# Impacts of climate change for Swiss winter and summer tourism: a general equilibrium analysis

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**Abstract**

Tourism could be greatly affected by climate change due to its strong dependence on weather. In Switzerland, the sector represents an appreciable share of the economy. Thus, studying climate effects on tourism is necessary for developing adequate adaptation strategies. While most of the studies focused on winter tourism, we investigate the climate change impacts on both winter and summer tourism in Switzerland. Using a computable general equilibrium (CGE) model, we simulate the impacts of temperature increase and snow decrease for climate scenarios A1B and RCP3PD. Our findings show that climate change has a positive effect on the Swiss tourism industry. Alpine resorts could adapt by developing their summer tourism offer. However, impacts are differentiated. While low-altitude ski resorts are more vulnerable to a snow decrease, high-altitude resorts benefit from their comparative advantage with respect to lower resorts in Switzerland and in Europe.

*Keywords:* Tourism, climate change, adaptation, Switzerland, computable general equilibrium model

## 1. Introduction

For Switzerland as for other continental regions, climatologists expect a temperature increase much higher than the global average. Even up to 2011, Switzerland has experienced an increase by 1.7° C since the beginning of institutionalized

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temperature measurements in 1864, while the average on-land warming in the northern hemisphere amounted to 1.1° C (Perroud and 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 limited 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.

In this study, we focus on tourism for two main reasons. First, the tourism industry is highly dependent on weather and climate. Thus, climate change could particularly affect the sector. Second, tourism represents an appreciable part of the Swiss economy, accounting for about 3% of GDP and employing 4.4% of the total workforce, with high regional disparity (Baumann and Schiess, 2008). In the canton of Graubünden, for instance, tourism accounts for around 3.3 billion Swiss francs (CHF) per year, just over 30% of GDP, and 30% of employment (Bergwelten 21/GRF Davos, 2015). In Valais, it represents about 25% of GDP and 30% of employment (Serquet and Rebetez, 2011).

Previous studies focused mainly on winter tourism and have shown that international effects might have a greater impact than domestic effects of climate change (Ecoplan/Sigmaplan, 2007; Faust et al., 2012). In this paper, we expand the analysis to summer tourism. The aim is to investigate the international effects of climate change on winter and summer tourism in Switzerland.

The rest of the paper is organized as follows. We present an overview of the existing literature in section 2 and the model used in 3. In section 4, we detail the socio-economic and climate scenarios used and how they are implemented in the model. In section 5, we present and discuss the results obtained. Finally, we conclude in section 6.

## 2. Literature-based assessment of climate change impacts on Swiss tourism

### *2.1. Climate change impacts on winter tourism*

In Switzerland, previous studies assessing climate change impacts have focused on winter tourism since the sector seems particularly affected. Indeed, rising temperature will decrease snow precipitation, restricting the number of snow-reliable ski areas (CH2014-Impacts, 2014). 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). Thus, many ski resorts are going to face serious challenges, including a shorter business season

(CH2014-Impacts, 2014; Klein et al., 2016). Meier (1998), who was the first to study the economic impacts of climate change on Swiss alpine tourism, estimated a cost between CHF 1.8 and 2.3 billion in 2050, using the simplifying assumption that value added would drop by 30%. Several studies also highlight the greater vulnerability of lower ski areas (Koenig and Abegg, 1997; Müller and Friedli, 2007; Gonseth, 2013; CH2014-Impacts, 2014; Abegg et al., 2013). However, Swiss winter tourism could benefit from climate change if international effects are taken into account. Indeed, Switzerland has more snow-reliable ski fields than its neighbouring countries, and thus international tourist flows may increase in Swiss ski resorts. For example, Faust et al. (2012) find a welfare gain of 83 million CHF in 2050 using a CGE framework. Higher snowmaking investments could also lower the sensitivity of skier visits to natural snow conditions (Gonseth, 2013). However, snowmaking requires large amounts of water and energy, and its economic and technical viability is not ensured in a future warmer climate. Hence, ski resorts might consider other adaptation measures, such as the promotion of summer tourism.

### *2.2. Climate change impacts on summer tourism*

Tourism 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). Moreover, since valleys are too hot during heat waves, tourists seek refuge at higher altitudes (Bergwelten 21/GRF Davos, 2015). Recent cantonal studies have provided new information about the economic impacts of climate change at the regional level. They show that the gains for summer tourism could offset part of the losses for winter tourism. For example in the canton of Graubünden, the reduction of snow cover could cost between CHF 12 and 25 million in 2060 while frequent heat waves could benefit summer tourism, with an expected gain between CHF 1 and 5 million in 2060. The projected cost and gain are even larger 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/Bergwelten 21/InnovaBridge/Consavis/RIBO architecture, 2016).

## 3. Model

### *3.1. Description*

The GEMINI-E3 model is a multi-sectoral multi-regional recursive-dynamic general equilibrium model (Bernard and Vielle, 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 (Winkler et al., 2014), as well as an analysis of the impact of climate change on heating and cooling on a global level (Labriet et al., 2015). Coupled with a geographical information system, GEMINI-E3 has helped assess economic impacts of sea level rise (Joshi et al., 2016). It has also been further developed to analyze the impact of climate change in Switzerland for the water, tourism, energy and agriculture sectors (Faust et al., 2015; Gonseth et al., 2017). We extend and update the model to assess the impacts of climate change on both winter and summer tourism.

GEMINI-E3 is built on the energy disaggregated input-output table of Nathani et al. (2011) for Switzerland, and on the GTAP-8 dataset (B. Narayanan et al., 2012) for the other regions of the world. The regional and industrial classifications used are specified in the table 1.

Table 1: GEMINI-E3 classifications

| | |
|---|---|
| Regional | |
| Switzerland (CH) | Other OCDE countries (OECD) |
| European Union (EU) | Brazil, Russia, India, China (BRIC) |
| United States of America (USA) | Rest of the World (ROW) |
| Industrial | |
| Coal | Transport nec |
| Oil | Sea Transport |
| Natural Gas | Air Transport |
| Petroleum Product | Insurance |
| Electricity | Health |
| Public Heat Supply | Other Services |
| Grain Soys | Winter Overnight Tourism |
| Other Crops | One-Day Winter Tourism |
| Animal | Other Form of Tourism |
| Forestry | Water |
| Industry | |

### 3.2. Modeling tourism

Since the tourism sector is not included in the standard version of GEMINI-E3, it was necessary to create and incorporate it into the model. Doing so, we separated the snow-dependent winter tourism activities from the rest of the tourism activities, thereby creating two tourism segments for each region of the model. In the following, the two segments are referred to as the "winter sports" and "other forms of tourism" (OFT) segments. The latter segment represents mainly "summer tourism".

In addition, the Swiss winter sports segment was split into two segments: "(snow-dependent) winter overnight tourism" (WOT) and "(snow-dependent) one-day winter tourism" (ODT). The former segment represents the part of winter alpine tourism whose production is intended for skiers generating one or several overnight stays. The latter segment complements the first one. Since the distribution of overnight and one-day ski tourists varies strongly across regions, the difference between the two segments has also a geographical interpretation upon which we rely for drawing insights and conclusions. Figures 1 and 2 show that one-day ski tourists mostly go skiing in lower lying ski areas located near city centers whereas overnight ski tourists predominate in higher lying ones. Therefore, the ODT segment is more representative for the lower and medium ski resorts, and the WOT segment for the higher lying ski resorts.

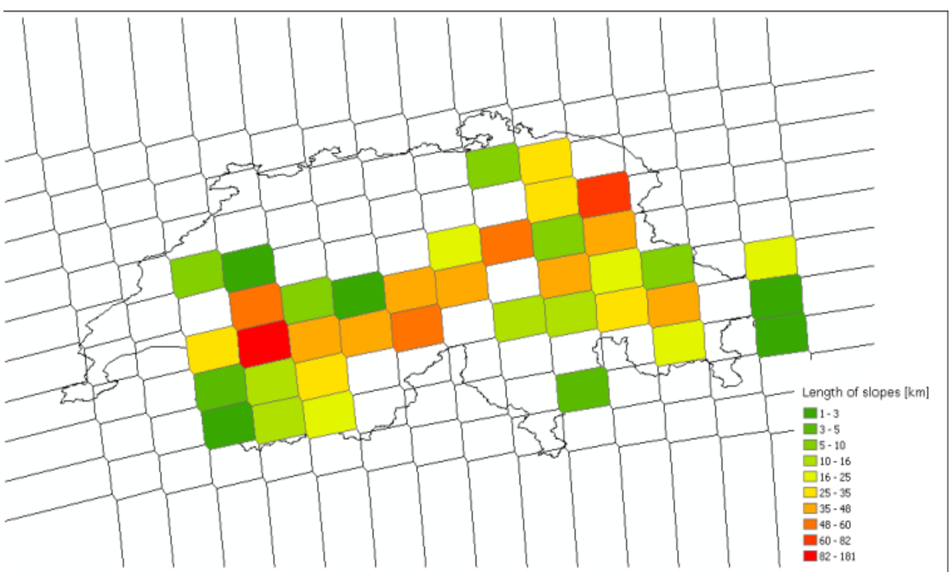


Figure 1: Regional weights used in the one-day winter tourism sector

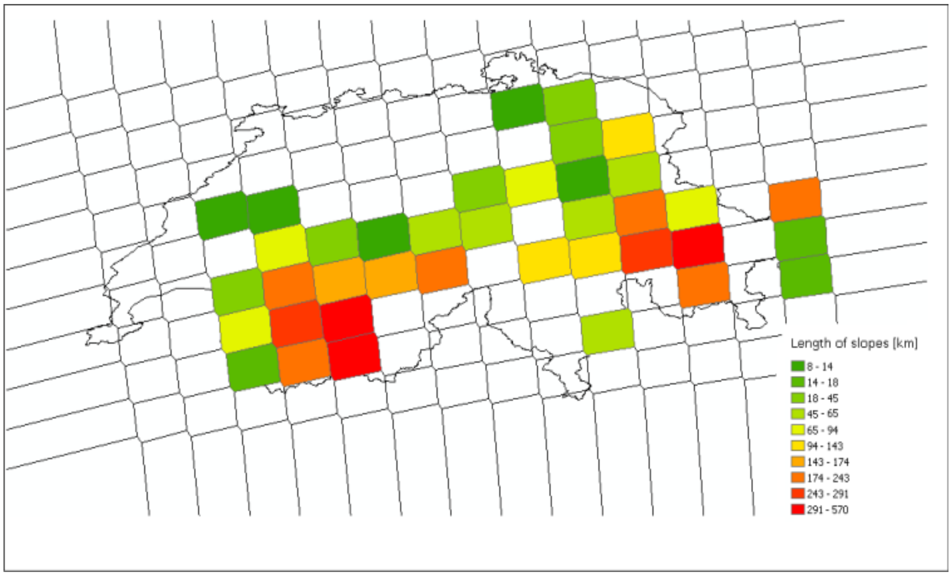


Figure 2: Regional weights used in the winter overnight tourism sector

The winter sports segment only accounts for 12% of the overall Swiss tourism revenues. This is due to the OFT segment including a very large spectrum of tourism activities, namely tourism activities that take place in rural and urban areas as well as summer and snow-independent winter tourism activities in alpine regions. Moreover, we build our work on a broad definition of tourism, i.e. the definition set by the UN World Tourism Organization (OMT, 1994) and used in national accounting.

As shown in figure 3, the goods produced by the WOT segment and the ODT segment are substitutes in the Swiss consumer's utility function. By combining the consumption of these two goods, Swiss consumers determine their final consumption of winter sports activities. At the higher node level, consumers substitute between their consumption of winter sports activities and their consumption of other tourism activities. Our quantitative assumptions regarding possibilities for consumers to substitute one tourism segment for another are given in table 2. Figure 3 also shows that goods and services produced in the different regions of the model by the same tourism segment are substitutes.[1]

[1]Note though that the WOT and ODT segments defined for Switzerland have no direct counterparts in the other regions of the model. In the case of the ODT segment, we assume no foreign trade. For this segment, consumptions by foreign residents in Switzerland or by Swiss residents

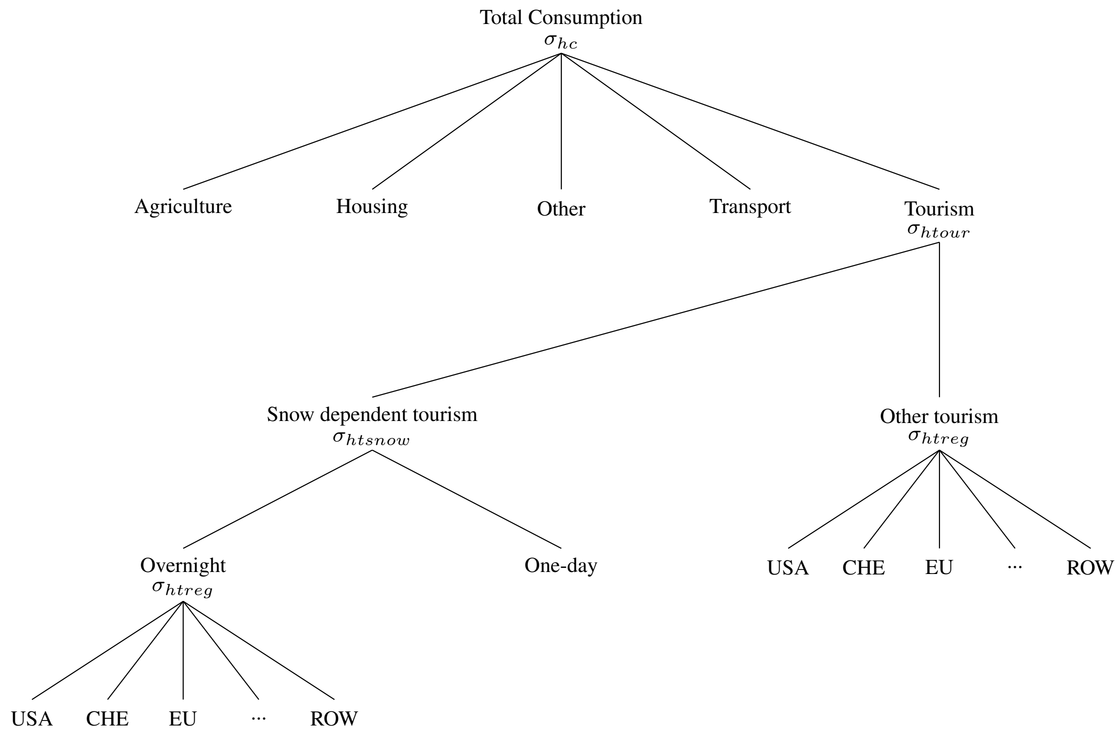


Figure 3: Structure of household consumption for Switzerland using nested CES expenditure functions. In order to keep the figure simple, only the tourism part of consumption is detailed.

The production structure of the winter sports segments, which nests CES production functions, is shown in figure 4. A natural snow resource has been introduced in the model. In section 4.3, we explain how the natural snow condition is calculated and how it was valued.

Next, the nested production structure assumes that winter sports segments respond to a reduction in natural snow availability in two steps. First, they can compensate it by producing more artificial snow.[2] This production requires a mix

abroad are in fact economically negligible. On the contrary, goods and services produced by the Swiss WOT segment can be substituted with those that are produced by the other regions' winter sports segments, and vice versa.

[2]In the context at hand, snowmaking is a central adaptation measure. Several studies have evaluated the increase in artificial snow production that could be triggered by climate change at different locations, such as in Austria (Steiger and Abegg, 2011), Québec (Scott and McBoyle,

of capital, electricity, labor and water inputs.[3] In the case of Switzerland, the water resource consists mainly of raw water which is directly extracted from surface waters or springs (Freiburghaus, 2009). Second, snow-dependent winter tourism segments can substitute other factors (i.e. typically capital) for the composite good "snow". This mechanism represents the segments' ability to adapt through investments which aim at operating ski areas with a continuously decreasing amount of snow. Two concrete examples are investments made to improve ski runs' preparation and maintenance and to modernize transport facilities. Table 2 provides values of the elasticities of substitution for the different nodes of figure 3 and figure 4. These values were chosen based on a literature review along with information drawn from interviews with experts in the field.

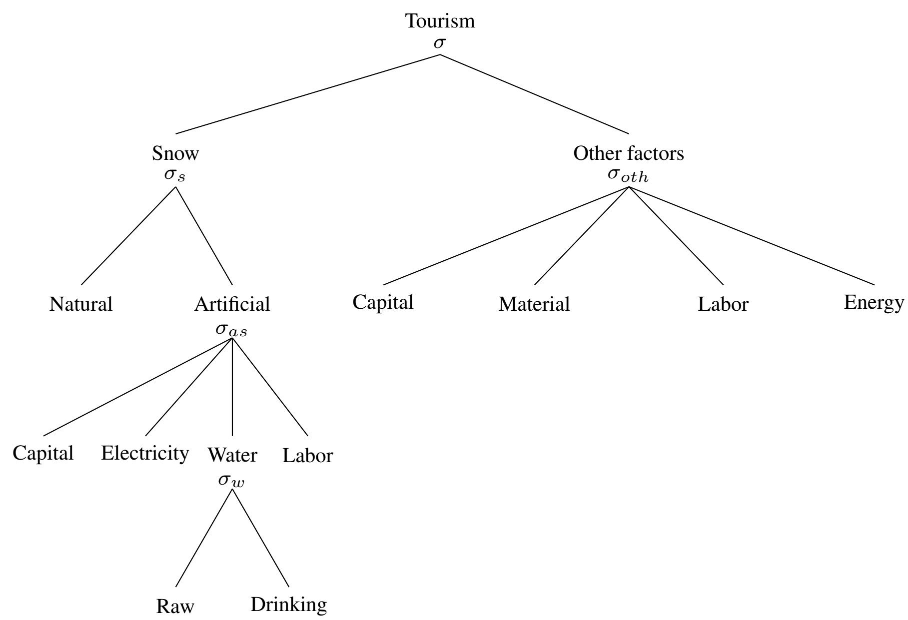


Figure 4: Nested CES production function defined for the winter sports segments.

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2007) and the US Northeast (Scott et al., 2008). In these studies, snow production increases in order to preserve the ski season length under both a capacity constraint (i.e. maximum depth of snow that can be produced per day) and a technological constraint based on temperature (i.e. threshold temperature to start efficient snowmaking).

[3] Our major sources of information on snowmaking are Agrawala et al. (2007), Gonseth (2013) and Bieger et al. (2009).

Eventually, it is worth noting that the two Swiss winter sports segments present a different profile in relation to climate change. As regards exposure, climate change impacts in terms of reduced snow endowment will be different for the two segments as shown in table 7 in the result section 5.1. Moreover, adaptive capacity across segments also differs. It is more difficult to produce artificial snow at lower and medium elevated ski resorts than at higher elevation sites because of shorter and less frequent periods with low temperatures. We translate this difference in adaptive capacity by using two segment-specific elasticities of substitution between the natural and artificial snow (cf. table 2).

Table 2: Elasticities of substitution defined for the tourism sector.

| | | |
|---|---|---|
| *Production function (winter sports segments)* | | |
| Snow and other factors | $\sigma$ | 0.1 |
| Natural and artificial snow (WOT) | $\sigma_s$ | 0.9 |
| Natural and artificial snow (ODT) | $\sigma_s$ | 0.45 |
| Among inputs used to produce artificial snow | $\sigma_{as}$ | 0.3 |
| Industrial and drinking water | $\sigma_w$ | 0.5 |
| *Household consumption* | | |
| Aggregated goods | $\sigma_{hc}$ | 0.4 |
| OFT and winter sports | $\sigma_{htour}$ | 0.7 |
| WOT and ODT | $\sigma_{htsnow}$ | 0.5 |
| Domestic and foreign tourism | $\sigma_{htreg}$ | 3 |

## 4. Scenarios and data

### *4.1. Baseline socio-economic scenario*

To simulate the evolution of the economy, GEMINI-E3 uses projections of population growth, GDP and energy prices, as well as assumptions on electricity generation.

We use the projection for the Swiss population as defined by the A-00-2015 scenario from the Federal Office of Statistics (Federal Office of Statistics, 2015). In this publication the population is projected up to 2045. Since the time horizon of our study is 2060, we extrapolate the population up to 2060 by assuming that its growth rate between 2045-2060 will be same as the one projected for the period 2040-2045 (i.e. 0.27% per year). Table 3 gives the projection of the Swiss population. In 2060, 10.6 million inhabitants are projected to live in Switzerland.

Table 3: Swiss Population in thousands (1st Jan.)

| | 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.

For Switzerland, GDP growth is forecast by the State Secretariat for Economic Affairs SECO by multiplying the labour 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 computed in the latest World Energy Outlook (WEO) 2015 of the International Energy Agency (IEA) up to 2040 (International Energy Agency, 2015). After 2040, we multiply the labour force by labor productivity based on what is retained by the IEA for the period 2013-2040. Table 4 shows the resulting GDP growth rates used in the reference scenario.

Table 4: Annual GDP growth rate in percentage

| | 2014-2020 | 2020-2030 | 2030-2040 | 2040-2050 | 2050-2060 |
|---|---|---|---|---|---|
| CH | 1.70% | 1.30% | 1.10% | 0.90% | 0.80% |
| EU | 1.80% | 1.70% | 1.50% | 1.40% | 1.30% |
| USA | 2.50% | 2.00% | 2.00% | 2.00% | 1.90% |
| OECD | 1.80% | 1.70% | 1.50% | 1.30% | 1.20% |
| BRIC | 6.10% | 4.20% | 3.60% | 3.30% | 3.10% |
| ROW | 3.20% | 4.90% | 4.10% | 3.40% | 2.90% |
| World | 3.00% | 3.00% | 2.70% | 2.50% | 2.40% |

### *4.2. Climate scenarios*

For the sake of comparability, we base our analysis on the two scenarios A1B and RCP3PD which have also been used in (CH2011, 2011) and (CH2014-Impacts, 2014). Figure 5 shows the assumed global greenhouse gas emissions pathways and the corresponding projected mean temperature changes for Switzerland (average of 2070-2099) as presented in (CH2011, 2011).

A1B is a non-intervention scenario originally developed for the IPCC’s Special Report on Emissions Scenarios (Nakicenovic et al., 2000). It assumes rapid economic growth and high technical progress. This reduces the dependence on

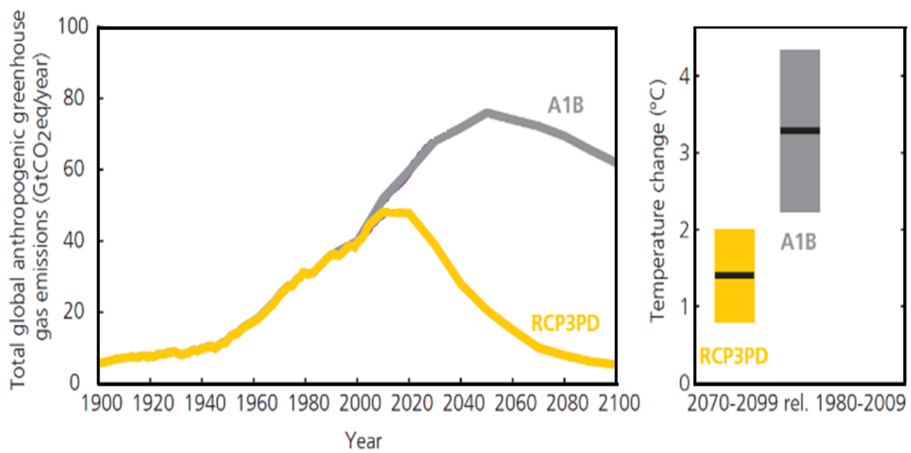


Figure 5: Pathways of past and future anthropogenic greenhouse gas emissions and projected annual mean warming for Switzerland for the 30-year average centered at 2085. Source: (CH2011, 2011)

fossil fuel and slows down population growth in the second half of the century. 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 (Stocker et al., 2014). 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 4.1. 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 the impacts of climate change which we are interested in.

*4.3. Winter tourism*

Climate change affects the natural snow conditions used as a production factor in winter tourism sectors (see Figure 4). We calculate the variation in snow endowment using the variable "Fractional Snow Cover" from ENSEMBLES[4] and CORDEX[5] projects. These projects provide results of Regional Climate Mod-

[4]http://ensembles-eu.metoffice.com/data.html
[5]http://www.cordex.org/

els (RCMs) simulations, respectively for IPCC SRES and RPC 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 regions and aggregate them at GEMINI-E3 level (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 separate 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 Figures 1 and 2. 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.

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 these weights are constant, i.e. we assume skiers do not change their behavior.

Table 5: Weights assigned to the winter season months.

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

Note: weights are equal to zero for the other months.

The regional and time aggregation give the annual fractional snow cover for Switzerland (winter overnight and one-day tourism) and Europe for each RCM and scenario (models C4I, DMI, KNMI, SMHI for A1B scenario and KNMI, SMHI for RCP3PD 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:

$$\%\,Variation\,FNS = \frac{FNS_{CH\ WOT,A1B,C4I,Year} - FNS_{CH\ WOT,A1B,C4I,2010}}{FNS_{CH\ WOT,A1B,C4I,2010}}$$

where FNS stands for the fractional snow cover. The results from different models for 2030, 2050, 2070 and 2090 for the Swiss winter overnight sector are presented in figures 6 and 7, including the model average, which we base our simulations on. Results for the Swiss one-day tourism sector and Europe are presented in figures A.1, A.2, A.3 and A.4 of the appendix.

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

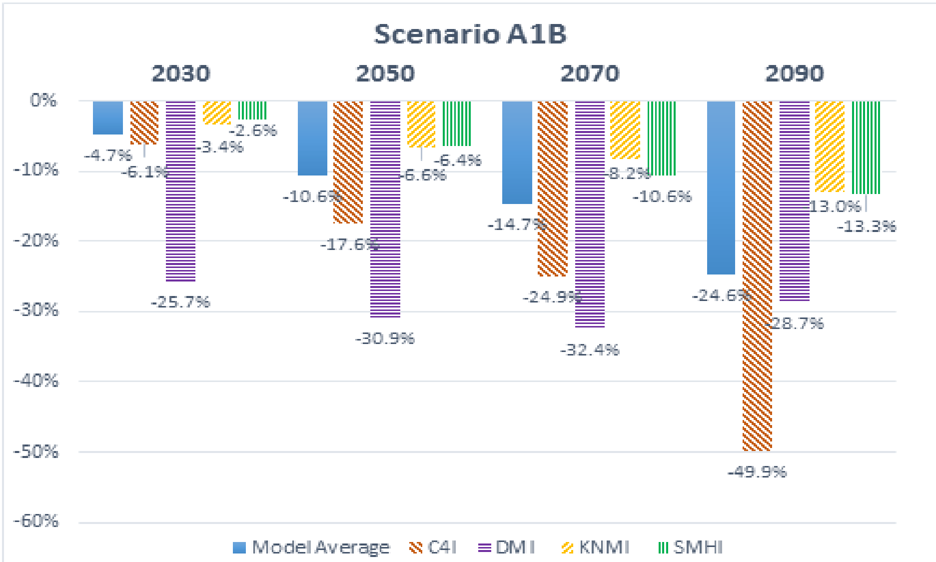


Figure 6: Snow cover variation of the Swiss WOT sector with respect to 2010 under A1B scenario

skiers visits and hotel overnight stays at the ski resort level. We use the econometric estimates of these effects in order to extrapolate, for the two Swiss winter tourism segments, the seasonal profit that is generated on average due to the current natural snow conditions. We mainly use data provided by the Swiss National Tourist Office. More information about the methods and data used are available in Faust et al. (2012) and Gonseth (2013).

Since we lack data to estimate the snow variations outside Europe, we simulate climate scenarios A1B and RCP3PD assuming three alternative snow variations outside Europe:

- In a first case, we assume that ski resorts 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 regions are supposed to be affected by climate change. We assume that the reduced snow resources roughly correspond to the ones computed for the EU (respectively -4% in RCP3PD scenario and -20% in A1B scenario)
- In the last case, reduced snow resources are equal to 50% of the variation used in the previous case.

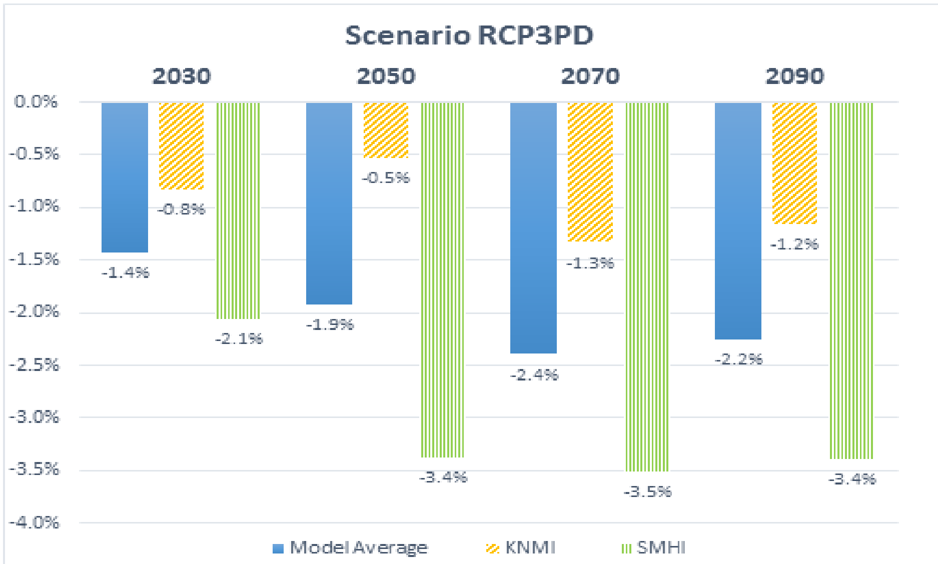


Figure 7: Snow cover variation of the Swiss WOT sector with respect to 2010 under RCP3PD scenario

Finally, for scenario A1B we simulate two cases, namely with and without changes in artificial snowmaking, 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.

### *4.4. Summer tourism*

Next, we generate inputs for the GEMINI-E3 model concerning variations in summer tourism flows. For this, we use the Hamburg Tourism Model (HTM) developed by Hamilton et al. (2005)[6]. 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 calculates domestic tourists flows, international arrivals and departures for 207 countries. Since summer tourism dominates winter tourism in most countries, HTM is calibrated on summer tourism. Results from the model have already been implemented in

[6]A detailed description of the model, related publications as well as the model code can be found on the model webpage https://www.fnu.zmaw.de/index.php?id=5681

CGE models to analyze scenarios of climate change and climate policies (Berrittella et al., 2006; Bosello et al., 2012). More information about the model, its limitations and the source of the dataset is available in Hamilton et al. (2005) and Bigano et al. (2007).

In the HTM model, the climatic variable of interest is the global mean temperature, which is then down-scaled to national means. Temperature change affects countries' attractiveness causing a reallocation of tourism flows between countries. We obtain simulations of global mean temperature from the IPCC Data Distribution Center for the A1B scenario and from the CMIP5 data archive for the RCP3PD scenario. We use the average global mean temperature simulated by 14 General Circulation Models (GCM) for the A1B scenario and by 32 GCMs for the RCP3PD scenario.

For each scenario, tourism flows (domestic, departures and arrivals) for all countries are simulated and then aggregated by GEMINI-E3 regions. Apart from climate issues, total number of tourists also depends on population and GDP growth in the HTM model. To allow comparisons between climate change scenarios A1B and RCP3PD, we remove the socioeconomic effects by keeping the total flows of tourists constant when implementing tourism flows variations in GEMINI-E3. To do that, we calculate the variations of tourists with respect to the same scenario without climate change. For example, let $CH_{A1B,Year}$ be domestic tourism in Switzerland for the scenario A1B in a given year, we have:

$$\%\,Variation\,CH_{A1B,Year} = \frac{CH_{A1B,Year} - CH_{A1B\ Without\ CC,Year}}{CH_{A1B\ Without\ CC,Year}}$$

For each simulation year and scenario, we get a matrix of results (see for instance table 6 for scenario A1B in 2060). Each cell (line i, column j) indicates 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 decrease by $0.11\%$ because of temperature increase in the A1B scenario in 2060. Diagonal cells correspond to domestic tourism.

The HTM results are then implemented in GEMINI-E3. We simulate the climate scenarios RCP3PD and A1B. The destination flows in GEMINI-E3 are modified according to the variations calculated with the HTM model. We assume that the results of the HTM simulation correspond to the "other forms of tourism" sector. We aggregate in this sector summer tourism, cultural tourism and all the other forms of tourism.

Table 6: Change in tourism flows. HTM results for A1B scenario in 2060

| A1B Medium, 2060 | 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% |

### *4.5. 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:

- Climate scenario RCP3PD, variations of snow endowment in all regions, and with adaptation (change in artificial snowmaking);
- Climate scenario A1B, variations of snow endowment in all regions, and with adaptation (change in artificial snowmaking).

## 5. Simulation results

We first look at winter and summer tourism separately and then simulate the combined effects.

### *5.1. Winter tourism*

The outcomes obtained with GEMINI-E3 for the nine scenarios outlined in section 4.3 are given in table 7. In the model, natural snow is used as a production factor to the goods winter overnight tourism (WOT) and one-day winter tourism (ODT). Climate change decreases natural snow endowment. Thus, producers must substitute it with more expensive production factors, such as artificial snow, and production prices increase. For example in the scenario A1B where we assume that snow resources outside Europe is impacted by climate change in the same magnitude as computed for the EU, Swiss producer prices increase 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 the 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. Consequently, low altitude Swiss ski resorts are more negatively impacted.

Higher Swiss ski resorts also benefit from international effects of climate change. Indeed, Swiss WOT gains from 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. In the scenario A1B with snow change outside Europe, Swiss production of tourism services decreases by 2.8% in ODT but increases in WOT by 0.6%. This induces an overall welfare improvement in Switzerland, which is however limited (+0.01%). On the other hand, when we assume that ski resort stations outside Europe suffer less from climate change, 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. Ski resorts cannot substitute natural snow by relatively cheap artificial snow. They need more capital, labor and energy to maintain and modernize ski slopes. In the A1B scenario with snow change outside Europe, Swiss producer prices increase by 9.1% for the ODT sector and by 6.4% for the WOT sector. This results in a decrease in production of 5.4% for the ODT sector and of 2.5% for the WOT sector. Despite this, Swiss welfare slightly improves, even more than in the case without snowmaking. This is due to improved 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 consumption and exports). Switzerland has a comparative advantage with respect to the EU, since its ski resorts are located at a higher altitude. In the scenario with adaptation (change in snowmaking), the EU can compensate its decrease in natural snow by investing in artificial snow, mitigating the Swiss comparative advantage. Thus, the positive welfare effect in Switzerland is larger in the admittedly unrealistic scenario without adaptation.

The RCP3PD scenario represents a more sustainable future, in which the decrease in snow endowment is very limited. Therefore, the economic impacts on Swiss winter tourism are very low. The WOT production change ranges between -0.1% to 0.0% and ODT production decreases by 0.4%. Swiss welfare remains essentially unchanged with respect to the baseline scenario.

In short, even if welfare impacts in Switzerland are slightly positive, the situation is ambiguous. Production of the one-day winter tourism sector decreases in all scenarios, highlighting the greater vulnerability of ski resorts located at low

Table 7: Impacts of climate change for the Swiss winter tourism sector and Swiss welfare, change to reference in 2060 in %

| | Scenario RCP3PD With Snowmaking | | | Scenario A1B With Snowmaking | | | Scenario A1B Without Snowmaking | | |
|---|---|---|---|---|---|---|---|---|---|
| Snow change outside Europe | | | | | | | | | |
| | No | 50% | Yes | No | 50% | Yes | No | 50% | Yes |
| Variations snow endowment 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 snow endowment oneday 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 oneday 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% |
| CH welfare change | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.01% | 0.02% | 0.02% | 0.03% |

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 use the fractional snow cover to model the change in natural snow. This method does not factor in snow quality. In reality, temperature change will increase snow temperature and density, lowering snow quality. This might increase the cost of ski slope preparation while decreasing people's willingness to ski. 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 and 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.

### 5.2. *Summer tourism*

The results presented in table 8 correspond to the simulations in GEMINI-E3 for scenarios A1B and RCP3PD in 2060. International tourism flows change according to the new temperature pattern. Cold countries like Canada, Norway or Russia become more attractive. Thus, regions OECD and BRIC increase their arrivals. For example, OECD arrivals increase by 12.1% in RCP3PD and by 35% in A1B. However, temperature increase reduces international tourism flows, i.e. total departures and arrivals decrease while domestic tourism increases. This effect is larger in A1B than in RCP3PD, because the temperature increase is more pronounced in the former scenario. International tourism trade decreases by 5.5% in A1B, but by only 2.5% in RCP3PD. 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: arrivals decrease by 1.6% while departures decrease by 12.9% in A1B.

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 (+0.56% in A1B and +0.21% in RCP3PD). Switzerland is better off with a moderate welfare gain (+0.16% in A1B and +0.08% in RCP3PD). One explanation is that more tourists will enjoy colder 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. Worldwide, climate change has a negative impact on tourism, lowering welfare by 0.06% in A1B and by 0.02% in RCP3PD due to the decrease in international trade.

The results presented above must be read with care. Even if we focus on climate change effects, the socioeconomic scenarios have a significant impact on the results, since they affect the reference case. However, the population and GDP levels in a distant future are more than difficult to predict. Moreover, the effect of temperature on tourists' preferences could evolve. For example, tourists could get used to higher temperatures, making tourism flows more robust to climate change. Consequently, the 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. In this respect, our results confirm those of Roson and Sartori (2016), who find a GDP gain of 1.47% for Switzerland in case of a 3°C temperature increase. They also show that benefits are concentrated in a few rich countries so that impacts have regressive distributional consequences.

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. The HTM model uses a representative temperature for each country. Switzerland's tourism sector benefits from a lower average annual temperature in comparison with other regions. It is likely that summer tourism will increase in cold alpine regions, while it is unsure what will happen in cities. Serquet and Rebetez (2011) for example find a significant correlation between tourism in mountain resorts and hot temperature at lower elevation, especially in alpine resorts located near cities. These results suggest that alpine resorts could adapt to climate change diversifying and developing their summer tourism offer.

### *5.3. Aggregate impact of climate change on tourism*

Finally, we simulate the impacts of climate change on winter and summer tourism simultaneously in GEMINI-E3, i.e. we model temperature increase and variation in snow endowment together. The simulations results are shown in table 9. The results obtained are similar to what we have seen before. International effects of climate change are stronger for summer tourism than for winter tourism, and they result in welfare gains for Swiss households.

There are however some interesting deviations from simply summing over the separate results of winter and summer tourism simulations due to general equilibrium effects. First, Swiss imports of winter tourism decrease less. Second, exports

Table 8: Impacts of climate change for the Swiss other forms of tourism sector and aggregate welfare, change to reference in 2060 in %

| | RCP3PD | A1B |
|---|---|---|
| Production | | |
| CHE | 1.4% | 3.0% |
| EU | 0.2% | 0.5% |
| USA | 0.6% | 0.6% |
| OECD | 8.0% | 22.3% |
| BRIC | 1.0% | 1.9% |
| ROW | -3.9% | -9.6% |
| World | 0.0% | 0.0% |
| Departures from | | |
| CHE | -6.0% | -12.9% |
| EU | -5.0% | -11.8% |
| USA | -12.4% | -25.6% |
| OECD | -14.5% | -39.2% |
| BRIC | 0.0% | 0.4% |
| ROW | 2.2% | 6.3% |
| World | -2.5% | -5.5% |
| Arrivals to | | |
| CHE | -0.7% | -1.6% |
| EU | -2.6% | -5.9% |
| USA | -3.5% | -9.3% |
| OECD | 12.1% | 35.0% |
| BRIC | 2.4% | 5.8% |
| ROW | -6.1% | -13.9% |
| World | -2.5% | -5.5% |
| Households consumption Other Tourism | | |
| CHE | 0.1% | 0.3% |
| EU | 0.0% | 0.0% |
| USA | 0.0% | 0.0% |
| OECD | 0.1% | 0.3% |
| BRIC | 0.1% | 0.2% |
| ROW | -0.2% | -0.4% |
| World | 0.0% | 0.0% |
| Surplus in % of Households consumption | | |
| CHE | 0.08% | 0.16% |
| EU | 0.00% | 0.00% |
| USA | -0.01% | -0.05% |
| OECD | 0.21% | 0.56% |
| BRIC | 0.01% | 0.02% |
| ROW | -0.12% | -0.31% |
| World | -0.02% | -0.06% |

of winter tourism increase less in A1B and turn negative in RCP3PD. This is due to two contradictory effects: climate attractiveness vs. exchange rates. Switzerland becomes more attractive when Europe is affected by climate change. Thus, the production of Swiss tourism increases, generating additional income for Swiss households, and the production of tourism in Europe decreases. This modifies the exchanges rates: the Swiss Franc becomes relatively stronger than 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.

Table 9: Impacts of climate change for the Swiss tourism sectors and Swiss welfare, change to reference in 2060 in % (Results of separated summer and winter simulations indicated in parenthesis)

| | RCP3PD | | A1B | |
|---|---|---|---|---|
| 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%) |
| CH welfare change | 0.08% | | 0.17% | |

## 6. Conclusion

In this paper, we implemented in a multiregional CGE framework climate change impacts on the Swiss tourism sector, enabling to include international effects. As an improvement on previous literature, we differentiated the methodology for winter and summer tourism to better take into account the specificities of each sector. Thus, we used two climate variables. For winter tourism, the decrease in natural snow endowment puts additional constraints on the supply of winter tourism, notably on skiing. For summer tourism, temperature change reallocates international tourist flows.

We have shown that climate change might have a positive effect on the Swiss tourism industry, when international effects are included. Effects on summer tourism are stronger and result in overall welfare gains for Switzerland. However, the situation is more contrasted inside the country. Low-altitude ski resorts are vulnerable to climate change since they suffer from a greater natural snow loss. On the other hand, high-altitude ski resorts benefit from a comparative advantage with respect to lower altitude ski resorts in Switzerland, but also in other parts of Europe. Our results also outline adaptation capacity of alpine resorts, which could develop their summer tourism offer. Indeed, more tourists could enjoy colder mountain areas due to more frequent heatwaves in cities.

There are some caveats associated with our approach. We point out some of these limitations to also inspire further research. First, tourism flows not only depend on climate but also on population and GDP. We used 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. Next, we treated 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 others production factors, for example increasing the share of artificial snowmaking. However, the preparation of ski slopes might be impractical in a warmer climate. Finally, 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. On the other hand, tourists could also get used to higher temperature, making summer tourism flows more robust to climate change. Better understanding people's preferences under climate change and changes thereof is challenging but crucial for developing adequate climate change adaptation strategies.

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## Appendix A.

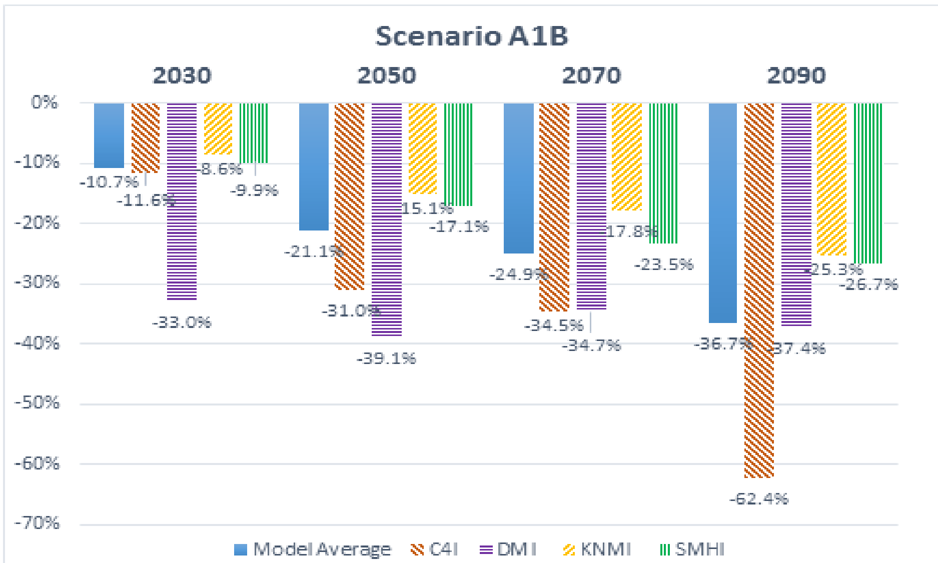


Figure A.1: Snow cover variation of the Swiss one-day winter tourism sector with respect to 2010 under A1B scenario

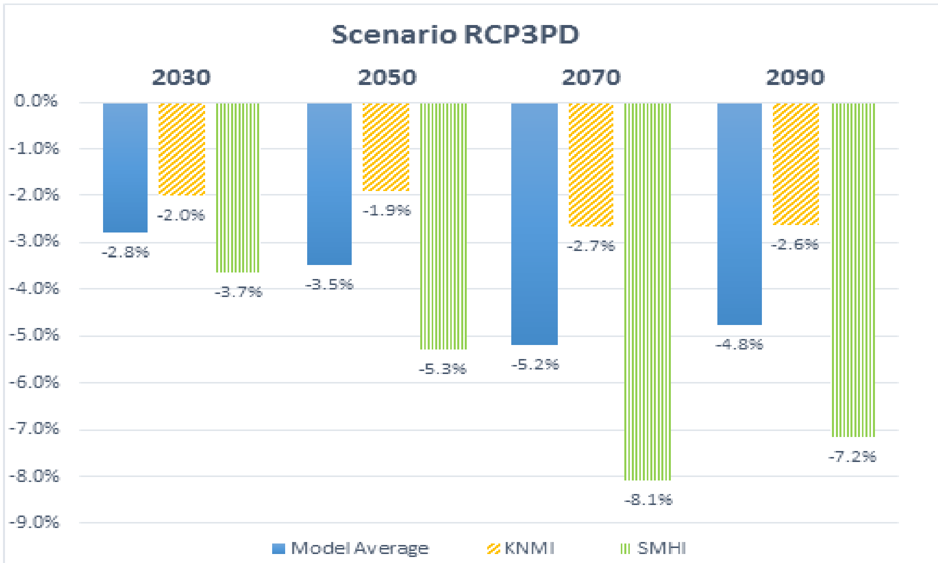


Figure A.2: Snow cover variation of the Swiss one-day winter tourism sector with respect to 2010 under RCP3PD scenario

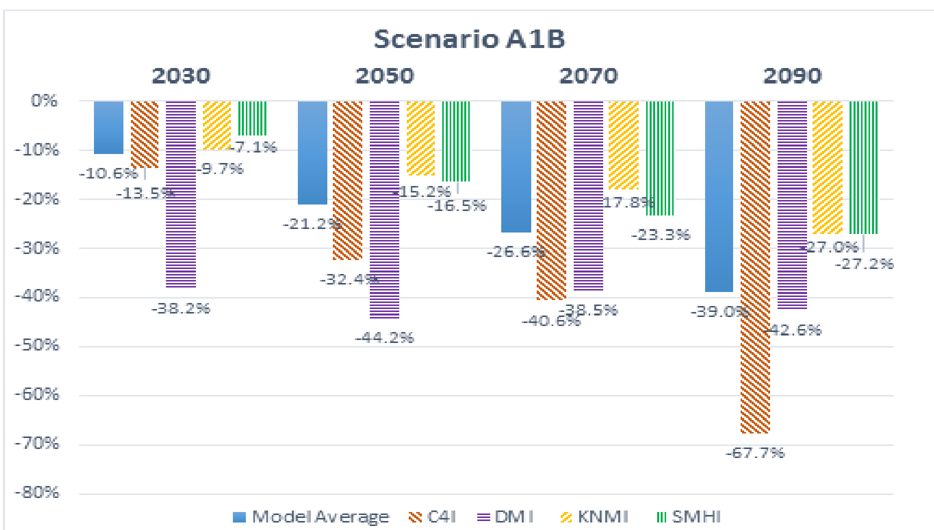


Figure A.3: Snow cover variation in Europe with respect to 2010 under A1B scenario

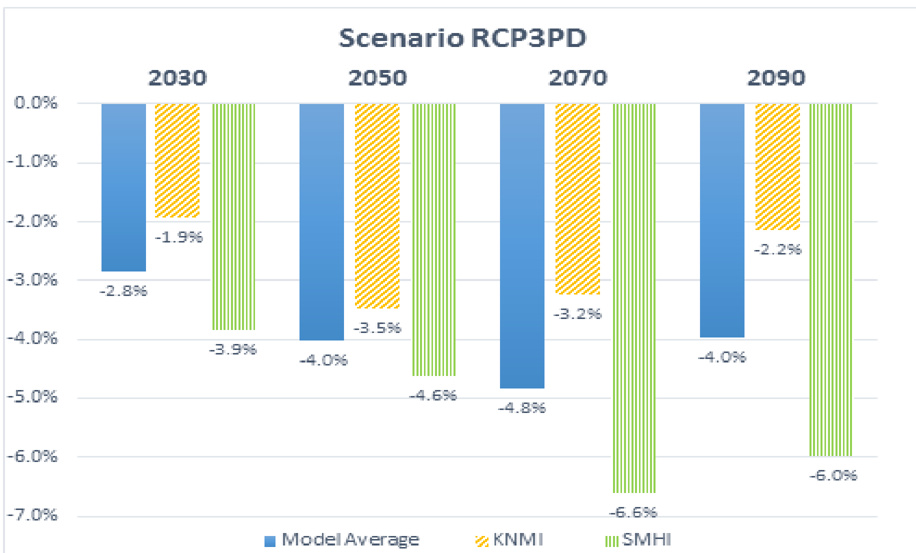


Figure A.4: Snow cover variation in Europe with respect to 2010 under RCP3PD scenario