Modeling Climate Change Adaptation in a Computable General Equilibrium Model: an Application to Tourism*

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Abstract

The issue of climate change adaptation becomes increasingly important in Switzerland, which has already faced higher than average global warming during the last decades. Winter tourism is expected to be one of the Swiss sectors most at risk from climate change mostly because of the increase in snowline altitude. In fact, several studies predicted high climate change costs for this sector. However, most of these studies have largely overlooked the role of adaptation in alleviating those costs. We tried to fill that gap with a better modeling of climate change adaptation in GEMINI-E3 which is a computable general equilibrium model. Future snow cover variations are derived using different climatic scenarios from the European ENSEMBLES project. By 2050, we find rather moderate welfare effects of a decreasing snowpack with costs ranging, for the Swiss economy, from 24 to 122 million USD which represent a 0.01% to 0.03% decrease in final household consumption.

Keywords : CGE modeling, climate change, adaptation, winter tourism, snowmaking

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1 Introduction

With the certainty that some amount of climatic warming will occur, the focus in climate change policy has moved gradually from mitigation to adaptation issues. Our research topic is in line with this evolution since our aim is to estimate climate change costs for the Swiss tourism sector as well as to gauge the role of adaptation processes and measures in alleviating those costs. The tourism sector is expected to be one of the Swiss sectors most at risk from climate change along with the agriculture, water distribution, health, insurances, energy and infrastructures sectors. [1]

For our purposes, we use the model GEMINI-E3 which is a multi-regional computable general equilibrium model (CGE model). So far, it has been largely used to assess general equilibrium costs and benefits of either European or Swiss energy and climate policies. However, it would not have been possible to analyze climate change impacts on the tourism sector without changing the standard version of GEMINI-E3.

It was first necessary to build a tourism sector within GEMINI-E3. This initial step has required using many different sources of information. Instead of one tourism sector, we actually built three tourism segments, two of which being snow-dependent. This dependency on snow is not only theoretical as we have added a natural snow resource to GEMINI-E3 in the form of a new factor of production. A large review of the literature has also been undertaken in order to identify adaptation options for the tourism sector. Adaptation options are distinguished according to whether they are *endogenous* or *exogenous*. Endogenous adaptation measures are different from exogenous ones since the former are undertaken by private actors whereas the latter are carried out by public actors. [2] In parallel with the modifications brought to the producing sectors, we have also change the consumer's utility function in order to integrate the tourism segments.

Snow endowment variations were eventually implemented using information of different climatic scenarios obtained from the European ENSEMBLES project. These data were used for their regional scale as they provide climatic information for a 25x25 grid mesh over Europe.

The paper is structured in the following way. Section 2 provides a description of the Swiss tourism sector. First, it begins by briefly mentioning its economic importance and then deals with climate change impacts and adaptation in the winter tourism sector. Section 3 presents the main features of the GEMINI-E3 model together with the changes and improvements that we have made to it for the present work. In particular, it details the way we have modeled tourism and gives some information on the calibration step, particularly on the way natural snow endowment was valuated. As regards the assumptions that we have adopted in order to build the scenario without climate change (i.e. the reference scenario), they are presented in section 4. Deviations from that baseline in the context of climate change will be tackled in section 5. The final section draws some conclusions and raises a series of key issues regarding sustainable climate change adaptation.

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[1] In this paper, we use the same broad definition of tourism as in national accounting systems [23] : "*Tourism comprises the activities of persons traveling to and staying in places outside their usual environment for not more than one consecutive year for leisure, business and other purposes.*"

[2] This terminology is not universal as endogenous adaptation could also be referred to as "*autonomous*", "*private*", "*market driven*", "*automatic*" or "*spontaneous*". In the same way, equivalent terms for exogenous adaptation are "*planned*", "*policy driven*" or "*public*" adaptation.

2 The Swiss tourism sector

2.1 Weight in the Swiss economy [3]

The economic weight of the tourism sector is non negligible as it represented 2.9% of GDP in 2005 (against 3.1% in 2001). Tourism revenues generated by foreign visitors amounted to 12.6 billion CHF in 2005 which make the tourism sector one of the biggest Swiss export sectors. Moreover, these revenues are higher than the expenditure of Swiss tourists abroad meaning that the Swiss tourism balance is positive. Due to a relatively small productivity, the tourism sector plays a more important role for employment than for value-added. In 2005, the sector accounted for 4.4% of total employment expressed as full-time job equivalents. The tourism sector also draws a part of its economic importance from the fact that it creates jobs in outlying mountain regions confronted to structural underemployment.

2.2 Climate change impacts

In Switzerland, a distinction is made between "urban", "rural" and "alpine" tourism depending on the location where tourism activities take place. Though climate change will impact all forms of tourism, it is largely agreed that "alpine" tourism will be the tourism segment most at risk from climate change. This is due to the fact that the alpine environment is highly sensitive to climate variations and also to the outdoor nature of tourism activities in mountain regions.

To our knowledge, three studies have estimated so far the economic impact of climate change for a part or the whole of the Swiss tourism sector. Müller and Weber [22] focused their analysis on "alpine" tourism while analyzing climate change impacts for the Bernese Oberland. Their estimate of winter season sales loss in 2030 amounts to 200 million CHF. They state that this loss could be reduced annually by 80 million CHF through higher summer visitations and by an additional 50 million CHF through the implementation of adequate adaptation measures during the winter season (i.e. snowmaking). Meier [21] studied climate change impacts for the whole alpine tourism segment and estimated costs ranging from 1 800 to 2 300 million CHF by 2050 (1 600 to 2 100 million CHF only for the winter season). Results of these first two studies demonstrate the fact that climate change will mostly impact the alpine tourism segment through deteriorating snow conditions. In addition, Müller and Weber [22] show that the winter tourism segment in alpine regions that does not generate overnight stays will be more impacted than the winter tourism segment in alpine regions that generates overnight stays. This translates the fact that one-day ski excursion destinations are generally low and medium ski areas, that is to say ski areas that are the most vulnerable to the detrimental effects of climate change (cf. [3, 5, 12, 29]).

Much more moderate in their estimates than Meier, the study by Ecoplan/Sigmaplan [14] predicts climate change costs in the order of 120 million CHF in 2050 (median value) for the tourism sector. This moderate cost estimate originates from the general equilibrium nature of their investigations. In fact, their estimates are obtained using a multi-regional CGE model. Accordingly, they were able to integrate effects, such as households reallocating their expenditures after some changes in relative prices, that were not taken into account in other studies. Moreover, the use of a multi-regional model is another strength of their approach as it allows modeling different climate change impacts for each competing tourism regions. This a particularly valuable feature in analyzing climate change costs for the Swiss tourism sector since snow cover reduction will have bigger impacts abroad than in Switzerland (cf. [5]).

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[3] Figures given in this subsection are taken from [7].

2.3 Climate change adaptation in winter alpine tourism

2.3.1 Possible adaptation measures

The previous subsection has shown that winter alpine tourism will be the tourism segment most at risk from climate change in Switzerland. Climate change will have many impacts but the decrease in natural snowpack will be the most important of them. With respect to the latter impact, many adaptation measures are possible with some of them relevant to ski customers and some of them relevant to ski area operators.

Ski area operators can implement either "technical" measures or "managerial" measures. Examples of the former include investments in (additional) snowmaking facilities, transport facilities modernization[4], improvements of the ski run preparation and maintenance[5] as well as ski area extension either at high altitude or on the northern mountainside. As for the latter, they include, for example, strategies that aim at diversifying revenues and/or at increasing them outside the winter season. Table 1 lists some possible adaptation measures on the supply side and divides them into "endogenous" and "exogenous" adaptation measures :

Table 1 – Possible adaptation measures on the supply side to a decrease in the snow cover. (Source : adapted from [28])

Adaptation - Supply side	Endogenous	Exogenous
Artificial snowmaking	X	
Improvements in ski run preparation and maintenance	X	
Ski area extension	X	
Transport facilities modernization	X	
Development of ski domes	X	X
Tourism offer diversification	X	
Insurances and weather derivatives	X	
Investments subsidies		X
Improvements in meteorological forecasts		X

The way we have introduced some of these adaptation measures into GEMINI-E3 is explained in subsection 3.2. Note that the most important part of these modeling efforts has been devoted to incorporate artificial snow production in GEMINI-E3. Relevant information concerning artificial snowmaking and its use in Switzerland are described below under subsection 2.3.2.

Possible adaptation measures on the demand side are presented in table 2.

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[4] This means replacing old ski lifts with chair lifts or cable cars, that do not need a snow cover for transporting skiers in altitude

[5] During the last decades, considerable progresses have already been done regarding ski run preparation and maintenance which has allowed decreasing the height of snow necessary for skiing activities.

Table 2 – Possible adaptation measures on the demand side to a decrease in the snow cover. (Source : adapted from [28])

Adaptation - Demand side	Endogenous	Exogenous
Adapt periods of ski within the winter season	X	
Change ski destinations	X	
Change leisure activities	X	
Improvements in meteorological forecasts		X
Improve the accuracy of weather and snow bulletins		X

Three out of the five adaptation measures listed in table 2 directly concern ski customers. These adaptation measures are endogenous by nature. They include possibilities for ski customers to modify periods at which they ski within the winter season, to change their ski destinations in favour of snow-reliable ones (in Switzerland or abroad) or to give up ski and replace it with other leisure activities. These adaptation measures, with one exception, are included in GEMINI-E3. We refer the reader to subsection 3.4 where we describe our assumptions on the way households arbitrate between the consumption of different tourism and non-tourism goods and services.

2.3.2 Artificial snowmaking

In Switzerland, investments in snowmaking facilities really took off in the beginning of the nineties. Public authorities supported this trend by subsidizing snowmaking facilities from the mid-nineties onwards [17]. Table 3 presents the evolution of snowmaking facilities investments between 2001 and 2005 for different Swiss ski regions.

Table 3 – Length of ski slopes (in km) that could be artificially snowed in different Swiss regions in 2001 and 2005. (Source : [31, 32], umbrella organizations of the ski lifts sector from Bern and Grisons)

	km ski slopes length	km with art. snow (% of total ski slopes length) 2001	2005
Grisons	1 900	170 (8.9%)	340 (17.9%)
Bernese Oberland	850	90 (10.6%)	180 (21.2%)
Valais	2 000	400 (20.0%)	520 (26.0%)
Other ski regions	1 200	80 (6.7%)	150 (12.5%)
Total Switzerland	5 950	740 (12.4%)	1190 (20.0%)

In 2008, 33% of the overall area of prepared ski slopes in Switzerland could be snowed [27]. This already large coverage is accompanied by an intensive use of resources. A recent study from the Swiss gas and water industry association [15] has estimated the water use for producing artificial snow to 16.7 million cubic meters. From these 16.7 million cubic meters, 10 million come from surface waters, 5 million from springs and the remaining 1.7 million from the drinking water network.

Different studies have analyzed the costs associated with snow production (cf. [1, 10]). In this work, we stick to the following indicative values given in [16] for the annual costs of operating one kilometer of ski slope with artificial snow :

- 35 000 to 55 000/km in \$ 2010
- 70 000 to 90 000/km in \$ 2010 (including interests and depreciation)

3 The GEMINI-E3 model

3.1 Overview of GEMINI-E3

GEMINI-E3 [6][9] is a multi-country, multi-sector, recursive computable general equilibrium model comparable to the other CGE models (GREEN, EPPA, MERGE, Linkage, WorldScan) built and implemented by other modeling teams and institutions, and sharing the same long experience in the design of this class of economic models. The standard model is based on the assumption of total flexibility in all markets, both macroeconomic markets such as the capital and the exchange markets (with the associated prices being the real rate of interest and the real exchange rate, which are then endogenous), and microeconomic or sector markets (goods, factors of production).

The model is built on a comprehensive energy-economy dataset, the GTAP-6 database [13], that incorporates a consistent representation of energy markets in physical units, social accounting matrices for each individualized country/region, and the whole set of bilateral trade flows. Additional statistical information accrues from OECD national accounts, IEA energy balances and energy prices/taxes and IMF Statistics (Government budget for non OECD countries). Carbon dioxide emissions are computed on the basis of fossil fuel energy consumption in physical units. For the modeling of non-CO_2 greenhouse gases emissions (CH_4, N_2O and F-gases), we employ region- and sector-specific marginal abatement cost curves and emission projections provided by the Energy Modeling Forum within the Working Group 21 [30].

The classifications - breakdowns by country/region and by sector/product - are framed according to the general context and the targets of each study. In this study we use the following reduced classification :

- CHE : Switzerland ;
- EUR : European Union ;
- USA : United States of America ;
- OEC : Other developed countries ;
- BRI : Brazil, Russia, India and China ;
- ROW : Rest of the world.

In this version, because we want to integrate climate change impacts in the Swiss economy, we have increased the number of sectors that are described. We represent 28 sectors instead of 18 usually represented in the standard version, the table 4 presents this new classification.

For each sector the model computes the demand on the basis of household consumption, government consumption, exports, investment, and intermediate uses. Total demand is then divided between domestic production and imports, using the Armington assumption [6]. Under this convention a domestically produced good is treated as a different commodity from an imported good produced in the same industry. Production technologies are described using nested CES functions (see figure 1).

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[6] The web site `http://gemini-e3.epfl.ch/` provides all information about the model, including its complete description.

Table 4 – Industrial classification

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

Time periods are linked in the model through endogenous real rates of interest determined by equilibrium between savings and investment. National and regional models are linked by endogenous real exchange rates resulting from constraints on foreign trade deficits or surpluses. The main outputs of the GEMINI-E3 model are by country on an annual basis : carbon taxes, marginal abatement costs and prices of tradable permits (when relevant), effective abatement of CO_2 emissions, net sales of tradable permits (when relevant), total net welfare loss and components (net loss from terms of trade, pure deadweight loss of taxation, net purchases of tradable permits when relevant), macro-economic aggregates (e.g. production, imports and final demand), real exchange rates and real interest rates, and data at the industry-level (e.g. change in production and in factors of production, prices of goods).

3.2 Modeling the tourism sector in GEMINI-E3

The tourism sector is not included in the standard version of the GEMINI-E3 model. Rather than adding one tourism sector that would have encompassed all tourism activities, we have decided to create and incorporate the three following tourism segments : "(snow-dependent) winter overnight tourism", "(snow-dependent) one-day winter tourism" and "other forms of tourism". The first of these segments represents a part of the winter alpine tourism whose production is intended to skiers generating one or several overnight stays. We use the term "skier-tourist" to designate this type of tourism customers. The second segment complements the first one as it represents the part of winter alpine tourism whose production is intended to skiers that do not generate overnight stays. We use the term "skier-day tripper" to designate this type of tourism customers. Finally, the third segment encompasses all the tourism activities not included in the first two segments. More precisely, this broad segment includes tourism activities that take place in rural and urban areas as well as summer and snow-independent winter tourism activities in alpine regions.

Each of these segments presents a different profile in relation to climate change. Their exposure, sensitivity and adaptive capacity towards climate change (in sum their vulnerability to climate change) are different. In particular, we have split the snow-dependent winter segment in two in order to take into account that not all ski resorts have the same vulnerability towards climate change (cf. subsection 2.2). The way consumers substitute one type of tourism for another has

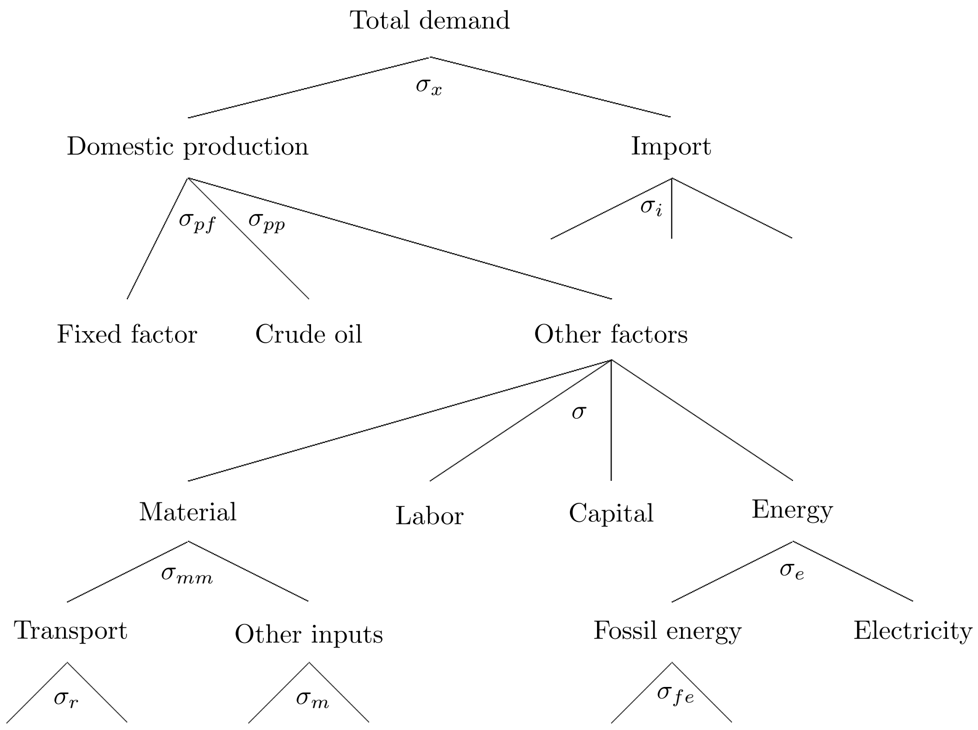

Figure 1 – Nesting CES structure of production in GEMINI-E3

also played a role when choosing how to disaggregate the tourism sector. The goods produced by the "(snow-dependent) winter overnight tourism" segment and the "(snow-dependent) one-day winter tourism" segment are substitute in the consumer's utility function. Therefore, it is by combining the consumption of these two goods that consumers determine their final consumption of winter sports activities. Our assumptions regarding possibilities for consumers to substitute one tourism segment for another are given in figure 9 and table 6 of subsection 3.4. Two additional important information are contained in figure 9. Firstly, we can see that goods and services produced in the different regions of the model by the same tourism segment are substitute.[7] The second point is that tourism consumption can be viewed as a consumption combining transport services with a bundle of goods and services consumed at the vacation destination. This model specification is interesting since it allows taking into account the impact of changing transportation costs on travel behaviors and tourism destination choices.

The production structure which is similar for both snow-dependent winter tourism segments is shown in figure 2. The nested structure allows visualizing our assumptions concerning substitution possibilities from which result the ease or difficulty to adapt to climate change impacts. Snow-dependent winter tourism segments respond to a reduction in natural snow availability in two steps. Firstly, they can compensate it by producing more artificial snow. Figure 2 shows that ski operators use a mix of capital, electricity, labor and water inputs to produce artificial snow (cf. subsection 2.3). The water resource consists mainly of raw water which is directly extracted from surface waters or springs (cf. [15]). Secondly, 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

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[7] The "(snow-dependent) one-day winter tourism" segment is an exception. In fact, its consumption by foreign residents within a region is economically negligible.

with a continuously decreasing amount of snow. Concretely, these investments match some of the adaptation measures listed in table 1 (i.e. improvements in ski run preparation and maintenance, ski area extension, transport facilities modernization).

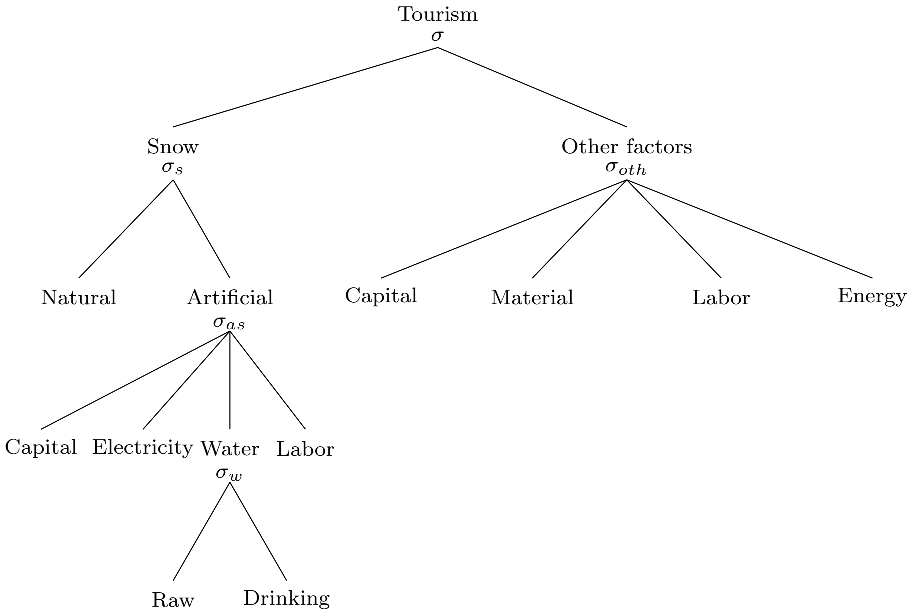

Figure 2 – Nested CES production function defined for both snow-dependent winter tourism segments.

Table 5 – Elasticities of substitution defined for the snow-dependent winter tourism segments

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
Industrial and drinking water	σ_w	0.5

One fundamental assumption that we make is that adaptation measures such as snowmaking will be available to ski area operators up to 2050. This is not a very strong assumption since our modeling approach permits constraining the future recourse to artificial snow production in several ways. For example, the impact of a decreasing water resource on snowmaking could be taken into account through the price mechanism (i.e. higher water prices). Also, many legal rules, which are another factor likely to constrain artificial snow production in the future, can be modeled within GEMINI-E3.

Eventually, the production structure displayed in figure 2 also permits modeling the higher vulnerability to climate change of the "(snow-dependent) one-day winter tourism" segment compared to the "(snow-dependent) winter overnight tourism" segment. This difference in vulnerability between the two snow-dependent winter tourism segments will be translated in two different ways : first, through a distinct decrease of the snow resource and, second, through a segment specific elasticity of substitution between natural and artificial snow (cf. table 5). This last point stems from the fact that it is more difficult to produce artificial snow at low and medium elevated ski resorts where periods of time with cold temperatures are less long and frequent than at higher altitudes.

3.3 Model calibration for the tourism sector

3.3.1 Information used for model calibration

A tourism sector does not exist neither in the GTAP database nor in the Swiss Input-Output table (SIOT). Therefore, it has been necessary to gather information from many sources in order to build the three tourism segments that we have defined in subsection 3.2. Building these tourism segments has meant defining, for each of them, the kind and quantities of goods and services consumed for the reference year 2001. The main sources of information that we have used are the following :

- Swiss tourism satellite account [7] ;
- Swiss tourism balance ;
- Regional tourism value-added studies [24, 25, 26] ;
- Swiss public transport statistics ;
- Swiss tourism accommodation statistics ;
- Travel Market Switzerland 2001 [20] ;
- Skier-visits statistics ;

Some of the information relevant for calibrating artificial snow production has already been given in subsection 2.3.2 whereas natural snow endowment valuation is explained below in subsection 3.3.3.

3.3.2 Presentation of the three tourism segments for the year 2001

Using the information on tourism expenditures and activities in Switzerland gathered for this work and briefly mentioned in subsection 3.3.1, we were able to build a tourism sector for the year 2001. As discussed in subsection 3.2, the tourism sector is made up of three distinct tourism segments.

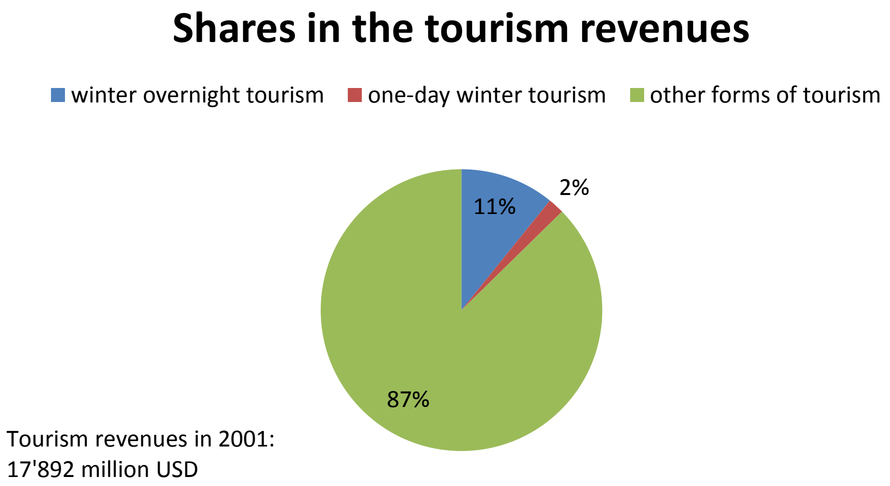

Figure 3 – Share of each segment in the total revenues generated by the Swiss tourism sector in 2001.

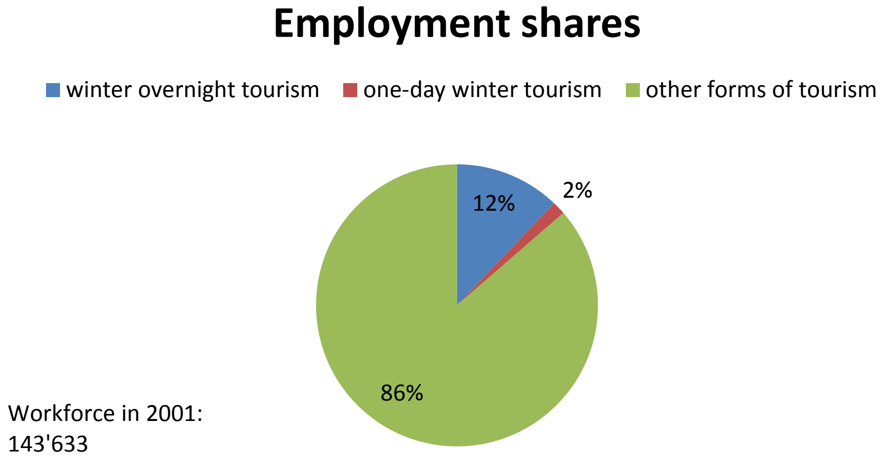

Figure 4 – Share of each segment in the tourism employment (expressed as full-time job equivalents) in 2001.

Snow dependent tourism segments only represented a relatively small part of the tourism sector in 2001 with a share of 13% in overall tourism revenues and 14% in tourism employment. Moreover, the segment "overnight winter tourism" is much larger in economic terms than the segment "one-day winter tourism". For Switzerland, the former result may seem weird. One reason for this result is that we have built our work on a very broad definition of tourism, i.e. the definition set by the UN World Tourism Organization (UNWTO) and used in the national accounting (cf. subsection 2.1).

Not only the size but also the "content" of the two snow-dependent tourism segments varies significantly as it appears from the two following figures. Figure 7 is added here as a complement and allows visualizing what are the broad classes of final goods and services that are consumed within the tourism segment "other forms of tourism".

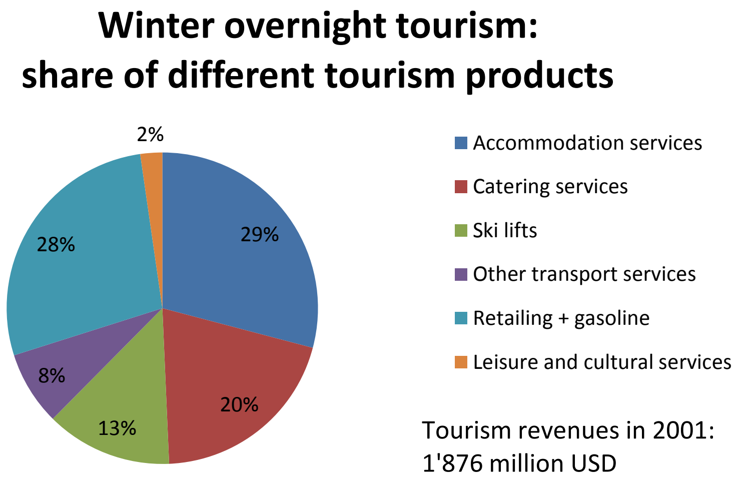

Figure 5 – Classes of final goods and services that are consumed within the tourism segment "winter overnight tourism".

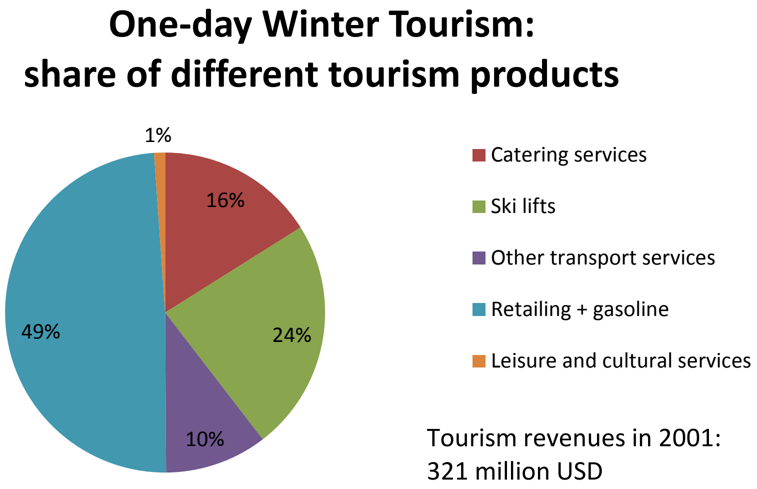

Figure 6 – Classes of final goods and services that are consumed within the tourism segment "one-day winter tourism".

The most notable differences between the two snow-dependent tourism segments concern the following expenditure items : accommodation, ski lifts and retailing+gasoline. First of all, the tourism segment "one-day winter tourism" does not include any accommodation services. On the other hand, expenditures for such items as ski lifts and retailing+gasoline are much more important in relative terms for the "one-day winter tourism" segment. The importance of the latter expenditure item reflects the fact that "skier-day trippers" mainly use their private cars for traveling.

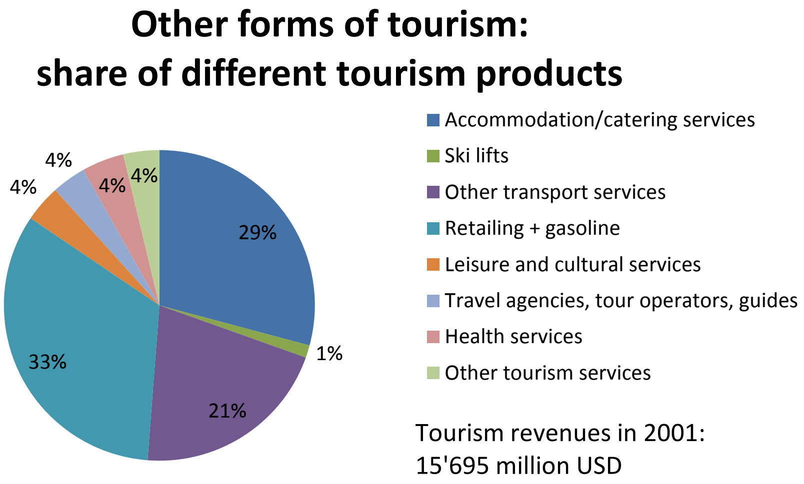

Figure 7 – Classes of final goods and services that are consumed within the tourism segment "other forms of tourism".

3.3.3 Valuation of the natural snow

This subsection is devoted to explain the methodology that was employed in order to valuate the natural snow endowment of the Swiss winter tourism sector. An econometric approach was chosen, the basic idea being to analyze the causal relationship between natural snow conditions and some economic or financial "outcome" from which we could derive a global value of natural snow endowment for the winter tourism in Switzerland. We have used daily mean data of snow heights simulated for a set of nearly 20 Swiss ski areas and four winter seasons.[8] For every winter seasons and ski areas, we transformed these data in order to obtain the number of days with a snow height that is sufficient for skiing.[9] We then assigned a ski lifts company to every ski areas and gathered the economic and financial information that were available for these companies. We decided to focus our analysis on winter transport revenues generated by the ski lifts companies. Therefore, winter transport revenues represent the dependent variable of our econometric analysis, the variable for which we would like to identify how it varies in sign and magnitude with a change in snow conditions (all other things being held constant). Identifying this effect is possible given that a range of problematic variables are controlled for (i.e. variables that are correlated with both winter transport revenues and snow conditions). With this respect, estimating equation 1 is advantageous as it allows controlling for many variables including a set of fixed effects (i.e. winter season and ski area fixed effects) and a set of observed variables. The latter, which are represented by the vector $\mathbf{x_{it}}$ in equation 1, includes transport and snowmaking facilities. Our interest lies in the estimation of the coefficient β_2. In equation 1, ski areas and winter seasons are distinguished using indexes, i ($i = 1, ..., 20$) for ski areas and t ($t = 1, ..., 4$) for winter seasons.

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[8] These data are presented and discussed in Uhlmann et al. [29].

[9] Different thresholds were used for that purpose, $\theta \in \{30, 50, 70cm\}$, depending on the altitude at which snow height data were simulated.

$$y_{it} = \alpha_i + \beta_{\mathbf{1}}\mathbf{x_{it}} + \beta_2 SD_{it} + \delta_t + \varepsilon_{it} \quad (1)$$

Where :

y_{it} : winter transport revenues (in logs)
α_i : a ski area fixed effect
$\mathbf{x_{it}}$: a set of control variables
SD_{it} : the number of days with enough snow ("snow days" at a specified altitude)
δ_t : a winter season fixed effect
ε_{it} : an error term

Preliminary results provide a value of β_2 equals to 0.0023. What it does mean is that one additional day during the winter season with sufficient snow conditions for skiing generate an increase of 0.23% in winter transport revenues at the ski lifts company level. Based on this estimate, it is possible to extrapolate the marginal effect on the profit of the whole Swiss ski lifts sector. Details are given in equation 2.

$$\begin{aligned} P_{SD} &= RATIO \cdot (\beta_2 \cdot TRANS) \\ P_{SD} &= 0.25 \cdot (0.0023 \cdot 321356580) \\ &= 184780 \quad (2) \end{aligned}$$

Where :

P_{SD} = Profit from one "snow day" for the ski lifts sector in USD
$RATIO$ = Earnings ratio of the ski lifts sector
$TRANS$ = Winter transport revenues of the ski lifts sector for the winter season 2000/01 in USD

Therefore, the profit that is realized over the entire winter season thanks to the good snow conditions can be derived using equation 3.

$$\begin{aligned} V_{snow} &= DAYS \cdot P_{SD} \\ V_{snow} &= 100 \cdot 184780 \\ &= 18478000 \quad (3) \end{aligned}$$

Where :

V_{snow} = Winter season profit from "snow days" for the ski lifts sector in USD
$DAYS$ = Average number of operating days in a winter season

The next equation is used to determine the profit generated by good snow conditions for our two snow-dependent winter tourism segments :

$$V_{j,snow} = \gamma_j \cdot V_{snow} \cdot MULT_j \quad (4)$$

Where :

$V_{j,snow}$ = Winter season profit in USD from “snow days” for tourism segment j
γ_j = Fraction of the winter transport revenues allocated to tourism segment j
$MULT_j$ = Multiplicative factor for tourism segment j equal to the ratio total tourism expenditures to ski lifts expenditures

Introducing numerical values in equation 4 that are specific to each snow-dependent winter tourism segment gives the following results :

$$\begin{aligned} V_{one-day,snow} &= \gamma_{one-day} \cdot V_{snow} \cdot MULT_{one-day} \\ V_{one-day,snow} &= 0.234 \cdot 18478000 \cdot 2 \\ &= 8647704 \end{aligned} \tag{5}$$

$$\begin{aligned} V_{overnight,snow} &= (1 - \gamma_{one-day}) \cdot V_{snow} \cdot MULT_{overnight} \\ V_{overnight,snow} &= (1 - 0.234) \cdot 18478000 \cdot 6 \\ &= 84924888 \end{aligned} \tag{6}$$

These two last values are our estimates of the value of natural snow for the two snow-dependent winter tourism segments.

3.4 The consumer’s utility function

In this version of GEMINI-E3, the household consumption is represented through nested CES functions instead of the usual Stone-Geary function. Figures 8 and 9 show the structure of the nested CES functions that we have retained.

Like other general equilibrium models, GEMINI-E3 assesses the welfare cost of policies through the measurement of the classical Dupuit’s surplus, i.e. in its modern formulation the Equivalent Variation of Income (EVI) or the Compensating Variation of Income (CVI). It is commonly acknowledged that surplus is preferable to change in GDP or change in Households’ Final Consumption because these aggregates are measured at constant prices according to the methods of National Accounting and do not capture the change in the structure of prices, a main effect of climate change policies [8]. Moreover, it is revealing to split the welfare cost between its two components, the domestic component or Deadweight Loss of Taxation (DWL) and the imported component or Gains from Terms of Trade (GTT).

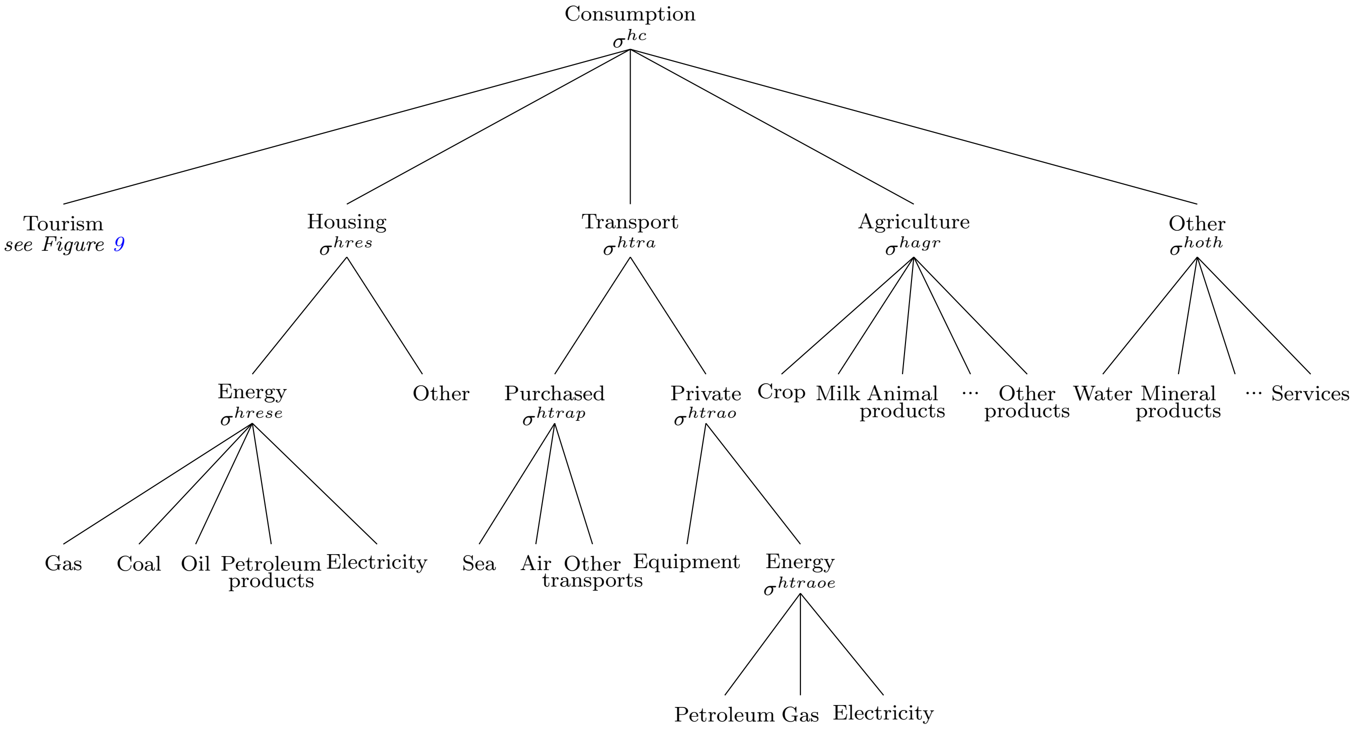

Figure 8 – Nested structure of household consumption

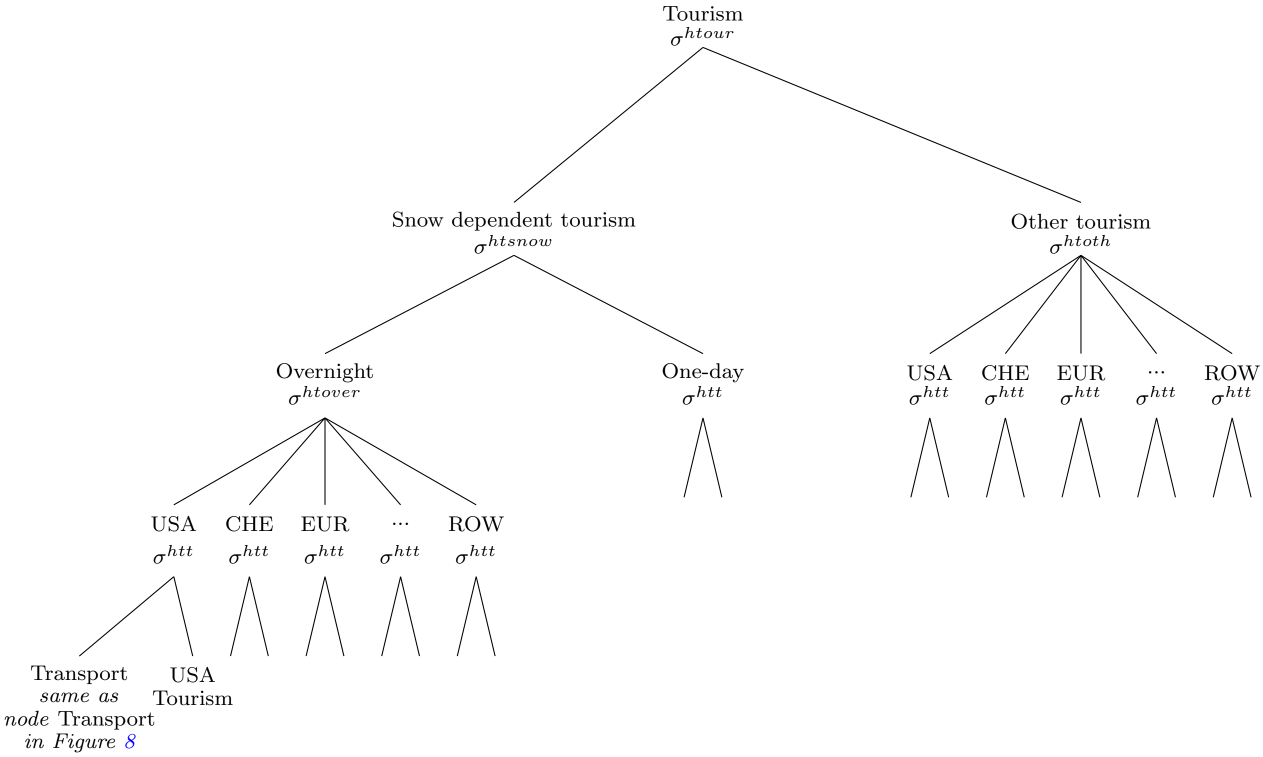

Figure 9 – Nesting of Tourism

Table 6 – Elasticities of substitution

Elasticities of substitution for the tourism segments		
Snow dependent and other tourism	σ^{htour}	0.7
Overnight and one-day tourism	σ^{htsnow}	0.5
Domestic and foreign tourism (overnight)	σ^{htover}	0.1
Domestic and foreign tourism (other tourism)	σ^{htoth}	0.1
Transport and other goods consumed	σ^{htt}	0.2

4 The reference scenario

Reference scenarios in CGE models are built from forecasts or assumptions on economic growth in the various countries/regions ; the prices of energy in world markets, in particular the oil price ; and national (energy) policies. Assumptions concerning GDP are based on the forecasts of the US Department of Energy (Energy Information Administration) published in the *2010 International Energy Outlook*[4]. Assumptions concerning energy prices are drawn from the *World Energy Outlook* of the International Energy Agency[2] : the oil price is assumed to reach 115$ in 2035 and to remain stable after, the price of imported gas in Europe is equal to 14 $ per Mbtu in 2035, and the price of steam coal imported in OECD countries reaches 110$ per ton. The tables 7 and 8 show respectively the GDP growth and the energy prices retained in this reference scenario.

Table 7 – GDP growth rate % per year

	2010-2020	2020-2030	2030-2040	2040-2050
Switzerland	1.5%	0.8%	0.8%	0.8%
European Union	1.6%	1.9%	1.7%	1.7%
USA	2.5%	2.7%	2.5%	2.5%
Other OECD Countries	1.3%	1.1%	1.0%	1.0%
BRIC	6.4%	4.4%	4.0%	4.0%
Rest of the World	4.2%	3.5%	3.6%	3.7%
World	3.0%	2.8%	2.8%	2.9%

Table 8 – Energy prices - $ 2008

	Unit	2000	2008	2015	2020	2025	2030-2050
IEA Crude oil imports	Baril	34.3	97.2	86.7	100.0	107.5	115.0
Natural gas imports Europe	Mbtu	3.5	10.3	10.5	12.1	13.1	14.0
OECD Steam coal imports	Tonne	41.2	120.6	91.1	104.2	107.1	109.4

Figure 10 shows the resulting energy consumption in the world. The world energy consumption would increase by 1.8% per year (on the period 2010-2050), the key driver of energy consumption being the GDP growth. The growth of energy consumption would be higher in BRIC and in the rest of the World (respectively +2.7% and 1.9% per year) than in the OECD countries (0.3% in EUR and 1% in USA). In 2050, DCs (BRIC and ROW) represent 76% of energy consumption against 60% in 2010. The energy mix of the economy is mainly driven by the change of relative energy prices and by technological changes. As in this scenario we do not assume different trends in fossil energy prices and technological breakthrough, the energy mix remains almost unchanged over the period. In 2050, oil would remain the dominant energy : oil represents 35% of World energy consumption and the transport sector would remain the main user of oil without significant penetration of biofuels and other potential substitutes. Electricity and coal contribute to respectively 28% and 22% of the energy balance whereas gas equals only 15% of energy consumption.

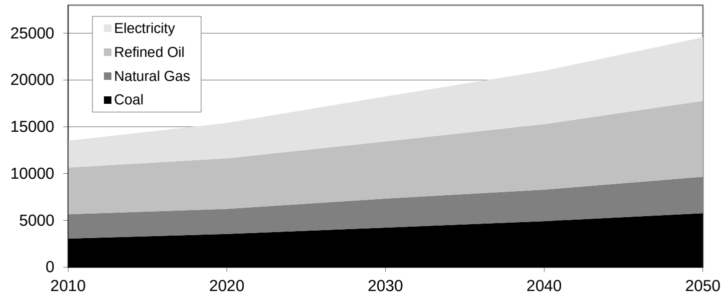

Figure 10 – World Energy Consumption in Mtoe

Finally in figure 11, we show the resulting evolution of GHG emissions at the world level. In 2050, the world GHG emissions represent 22 GtC-eq.

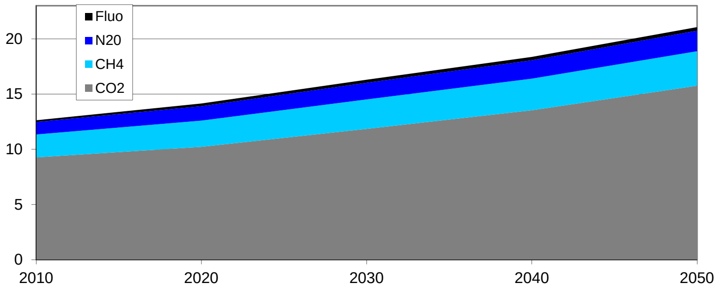

Figure 11 – World GHG emissions in MtC-eq

5 Climate change impacts on the tourism sector

5.1 Future change in snow endowment

The climate module of GEMINI-E3 provides only temperature variations at the level of our planet, yet the assessment of impacts of climate change requires a regionalization of this information and concerning Swiss winter tourism, data on snow cover in Switzerland during the period 2010-2050. We therefore decided to use the results of the European project ENSEMBLES [10] [19]. The objectives of the project ENSEMBLES was to develop an ensemble prediction system based on state-of-the-art, high resolution, global and regional Earth System models developed in Europe. In particular, it produced regional climate scenarios at European level for impacts assessments using the high resolution RCM ensemble system and downscaling methods. This information on European regional climate are given for the period 1950-2050 (sometimes up to 2100) at 25km resolution. We use simulation results obtained with four couplings of global and regional climate models realized in the framework of the European project ENSEMBLES. These four GCM-RCM couplings are the following :

Table 9 – Four GCM-RCM couplings from the ENSEMBLES project (with indication of the simulation period).

1.	KNMI - ECHAM5-r3 avec RACMO (1951-2100)
2.	SMHI - BCM-RCA (1961-2100)
3.	C4I - HadCM3Q16-RCA3 (1951-2099)
4.	DMI - ARPEGE-HIRHAM (1951-2100)

All these models have the same rotated grid thereby facilitating climatic data handling and analysis. They have also been chosen in order to get the maximum diversity of models represented. Their simulation period generally covers the period 1951–2100. The base period (i.e. period without climate change) taken for our simulations is 1961-1990. For every decades with climate change, we have used ten years' average (that is, from 1.1.1995 to 31.12.2004 for the 2000s, from 1.1.2005 to 31.12.2014 for the 2010s, from 1.1.2015 to 31.12.2024 for the 2020s, from 1.1.2025 to 31.12.2034 for the 2030s, from 1.1.2035 to 31.12.2044 for the 2040s and from 1.1.2045 to 31.12.2054 for the 2050s).

The variation in snow endowment is computed using the variable "Fractional Snow Cover" whose values are given by the ENSEMBLES project. We derive variations of this variable for each of the twelve months for the periods 1961-1990, 2000, 2010, 2020, 2030, 2040 and 2050. These variations are first computed on every grid points located on the Swiss territory that are available with the four ENSEMBLES models. In a second step, the variations obtained at each of the 176 grid points located on the Swiss territory need to be aggregated in one single value for a given period. This is done by assigning a given weight to every grid points with the weights being specific to each snow-dependent tourism segment. Figures 12 and 13 present these weights whose values have been derived using geographic information on the transport capacities of the Swiss ski lift sectors (cf. [11]) as well as information on the repartition between "skier-tourists" and "skier-day trippers" that was estimated for different Swiss ski regions (cf. [20]).

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[10] The ENSEMBLES data used in this work was funded by the EU FP6 Integrated Project ENSEMBLES (Contract number 505539) whose support is gratefully acknowledged. For more details see http ://ensembles-eu.metoffice.com/

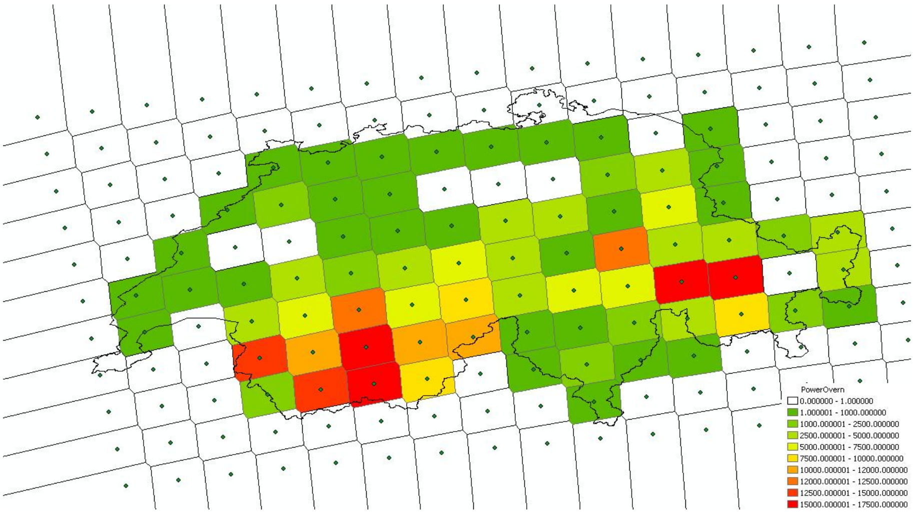

Figure 12 – Weights that are used for the tourism segment “winter overnight tourism”.

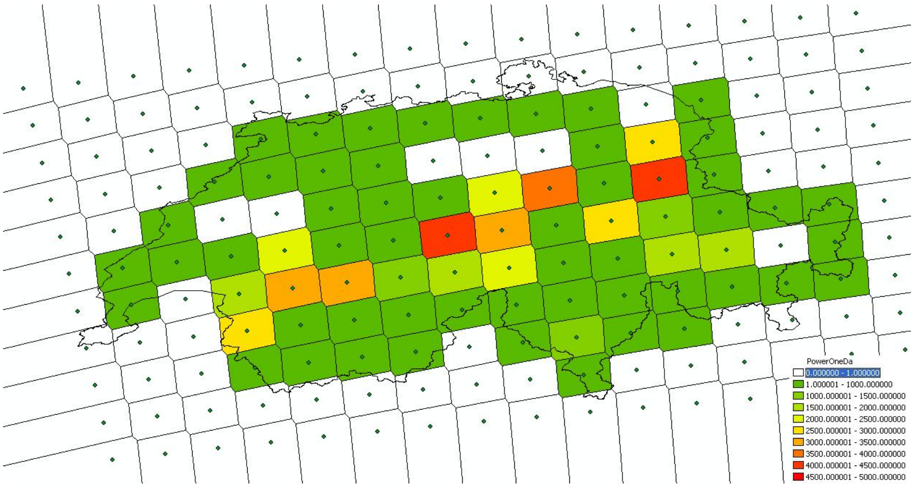

Figure 13 – Weights that are used for the tourism segment “one-day winter tourism”.

For the segment “winter overnight tourism”, we can observe that the largest weights are assigned to those grid points that are located in high elevated, distant from urban centers Alpine regions. The difference in weight allocation pattern is significant with the segment “one-day winter tourism”. For this segment, largest weights are assigned to the grid points located in Prealpine regions. We make the assumption that both sets of weights stay constant until 2050. Using these weights, we obtain evolutions of the snow endowment for the two snow-dependent tourism segments. These evolutions are displayed in figures 14 and 15.

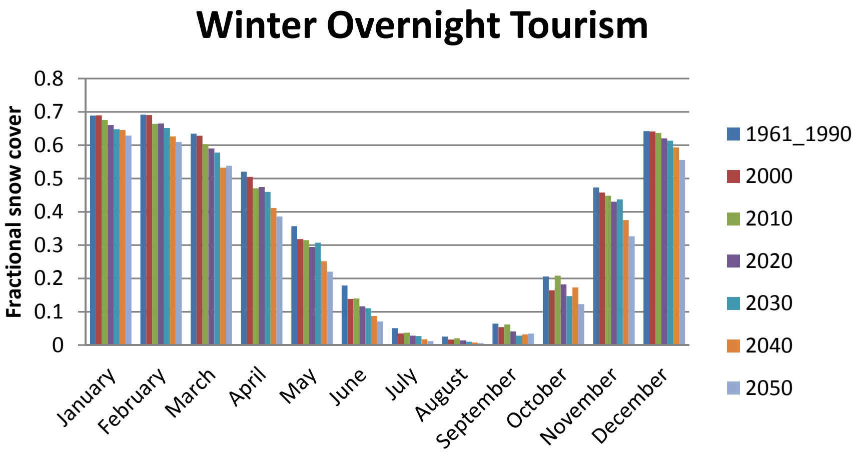

Figure 14 – Evolution of the snow cover from 1961–1990 to 2050 for the tourism segment "winter overnight tourism".

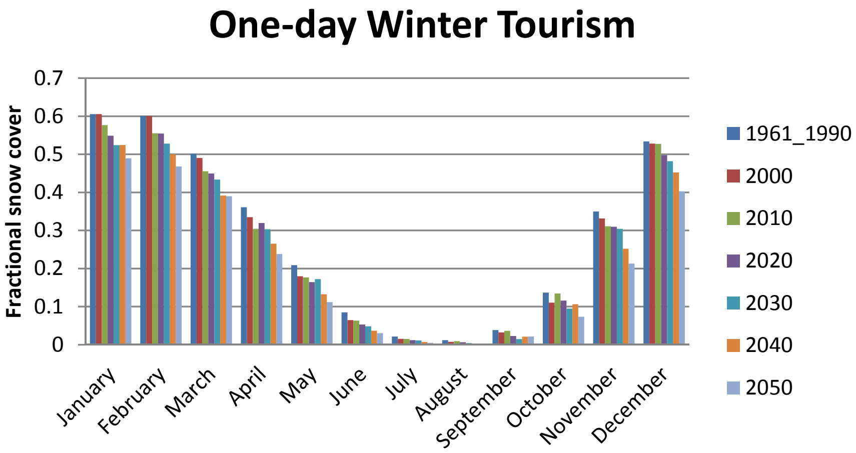

Figure 15 – Evolution of the snow cover from 1961–1990 to 2050 for the tourism segment "one-day winter tourism".

One additional step is needed in order to obtain a snow endowment variation relevant for the winter season at different periods. What is required is therefore a set of weights that allows aggregating variation values obtained for each of the twelve months. Ideally, we would like these weights to reflect the monthly distribution of winter transport revenues in the Swiss ski lifts sector. Unfortunately, this information is not gathered systematically at the company level in Switzerland and therefore not available at the sector level. However, such information is available for the Austrian ski lifts sector which is quite similar to the Swiss sector :

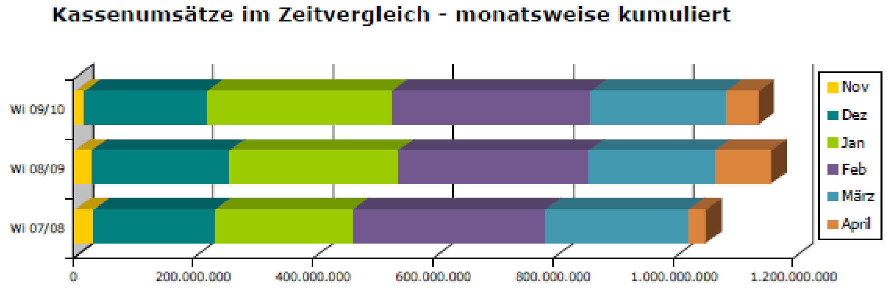

Figure 16 – Monthly distribution of transport revenues in the Austrian ski lifts sector during the winter season. (Source : [18])

Based on figure 16 as well as on information gathered for different Swiss ski lifts companies, we chose the following weights for the different months composing the winter season :

Table 10 – Weights assigned to each month of the winter season.

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

Averaging variations across months using the set of weights displayed in table 10, we eventually obtain the following variations in snow cover in 2050 compared to the base period 1961–1990 :

Table 11 – Snow cover variations between the reference period 1961-1990 and 2050.

Segment	$(\Delta_{2050}/SC_{ref})^*$
Overnight	-13.1%
One-day	-22.9%

$^*(SC_{ref})$: snow cover in the reference period 1961–1990

5.2 Economic impacts of natural snow reduction

Our simulations of the economic impacts of natural snow reduction are based on six scenarios. The first scenario “With Adapt.” combines the snow cover reduction derived from the ENSEMBLES data together with adaptation possibilities on both the consumer and producer sides. We have also tested five other scenarios that are different from the scenario “With Adapt.” in one or several ways. Below, we give a brief description of each of these six scenarios :

1. *With adaptation* : scenario with a snow cover reduction derived from the ENSEMBLES data that takes adaptation on the demand and supply sides into account.
2. *Without adaptation* : scenario without adaptation from producers (i.e. σ=0 and σ_{as}=0).
3. *With high adaptation* : high adaptation potential of producers (σ and σ_{as} are multiplied by 2).
4. *Low elasticity of consumption* : consumptions of final goods provided by the different tourism segments are hardly substitutable (σ_{htour} and σ_{htsnow} are divided by 2).
5. *High elasticity of consumption* : consumptions of final goods provided by the different tourism segments are easily substitutable (σ_{htour} and σ_{htsnow} are multiplied by 2).

6. *High snow endowment variations* : snow endowment decrease is multiplied by 2 compared to the ENSEMBLES projections.
7. *High snow decrease with government subsidies* : We suppose that snow endowment variations are multiplied by 2 and that government implements subsidies on the cost of artificial snow (25%) ; Subsidies financed through lump sum transfer.
8. *High snow decrease with high government subsidies* : We suppose that snow endowment variations are multiplied by 2 and that government implements subsidies on the cost of artificial snow (50%) ; Subsidies financed through lump sum transfer.

The economic impacts obtained with GEMINI-E3 for the six scenarios are given in table 12.

Table 12 – Potential economic impacts in 2050 of a reduction in the availability of natural snow.

	With Adapt.	Without Adapt.	With High Adapt.	Low elas. Conso.	High elas. Conso.	High Snow ↘	High Snow ↘ + sub. 25%	High Snow ↘ +sub. 50%
Ski Overnight								
Production*	-2.6%	-13.1%	-1.4%	-2.0%	-3.5%	-6.3%	-4.3%	-1.7%
Natural Snow	-13.1%	-13.1%	-13.1%	-13.1%	-13.1%	-26.2%	-26.2%	-26.2%
Artificial Snow	19.8%	-13.1%	25.7%	21.8%	16.7%	45.3%	66.5%	100.0%
Production price	2.8%	16.3%	1.5%	2.9%	2.5%	6.7%	4.1%	1.0%
Employment†	-283	-1946	-110	-208	-372	-716	-428	-67
Ski One day								
Production*	-5.4%	-22.9%	-2.6%	-3.3%	-8.2%	-19.4%	-18.5%	-17.3%
Natural Snow	-22.9%	-22.9%	-22.9%	-22.9%	-22.9%	-45.9%	-45.9%	-45.9%
Artificial Snow	23.9%	-22.9%	35.1%	31.3%	14.5%	60.9%	82.1%	116.8%
Production price	10.7%	59.9%	4.9%	12.8%	8.2%	49.8%	47.3%	44.3%
Employment†	-95	-575	-33	-40	-139	-362	-337	-306
Other Tourism								
Employment†	121	670	51	14	267	384	310	219
Total Tourism								
Employment†	-258	-1852	-92	-234	-243	-693	-456	-154
Consumption								
Ski Overnight	-1.8%	-9.2%	-0.9%	-1.0%	-3.0%	-4.6%	-3.2%	-1.6%
Ski One day	-5.4%	-22.9%	-2.6%	-3.3%	-8.2%	-8.2%	-18.4%	-17.3%
Other Tourism	0.1%	0.5%	0.0%	0.0%	0.2%	0.3%	0.2%	0.2%
Consumption for non resident								
Ski Overnight	-5.0%	-25.0%	-2.5%	-5.3%	-4.6%	-11.7%	-7.4%	-2.0%
Ski One day	–	–	–	–	–	–	–	–
Other Tourism	0.0%	0.2%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%
Surplus Mio USD_{2010}	-35	-122	-24	-28	-41	-108	-93	-75
in % Household Final Consumption	-0.01%	-0.03%	-0.01%	-0.01%	-0.01%	-0.02%	-0.02%	-0.02%

*Constant price sales revenue

†Employment expressed as full-time job equivalents

In the scenario "With Adapt.", climate change impacts on the Swiss economy through a decrease in snow availability are moderate. In 2050, the impact on household welfare amounts to 35 million USD which corresponds to a 0.01% decrease of their final consumption. The tourism sector is only slighly impacted in 2050 with a negligible change in the employment level expressed as full-time job equivalents (-258 jobs compared to the baseline scenario without climate change). However, the two snow-dependent tourism segments will experience larger losses due to the reduction in snow cover. Compared to the baseline, the value of the production will be reduced by 5.4% for the “one-day winter tourism” whereas a 2.6% reduction is expected for the “overnight winter tourism”.

Our results also underline the key role of adaptation processes in alleviating the costs of climate change. Regarding the effect of endogenous adaptation processes on the demand side, it is more easily pinned down in the scenario “Without Adapt.”. Results from this scenario show that domestic consumptions for the products of the two snow-dependent tourism segments are reduced compared to the baseline by -9.2% for the “overnight winter tourism” and by -22.9% for the “one-day winter tourism”. However, these decreases are partially compensated since domestic households increase their consumption of other goods and services produced in Switzerland. Notably, they consume more of other tourism activities produced in Switzerland (+0.5%). Accordingly, general equilibrium costs from climate change for the Swiss economy are estimated to be equal to 122 million USD in 2050, a figure which is largely smaller than the expected production loss for the snow-dependent tourism segments which is estimated at 377 million USD. Secondly, endogenous adaptation on the supply side further reduces climate change costs. For example, costs are reduced by a factor 3.5 in the scenario “With Adapt.” compared to the scenario “Without Adapt.” (-35 million USD versus -122 million USD) whereas they are reduced by a factor 5 in the scenario that assumes a high adaptation potential of producers (-24 million USD versus -122 million USD). Thirdly, exogenous adaptation through subsidies on the cost of artificial snow can also reduce the detrimental economic impacts of climate change as can be seen from table 12 where costs are reduced from 108 million USD in 2050 to 93 resp. 75 million USD depending on the level of subsidies.

As expected, artificial snow production increases in all scenarios that take producers’ adaptation into account. Figure 17 presents how total artificial snow production is predicted to evolve according to the scenario “With Adapt.”. Compared to the baseline, artificial snow production increases globally by 20.4% in 2050 : it increases by 19.8% for the segment “overnight winter tourism” resp. by 23.9% for the segment “one-day winter touris”. Due to nearly unchanged relative prices, these figures also give the increase in the use of both water and electricity to produce artificial snow compared to the baseline. Note also that the scenario “With Adapt.” predicts a 70.8% increase in total artificial snow production from 2010 to 2050 versus a 42.2% increase in the baseline.[11] As regards CO_2 emissions, they will increase as a consequence of higher energy requirements for producing artificial snow as shown in figure 18. For the year 2050, they will increase by 20.4% in the scenario “With Adapt.” compared to the baseline. Moreover, snowmaking related CO_2 emissions are predicted to increase by 31.5% in the scenario “With Adapt.” (resp. by 9.4% in the baseline) between 2010 and 2050. However, one has to keep in mind that snowmaking related CO_2 emissions are and will remain marginal with a share in overall Swiss CO_2 emissions around 0.0014%. The evolution presented in figures 17 and 18 are not exactly the same because CO_2 emissions also depend heavily on the model assumptions concerning the evolution of the energy mix for electricity production.

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[11] The increase over the period 2010–2050 is the same for the production factors. At this point, it is necessary to emphasize that no legal constraints have been taken into account when assessing the future production of artificial snow though such rules already exist in some regions of Switzerland (period for running the equipment, ski slopes that could be equipped, limits on water withdrawal). Rising temperatures and a decreasing water resource could put additional constraints on future snow production. It is planned to introduce the latter restriction (i.e. water shortage) in future simulations.

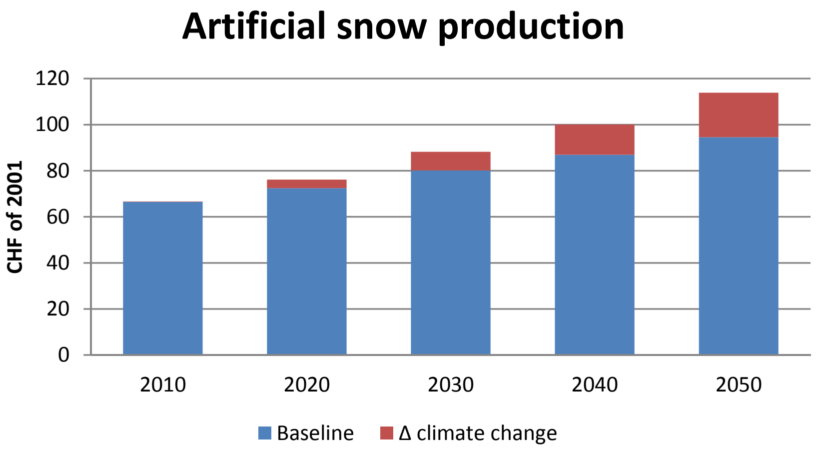

Figure 17 – Evolution of artificial snow production in both baseline and “With Adapt.” scenarios during the period 2010–2050.

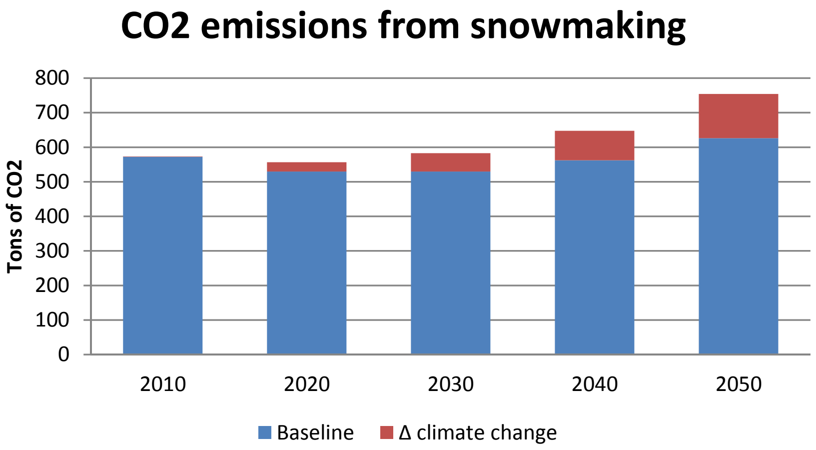

Figure 18 – Evolution of CO_2 emissions related to snowmaking in both baseline and “With Adapt.” scenarios during the period 2010–2050.

At this time, we have not simulated the impacts of a climate change related decrease in snow cover for the other regions included in the model. This is the reason why we can observe, in the first column (scenario “With Adapt.”) of table 12, a decrease in foreign consumption for the final goods and services produced by the segment “overnight winter tourism”. Eventually, doubling the magnitude of the decrease in natural snow compared to the “With Adapt.” scenario more than double climate change costs. This result underlines the importance of the choice of climatic scenarios for the simulation results and also emphasizes the need to make a better use of their inter-variability.[12]

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[12] Up to now, outputs of the four GCM/RCM combinations taken from the ENSEMBLES project have been averaged before computing the variation in the variable “fractional snow cover”.

6 Conclusion

Tourism is one of the sectors most at risk from climate change in the Swiss economy. More precisely, large losses of revenues are expected to arise in winter tourism due to a lack of snow. Different studies have tried to estimate these losses but our study is only the second one to use a CGE model, namely the GEMINI-E3 model which is a multi-country, multi-sector, recursive CGE model. Our study also innovates compared to the previous ones by the care that is given to model adaptation processes and measures both on the demand and supply sides. Under a decrease in snow cover obtained using climatic scenarios from the European project ENSEMBLES, we have obtained welfare losses in 2050 for different scenarios that vary according to adaptation possibilities. Welfare losses range from 24 to 122 million USD which represent a 0.01% to 0.03% decrease in final household consumption. Therefore, we estimate rather small costs of climate change for the Swiss economy which is not surprising given the broad spectrum of adaptation possibilities that we have taken into account in our analysis. The costs for the Swiss tourism sector is also expected to be limited with virtually no impact on employment. In fact, tourism activities in Switzerland that do not depend on snow conditions will benefit from the snow cover reduction. Obviously, the largest impacts are estimated for the two snow-dependent winter tourism segments. The "one-day winter tourism" will be more impacted than the "overnight winter tourism" both because of higher exposure and smaller adaptive capacity to climate change. It is also worth mentioning that the estimated costs for the Swiss economy would have probably been even smaller in case we had also impacted the tourism sector of the other regions included in GEMINI-E3.

Of particular importance for adaptation is artificial snowmaking whose increasing production allows alleviating climate change costs in some substantial amount. However, artificial snowmaking raises concerns about its sustainability and one of our simulations has shown that artificial snow production could rise by up to 70.8% between 2010 and 2050. Our opinion is that sustainability concerns should focus rather on water utilization than on CO_2 emissions. Even in the future, snowmaking related CO_2 emissions will account for a negligible part of Swiss CO_2 emissions. Local impacts of snowmaking in terms of water use is certainly going to be a much more important issue. In fact, snowmaking can create problems and conflicts linked to water management in local communities. These water management conflicts can be exacerbated in case climate change simultaneously reduces water availability in mountain regions. We have not yet analyzed the impact of such a reduction on snowmaking production and households' welfare. However, it could be assessed with GEMINI-E3 in future simulations since a water resource has also been introduced in the model.

In conclusion, we provide some evidence that, by 2050, winter tourism will not be jeopardized by climate change in Switzerland, at least when the sector, facing a moderate snow cover reduction, is able to implement a minimum level of adaptation.

References

[1] Les chiffres clés du tourisme de montagne en France : 7ème édition. Technical report, Observation, Développement et Ingénierie Touristique France (ODIT). 6

[2] *World Energy Outlook 2009*. International Energy Agency, 2009. 17

[3] Bruno Abegg. Klimaänderung und Tourismus — Klimafolgenforschung am Beispiel des

Wintertourismus in den Schweizer Alpen. Technical report, Schlussbericht NFP 31. vdf, Zürich, 1996. 3

[4] Energy Information Administration. International Energy Outlook. Technical report, U.S. Department of Energy, July 2010. 17

[5] Shardul Agrawala, Bruno Abegg, Simon Jetté-Nantel, Florence Crick, and Anne de Montfalcon. *Climate Change in the European Alps : Adapting Winter Tourism and Natural Hazards Management.* OECD, Paris, 2007. 3

[6] Paul S. Armington. A Theory of Demand for Products Distinguished by Place of Production. *IMF Staff Papers*, 16 :159–78, 1969. 6

[7] Thomas Baumann and Ueli Schiess. Compte satellite du tourisme de la Suisse, 2001 et 2005 : Principes, méthode et résultats. Technical report, Office fédéral de la statistique (OFS), Neuchâtel, 2008. 3, 10

[8] A. Bernard and M. Vielle. Measuring the Welfare Cost of Climate Change Policies : A Comparative Assessment Based on the Computable General Equilibrium Model GEMINI-E3. *Environmental Modeling & Assessment*, 8(3) :199–217, 2003. 15

[9] A. Bernard and M. Vielle. GEMINI-E3, A General Equilibrium Model of International-National Interactions between Economy, Energy and the Environment. *Computational Management Science*, 5(3) :173–206, May 2008. 6

[10] Thomas Bieger, Thomas Riklin, and Catherine Baudenbacher. Umfrage zur aktuellen Situation und zu den wirtschaftlichen Perspektiven der Beschneiung in der Schweiz. Universität St.Gallen, Institut für Öffentliche Dienstleistungen und Tourismus, März 2009. 6

[11] Fritz Bosshart. Statistique ITT : Installations de transport touristiques en Suisse (6e édition). Technical report, Office fédéral du développement territorial, 2001. 19

[12] Rolf Bürki. Klimaänderung und Anpassungsprozesse im Tourismus — dargestellt am Beispiel des Wintertourismus. Technical report, Publikation der Ostschweizerischen Geographischen Gesellschaft NF H 6, St. Gallen, 2000. 3

[13] B. V. Dimaranan. *Global Trade, Assistance, and Production : The GTAP 6 Data Base.* Center for Global Trade Analysis Purdue University, Center for Global Trade Analysis, Purdue University, December 2006. 6

[14] Arbeitsgemeinschaft Ecoplan/Sigmaplan. Auswirkungen der Klimaänderung auf die Schweizer Volkswirtschaft (nationale Einflüsse). Technical report, Swiss Federal Office for the Environment and Swiss Federal Office of Energy, Bern, 2007. 3

[15] Matthias Freiburghaus. Wasserbedarf der Schweizer Wirtschaft. Technical report, Schweizerische Verein des Gas- und Wasserfaches (SVGW), 2009. 5, 8

[16] Peter Furger. L'avenir des remontées mécaniques des Alpes vaudoises. Technical report, Service de l'économie et du tourisme du Département de l'économie du Canton de Vaud, 2002. 6

[17] Camille Gonseth. *Adapting ski area operations to a warmer climate in the Swiss Alps through snowmaking investments and efficiency improvements.* PhD thesis, École Polytechnique Fédérale de Lausanne, 2008. 5

[18] Klaus Grabler and Jan Stirnweis. Wirtschaftsbericht der Seilbahnen : Trends Winter 2009/2010, 2010. URL `www.manova.at`. 22

[19] Chris D. Hewitt and Davis J. Griggs. Ensembles-based predictions of climate changes and their impacts. *EOS*, 85(52), 2004. 19

[20] Christian Laesser. Die Pistentage der Schweizer Bevölkerung — Eine erste Schätzung. *IDT-Blickpunkt*, 8 :2–3, Mai 2003. Universität St.Gallen. 10, 19

[21] Ruedi Meier. Sozioökonomische Aspekte von Klimaänderungen und Naturkatastrophen in der Schweiz. Technical report, vdf Hochschulverlag, ETH Zürich, Zürich, 1998. 3

[22] Hansruedi Müller and Fabian Weber. Klimaänderung und Tourismus : Szenarienanalyse für das Berner Oberland 2030. Technical report, Forschungsinstitut für Freizeit und Tourismus (FIF) der Universität Bern, Bern, 2007. 3

[23] OMT. Recommandations sur les statistiques du tourisme. Technical report, Organisation Mondiale du Tourisme (OMT), Nations Unies (ONU), 1994. 2

[24] Heinz Rütter, Hansruedi Müller, Doris Guhl, and Jürg Stettler. Tourismus im Kanton Bern : Wertschöpfungsstudie. Technical report, Forschungsinstitut für Freizeit und Tourismus (FIF) der Universität Bern, 1995. 10

[25] Heinz Rütter, Adrian Berwert, Ursula Rütter-Fischbacher, and Michael Landolt. Der Tourismus im Wallis : Wertschöpfungsstudie. Technical report, Finanz- und Volkswirtschaftsdepartement des Kantons Wallis, Dienststelle für Tourismus- und Wirtschaftsförderung, 2001. 10

[26] Heinz Rütter, Adrian Berwert, Ursula Rütter-Fischbacher, and Sabine Schneiter. L'importance du tourisme pour l'économie vaudoise. Technical report, Etat de Vaud : Département de l'économie (DEC), Service de l'économie, du logement et du tourisme (SELT), 2004. 10

[27] Seilbahnen Schweiz (SBS). Fakten und Zahlen, 2008. 5

[28] Daniel Scott and Geoff McBoyle. Climate change adaptation in the ski industry. *Mitigation and Adaptation Strategies for Global Change*, 12 :1411–1431, 2007. 4, 5

[29] Bastienne Uhlmann, Stéphane Goyette, and Martin Beniston. Sensitivity analysis of snow patterns in Swiss ski resorts to shifts in temperature, precipitation and humidity under conditions of climate change. *International Journal of Climatology*, 29 :1048–1055, 2009. 3, 13

[30] Detlef P. van Vuuren, John Weyant, and Francisco de la Chesnaye. Multi-gas Scenarios to Stabilize Radiative Forcing. *Energy Economics*, 28(1) :102–120, January 2006. 6

[31] Roland Zegg and Regina Gujan. Branchenanalyse, Wertschöpfungswirkungen und Kennzahlen der Bergbahnunternehmen im Kanton Bern 2000/01 im Vergleich mit 1996/97. Technical report, Grischconsulta AG, Chur, August 2003. 5

[32] Klaus Zurschmitten and Stefan Gehrig. Die Bergbahnen im Kanton Wallis : Analyse, Entwicklungsperspektiven und Strategien. Technical report, Kanton Wallis, Departement für Volkswirtschaft, Institutionen und Sicherheit, Dienststelle für Tourismus und Regionalentwicklung, 2004. 5