the approach of the Cantonal risk studies, total labor productivity under climate change falls by about 0.4% until 2060. This is a potentially severe economic impact, which could be mitigated to some extent by adaptation measures, more easily of course for indoor jobs.

Table 34: Overview of economically relevant influences of climate change in Switzerland

	average temperature change	change in precipitation patterns	extreme weather events	influences from abroad
health	cardiovascular, respiratory and vector-borne diseases, mortality, reduced labor productivity		cardiovascular, respiratory and vector-borne diseases, mortality, reduced labor productivity	reduced labor productivity abroad influences terms of trade
buildings & infrastructure	heat-related and frost-related damages, permafrost melting		floods, mudslides, storms, hail, heat, frost	
energy	space heating and cooling, cooling for thermal electricity generation plants	runoff changes influence hydropower, water availability for cooling of thermal electricity generation plants	energy infrastructure: floods, mudslides, storms, hail, heat, frost	European electricity prices
water management		need for irrigation, lower ground water level	drought: irrigation, ground water level, drinking water quality	
agriculture	longer growth periods, heat stress, pests	need for irrigation	losses due to drought, heavy precipitation, heat, frost	higher prices for imported grains & oilseeds
forestry	longer growth periods, heat stress, pests	dry conditions	storm, heat waves, droughts, forest fires	timber price
ecosystems	migration of species, biodiversity		stress and damage to habitat and creatures	migration of species
tourism	reduced snow cover, shift from winter to summer tourism	reduced snow cover, days of sun	damage to alpine infrastructure	international tourism flows, terms of trade
other		water transport		immigration, international conflict, trade volumes and terms of trade, financial flows, reinsurance payments
legend	positive effect			
	important positive effect			
	negative effect			
	important negative effect			
	effect which has not been simulated due to rather low economic importance			
	potentially important effect which has not been simulated due to data constraints			

The impacts will be even more severe when extreme heat waves occur. Indeed, we know from the 2003 (and 2015) heat waves that about 1 000 (respectively 800) people died prematurely in Switzerland (Grize et al. 2015, FOEN 2016). This also reveals that adaptation could be more difficult than expected, given that adaptation measures implemented since 2005 do not seem to have had a major effect in reducing mortality during the heat wave of 2015, at least not in all regions of Switzerland. Labor productivity and health costs could also be particularly affected by heat waves, although current data does not indicate any related significant increase in health costs so far.

We have not been able to include the presumably important impacts of heat waves on labor productivity and human health in our simulations. This is due to the fact that data is available only for heat waves which in 2060 will not be extreme under climate change. Indeed, the regular summer climate of 2060 would be warmer than that of 2003, a summer which had been considered the warmest in at least 250 years. An extreme heat event in 2060 would thus be much hotter than anything we have seen in Switzerland so far. This implies methodological difficulties: If we wanted to quantify the damage of an extreme heat event with a return period of 20 years under a warmer climate in 2060, we would neither know how to define the progression of temperature, nor what damages this particular progression of temperature would cause. These are important research tasks for the near future.

Agriculture and forestry are sectors that are particularly sensitive to climate and weather conditions. There are multiple influences of climate change on production, especially but not only on crop and timber production. Higher temperatures prolong growth periods, raise the timber line, and intensify plant growth, but also the prevalence of pests. Decreased precipitation in summer reduces the availability of water for irrigation and leads to overly dry conditions for forests in some regions. Weather extremes of all kinds (e.g. heat, drought, heavy precipitation and flooding, hail and storms) can be a threat to production. As in the health domain, we had to restrict the quantification of impacts to average conditions under climate change, but large additional expected impacts are likely to also arise from weather extremes, notably from extreme heat and drought.

Despite these risks, the overall picture for Swiss agriculture seems to be rather positive. Of the many influences of climate change on agriculture, extended cultivation periods could be the dominant one, provided that sensible adaptation measures are taken. In our simulations, we focus on two particular issues: (1) a potential scarcity of irrigation water and (2) modified import prices for agricultural commodities.

In the absence of weather extremes, scarcity of irrigation water is an issue for only a few catchments, mostly in the western part of Switzerland. Assuming some adaptation, the negative impacts on national crop production remain below 0.2%, and the resulting aggregate welfare changes are negligible.

Impacts of climate change on agriculture are more pronounced abroad, especially in developing countries. Crop import prices are expected to increase mostly for grains and oilseeds (Wiebe et al. 2015), which according to our simulations causes a welfare loss of 0.02% in Switzerland.

Tourism is another sector where international aspects are particularly important, given that more than 9 million foreign tourists visit Switzerland per year. Foreign guests spend almost 16 billion CHF per year in Switzerland, and Swiss tourists spend almost the same amount abroad (Schweizer Tourismus-Verband 2016).

The main concern for tourism with respect to climate change is the retreating snow cover, which constitutes a serious challenge to ski resorts, especially below an altitude of about 1800 m. At the same time, high-lying ski resorts might benefit from a shift in demand from low-lying resorts inside and outside Switzerland. Also, artificial snowmaking mitigates some of the negative effects. Altogether, our simulations for the A1B scenario show an increase of overnight winter tourism by 0.3% and a decrease of one-day winter tourism by 2.8% in 2060 relative to the reference scenario without climate change.

Although there are risks especially for one-day winter tourism, the Swiss tourism sector as a whole is likely to benefit from climate change. In the simulations, the estimated welfare gain amounts to almost 0.2% of household consumption. Under climate change, more tourists choose mountain areas rather than hot city or seaside destinations. Moreover, the summer tourism season expands more into spring and autumn. We simulate a decrease in international arrivals, which is, however, more than compensated by a drop in departures by Swiss residents and a resulting increase in domestic tourism. This seems to be good news at least for a major part of the Swiss tourism sector. It has to be noted, however, that projections of international tourism flows under climate change are very uncertain.

In the **energy** domain, Switzerland is also highly integrated with international markets. Climate change influences the demand for heating and cooling in different world regions. It also influences conditions for electricity generation, with its dependence on sunshine hours, wind conditions, and water for hydropower and cooling of thermal plants. Hence, it can be suspected that the terms of trade for energy carriers are affected by climate change.

In our simulations, we found only minor effects in this regard, at least at an aggregate level. For example, electricity import prices vary for the different neighbouring countries for different reasons, but the aggregate effect of these changes on Switzerland could be almost negligible. For electricity, the comparison of mitigation and business-as-usual scenarios reveals that mitigation policies have a higher influence on import prices to Switzerland than climate change itself. For the RCP3PD scenario, which entails considerable mitigation, we find a medium increase of electricity consumer prices of 1.5%. In the past decade, however, mitigation policies have reduced electricity import prices, mainly as a consequence of the feed-in tariffs for renewables in Germany. Whether the simulated effect is going to emerge will, thus, depend on the instruments that are employed for mitigation.

Domestic impacts in the energy field are dominated by the demand side. In the A1B medium scenario, increased energy demand for cooling raises total energy consumption by about 0.8%. However, reduced energy demand for heating is much more important and lowers total energy consumption by 2.6%. Aggregating both of these effects, we have simulated a welfare increase of 0.25%. This is a much larger impact than any of the supply side effects that can be expected (impacts of change in river runoff on hydropower generation, lower availability of cooling water for thermal plants, damage to energy infrastructure).

Concerning damages to **infrastructure and buildings**, there will be some changes in the incidence of heat and cold related damages. Yet, the main issue with climate change are potentially increased risks associated with extreme weather events such as storms, heavy precipitation (floods and mudslides), heavy snowfall (avalanches), and hail. Climate change may alter both the frequency and the intensity of such events. It is, however, especially difficult to scientifically substantiate that this will be the case. While it is difficult to simulate expected average changes of the climate, it is even far more difficult to simulate expected changes in extreme weather events.

Yet, this is an important risk-related topic, given that we have seen large flood (1999, 2000, 2005, 2007) and storm (1999) events in the last two decades. For example, the damage of the 2005 flood event has been estimated at about 3 billion CHF. Despite this, it would be incorrect to assume considerable additional damages to buildings and infrastructure as long as scientific confirmation is missing that these risks have to be expected to increase due to climate change.

We attempted to identify the most considerable impacts of climate change in Switzerland, even if there will be many more impacts, most of which can be expected to be of minor economic relevance. As an exception, there might be **further international impacts** that could be economically important for Switzerland: Climate change could spawn international conflict and migration and reduce trade. This could impact the Swiss labor market, trade volumes and terms of trade, as well as financial flows between the Swiss banking system and the rest of the world. These impacts are very difficult to project and quantify, and deserve more attention. Furthermore, the reinsurance sector, which is prominent in Switzerland, is affected by extreme weather events around the world.

Given that many important – and predominantly negative – risks are not taken into account (see again Table 34), we are aware that there is limited value in presenting aggregate numbers of our simulations for Switzerland. Already for the simulated impacts, net annual damage of climate change in 2060 is about 2.8 billion CHF_{2008} or 0.43% of total consumption[20]. This includes the monetization of excess premature deaths at 5 million CHF per person[21]. This monetization, which has been chosen in accordance with the approach of the cantonal risk studies, is highly controversial. Some argue that, as saving lives should be first priority, the value of human life should not be expressed in terms of money. Others will note that, when following standard monetization approaches, the statistical value of life would have to increase with average income between today and 2060, which would result in a much higher value per person.

In summary, it can be concluded that uncertainties about the overall impact of climate change are still enormous. Especially, the full consequences of future extreme weather events remain unknown. Despite the new research presented in this report, we still know too little about the repercussions of global consequences of climate change on Switzerland. The domestic impacts of average temperature change are much better studied. We find that they are dominated by detrimental effects of high temperatures on human mortality and labor productivity. The related costs are only partially compensated by positive impacts, mostly by savings in heating needs and new opportunities for summer tourism.

20 Total impacts in each scenario are largely congruent with the sum of the individual effects that we have simulated. In other words, we do not find any sizable general equilibrium effects, i.e. reciprocal effects between different impacts that would be of macroeconomic relevance.

21 Based on a willingness-to-pay approach conducted in the Swiss PLANAT risk concept (Bründl 2009), representing the sum of money society is willing to pay to protect a life.

REFERENCES

Aaheim, A. & Schjolden, A., 2004, An approach to utilise climate change impacts studies in national assessments, *Global Environmental Change* 14(2), 147-160, available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378003000979 [accessed December 15, 2014].

Aaheim, A., Amundsen, H., Dokken, T. & Wei, T., 2012, Impacts and adaptation to climate change in European economies, *Global Environmental Change* 22(4), 959-968, available at: http://linkinghub.elsevier.com/retrieve/pii/S0959378012000672.

Abegg, B., Steiger, R. & Walser, R., 2013, Herausforderung Klimawandel: Chancen und Risiken für den Tourismus in Graubünden, Amt für Wirtschaft und Tourismus Graubünden, Chur/Innsbruck.

Aebischer, B., Catenazzi, G., Henderson, G. & Jakob, M., 2007, Impact of climate change on thermal comfort, heating and cooling energy demand in Europe. In: Saving energy - just do it!, European Council for an Energy Efficient Economy ECEEE.

Anderson, B.G. & Bell, M.L., 2009, Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States, *Epidemiology* 20(2), 205-213.

Aström, D. O., Forsberg, B., Ebi, K. L. & Rocklöv, J., 2013, Attributing mortality from extreme temperatures to climate change in Stockholm, Sweden, *Nature Climate Change* 3, 1050-1054.

Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H.R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabczenko, D., Schindler, C. & Michelozzi, P., 2008, Heat Effects on Mortality in 15 European Cities, *Epidemiology* 19(5), 711-719.

Barrios, S. & Ibañez Rivas, J.N., 2014, Time is of the essence: Adaptation of tourism demand to climate change in Europe, Nota di Lavoro 19.2014, Fondazione Eni Enrico Mattei.

Baumann, T. & Schiess, U., 2008, Compte satellite du tourisme de la Suisse, 2001 et 2005: Principes, méthode et résultats. Office Fédéral de la Statistique (OFS), Neuchâtel.

Bergwelten 21 & GRF Davos, 2015, Klimawandel Graubünden, Arbeitspapier 3: Risiken und Chancen. 23. November 2015, Chur.

Bernard, A., Drouet, L. & Vielle, M., 2008, GEMINI-E3, A General Equilibrium Model of International-National Interactions between Economy, Energy and the Environment, V5. 3. *Computational Management Science*, 173-206, available at: http://gemini-e3.epfl.ch/webdav/site/gemini-e3/shared/GEMINI-E3v53.pdf.

Berrittella, M., Bigano, A., Roson, R. & Tol, R.S.J., 2006, A general equilibrium analysis of climate change impacts on tourism, *Tour. Manag.* 27, 913-924.

Bezzola, G. R. & Hegg, C., (eds.), 2007, Ereignisanalyse Hochwasser 2005, Teil 1 – Prozesse, Schäden und erste Einordnung. Bundesamt für Umwelt BAFU, Eidgenössische Forschungsanstalt WSL, Umwelt-Wissen Nr. 0707.

Bigano, A., Hamilton, J.M. & Tol, R.S.J., 2007, The impact of climate change on domestic and international tourism: A simulation study, *Integr. Assess. Journal* 7, 25-49.

Bosello, F., Eboli, F. & Pierfederici, R., 2012, Assessing the economic impacts of climate change. An updated CGE point of view, Fondazione Eni Enrico Mattei, Nota di Lavoro 2.2012.

Bosello, F., Roson, R. & Tol, R.S.J., 2006, Economy-wide estimates of the implications of climate change, Human health, *Ecological Economics* 58, 579-591.

Bosshard, T., Kotlarski, S. & Schär, C., 2015, Local scenarios at daily resolution for emission scenarios A2 and RCP3PD, CH2011 Extension Series No. 1, Zürich.

Bründl, M. (ed.), 2009, Risikokonzept für Naturgefahren – Leitfaden, Nationale Plattform für Naturgefahren PLANAT, Bern.

Bux, K., 2006, Klima am Arbeitsplatz – Stand arbeitswissenschaftlicher Erkenntnisse - Bedarfsanalyse für weitere Forschungen, Bundesamt für Arbeitsschutz und Arbeitsmedizin, Dortmund.

Calanca, P., Fuhrer, J., Jasper, K., Torriani, D., Keller, F., & Dueri, S., 2005, Klimawandel und landwirtschaftliche Produktion. *Agrarforschung* 12, 392-397.

CH2011, 2011, Swiss Climate Change Scenarios CH2011, published by C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC, Zürich.

CH2014-Impacts, 2014, Toward Quantitative Scenarios of Climate Change Impacts in Switzerland, published by OCCR, FOEN, MeteoSwiss, C2SM, Agroscope, and ProClim. Bern.

Chambwera, M. et al., 2014, Economics of Adaptation, in: Climate Change 2014, Impacts, Adaptation, and Vulnerability, Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 945-977.

Christenson, M., Manz, H. & Gyalistras, D., 2006, Climate warming impact on degree-days and building energy demand in Switzerland, *Energy Conversion and Management* 47, 671-686.

Christidis, N., Jones, G.S. & Stott, P.A., 2014, Dramatically increasing chance of extremely hot summers since the 2003 European heatwave, *Nature Climate Change* 5, 46-50.

Ciscar, J.-C. & Dowling, P., 2014, Integrated assessment of climate impacts and adaptation in the energy sector, *Energy Economics* 46, 531-538.

Ciscar, J.C., Feyen, L., Soria, A., Lavalle, C., Raes, F., Perry, M., Nemry, F., Demirel, H., Rozsai, M., Dosio, A., Donatelli, M., Srivastava, A., Fumagalli, D., Niemeyer, S., Shrestha, S., Ciaian, P., Himics, M., Van Doorslaer, B., Barrios, S., Ibáñez, N., Forzieri, G., Rojas, R., Bianchi, A., Dowling, P., Camia, A., Libertà, G., San Miguel, J., de Rigo, D., Caudullo, G., Barredo, J.I., Paci, D., Pycroft, J., Saveyn, B., Van Regemorter, D., Revesz, T., Vandyck, T., Vrontisi, Z., Baranzelli, C., Vandecasteele, I., Batista e Silva, F., and Ibarreta, D., 2014, Climate impacts in Europe, The JRC PESETA II Project, JRC Scientific and Policy Reports.

ClimAlpTour, 2011, Climate change and its impacts on tourism in the Alpine space, Zalozba ZRC, Ljubljana.

Costa, H., Floater, G., Hooybergs, H., Verbeke, Stijn, & De Ridder, K., 2016, Climate change, heat stress and labour productivity, A cost methodology for city economies, Centre for Climate Change Economics Policy Working Paper No. 278 and Grantham Research Institute on Climate Change and the Environment Working Paper No. 248.

Curriero, F.C., Heiner, K.S., Samet, J., Zeger, S.L., Strug, L. & Patz, J.A., 2012, Temperature and mortality in 11 cities of the Eastern United States, *American Journal of Epidemiology* 155(1), 81-87.

De Bruin, K.C., Dellink, R.B. & Tol, R.S.J., 2009, AD-DICE: an implementation of adaptation in the DICE model. *Climatic Change* 95(1-2), 63-81, available at: http://link.springer.com/10.1007/s10584-008-9535-5 [Accessed January 2, 2015].

Dowling, P., 2013, The Impact of Climate Change on the European Energy System, *Energy Policy* 60, 406-417.

Eboli, F., Parrado, R. & Roson, R., 2010, Climate-change feedback on economic growth, explorations with a dynamic general equilibrium model, *Environment and Development Economics*, 15(5), 515-533, available at: http://www.journals.cambridge.org/abstract_S1355770X10000252 [Accessed December 15, 2014].

Econcept, 2013, Klimawandel im Grossraum Zürich, Auswirkungen und Anpassungsmassnahmen, Wissenschaftliche Grundlagen – Schlussbericht, Zürich.

Ecoplan & Sigmaplan, 2007, Auswirkungen der Klimaänderung auf die Schweizer Volkswirtschaft (nationale Einflüsse), Commissioned by Federal Office for the Environment (FOEN) and Swiss Federal Office of Energy (SFOE), 31 July 2007.

ECDC (European Centre for Disease Prevention and Control), 2012, The climatic suitability for dengue transmission in continental Europe, Stockholm.

Ernst Basler + Partner, 2009, Überblick finanzielle Kenngrössen der Schweizer Wasserwirtschaft, Commissioned by Federal Office for the Environment (FOEN), Bern.

Ernst Basler + Partner/CSD Ingenieurs, 2015, Risiken und Chancen des Klimawandels im Kanton Freiburg.

Ernst Basler + Partner, Eidg. Forschungsanstalt WSL, WSL-Institut für Schnee und Lawinenforschung SLF, 2013, Risiken und Chancen des Klimawandels im Kanton Aargau; Commissioned by Federal Office for the Environment (FOEN), Bern.

Euromonitor, 2002, Global market information database.

Faust, A.-K., Gonseth, C. & Vielle, M., 2012, Modélisation de l'adaptation aux changements climatiques dans un modèle économique intégré. Laboratoire de Recherches en Economie et Management de l'Environnement (REME), EPFL, Commissioned by Federal Office for the Environment (FOEN).

Faust, A.-K., Gonseth, C. & Vielle, M., 2015, The economic impact of climate driven changes in water availability in Switzerland, Water Policy (available online, doi:10.2166/wp.2015.064).

FIF (Forschungsinstitut für Freizeit und Tourismus der Universität Bern), 2011, Der Schweizer Tourismus im Klimawandel: Auswirkungen und Anpassungsoptionen, State Secretariat for Economic Affairs (SECO), Bern.

Fischer, A. M., Liniger, M. A. & Appenzeller, C., 2015, Climate scenarios of seasonal means: extensions in time and space, CH2011 Extension Series No. 2, Zürich.

Fischer, A. M., Liniger, M. A. & Appenzeller, C., 2016, Climate scenarios of seasonal means: inter-variable and inter-seasonal correlations of change estimates. CH2011 Extension Series No. 3, Zürich.

FOAG (Federal Office for Agriculture), 2004, Agrarbericht 2004 des Bundesamtes für Landwirtschaft.

FOEN (Federal Office for the Environment), 2012a, Effects of Climate Change on Water Resources and Waters – Synthesis report on “Climate Change and Hydrology in Switzerland” (CCHydro) project, Bern.

FOEN (Federal Office for the Environment), 2012b, Umgang mit lokaler Wasserknappheit in der Schweiz. Bericht des Bundesrates zum Postulat „Wasser und Landwirtschaft. Zukünftige Herausforderungen“, Bern.

FOEN (Federal Office for the Environment), 2014, Grundlagen für die Wasserversorgung 2025, Risiken, Herausforderungen und Empfehlungen, Bern.

FOEN (Federal Office for the Environment, ed.), 2016, Hitze und Trockenheit im Sommer 2015, Auswirkungen auf Mensch und Umwelt, Umweltzustand Nr. 1629, Bern.

FOPH/FOEN (Federal Office of Public Health & Federal Office for the Environment), 2007, Schutz bei Hitzewelle. Klimaänderung: Auswirkungen auf die Gesundheit.

Franchini, M., & Mannucci, P.M., 2015, Impact on human health of climate changes, *European Journal of International Medicine* 26(1), 1-5.

Frehner, M., 2005, Gebirgswaldbau – vom finanziellen Rückgrat der Berggemeinden zum Risikomanagement, *Schweizer Zeitschrift für Forstwesen* 156(12), 516-520.

FSO (Federal Statistical Office), 2008, Tourism Satellite Account.

FSO (Federal Statistical Office), 2010, Szenarien zur Bevölkerungsentwicklung der Schweiz 2010-2060, Neuchâtel.

FSO (Federal Statistical Office), 2012-2016, Medizinische Statistik der Krankenhäuser. Anzahl Fälle nach Hauptdiagnose, pro Altersklasse und Geschlecht.

FSO (Federal Statistical Office), 2015, Les scénarios de l'évolution de la population de la Suisse 2015-2045.

FSO (Federal Statistical Office), 2016, Entwicklung der Produzentenpreise, nach Wirtschaftszweigen, Destination und Art der Produkte.

Fuhrer, J., & Calanca, P., 2014, Bewässerungsbedarf und Wasserdargebot unter Klimawandel, eine regionale Defizitanalyse. *Agrarforschung Schweiz* 5(6): *256*–263.

Gaudard, L., 2014, Impact of climate change and electricity market liberalization on hydropower plants with reservoir, PhD thesis Nr. 39499, University of Geneva.

Gonseth, C., 2013, Impact of snow variability on the Swiss winter tourism sector, implications in an era of climate change, *Climatic Change* 119(2), 307-320.

Gonseth, C., Thalmann, P. & Vielle, M., 2015, Impacts of global warming on energy use for heating and cooling with full rebound effects, Mimeo.

Gonseth, C. & Vielle, M., 2012a, Modeling Climate Change Adaptation in a Computable General Equilibrium Model: an Application to Tourism.

Gonseth, C. & Vielle, M., 2012b, Modeling the Impacts of Climate Change on the Energy Sector: a Swiss perspective. Working paper – Draft presented at the 15th Annual Conference on Global Economic Analysis (GTAP), Geneva, Switzerland, June 28-29, 2012.

Grêt-Regamey, A., Bishop, I.D. & Bebi, P., 2007, Predicting the scenic beauty value of mapped landscape changes in a mountainous region through the use of GIS. Environ. Plan. B Plan. Des. 34, 50–67.

Grize, L., Huss, A., Thommen, O., Schindler, C. & Braun-Fahrländer, C., 2005, Heat wave 2003 and mortality in Switzerland, *Swiss Medical Weekly* 135, 200-205.

Hajat, S., Armstrong, B., Baccini, M., Biggeri, A., Bisanti, L., Russo, A., Paldy, A., Menne, B. & Kosatsky, T., 2006, Impact of high temperatures on mortality: is there an added heat wave effect?, *Epidemiology* 17(6), 632-638.

Hanna, E. G. & Tait, P.W., 2015, Limitations to Thermoregulation and Acclimatization Challenge Human Adaptation to Global Warming, *International Journal of Environmental Research and Public Health* 12, 8034-8074.

Hamilton, J.M., Maddison, D.J. & Tol, R.S.J., 2005, Climate change and international tourism, A simulation study, *Glob. Environ. Change* 15, 253-266.

Hausmann, P., Kurz, C. & Rebuffoni, G., 2012, Floods in Switzerland – an underestimated risk, Swiss Re, Zürich.

Holzkämper, A., Fossati, D., Hiltbrunner, J., & Fuhrer, J., 2015. Spatial and temporal trends in agro-climatic limitations to production potentials for grain maize and winter wheat in Switzerland. *Regional Environmental Change*, 15(1), 109-122.

IFEC, Bergwelten 21, InnovaBridge, Consavis & RIBO architecture, 2016, Analyse klimabedingter Risiken und Chancen in der Schweiz, Fallstudie Kanton Tessin.

IfW (Institut für Weltwirtschaft Kiel), 2007, Kosten des Klimawandels, Die Wirkung steigender Temperaturen auf Gesundheit und Leistungsfähigkeit, Aktualisierte Fassung 07/2007, Studie im Auftrag des WWF Deutschland Frankfurt.

Indermühle, M., Raetz, P. & Volz, R., 2005, Lothar – Ursächliche Zusammenhänge und Risikoentwicklung, Synthese des Teilprogramms 6, Umwelt-Materialien Nr. 184. Office for the Environment, Forests and Landscape (BUWAL), Bern.

INFRAS, Ecologic & Rütter und Partner, 2007, Auswirkungen der Klimaänderung auf die Schweizer Volkswirtschaft (internationale Einflüsse), Commissioned by Federal Office for the Environment (FOEN).

INFRAS & Egli Engineering, 2014a, Klimabedingte Risiken und Chancen 2060. Regionale Fallstudie Kanton Basel-Stadt. Entwurf Schlussbericht zur Kommentierung durch Fachstellen, Zürich.

INFRAS & Egli Engineering, 2014b, Klimabedingte Risiken und Chancen 2060. Regionale Fallstudie Kanton Uri, Zürich.

INFRAS, Egli Engineering, Sofies & INDDIGO, 2015, Analyse des Risques et Opportunités liés aux changements climatiques en Suisse, Etude de cas Canton Genève et Grand-Genève, Genève.

IEA (International Energy Agency), 2015, World Energy Outlook 2015.

IPCC, 2007a, Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson (eds.). Cambridge, UK.

IPCC, 2007b, Climate Change 2007: Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. R. K. Pachauri and A. Reisinger (eds.). Geneva.

IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge, UK and New York, USA.

Jorgenson, D.W., Goettle, R.J., Hurd, B.H., Smith, J.B., Chestnut, L.G. & Mills, D.M., 2004, U.S. market consequences of global climate change, Prepared for the Pew Center on Global Climate Change.

Joshi, S.R. et al., 2013, Physical and economic consequences of sea-level rise: A coupled GIS and CGE analysis under uncertainties. Environmental and Resource Economics (submitted).

Kantonsforstamt Sankt Gallen, 2008, Waldpflege und Waldverjüngung unter dem Aspekt der Klimaveränderung, Strategiepapier, Empfehlungen des Forstdienstes des Kantons St. Gallen.

Karremann, M.K., Pinto, J.G., Reyers, M. & Klawa, M., 2014, Return periods of losses associated with European windstorm series in a changing climate, *Environmental Research Letters* 9.

Kemmler, A., Piégsa, A., Wüthrich, P., Keller, M., Jakob, M. & Catenazzi, G., 2015, Analyse des schweizerischen Energieverbrauchs 2000–2014 nach Verwendungszwecken, Commissioned by the Swiss Federal Office of Energy (SFOE).

Kirchner, A., Kemmler, A., Hofer, P., Keller, M., Jakob, M. & Catenazzi, G., 2010, Analyse des schweizerischen Energieverbrauchs 2000-2009 nach Verwendungszwecken, Commissioned by the Swiss Federal Office of Energy (SFOE).

Köberl, J. et al., 2014, Chapter 19: Tourism, in: Steininger, K.W. et al. (eds.), Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria, 367-390, Springer Climate, John Dodson, Menai, Australia.

Koenig, U. & Abegg, B., 1997, Impacts of climate change on winter tourism in the Alps, *Journal of Sustainable Tourism* 5(1), 46-58.

Köplin, N., Schädler, B., Viviroli, D., & Weingartner, R., 2012, Relating climate change signals and physiographic catchment properties to clustered hydrological response types, *Hydrology and Earth System Sciences* 16(7), 2267-2283.

Labriet, M., Joshi, S. R., Vielle, M., Holden, P. B., Edwards, N. R., Kanudia, A., Loulou, R. & Babonneau, F., 2013, Worldwide impacts of climate change on energy for heating and cooling, *Mitigation and Adaptation Strategies for Global Change* 20(7), 1111–1136.

Lehmann, N., Finger, R., Klein, T., Calanca, P. & Walter, A., 2013, Adapting crop management practices to climate change: Modeling optimal solutions at the field scale. *Agricultural Systems* 117, 55-65.

Lemke, B. & Kjellstrom, T., 2012, Calculating Workplace WBGT from Meteorological Data: A Tool for Climate Change Assessment, *Industrial Health* 50, 267-278.

Liljegren, J.C., Carhart, R.A., Lawday, P., Tschopp, S. & Sharp, R., 2008, Modeling the Wet Bulb Globe Temperature Using Standard Meteorological Measurements. *Journal of Occupational and Environmental Hygiene*, 5(10), 645-655.

Macagno, G., Loureiro, M., Nunes, P.A.L.D. & Tol, R., 2009, Assessing the impact of biodiversity on tourism flows: A model for tourist behavior and its policy implications. ESRI Working Paper 281.

Mani, P. & Caduff, U., 2012, Klimasensitivität Naturgefahren, Teil 1 Methodenbericht, Commissioned by Federal Office for the Environment (FOEN).

Matasci, C., 2010, The vulnerability of Switzerland towards climate change: the case of tourism. 2010 Belpasso International Summer School.

Matasci, C., Kruse, S., Barawid, N. & Thalmann, P., 2014, Exploring barriers to climate change adaptation in the Swiss tourism sector, *Mitigation and Adaptation Strategy for Global Change* 19, 1239-1254.

McDermott, G.R., Nilsen, O.A., 2012, Electricity prices, river temperatures and cooling water, IZA Discussion Paper 6842, Institute for the Study of Labor (IZA).

Meier, R., 1998, Sozioökonomische Aspekte von Klimaänderungen und Naturkatastrophen in der Schweiz. Final Report of the Project NFP31. Zürich.

Mideska, T. & Kallbekken, S., 2010, The Impact of Climate Change on the Electricity Market: A Review, *Energy Policy* 38, 3579-3585.

Mima, S. & Criqui, P., 2015, The Costs of Climate Change for the European Energy System, An Assessment with the POLES Model, *Environmental Modeling & Assessment* 20(4), 303-319.

Moshammer, H., Geresdorfer, A., Geresdorfer, T., Hutter, H.-P., Formayer, H., Kromp-Kolb, H. & Leitner, B., 2007, Abschätzung der Auswirkung von Hitze auf die Sterblichkeit in Oberösterreich.

Moshammer, H., Hutter, H.P., Frank, A., Geresdorfer, T., Hlava, A., Sprinzl, G. & Leitner, B., 2006, Einflüsse der Temperatur auf Mortalität und Morbidität in Wien. StartClim2005.A1a.

Müller, H. & Weber, F., 2007, Klimaänderung und Tourismus: Szenarienanalyse für das Berner Oberland 2030. Forschungsinstitut für Freizeit und Tourismus (FIF) der Universität Bern, Bern.

Munich Re, 2002, Winter storms in Europe (II). Analysis of 1999 losses and loss potentials, Munich.

Nakicenovic, N. et al. (eds.), 2000, Special Report on Emissions Scenarios: A Special Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, U.K., available online at: http://www.grida.no/climate/ipcc/emission/index.htm

Nathani, C., Schmid, C. & van Nieuwkoop, R., 2011, Schätzung einer Input-Output- Tabelle der Schweiz 2008.

NELAK, 2013, Neue Seen als Folge des Gletscherschwundes im Hochgebirge – Chancen und Risiken. Formation des nouveux lacs suite au recul des glaciers en haute montagne – chances et risques. Forschungsbericht NFP 61. Haeberli, W., Bütler, M., Huggel, C., Müller, H. & Schleiss, A. (Hrsg.). Zürich.

OcCC/ProClim, 2007, Klimaänderung und die Schweiz 2050. Erwartete Auswirkungen auf Umwelt, Gesellschaft und Wirtschaft. Bern.

Nelson, G. C., Mensbrugghe, D., Ahammad, H., Blanc, E., Calvin, K., Hasegawa, T., ... & Willenbockel, D. (2014). Agriculture and climate change in global scenarios: why don't the models agree. Agricultural Economics, 45(1), 85-101.

OcCC & ProClim, 2007, Klimaänderung und die Schweiz 2050 – Erwartete Auswirkungen auf Umwelt, Gesellschaft und Wirtschaft, Bern.

OECD (Organisation for Economic Co-operation and Development), 2004, The Benefits of Climate Change Policies, OECD Publications, Paris.

OECD (Organisation for Economic Co-operation and Development), 2015, The Economic Consequences of Climate Change. Environment Directorate and Environment Policy Committee, OECD, ENV/EPOC(2015)12/FINAL.

Olefs, M., Fischer, A. & Lang, J., 2010, Boundary Conditions for Artificial Snow Production in the Austrian Alps. *J. Appl. Meteorol. Climatol.* 49, 1096–1113.

Paci, D., 2014, Human Health Impacts of Climate Change in Europe. Report for the PESETA II project.

Perch-Nielsen, S.L., Amelung, B. & Knutti, R., 2010, Future climate resources for tourism in Europe based on the daily Tourism Climatic Index. *Clim. Change* 103, 363–381.

Perroud, M. & Bader, S., 2013, Klimaänderung in der Schweiz. Indikatoren zu Ursachen, Auswirkungen, Massnahmen. Federal Office for the Environment (FOEN), Bern, and MeteoSchweiz, Zürich.

Petrini, O., Tonolla, M., Flacio, E. & Engeler, L., 2012, SWISS-TIGER. Assessing the potential distribution of the tiger mosquito *Aedes albopictus* in Switzerland, Commissioned by Federal Office for the Environment (FOEN), Technical report FEM-CRI PGIS.

Prognos, 2012, Die Energieperspektiven für die Schweiz bis 2050. Energienachfrage und Elektrizitätsangebot in der Schweiz 2000-2050. Ergebnisse der Modellrechnungen für das Energiesystem, Commissioned by Swiss Federal Office of Energy (SFOE).

Reilly, J., Paltsev, S., Strzepek, K., Selin, N.E., Cai, Y., Nam, K.-M., Monier, E., Dutkiewicz, S., Scott, J., Webster, M. & Sokolov, A., 2012, Valuing Climate Impacts in Integrated Assessment Models: The MIT IGSM, MIT Joint Program on the Science and Policy of Global Change, Report No. 219.

Rixen, C., Teich, M., Lardelli, C., Gallati, D., Pohl, M., Pütz, M. & Bebi, P., 2011, Winter Tourism and Climate Change in the Alps: An Assessment of Resource Consumption, Snow Reliability, and Future Snowmaking Potential. *Mt. Res. Dev.* 31, 229–236.

Rosenzweig et al., 2014, Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison, *Proceedings of the National Academy of Sciences* 111(9), 3268-3273.

Roson, R. & Sartori, M., 2014, Climate change, tourism and water resources in the Mediterranean: A general equilibrium analysis. *Int. J. Clim. Change Strateg. Manag.* 6, 212–228.

Royer, J.-F., Lowe, J., Johns, T., van Vuuren, D., Stehfest, E., Denoblet-Ducoudré, N., Boucher, O., Rognerud, B. & Huebener, H., 2009, The new ENSEMBLES E1 mitigation scenario for future climate simulations. *Geophysical Research Abstracts* 11.

Schweizer Tourismus-Verband, 2016, Schweizer Tourismus in Zahlen – Struktur- und Branchendaten.

Schwierz, C., Köllner-Heck, P., Zenklusen Mutter, E., Bresch, D.N., Vidale, P.-L., Wild, M. & Schär, C., 2010, Modelling European winter wind storm losses in current and future climate, *Climatic Change* 101, 485-514.

SCNAT (Swiss Academy of Sciences), 2008, Biodiversität und Klima – Konflikte und Synergien im Massnahmenbereich, Akademie der Naturwissenschaften Schweiz, Bern.

Scott, D. & McBoyle, G., 2007, Climate change adaptation in the ski industry, *Mitigation and Adaptation Strategy for Global Change* 12, 1411-1431.

Scott, D., McBoyle, G., Schwartzentruber, M., et al., 2004, Climate change and the distribution of climatic resources for tourism in North America, *Clim. Res.* 27, 105–117.

Serquet, G. & Rebetez, M., 2011, Relationship between tourism demand in the Swiss Alps and hot summer air temperature associated with climate change, *Climatic Change* 108, 291-300.

Serquet, G. & Rebetez, M., 2013, Changements Climatiques: Quel avenir pour les destinations touristiques des Alpes et du Jura Vaudois? Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

Serquet, G. & Thalmann, P., 2012, Impacts des changements climatiques pour le tourisme à Verbier. EPFL, Lausanne.

SFOE (Swiss Federal Office of Energy), 2015, Schweizerische Elektrizitätsstatistik 2014, Bern.

SGHL (Swiss Hydrological and Limnological Society) & CHy (Swiss Hydrological Commission), 2011, Auswirkungen der Klimaänderung auf die Wasserkraftnutzung, Synthesebericht, Bern.

Sutherst, R.W., 2004, Global Change and Human Vulnerability to Vector-Borne Diseases, *Clinical Micro-biology Review* 17(1), 136-173.

Swiss Academies of Arts and Sciences, 2016, Brennpunkt Klima Schweiz: Grundlagen, Folgen und Per-spektiven, *Swiss Academies Reports* 11(5).

Swiss Confederation, 2012a, Adaptation to Climate Change in Switzerland – goals, challenges and areas of action. Part 1 of the Federal Council's strategy of 2 March 2012. Publ. by Federal Office for the Environment (FOEN), Bern.

Swiss Confederation, 2012b, Swiss Biodiversity Strategy – In fulfilment of Measure 69 (Objective 13, Art. 14, Section 5) of the Legislature Plan 2007–2011: Development of a Strategy for the Conservation and Promotion of Biodiversity. Publ. by Federal Office for the Environment (FOEN), Bern.

Swiss Confederation, 2014, Anpassung an den Klimawandel in der Schweiz, Aktionsplan 2014-2019. Zweiter Teil der Strategie des Bundesrates vom 9. April 2014. Publ. by Federal Office for the Environment (FOEN), Bern.

Thieken, A.H., Cammerer, H., Dobler C., Lammel, J. & Schöberl, F., 2014, Estimating changes in flood risks and benefits of non-structural adaptation strategies - a case study from Tyrol, Austria, *Mitigation and Adaptation Strategies for Global Change*. Published online: 31 October 2014.

Tranos, E. & Davoudi, S., 2014, The Regional Impact of Climate Change on Winter Tourism in Europe. *Tour. Plan. Dev.* 11, 163–178.

United Nations, Department of Economic and Social Affairs, Population Division, 2015, World Population Prospects: The 2015 Revision, DVD Edition.

Urbinello, D. & Röösli, M., 2014, Hitzewellen und Gesundheit, Newsletter Nr. 1, Dezember, Swiss Tropical and Public Health Institute.

Van Vliet, M., Vögele, S. & Rübbelke, D., 2013, Water Constraints on European Power Supply Under Climate Change: Impacts on Electricity Prices, *Environmental Research Letters* 8(3), 035010.

Wiebe, Keith, et al., 2015, Climate change impacts on agriculture in 2050 under a range of plausible socio-economic and emissions scenarios, *Environmental Research Letters* 10(8), 085010.

Winkler, R., Almer, C., Bader, C., Gonseth, C., Laurant-Lucchetti, J., Thalmann, P. & Vielle, M., 2014, Energy consumption of buildings – direct impacts of a warming climate and rebound effects, in: CH2014-Impacts: Toward quantitative scenarios of climate change impacts in Switzerland. OCCR, FOEN, MeteoSwiss, C2SM, Agroscope, and ProClim, 99-105.

Worldbank, 2016, Forest area (sq. km), Overview per country, http://data.worldbank.org/indicator/AG.LND.TOTL.K2

WRI (World Resources Institute), 2000, World Resources Database 2000–2001, Washington, DC.

WSL & BUWAL (eds.), 2001, Lothar. Der Orkan 1999. Ereignisanalyse. Swiss Federal Institute for Forest, Snow and Landscape Research and Federal Office for the Environment, Forests and Landscape, Birmensdorf, Bern.

Yu, W., Mengersen, K., Wang, X., Ye, X., Guo, Y., Pan, X. & Tong, S., 2012, Daily average temperature and mortality among the elderly: A meta-analysis and systematic review of epidemiological evidence, *International Journal of Biometeorology* 56, 569–581.

APPENDIX: LITERATURE OVERVIEW BY CLIMATE-CHANGE SENSITIVE AREA

Health

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan / Sigmaplan 2007	2030 2050 2070 2100	- Risk analysis with quantification whenever possible. - CC impacts with adaptation. - Tourism: includes CGE model. - Health: quantitative analysis of productivity loss and increased mortality due to extreme events (heat waves).	✓	- Health: no significant CC impacts before 2050.	- Detailed description of methods. - Impacts with adaptation. - Only two types of health impacts analysed. - No socio-economic scenario included. - Total cost: share of adaptation unclear.
INFRAS / Egli Engineering 2014a	2060	- Case study for canton Basel-Stadt. - Risk analysis with quantification whenever possible. - Two scenarios for climate change: 'strong' and 'weak'. Basis: IPCC emission scenarios RCP3PB and A1B. - One socio-economic scenario. - Health: quantitative analysis restricted to impacts of heatwaves (incl. ground-level ozone) on mortality and productivity, but qualitative results are monetized, too. - Results are presented in the form of two expected values: annual average and 100-year events. - Assessment of uncertainty on a 4-point scale.	✓	- Health: Highest CC impact of all areas surveyed. - CC impacts on health without adaptation in the range from CHF 170 to 520 million in 2060. - Socio-economic scenario suggests additional cost of 260-580 million CHF in 2060. - 100-year heatwave might cost up to CHF 4.7 billion in strong climate change scenario. - Influence of heat island effect in urban area is high. - High level of uncertainty remains, especially for socio-economic scenario and 100-year events.	- Impacts without adaptation. - Detailed consideration of uncertainty in analysis. - Very detailed description of calculation of impacts of heatwaves on mortality and productivity; integration of heat island effect in urban areas. - Analysis for 100-year extreme events included. - High level of uncertainty remaining. - Linear relation between climate change and impacts assumed. - No analysis of CiC impacts via interdependence of markets (nationally or internationally).

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
INFRAS / Egli Engineering 2014b	2060	- Case study for canton Uri. - Risk analysis with quantification whenever possible. - Two scenarios for climate change: 'strong' and 'weak'. Basis: IPCC emission scenarios RCP3PB and A1B. - One socio-economic scenario with qualitative results. - Health: quantitative analysis restricted to impacts of heavy snowfall on number of road deaths and productivity loss due to hot days. - Qualitative results for numerous additional factors. - Results are presented in the form of two expected values: annual average and 100-year events. - Assessment of uncertainty on a 4-point scale.	✓	- Health: Highest CC impact of all areas surveyed. - Highest impact from loss of productivity during heat waves: range from 2.1 to 6.4 million CHF in 2060. - Small positive impact because of reduced road deaths due to heavy snowfall. - Health: total CC impacts without adaptation 3.6 to 11.4 million CHF in 2060. - Socio-economic scenario revealed no additional cost.	- Impacts without adaptation in mountain region. - Analysis of road deaths due to heavy snowfall. - Qualitative results are not monetized due to high uncertainty. - Linear relation between climate change and impacts assumed. - No analysis of CiC impacts via interdependence of markets (nationally or internationally).
CH2014-Impacts 2014	Three 30-year mean projections centred around 2035, 2060, 2085	- Based on three CH2011 climate scenarios (A2, A1B, RCP3PD), three time horizons and three uncertainty levels. - Applies empirical relationships between observed temperature and precipitation and three health indicators to climate scenarios: how do pharmaceutical sales, doctor visits, hospitalizations react to climate change?	✗	- Sales of registered products in pharmacies increase about 2% (with slight variations among scenarios) - Doctor visits go up 5%, but results are statistically insignificant - Hospitalization increases in all scenarios about 4%	Impacts without adaptation. - No monetization of impacts. - Only impacts of average climate changes are assessed since CH2011 scenarios do not incorporate extreme weather events. - Very limited number of indicators. - All other influences (e.g. socio-economic factors) held constant.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ernst Basler + Partner / WSL 2013	2060	- Case study for canton Aargau. - Two scenarios for climate change: 'strong' and 'weak'. Basis: IPCC emission scenarios RCP3PB and A1B. - One scenario for socio-economic and demographic change. - Adaptation is not part of the analysis, only some autonomous adaptation is included. - Aim of the study: detect areas where adaptation is most urgently required. - Results are presented in the form of two expected values: annual average and 100-year events. - Assessment of uncertainty on a 3-point scale.	✓	- Health: Highest impacts of all areas surveyed. - CC impacts on health without adaptation in the range from CHF 100 to 300 million in 2060. - Extreme (100-year) heatwave may amount to CHF 3.8 billion in strong climate change scenario. - High level of uncertainty.	- Calculation of impacts without adaptation. - Definition of indicators for heat exposure, morbidity, mortality and reduction in productivity. - Exploratory analysis for 100-year extreme events. - Still high level of uncertainty. - Important effects (i.e. possible spread of infectious diseases) are not included. - Socio-economic scenario not included in analysis of impacts on health. - No analysis of CC impacts via interdependence of markets (nationally or internationally).
Econcept 2013	2060	- Case study for canton Zürich. - Literature review plus expert interviews. - Based on one CH2011 climate scenario (A1B) and one socio-economic scenario. - Analysis of CC impacts from an urban perspective. - Limited to effects on open spaces, buildings, health. - Analysis restricted to heatwaves and allergic disorders / distribution of allergenic species.	✗	- Population density, socio-economic structure, small amount of undeveloped spaces intensify CC impacts in urban areas. - Heatwaves and spread of allergenic species / infectious diseases determine need for action. - Socio-economic structure will aggravate the impacts in some districts.	- Spotlight on CC impacts in an urban area. - Impacts without adaptation. - Specific adaptation measures are identified and prioritized. Only qualitative results.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Jorgenson et al. 2004	2050/ 2100	- Dynamic CGE model approach (IGEM) - USA, 35 sectors - Five climate scenarios - Covers impacts of cardiovascular and respiratory diseases and ozone exposure on morbidity, mortality and labor productivity	✓	- Excess mortality: 13,080 annually 2000-2100 - Excess morbidity: 387,057 annually 2000-2100 - Mortality and morbidity account for 6 to 9 % of the GDP effect in 2100, but 13 to 16 % of the welfare effect	- Comprehensive study of a large variety of CC impacts - Dynamic CGE
Bosello et al. 2006	2050	- Static CGE model approach (GTAP-E) - World, 8 regions, 17 sectors - One climate scenario: B1. - Covers cardiovascular and respiratory diseases; diarrhoea, malaria, dengue fever and schistosomiasis - Estimation of economy-wide effects through changes in labour productivity and public and private demand for health care Aim of the study: detect areas where adaptation is most urgently required.	✓	- Health related CC impacts may increase GDP in 2050 by 0.08% (Rest of Annex I) or reduce it by 0.07% (in the Rest of the World, including Africa)	- Early study that differentiates between direct and indirect costs (via labor productivity and demand for health services) - Only one climate scenario - Only productivity loss covered
Reilly et al. 2012	2100	- CGE model approach (MIT IGSM) - World, 16 regions - Covers ozone pollution - Three emissions scenarios	✓	- Health: Change in ozone concentrations causes worldwide impact of over 1 trillion US$ until 2100	- Monte Carlo simulation of future emissions in five policy scenarios - Only ozone pollution covered
Bosello et al. 2012	2050	- Recursive dynamic CGE model approach (ICES) - World, 14 regions, 17 sectors - One emissions scenario (A1B) - Health: productivity loss due to thermal discomfort.	✓	- Health: significant productivity losses only in Mediterranean Europe: resulting in -0.19% of GDP in 2050	- Methodology well documented - One emissions scenario only - Only productivity loss covered

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ciscar et al. 2014	2071-2100	- Comparative static CGE model approach (GEM E3) - Europe, 5 regions, 18 sectors - Two emissions scenarios (A1B, E1) - Covers high temperature, respiratory, cardiovascular diseases and renal failure; food and water-borne diseases - Estimates impacts on labor productivity, health care cost, reduction of total available hours, premature deaths	✓	- Health: 177,000 to 200'000 excess mortality/per year on EU level - Health impacts account for 2/3 of total GDP loss	- Comprehensive study - Methodology well documented - Comparative static approach
OECD 2015	2060, post 2060	- Dynamic CGE model approach (ENV Linkages, AD DICE for post 2060) - World, 25 regions, 35 sectors - One emissions scenario (RCP8.5) - Health: morbidity from heat and cold exposure, morbidity and mortality from infectious diseases, cardiovascular and respiratory diseases		- Health impacts: -0.9% GDP loss in 2060 - Health impacts most dominant of all modelled impacts in 2060	- Comprehensive study - Dynamic CGE - Methodology well documented - Mortality from heat exposure not modelled

Buildings and infrastructure

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan / Sigmaplan 2007	2030 / 2050 / 2070 / 2100	- Risk analysis with quantification whenever possible. - CC impacts with adaptation. - Impacts of floods, landslides and bedload analysed. - Floods: analysis of typical event, extrapolation of costs and frequency to 2050.	✓	- CC impacts on buildings and infrastructure in comparison with other areas rather low. - Floods: Expected value for impact without adaptation in 2050 ranges from CHF 46.6 to 101.2 million, depending on assumptions. With adaptation: CHF 70.86 million in 2050 (max). - Landslides, impact with adaptation: CHF 60.8 million in 2050 (max); highly uncertain. - Bedload, impact with adaptation: 40 mill. CHF in 2050 (max); highly uncertain.	- Detailed description of methods. - Impacts with adaptation. - Floods: impacts with and without adaptation. - High level of uncertainty remaining.
INFRAS / Egli Engineering 2014a	2060	- Case study for canton Basel-Stadt - Risk analysis with quantification whenever possible - Two scenarios for climate change: "strong" and "weak". Basis: IPCC emission scenarios RCP3PB and A1B - One socio-economic scenario - Results are presented in the form of two expected values: annual average and 100-year events - Assessment of uncertainty on a 4-point scale	✓	- Floods: substantial impacts only through 100-year events. - Hail and heavy rainfall: 30-year and 100-year-events calculated, too high uncertainty for annual average expectancy values. - Storms: sensitivity analysis only.	- Impacts without adaptation. - Analysis for 100-year extreme events included. - High level of uncertainty remaining. - Only sensitivity analysis. - Qualitative results for socio-economic scenario. - No analysis of CiC impacts via interdependence of markets (nationally or internationally).

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
INFRAS / Egli Engineering 2014b	2060	- Case study for canton Uri. - Risk analysis with quantification whenever possible. - Two scenarios for climate change: 'strong' and 'weak'. Basis: IPCC emission scenarios RCP3PB and A1B - Results are presented in the form of two expected values: annual average and 100-year events, - Assessment of uncertainty on a 4-point scale.	✓	Estimated range of CC impacts in 2060, depending on climate scenario, in million CHF: - Avalanches: 4.2 to 3.8 - Heavy snowfall: 2.0 to 1.6 - Floods: 22.6 to 25.8 - Landslides: 2.5 to 2.8 - Hail: 0.225 to 0.075 (highly uncertain) - Rockfall: 2.3 to 2.2 - Storms: 3.75 to 1.25 (highly uncertain).	- Impacts without adaptation in mountain region. - Linear relation between climate change and impacts assumed. - No analysis of CiC impacts via interdependence of markets (nationally or internationally).
Ernst Basler + Partner / WSL 2013	2060	- Case study for canton Aargau. - Two scenarios for climate change: 'strong' and 'weak'. Basis: IPCC emission scenarios RCP3PB and A1B. - One scenario for socio-economic and demographic change. - Adaptation is not part of the analysis, only some autonomous adaptation is included. - Aim of the study: detect areas where adaptation is most urgently required. - Results are presented in the form of two expected values: annual average and 100-year events. - Assessment of uncertainty on a 3-point scale.	✓	- Floods: only sensitivity analysis due to high uncertainty. - Winter road maintenance: savings of CHF 8 to 13 million in 2060.	- Impacts without adaptation. - Still high level of uncertainty. - Only sensitivity analysis for floods. - No analysis of CC impacts via interdependence of markets (nationally or internationally).

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Econcept 2013	2060	- Case study for canton Zürich. - Literature review plus expert interviews. - Based on one CH2011 climate scenario (A1B) and one socio-economic scenario. - Analysis of CC impacts from an urban perspective. - Limited to effects on open spaces, buildings, health.	✗	Description of impacts on buildings.	- Spotlight on CC impacts in an urban area. - Impacts without adaptation. - Specific adaptation measures are identified and prioritized.
Schwierz et al. 2010	2071-2100	- Study encompasses all of Europe. - Coupling of two regional climate models with an operational insurance loss model. - Based on IPCC A2 scenario. - Limited to impacts of winter wind storms on insurance portfolio.	✓	- Climate change leads to higher European-wide losses: Annual expected loss: +44% 10 years loss: +23% 30 years loss: +50% 100 years loss: +104%. Impact in Switzerland is below European mean: annual expected loss: +19%	- Coupling of climate and insurance models is interesting approach. - Prognosis of impacts of extreme events - Only impacts from winter wind storms.
OECD 2015	2060, post 2060	- Dynamic CGE model approach (ENV Linkages, AD DICE for post 2060) - World, 25 regions, 35 sectors - One emissions scenario (RCP8.5) - B&I: damages from storms included	✓	- Buildings an infrastructure: impacts in 2060 very low	- Comprehensive study - Dynamic CGE Methodology well documented
Bosello et al. 2012	2050	- Recursive dynamic CGE model approach (ICES) - World, 14 regions, 17 sectors - One emissions scenario (A1B) - B&I: river flood damages modelled	✓	- Buildings an infrastructure: impacts in 2050 very low	- Applies LISFLOOD flood damage model which separates CC impacts from socio-economic factors - LISFLOOD model includes only EU27

Energy demand

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
CH2014-Impacts 2014	2035 2060 2085	- The effect of climate change on the GDP through energy demand for indoor cooling and heating is examined with the help of a CGE analysis. - Past temperature data is correlated with energy demand for heating and cooling to project direct effects on demand. Indirect rebound effects are also modelled.	✓	The total effect is expected to be a saving in the range of 0.04% to 0.23% of consumption (depending on the global emissions scenario).	Energy part is a very comprehensive overview of climate change impacts on cooling/heating energy demand that includes some adaption effects. Energy efficiency gains are assumed to increase at a constant rate.
Ernst Basler + Partner / WSL 2013	2060	- Two climatic scenarios: weak and strong, based on the RCP3PB and A1B IPCC scenarios. - Constant electricity prices are assumed. - The effects of climate change are compared to status quo, in order to find areas where adaptation is necessary.	✓	Heating is expected to decrease and this effect is not offset by increase of cooling energy demand.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. Indirect (price) or international effects are left out in the energy sector.
INFRAS / Egli Engineering 2014a	2060	The same basis as the Uri case study, however, there is a threshold of costs: effects below CHF 0.5 million are not considered for quantification.	✓	Quantitative effects considered: - Change in heating energy demand through cold spells: reduced by 12% (weak) or 30% (strong scenario) from today CHF 137 million. - Change in cooling energy demand through hot spells: increase by 55% (weak) or 140% (strong scenario) from CHF 0.7 million today.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. Indirect (price) or international effects are left out in the energy sector.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
INFRAS / Egli Engineering 2014b	2060	The basis is the same as in Ernst Basler + Partner et al. 2013.	✓	Change of energy demand for indoor heating: Today's cost: CHF 33.2 million decline by 15% (weak) or 30% (strong scenario).	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. - Indirect (price) or international effects are left out in the energy sector. - Effects on cooling demand not quantified.
Ecoplan, Sigmaplan 2007	2100	Detailed CGE analysis of four sectors, including monetization. Global climatic threshold events were not considered, neither were local large scale catastrophes and non-market damages. Climate change costs are calculated by adaption measures and costs that occur through climate change and cannot be prevented by adaption measures.	✓	- Electricity demand from cooling will increase, while heating will decrease. - Economic effects included in overall assessment of costs for energy sector (CHF ~750 million can be expected annually by 2050).	- Includes adaption to climate change. - Comprehensive economic valuation. - Includes projects on future development of energy prices. - Indirect effects (price and crowding out effects from other markets) are not modelled for energy. - Newer results are available for space cooling (see CH2014).
Faust et al. 2015	2050	Gemini CGE model approach with 28 sectors and 6 regions.	✓	- Projects a total welfare gain of 0.2% of consumption due decreasing demand amid rising electricity prices (caused by changing runoff regimes and demand patterns). - Due to decreased demand for heating (only partly offset by increased cooling demand), welfare gains of 0.19% are projected.	Includes endogenous adaption to climate change.
Gonseth et al. 2015	2060	- CGE model approach (Gemini-E3) - Energy demand modelled using the HDD and CDD methods. - Main analysis for A1B scenario, but sensitivity analysis is also available for A2 and RCP3PD	✓	- With regard to cost/benefit impact, heating energy demand decrease clearly outweighs cooling energy demand increase. - Welfare gain is projected to be 733m USD, or 0.16% of consumption.	- General equilibrium approach - Modelled in Gemini-E3

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ciscar & Dowling 2014	-	Literature Review	✗	- Overview of CC impact research in different areas of the electricity market. - Many sub-areas are still relatively little researched.	Overview over aspects of climate impacts in the electricity market that are well/little researched.
Bosello et al. 2012	2050	- General equilibrium model (ICES) - A1B climate scenario	(✓)	Electricity demand projected to increase in Europe by 6.91% (Mediterranean), 0.33% (Northern), 0.15% (Eastern Europe)	Worldwide integrated model - No supply side energy effects considered - No explicit referral to price effects
Dowling 2013	2050	- Partial equilibrium modelling (POLES) - Two climate scenarios: A1B and E1	✓	- Generally lower electricity prices in 2050 in most regions - Demand side impacts are more significant than supply side effects	Includes modelling of price effects in electricity markets - The electricity prices are not the spot prices, but generation costs. They only include supply side and not demand side effects - Time horizon only 2050
Mima & Criqui 2015	2100	- Partial equilibrium modelling (POLES) - Two climate scenarios: A1B and E1	✓	- Climate causes net decrease of energy demand, as decrease in heating is stronger than increase in cooling demand - Electricity supply is expected to decrease, mostly due to a lack of cooling water during heat waves. - Economic impact is low overall and positive in Northern Europe (less expenditure for heating), but negative in Southern Europe (higher expenditure for cooling)	Captures both supply and demand side effects. - While Switzerland is included, only results for aggregated European regions are available.
OECD (2015)	2060+	- General equilibrium modelling approach - RCP8.5 climate scenario	✓	- Worldwide total electricity demand increase from cooling and decrease from heating will balance out until 2060.	- Worldwide simulation - Uses new RCP scenario The effect of climate change on energy supply is not modelled quantitatively.

Energy Supply

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ernst Basler + Partner / WSL 2013	2060	- Two climatic scenarios: weak and strong, based on the RCP3PB and A1B IPCC scenarios. - Constant electricity prices are assumed. - The effects of climate change are compared to status quo, in order to find areas where adaptation is necessary.	✓	- Hydropower total output will increase as more water can be expected from melting of glaciers, but a shift in the seasonal pattern will become evident. - Water supply will in future also be met, though at a slightly higher cost.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. Indirect (price) or international effects are left out in the energy sector.
INFRAS / Egli Engineering 2014a	2060	The same basis as the Uri case study, however, there is a threshold of costs: effects below CHF 0.5 million are not considered for quantification.	✓	Quantitative effects considered: - Effects on hydropower through floods: Effects on production are small and neglected. - No significant change in hydropower production expected.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. Indirect (price) or international effects are left out in the energy sector.
INFRAS / Egli Engineering 2014b	2060	The basis is the same as in Ernst Basler + Partner et al. 2013. The most important differences are the following: - Different treatment of uncertainties. - Damages and revenues are assumed to develop linearly to occurrence of events, even though there might likely be non-linear relation. - Some current cost data is obtained through interviews (utility CKW in the energy section).	✓	Quantitative effects considered: - Change of water regime for hydropower: assumed not to have a significant effect. - Floods: CHF 50k/yr and CHF 1.3 million of damages for a 100-year flood (current costs). +5% for weak and +20% for strong scenario. - Damages through mudslides: currently CHF 10k/yr and assumption for a 100-year event: CHF 200k. +5% for weak and +20% for strong scenario.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. - Indirect (price) or international effects are left out in the energy sector. - Not quantified chances for pump storage through increasing volatility of electricity prices and an increase in melt water from glaciers.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan / Sigmaplan 2007	2100	Detailed CGE analysis of four sectors, including monetization. Global climatic threshold events were not considered, neither were local large scale catastrophes and non-market damages. Climate change costs are calculated by adaption measures and costs that occur through climate change and cannot be prevented by adaption measures.	✓	- CC affects hydropower and nuclear power (availability of cooling water) - Heat spells like in 2003 (in that year nuclear power production was 4% lower) will increase - Overall additional costs of CHF ~750 million can be expected annually by 2050 (including increased demand for cooling and reduced demand for heating)	- Includes adaption to climate change. - Comprehensive economic valuation. - Includes projects on future development of energy prices. - Indirect effects (price and crowding out effects from other markets) are not modelled for energy. - Historical analysis. No projections about the future. - No monetization.
Faust et al. 2012	2100	Gemini CGE model approach with 28 sectors and 6 regions.	✓	- Decrease in heating energy is economically more significant than the increase in cooling energy. - Increasing loss of nuclear power capacity due to scarcity of cooling water.	Includes endogenous adaption to climate change. Nuclear power capacity loss is estimated with an econometric model that uses air temperature as a proxy for water temperature.
Faust et al. 2015	2050	Gemini CGE model approach with 28 sectors and 6 regions.	✓	- Hydropower production is projected to decrease by more than 800 GWh due to runoff change (-2.2% average from different climate scenarios), which is compensated by gas and renewable energy in the model	Includes endogenous adaption to climate change.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Gaudard 2014	2020-50 and 2070-2100	Statistical forecasting of runoff and electricity prices. Investment and reservoir management optimisation model for a few dams.	✓	- Runoff will decrease in the vicinity of 18 to 21% - Hydropower production will decrease slightly less - Thanks to smart reservoir management, revenue loss is only about half as large as the decrease in runoff - Uncertainty about electricity prices is much greater than uncertainty in runoff	Adaptation through reservoir management. Extrapolation from a few dams only.
SGHL/CHy 2011	Two periods of 30 years, around 2035 and 2085	The report considers temperature and precipitation, as well as runoff from glaciers that affect the amount of power that can be produced. Furthermore effects on the cost of hydropower production through a change in river bed load are modelled.	(✓)	- Overall average temperatures will increase, by up to 3-4.5°C in 2085 - No clear overall trend can be observed for precipitation. - Extreme events (heat waves and floods) tend to increase (with great uncertainty)	Comprehensive analysis of cc-impacts specific to hydropower The economic analyses are very particular to the case studies and cannot be generalised
Ciscar & Dowling 2014	-	Literature Review	✗	- Overview of CC impact research in different areas of the electricity market. - Many sub-areas are still relatively little researched.	Overview over aspects of climate impacts in the electricity market that are well/little researched.
Dowling 2013	2050	- Partial equilibrium modelling (POLES) - Two climate scenarios: A1B and E1	✓	- Generally lower electricity prices in 2050 in most regions - Demand side impacts are more significant than supply side effects	Includes modelling of price effects in electricity markets - The electricity prices are not the spot prices, but generation costs. They only include supply side and not demand side effects - Time horizon only 2050

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
McDermott & Nilson 2012	-	- Examination of German electricity market data of 2002-2009 to find effects of cooling water scarcity and temperatures on electricity prices (day-ahead spot prices), through regression analysis. - Electricity production function incorporates efficiency effects for water availability and temperature.	(✓)	- Electricity price increases by 0.277% with every percent of temperature increase (only above threshold of 25° C water temperature) - Water scarcity: ~1% price increase for 1% water level decrease. - Demand increase of 1% leads to 6% price increase.	Coefficients could help to estimate climate change effects on electricity prices. German power data only
Mideska & Kallbekken 2010	-	- Physical model to simulate daily river flows and water temperatures (probability distribution function) on the base of climate scenarios A2 and B1. - The mean number of days exceeding 23°C for Europe was calculated, the threshold from which production is required to be throttled. - This data is then combined with 35 power-plant specific cooling data (11% of electricity production covered).	✗	- Exposure depends strongly on cooling technology type (once-through vs. Recirculation) - Summer average power capacity is expected to decrease by 13-19% (A1-B2) in Europe for once through power-plants. - Recirculation power plants useable summer capacity is expected to decrease by 4.4-5.9% (A1-B2).	- Could be useful to model European electricity supply side effects. - Based on old emission scenarios - Doesn't model price effects - Some of the modelled power plants might be taken out of operation during the examined period."
Mima & Criqui 2015	2100	- Partial equilibrium modelling (POLES) - Two climate scenarios: A1B and E1	✓	- Climate causes net decrease of energy demand, as decrease in heating is stronger than increase in cooling demand - Electricity supply will decrease, mostly due to a lack of cooling water during heat waves. - Economic impact is low overall and positive in Northern Europe (less expenditure for heating), but negative in Southern Europe (higher expenditure for cooling)	Captures both supply and demand side effects. - While Switzerland is included, only results for grouped countries are available.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Van Vilet et al. 2013	2060	- Simulations of daily river flows and water temperatures are used to find supply side impacts of future climate on power production - Demand, future installed capacities, electricity exchange capacities are based on (exogenous) scenarios of the European Network of Transmission System Operators for Electricity (ENTSO-E) - A2 climate scenario	✓	- Both thermoelectric and hydropower generating potential are expected to decline in most of Europe. - As a consequence, higher wholesale prices are projected for most countries (except Sweden and Norway).	- Time horizon 2060 - Could be useful to model some European supply side effects. Only considers water related constraints.

Water management

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ernst Basler + Partner et al. 2013	2060	Two climatic scenarios: weak and strong, based on the RCP3PB and A1B IPCC scenarios	✓	Water supply will in future also be met, though at a slightly higher cost.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. Some effects are not quantified (e.g. drinking water quality).

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
INFRAS / Egli Engineering 2014a	2060	The same basis as the Uri case study, however, there is a threshold of costs: effects below CHF 0.5 million are not considered for quantification.	✓	- No quantitative effects considered. - From 'normal' flood events, no damages are expected. A 300-year event could cause drinking water contamination, but the service provider is prepared for such an event. - Strong precipitation events are expected to increase, which might put additional strain on waste water treatment facilities - No significant effects from dry spells are expected - No chances are identified, but the risks from CC on water management are rather small.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. No quantitative effects considered.
INFRAS / Egli Engineering 2014b	2060	The basis is the same as in Ernst Basler + Partner et al. 2013. The most important differences are the following: - Different treatment of uncertainties - Damages and revenues are assumed to develop linearly to occurrence of events, even though there might likely be non-linear relation.	✓	Quantitative effects considered: - Damages on infrastructure through flood events: +5% (weak) or +20% (strong scenario), from today CHF 0.5 million (average annual events) and CHF 5.5 million (100-year event). - Damages through mudslides: + 10% (weak) to +30% (strong scenario), from today CHF 170k (average annual event) and CHF 7 million (100-year event). - Damages on infrastructure through hail/thunderstorms: No changes - Maintenance of water supply/quality in case of dry spell: no change (weak) or +10% (strong scenario) from today CHF 50k (annual average) and CHF 120k (100-year event). - Overall: The additional costs are rather low.	In connection with the case studies of the other regions and an appropriate aggregation, this potentially provides a complete image of effects on Switzerland. Some effects are not quantified (e.g. drinking water quality).
Ecoplan / Sigmaplan 2007	2100	Detailed CGE analysis of four sectors, including monetization. Global climatic threshold events, large scale catastrophes and non-market damages were not considered. Climate change costs are calculated by adaption measures and costs that occur through climate change and cannot be prevented by adaption measures.	✓	- Ground water level is probable to decreased, while demand is likely to increase in summer. - Exploitation of new water resources might become necessary to ensure security of supply. - While costs of measures are uncertain, it is likely that they are relatively low.	Includes adaption to climate change. The water management sector is not monetized.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
FOEN 2014	2025	Based on a survey of the cantons. No quantitative part.	✗	With appropriate planning, water will be sufficiently available despite climate change.	May serve as a starting point to find relevant areas of action and future issues related to drinking water management. - Temporal scope - No economic effects or quantified data.
CH-2014 Impacts 2014	2035 2060 2085	- Based on CCHydro, amended with the effects of different GHG scenarios and detailed examination of model uncertainties. - Socio-economic effects are not modelled.	✗	- The various catchments can be divided into seven response types. - They have in common that runoff decreases in summer and increases in winter, but stays approximately the same averaged over the course of a year. - River groundwater temperatures are very likely to increase and therefore quality maybe affected due to increased microbiological activity, as well as potential issues with pumping systems.	Swiss water catchment areas grouped by subtypes, which allows a better generalisation. No economic valuation.
Perroud & Bader, 2013	2010	Basically a collection of time series data of various indicators related to climate change.	✗	- Climate change is clearly evident in Switzerland. - Average temperatures have increased by 1.7°C between 1864 and 2011, which is higher than the northern hemisphere average of 1.1°C. - Average precipitation does not show a clear trend.	Contains a comprehensive overview over climatic changes that already have accrued up to today on a large number of indicators. Also contains a list of climate mitigation measures and policies. - It's all about the past. There are no projections about the future. - No monetization, also because it is hard to clearly attribute monetary effect to climate change as the sole cause.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
FOEN 2012a	2100	- Swiss climate scenarios are the foundation. - High resolution overall water flow model with the incorporation of: - glacier melting - snow melting - floods and low water events - precipitation changes.	✗	- Water flows will increase slightly in glaciated regions due to increased melting. In the long term a slight decrease is expected. - Glacial areas will have disappeared almost completely by 2100. - Shift in seasonal stream flow pattern: increase in winter and decrease in summer. - Flooding season will shift from summer to winter, vice versa for low water events. - Precipitation increase in North, decrease in South. - Increased possibility of droughts, due to decreased melt water, precipitation and higher temperatures in summer.	Very detailed water flow model, with CC impacts on the physical equilibrium. - Focus is clearly on scientific examination on hydrological balance in Switzerland, no economic effects - For high-precipitation events, no projection is possible - Uncertainty in underlying climate models is high - Projections for the Alps are not possible.
Faust et al. 2015	2050	Gemini CGE model approach with 28 sectors and 6 regions. Differentiates between different models that have different adaption capabilities. All scenarios but one are based on the same climate scenario (ETHZ, A1B).	✓	- The production price of water increases by 28% to 149.4% (depending on scenario), even a decrease by 32.8% is possible (SMHI scenario) in the industrial sector - Price increase for drinking water is projected at 7.3% to 39.7%, while the SMHI climate scenario proposes a decrease by 8.8%. - The production price of the raw water resource (as an input factor) is projected to increase by 68.5% to 222.6%, while in the SMHI climate scenario a decrease by 79.9% is suggested. - A scenario in which water availability is restricted arbitrarily by 20% projects even steeper price increases than the top end values above.	Includes endogenous adaption to climate change. It does not offer a global assessment of the impact of climate change as it only partly considers changes in seasonality and does not integrate extreme events like floods and droughts.

Agriculture

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan / Sigmaplan 2007	2100		✗	- Qualitative statements only. - Climate-induced impacts -2050 not of large relevance.	
CH2014-Impacts 2014	2035 2060 2085	Three case studies: - Animal production: dairy cows' performance is quantified using the temperature-humidity index. - Pest management in fruit production: specifying a sigmoidal response function to changes in temperature. - Plant production (viticulture): Huglin index.	✗	- Performance of dairy cows suffers under heat stress: as warm spell days increase, heat stress increases, progressive decline in milk production. - Pest management in apple production: risk of second – and a smaller for third – generation of larval emergence start of the codling moth. - Viticulture: by 2035 climate change beneficial, more different grapes could grow. By 2060 and 2085 extremes in temperature could lead to negative impacts.	Quantitative analysis of responses to CC of 3 aspects of agricultural production. Partial analysis.
Ernst Basler + Partner / WSL 2013	2060	- Based on CH2011 scenarios - Literature analysis for each area of impacts, then quantitative analysis for those with high impact. - Quantified indicators: changes in yields and production costs due to changes in temperature and precipitation - Financial losses derived by hail insurance payments - Losses due to overcoming of different natural hazards.	✓	- Through approach for monetization rough direction is derived - Change in temperature leads to increase in revenue, decrease in summer precipitation to a decrease. - Yields today: CHF 650 million -> scenario 2060-weak: CHF 675 million, scenario 2060-strong: CHF 610 million. - Effective change difficult to quantify and depends on emission scenario.	Approach for monetization. Only direct impacts for economic valuation.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
INFRAS / Egli Engineering 2014b	2060	- Methodology as in Aargau study but extension with respect to uncertainty margins. - Uncertainty includes costs of inflation and land improvement. - Today's cost are linearly projected into the future, uncertain margins account for possible non-linear relations (considering changes in hazards). - Impacts only for agricultural production and their productive area: impacts on agricultural infrastructure in section 'infrastructure and buildings'. - Quantified indicators (risks and effects): avalanches, intense snowfall, floods, mudflow, heat waves, rockfall, change in temperature. - If no reliable projection possible: sensitivity analysis. - Qualitative analysis of interference of animal wellbeing.	✓	- Expected costs for each hazard derived. - Cost savings of CHF 24,000 to 48,000/yr through change in avalanches, snowfall, rockfall. - Yields of CHF 0.7-1.4 million/yr through increase in temperature - Floods, mudflow, droughts: costs of CHF 110,000 to 400,000/yr. - Net increase in yields of CHF 0.6 to 1 million/yr.	Assessment of uncertainty margins.
Faust et al. 2015	2050	- CGE modelling approach for different degrees of sector-specific adaptation concerned with the impact of changes in water availability. - Raw water as a production factor for irrigation in the agriculture sector.	✓	- Production price of irrigation water is projected to increase by 37.9 % (high agricultural adaptation) to 240.1 % (low agricultural adaptation)	CGE modelling approach. Considers only irrigation.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Nelson et al. 2014	2030, 2050	They use a combination of general circulation models, crop modelling suites, CGEs and partial equilibrium models (for agricultural sector)	✓	- Crop area projected to increase for almost all models - Yield reductions projected for all models, magnitudes differ - Prices projected to increase across all models, significant inter-model variation	+ CGE modelling approach. - Only one emission scenario modelled
Rosenzweig et al. 2014	2020, 2050, 2090	Model intercomparison of crop models, forced with four different emission scenarios	✗	- Models agree on sign of yield effects (negative) - Mid-latitude sign still uncertain	
Wiebe et al. 2015	2050	Model intercomparison of climate and economic models using shared socioeconomic pathways (SSP 1, 2 and 3)	✓	- Modelled for agricultural yields, area, production, consumption, prices and trade for coarse grains, rice, wheat, oilseeds and sugar crops - Impacts from climate change similar for SSP 1 – 3	+ CGE modelling approach + impacts on yields and prices given

Forestry

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan / Sigmaplan 2007	2100		✗	Qualitative statements only, climate-induced impacts until 2050 not of large relevance.	
CH2014-Impacts 2014	2035, 2060, 2085 / Land-Clim and For-Clim: 2300 (?)	- Growth of Norway spruce: relationship between radial stem increment and mean temperature and precipitation sum over growing season. Sample of 156 trees from 11 sites. Potential impacts discussed for Biel and Goppenstein. - Climatic suitability: distribution of spruce and beech, derived by 6 species distribution models for each species. Maps represent climatic potential of tree species. - Forest dynamics: models forclim and landclim to get appropriate sensitivity to climate with high local resolution. - Ecosystem services: simulated with landclim and forclim in Saas (VS) and Dischma (GR) -> comparison of impacts on these two different ecosystems. - Bark beetles: estimate changing infestation potential.	✗	- Growth of Norway spruce: strongly reduced if mean T > 15C and P < 600mm during growing season, for RCP-3PD moderate warming stimulates growth. In A1B and A2 droughts can have severe impacts e.g. in central Valais. - Climatic suitability: SDMs predict unsuitability of some large areas - in contrast to empirical growth projections. - Forest dynamics: minor changes in near future, major changes only for A1B and A2 in after 2050. - Ecosystem services: trends diverse. Large negative impacts projected for low and intermediate elevations and in warm-dry areas. High-elevation forests and cool-wet areas robust to CC. - Bark beetles: increase in populations due to warmer and drier climate; this might lead to increased susceptibility to bark beetle attacks of forests.	Comprehensive quantification of impacts on forestry: studies on growth of Norway spruce, climatic suitability, forest dynamics, ecosystem services and bark beetles.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ernst Basler + Partner / WSL 2013	2060	- Based on CH2011 scenarios. - Literature analysis for each area of impacts, then quantitative analysis for those with high impact. - Quantified indicators: yields, production costs, financial losses (e.g. through storm damages).	✓	- Slight positive economic impact for 2060-weak, negative for 2060-strong. - High uncertainties concerning change in growth rates of different tree species and quantity of damaged wood due to dryness, storms and bark beetles.	- Smart forester assumption (adaptation of tree species-distribution). - Not quantified impacts larger than quantified ones. Only direct impacts for economic valuation.
INFRAS/Egli Engineering 2014b	2060	- Forest damages through storms quantified. - Further aspects qualitatively investigated.	✓	- Rise in temperature -> rise in timberline: increase of potential growth area. - Increase of forced usage due to extreme meteorological events (600,000 to 1,350,000 CHF/yr). - Benefits > costs.	- Approach for monetization. - Benefits > costs.

Biodiversity

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan/ Sigmaplan 2007	2100		✗	- Qualitative statements only - How CH flora and fauna will behave with climate change -> species loss and immigration of foreign plant and animal species from warmer regions. CH flora and fauna will become more similar to those of southern regions. - Impacts of agriculture and other land uses will affect biodiversity more than CC. - Changes in extremes might have big impacts locally.	Rough direction of impacts on biodiversity
CH2014-Impacts 2014	2020 2050 2090	- Analysis of distribution of bird and vascular plants - Use of species distribution	✗	- Changes in species composition of birds and vascular plants - Uncertainty in turnover decreases wrt different climate models in the further future / as impacts become stronger	Comprehensive quantification of impacts on biodiversity (birds and vascular plants).

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
		models (SDMs), calibrated with European data of climate and known locations of occurrences, then validated with Swiss (independent) data (e.g. Swiss biodiversity monitoring program). Application to maps of projected future climate of CH. - Susceptibility of current species assemblages to cc: comparing simulated current and future species composition (Sorensen similarity index)		- Low-elevation cantons among the most highly impacted by climate-driven changes in species distributions - 79 bird and 135 plant species could be analysed (auc ≥ 0.7): of these only few have suitable climate at high elevations / most species find suitable conditions in low elevation of CH / substantial of both species	Immigration of new species into CH not considered.
Ernst Basler + Partner / WSL 2013	2060	Kessler-index for level of biodiversity of respective area.	✗	- Only qualitative analysis / discussion, e.g. Insects as winners of cc, mobile species less affected - Potential for conflict between climate protection and biodiversity protection - Biodiversity ~more affected by growing settlement, leisure, agriculture and forestry	Rough direction of impacts on biodiversity.
INFRAS/ Egli Engineering 2014b	2060	Qualitative analysis.	✗	- Strong negative effects in alpine altitudinal belt. - Socioeconomic development is important.	Insights for alpine altitudinal belt.
INFRAS/ Egli Engineering 2014a	2060	Biodiversity and green areas qualitatively analysed.	✗	- Highly adaptive species in cities, water ecology. - Spread of invasive alien species: impact of socioeconomic factors > impact from CC. - Dry habitats less endangered than moist habitats.	Insights for urban biodiversity.
SCNAT 2008		Assess synergies and conflicts between biodiversity and climate.	✗	Potential for synergies largest in management of terrestrial ecosystems.	

Tourism

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Faust et al. 2012	2050	- CGE model GEMINI-E3 using ENSEMBLES simulations - 3 tourism segments modelled: winter overnight tourism, one-day winter tourism and other forms of tourisms - 6 scenarios for winter tourism	✓	- Endogenous adaptation reduces CC costs but is not sufficient to compensate for the whole costs. Public measures are necessary. - Lower altitude ski areas see their activity reduced. - Higher altitude ski areas benefit from CC due to a reallocation of tourist flows. - Positive gain for households' welfare: 83 million CHF. - Winter tourism adaptation costs for lower ski resort: 7.9 million CHF (4 million CHF for artificial snow). - For higher ski resort 56.8 million CHF (39 million CHF for artificial snow). - If artificial snowmaking is subsidised, this reduces welfare gains by 10 million CHF due to distorted allocation of investments.	- Comprehensive and very detailed study. Extensive simulations with adaptation and multiple scenarios. - Clear and detailed methodology. - Model includes international interdependencies. - Environmental costs not taken into account (for example for the production of artificial snow) - Regional disparities not taken into account: aggregated results only. - Catastrophic events not considered.
Gonseth & Vielle 2012a	2050	- Simulation performed with CGE model GEMINI-E3. - Climatic scenarios from the ENSEMBLES project. - 8 scenarios: with, without and with high adaptation, low and high elasticities of consumption, high snow decrease with, without and with high government subsidies.	✓	- Moderate impacts on the Swiss economy, from 24 to 122 million USD, 0.01% to 0.03% decrease in final household consumption. - Adaptation changes drastically the size of the welfare impacts.	- Description of the Swiss tourism sector (weight, CC impacts, and adaptation measures). - Detailed model (multi-country, multi-sector, recursive) and results, including production, natural and artificial snow, employment and consumption

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
					- No analysis of the economic and technical feasibility of snowmaking in a future warmer climate. - Regional disparities not taken into account: aggregated results. - Catastrophic events not considered.
Gonseth 2013	2005/06 to 2008/09	- Linear panel regression model describing the number of skier visits. - Data from a sample of 70 Swiss ski areas across the winter season 2005/06 to 2007/08 and 62 ski areas during the 2008/09 winter season.	✗	- Higher snowmaking investment lowers the effect of snow conditions on skier visits. - Competitive interactions between lower and higher lying ski areas located in the same tourism regions: better snow conditions in lower ski stations reduce visitation rates in higher ski stations. - Sunny conditions have a positive impact on skier visits.	- Quantitative analysis of artificial snow influence on skier visits. - Wide range of indicators and variables that influence ski tourism and their effects on skier visits. - No economic valuation. - No future projections. - No quantitative information about neighbouring countries. - No analysis of the economic and technical feasibility of snowmaking in a future warmer climate.
Matasci et al. 2014		- Online survey directed of Swiss tourism stakeholders	✗	- Economic and social feasibility barriers are important impediments to the adjustment process; acceptability among inhabitants and willingness to act of stakeholders is less critical - Adaptation can be facilitated with better information about the regional consequences of CC and feasible adaptation measures, by some top-down leadership and coordination and by providing financial support	- Detailed description of the barriers to CC adaptation - Ranking of these barriers - No economic valuation - No future projections: current barriers. Perceptions could change in the future.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Ecoplan / Sigmaplan 2007	2100	- Static equilibrium model that includes several countries. - Direct and indirect effects taken into account as well as international interdependencies. - Monte Carlo simulation to deal with uncertainties.	✓	About 0.10% GDP loss for tourism in 2100 but wide margin of uncertainty, so the loss could range between 0% and 0.95%.	- Comprehensive study. - Direct and indirect effects taken into account, as well as international economic interdependencies. - Only winter tourism, no summer tourism. - High uncertainty. - Adaptation costs not taken into account.
Müller & Weber 2007	2030	- Model of the impacts of CC on alpine tourism. - Several scenarios: with or without adaptation.	✓	- 200 million CHF revenue loss for Bernese Oberland alpine tourism. - Lower altitude ski resorts more impacted because one-day ski tourism more affected. - Adaptation could save about 50 million CHF. - Summer tourism: 80 million CHF gain	- Include a wide range of ecological impact, such as scenic beauty. - Only Bern, no interdependencies between regions. - Time horizon is 2030.
Meier 1998	2050	- Impacts derived from the NRP 31 "Climatic changes and natural hazards" - Economic valuation based on 20 studies that use General Equilibrium Model, Input/Output Model or Partial Equilibrium Model	✓	CC cost: between 1800 and 2300 million CHF for alpine tourism, including between 1600 and 2100 million CHF for winter tourism	- Outdated data. - Partial equilibrium model: cross-sector and international relations not included.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
CH2014-Impacts 2014	2035 2060 2085	- Climate projections using 3 GHG scenarios, 3 future time periods and 3 climate uncertainty levels. - Impacts shown with respect to the reference period 1980-2009. - Impacts on ski tourism modelled with 'SkiSim 2.0'.	✗	- Ski tourism is projected to face serious challenges under the scenario A2 for 2060 but ski areas at high elevations might benefit from CC by increasing their market share. - Snowmaking is an important option to mitigate economic losses. - Around 90% of the glacier ice volume is projected to melt and large areas are glacier free by the end of this century under the A1B scenario. - Increase in the number of summer days and emergence of new lakes: opportunities for tourism.	- Detailed study: 3 GHG scenarios, 3 time period, 3 levels of uncertainties. - Quantitative description: number of summer days, of tropical nights, % of glacier melting, etc. - No economic valuation, for example indicators used to assess ski tourism provide information about the snow cover. - No study of the skier market, so no information about the relative vulnerability of ski destinations. - Only one canton studied. - Summer tourism almost absent. - Complicated to translate impacts on scenic beauty (glacier melting) in economic terms. - New opportunities like the emergence of lakes not quantified.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
INFRAS / Egli Engineering 2014b	2060	Same basis as in Ernst Basler + Partner et al. 2013. Some differences: - Different treatment of uncertainties. - Damages and revenues assumed to develop linearly to occurrence of events. - An additional degree of uncertainties for very low uncertainties introduced. - Socio-economic scenarios only treated qualitatively. - Some current cost data obtained through interviews.	✓	- Summer tourism: between 0.5 and 2.5 million CHF gain per year. - Winter tourism: between 1.5 and 3 million CHF loss per year.	- Common methodology with other cantonal reports. - Economic valuation of summer and winter tourism. - Only canton of Uri studied. - Socio-economic development (demographic development, leisure trend…), international influences and adaptation not modelled.
INFRAS / Egli Engineering 2014a		- Same basis as in INFRAS/ Egli Engineering 2014b. - Some difference: Threshold of costs: effects below 0.5 million CHF not considered for quantification.	✓	Tourism impacts not quantified.	- Common methodology with other cantonal reports - Only canton of Basel-Stadt studied. - No result for tourism (lower than 0.5 million CHF)
Ernst Basler + Partner / WSL 2013	2060	- 2 climate scenarios, based on the RCP3PB and A1B IPCC emission pathways. - Constant electricity prices assumed. - The effects of CC are compared to status quo to find areas where adaptation is necessary. - Adaptation measures are thus not included into the CC effects.	✓	Low impact for tourism in the canton of Aargau because low climate sensitivity.	- - Common methodology with other cantonal reports - - Only canton of Aargau studied. - - Only qualitative results for tourism because impacts are low in the canton of Aargau

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
ClimAlpTour 2011		- Case studies on 22 pilot sites in Europe: SWOT analysis, product portfolio development including vulnerability analysis, workshops to develop adaptation strategies. - Delphi expert survey to learn about adaptation strategies.	✗	List of adaptation strategies and policy recommendations depending on the characteristics of the ski area.	- Comprehensive list of adaptation strategies. - Vulnerability assessment for different tourism products, and not only winter activities. - No economic valuation. - No future projections. - No comprehensive model, only pilot sites. - Vulnerability estimated, and not based on a model.
Serquet & Thalmann 2012	2100	- Literature review. - Interviews.	✗	- Temperature increase will cause an elevation shift of the snow line, glaciers and permafrost melting and heat waves. - In Verbier, summer ski had to be stopped due to the melting of the Tortin glacier and to the lack of snow in the summer season.	Gather in a same study several environmental impacts related to winter tourism (such as glacier melting, biodiversity, water and natural disasters) as well as adaptation measures - No economic valuation. - Mainly qualitative information.
Koenig & Abegg 1997		- Case study using 3 consecutive snow-deficient winters at the end of the 1980s. - Statistical analysis: comparison of the transport facilities altitude with the minimum altitude corresponding to the line of snow reliability (1200m under current climate condition, 1500m with a 2°C temperature rise).	✗	- Ski areas at higher altitudes benefit from the lack of snow in lower areas. - Snow reliability of Swiss ski fields: - 85% under current climate - 63% with a 2°C temperature rise.	- Interesting results for the snow reliability of Swiss ski fields - No economic valuation. - No model and no projection: use of data from the 80s.

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Scott & McBoyle 2007		Literature review.	✗	Inventory of CC adaptation options in the ski industry.	- Detailed inventory of adaptation measures. - No economic valuation. - No model of the adaptation measures.
Grêt-Regamey, Bishop & Bebi 2007		- Calculation of visual magnitude (VM) thanks to a 3 dimensional GIS. - Evaluation of scenic preferences using a web-based survey in Davos region. - Willingness-to-pay (WTP) responses used to identify preferred landscapes. - Regression analysis between VM and WTP to test if the GIS-based variables could be used to predict scenic beauty preferences	✗	- A GIS-based approach to predict scenic beauty preferences is viable. The height of standing objects should be included in the model. - The visual magnitudes of the land-cover areas is correlated with the willingness-to-pay (WTP) values expressed by the respondents of the study.	Interesting methodology to predict scenic beauty preferences using a GIS-based approach. - Only 3 types of land-use changes included: raising of the treeline, new ski runs, and urban expansion. - Study only in Davos region: validity restricted to similar cases. - Prototypical approach: needs to be further tested.
Rixen et al. 2011	2030 2050	- Study on 3 tourism destinations in the Swiss Alps: Davos, Scuol, Braunwald - Regression model - Possible snowmaking days based on dew point temperature	✗	- Energy and water consumption in snowmaking - Snow days for each location (regression analysis) in function of altitude and temperature - Number of possible snowmaking days depending on altitude for each location	- Results could be replicated - Only 3 locations, different equations for each location
Olefs et al. 2010	1948-2007	- Calculation of wet-bulb temperature (temperature, humidity) - Threshold of -2°C for artificial snow production - Data from 14 Austrian stations - Linear regression	✗	- Wet-bulb temperature increase between +1.5°C and 3.1°C results in a snowmaking days per season decrease by -20 to -34	- Relation between snowmaking potential and wet bulb temperature - Does not take into account technological progress

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Tranos & Davoudi 2014	2071-2100	- Impact = Exposure x Sensitivity - Exposure based on scenarios: SRES A1B - Sensitivity based on number of beds in hotels	✗	- Maps with impacts on winter tourism in Europe	- Interesting methodology - Impacts for Europe - Only winter tourism - Only Europe - No relation between the impact and the demand change
Serquet & Rebetez 2011	1997-2007	- Statistical analysis using data from 40 Swiss Alpine resorts - Calculation of the correlation	✗	- Significant correlations between the number of night spent in mountain resorts and hot temperatures at lower elevations, especially in June	- Correlation coefficients for overnight stays in relation with temperature / sunshine duration, for 40 Swiss Alpine resorts - Short-term reaction; no information about long-term behaviours
FIF 2011		- Literature review	✗	- Ecological consequences on tourism: change in snow precipitation (more snow in high altitude, less in low altitude), permafrost degradation, glacier melting, emergence of new lakes, - Adaptation measures: change in offer (diversification), risk minimization, communication	- Good qualitative overview - No economic valuation
Abegg, Steiger & Walser 2013	2035 2060 2085	- Literature review - Snowpack simulation with SkiSim 2.0 model	✗	- Deterioration of natural snow condition could partially be offset by snowmaking but it requires high investment; improvement of climatic conditions for summer tourism; expected development of demand (comparative advantages in Grison for winter tourism, climatic benefits for summer tourism); adaptation is context-specific; tourism responsible for significant CO2 emissions	- Good description of effects on tourism - Evolution of climatic variables - Interesting methodology with SkiSim 2.0 model - Consistent with CH2014 - No economic valuation - Only one canton studied

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
NELAK 2013		- Cost benefit analysis using an enhanced, integrated risk management approach that also includes secondary (operation failure) and tertiary (damage to reputation) damage and loss factors - Case study	✗	- Emergence of new lakes benefits tourism but also glacier retreat (new via ferratas and trails) - But negative effect for scenic beauty - More difficult to groom ski runs at high altitude due to glacial routes changes, and natural hazard (rockfalls) due to melting permafrost - Planning, organisational and construction measures needed to manage conflicts	- Deal with landscape changes, glacier retreat, new lakes and scenic beauty - Interesting methodology - Example of how it is possible to adapt to landscape changes - One case study, mainly qualitative data - Complicated to reproduce at the Swiss scale - Not enough information to link landscape change and economic impacts
Köberl et al 2014	2065	- Dynamic multiple regression models to quantify sensitivity of overnight stays towards weather - Apply the resulting sensitivities on CC and socio-economic scenarios - Transform the resulting impacts into monetary terms using average tourist expenditures - Evaluate the effects of the tourism impacts in a macroeconomic CGE model	✓	- Negative impacts on winter tourism and positive impacts on summer tourism, net impact negative - Resulting spillover effects to other economic sectors are higher than the impacts on tourism	- Interesting methodology - Model includes temperature, snow conditions and precipitation - Regional sensitivity takes into account the differences between regions - Includes winter and summer tourism - Results implemented in a CGE model - Only Austria, the sensitivity should be calculated for each Swiss regions to reproduce the methodology - Does not take into account international effects

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Hamilton, Maddison & Tol 2005	2100	- Model of international tourist flows from and to 207 countries - Climate change scenarios: SRES scenarios derived with the FUND model. Spatial patterns taken from the COSMIC model	✗	- Simulation model of tourist flows, including tourists departure and tourists arrival, in function of Area, Length of Coast, Temperature, per capita income - Globally, tourism will grow. Low impacts due to CC - In Switzerland, CC has a positive impact on market share of arrivals	- Interesting model - No economic valuation - Calibration year: 1995 - Calibrated with summer tourism - Do not include tourist preferences and behaviour. - Constant income elasticity, ignoring possible saturation
Bigano, Hamilton & Tol 2007	2100	- Updated and extended version of the Hamburg Tourism Model developed by Hamilton, Maddison & Tol 2005	✓	- HTM model extended to include domestic tourism, length of stay, tourism expenditures - CC would shift patterns of tourism towards higher altitudes - Domestic tourism may double in colder countries and fall by 20% in warmer countries	- Interesting model - Calibration year: 1995 - Calibrated with summer tourism - Do not include tourist preferences and behaviour
Berrittella et al. 2006	2050	- CGE model: GTAP - Change in tourism flow based on the Hamburg Tourism Model (Hamilton et al 2005) - Impact modelled by shocking specific exogenous variables in the model: change in the structure of final consumption and international income transfers	✓	- Variation of tourist flows affect regional economies: global welfare loss	- Example of implementation of tourist flows variation calculated in the Hamburg Tourism Model - Tourist flows data - Annual variation (no summer/winter) - CGE model aggregation different than GEMINI-E3
Bosello et al. 2012	2050	- CGE model: ICES - Change in tourist flows from the Hamburg Tourism Model (Bigano et al 2007) - Impacts modelled by exogenous variations in the households' demand and adjustment of national incomes	✓	- Redistribution of tourism flow: northern Europe benefits from CC while Mediterranean Europe endures economic loss - Global tourism GDP loss about 0.1% in 2050	- Example of implementation of tourist flows variation calculated in the Hamburg Tourism Model - Annual variation (no summer/winter) - CGE model aggregation different than GEMINI-E3

Publication	Temp. scope	Methods	Econ. valua-tion	Main results	Usability / caveats for this project
Scott et al 2004	2050 2080	- Tourism Climate Index calculation - Scenarios CGCM2-B2, HadCM3-A1F1	✗	- Evolution of TCI in North America	- Interesting methodology - Only North America - No link TCI / tourist flows
Perch-Nielsen et al. 2010	2071 - 2100	- Adjusted Tourism Climatic Index (Temperature, sunshine, precipitation, wind…) calculated in Europe - Comparison of the evolution of TCI - Scenario SRES A2	✗	- Southern Europe's suitability for sightseeing tourism drops in the summer but is partially compensated by improvements between October and April - Climate resource in Northern and Central Europe improves	- Interesting Methodology - TCI for Europe - No link TCI-tourist flows - Aggregation: 8 European regions, Switzerland included in the Alps
Roson & Sartori 2014	2065	- CGE model - TCI indicator of climate suitability for tourism: Elasticity value of TCI-tourist flows for Mallorca, assumption same for all countries - Scenario A1B	✗	- Increase in income and welfare thanks to more incoming tourists - Expansion of services induce a decline in agriculture and manufacturing - The lower demand for water due to agriculture decline counteracts the additional demand for water coming from tourists, overall lower water consumption	- Use of TCI to evaluate tourist flows changes - Implementation in a CGE model - Focus on costal tourism and Mediterranean countries - High uncertainties: elasticity value of TCI-tourist flows only for Mallorca
Barrios & Ibañez Rivas 2014	2100	- Hedonic valuation of climatic conditions combining hotel price information and travel cost estimations - Hedonic price regressions include temperature, humidity, precipitations - Scenarios for adaptation of holiday in terms of frequency and duration	✓	- Climate dimension plays a significant role in explaining hedonic valuations of tourism services - Southern EU Mediterranean countries GDP loss of 0.45% per year due to lower tourism revenues - Northern European countries GDP gain of 0.32% per year	- Detailed hedonic model of recreational demand - Only EU