Effects of climate change on future snow conditions, winter tourism and economy in Tyrol and Styria (Austria): CC-Snow, an interdisciplinary project

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Abstract

The interdisciplinary project CC-Snow aims at determining the effect of climate change on natural and artificial snow conditions and on tourism and economy in the provinces Tyrol and Styria (Austrian Alps). Downscaled and bias corrected climate model output of historical and scenario conditions is used to force two snow models at different spatial scales. At the local scale, the deterministic snow model AMUNDSEN is applied for the case study sites Kitzbuehel and Schladming. The resulting high resolution snow cover pattern time series are used to train the regional-scale, conceptual snow model SNOWREG to be applied for Tyrol and Styria. Both snow models provide simulation results for snow reliability at the respective scales and regions, and a comprehensive set of indicators. The latter are utilized for the interface of the natural sciences modelling approach and the socio-economic analysis. Their analysis enables to determine potential effects on tourism and economic structure. Collaboration with stakeholders from the two study sites is fostered from an early stage of the project to jointly develop adaptation strategies in order to cope with the effects of climate change on natural and artificial snow conditions, economy and tourism.

Keywords: future climate scenario, artificial snow production, regional economic and tourism effects, human-environment system research, participatory approach

1 Introduction

CC-Snow focuses on investigating the effects of climate change on natural and artificial snow conditions, the consequences on economy and tourism and on the development of adaptation strategies for skiing tourism in Tyrol and Styria. This thematic view has been proposed by the calls of the Austrian Climate Research Programme (ACRP) that has been launched in 2008. This program has been initiated under the leadership of the Climate and Energy Fund of the Federal Government of Austria to support research relevant for climate and energy on a broad basis. For enabling the funding of an interdisciplinary consortium project, for which no explicit (large enough) funding pool exists, a strategy has been developed to split the project over three phases: the first phase (CC-Snow I), supported by ACRP 1st call funds, is to develop the climate and natural snow condition scenarios (the natural science part).

The first phase started in January 2010 and lasts until December 2011. Phase 2 (CC-Snow II), supported by the ACRP 2nd call funds, integrates the socio-economic view and started in January 2011. In this second phase, the natural science partners provide future conditions of artificial snowmaking, but the project's phase main focus is on the effects on economy and tourism. Phase 3 will be submitted to the 4th call of the ACRP and focus on the transdisciplinary development of adaptation strategies. In this last phase, the stakeholders in various societal fields in the study sites will be involved in mutual generation of modelling and analysis pathways for a series of commonly developed future scenarios. This article gives a short introduction to the sectoral methods, and the integration concept of the first two phases of the CC-Snow series of projects.

2 Climate change scenarios

CC-Snow is based on four representative regional climate scenarios from the ENSEMBLES project (http://www.ensembles-eu.org) driven by the A1B emission scenario (Nakicenovic et al. 2000). The selected scenarios represent average as well as above average cold/warm and wet/dry conditions in the winter half year (November to April) over the study regions. This enables to roughly cover climate scenario uncertainty without overburdening the entire CC-Snow analysis chain with too many simulations.

The following four simulations have been selected (average, hot-humid, cool-humid, cool-dry). A description of the models denoted by the following acronyms is given in van der Linden and Mitchell (2009):

- ICTP-REGCM3 (RegCM3 regional climate model (RCM) driven by the ECHAM5-r3 global climate model (GCM)): Little warming and drier conditions
- SMHIRCA (RCM: RCA, GCM: BCM): Little warming and humid conditions
- METNO (RCM: HIRHAM, GCM: HadCM3Q0): Average
- C4I (RCM: RCA3, GCM: HadCM2Q16): Strong warming and humid conditions.

As the regional and the local snow models used in CC-Snow require different meteorological input data, two different datasets for each of the four selected climate scenarios have been prepared.

- Daily meteorological data: 2 m temperature and precipitation sum at the locations of stations for entire Austria
- 3-hourly meteorological data: 2 m temperature, precipitation, relative humidity, wind speed and global radiation at selected stations (available stations in the study regions and close vicinity).

For the historical climate two different datasets per model have been considered: RCMs driven by boundary conditions from re-analysis representing the historical weather and RCMs driven by boundary conditions from GCMs with no correlation to historical weather. As the weather simulations aim at reproducing actual weather for a given point of time within the historical period, these simulations allow for a short-term comparison to observations and are particularly suitable for a validation of the snow model simulations. The climate simulations with no correlation to historical weather represent the reference for a comparison with scenario conditions, where each RCM is driven by the same GCM as in historical climate.

The preparation of the input data for the snow models includes downscaling to the required scale and climate model error correction. Observation data from over 380 stations of the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) station network has been collected and processed for the period from 1961 to 2009 and is used for calibrating the empirical-statistical downscaling and error correction method, which is applied to simulations of the historical period and the future period of each of the four simulations. Downscaling and error correction is realized by a quantile-based method, which has been demonstrated to yield good results for daily temperature and precipitation (Themeßl et al. 2010, 2011). In CC-Snow, the method has been extended to further parameters such as global radiation, relative humidity and wind speed.

Figure 1 shows the bias of relative humidity defined as the difference between daily model results and observed station data for each meteorological station in Austria between 1961 and 2009. The error characteristics of the uncorrected model not only reflect model deficiencies, but can also be traced back to scale discrepancies between the regional climate model and the local scale of the observations. The mean and median error can be successfully reduced to near-zero, but the temporal correlation between simulation and observation cannot be improved. In a climate context, temporal correlation is not an issue anyway, since climate simulations do not correlate with actual weather. One major advantage of the applied quantile mapping approach is its flexibility. It cannot only be applied to the "traditional" parameters temperature and precipitation, but also to other meteorological parameters. By the described means we provide the input data required by the snow modelling at the two scales.

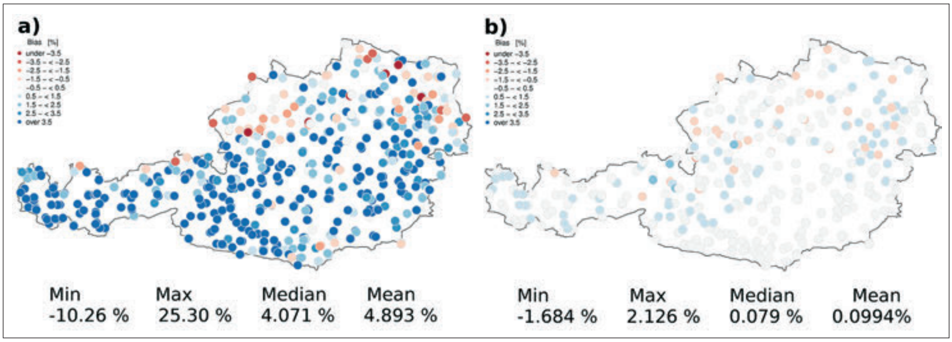

Figure 1: Bias error characteristics of relative humidity from the C4I (strong warming and humid) model a) before and b) after error correction (1961–2009).

3 Snow modelling at the local and regional scale

In CC-Snow the modular, physically based, distributed modelling system AMUNDSEN (**A**lpine **MU**ltiscale **N**umerical **D**istributed **S**imulation **EN**gine) is applied. AMUNDSEN has been designed to specifically address the requirements of snow modelling in mountain regions for climate change scenarios (Strasser 2008). The range of functionalities of AMUNDSEN includes: several interpolation routines for scattered meteorological measurements, rapid computation of topographic parameters from a digital elevation model, simulation of shortwave and longwave radiative fluxes including consideration of topography with shadows and cloudiness, parameterization of snow albedo, modelling of snowmelt and icemelt melt with either an energy balance model or an enhanced temperature index model considering radiation and albedo, modelling of the forest snow processes interception, sublimation and melt unload including the effect of the trees on the micrometeorological conditions at the ground, calculation of evapotranspiration from different types of land cover, simulation of wind-induced snow transport as well as gravitational redistribution of snow. Currently, a module to simulate artificial snow production is developed. All parameterizations are based on physical process descriptions, and no site-specific calibrations are required. In particular, the system facilitates operational application, as well as short-, medium- and long-term temporal horizon (i. e., until 2050).

For the local scale of the AMUNDSEN application in the two case study sites Kitzbuehel (Tyrol) and Schladming (Styria), 50 m is chosen as spatial model resolution: on the one hand, it can be assumed that at this spatial resolution the main atmosphere-snow surface interaction processes which force the evolution and distribution of the snow cover can be realistically reproduced; this includes the provision of meteorological forcing, e. g. a proper conversion and distribution of downscaled climate model output, and the sophisticated modelling of topographic effects. On the other hand, a 50 m resolution allows the dissolving of the typical patterns of lateral processes of snow redistribution for the given Alpine topography, and a proper representation of the management of skiing slopes with artificial snow production.

On the regional scale of the two provinces Tyrol and Styria, the conceptual snow model SNOWREG is applied. SNOWREG is a data fusion algorithm working on a 250 m grid, providing a physically-based driven interpolation method for deriving accurate data on snow distribution. The calculation is based on a degree-day factor approach with additional radiance correction. It focuses on the simulation of snow depth and snow water equivalent (SWE) based on daily mean temperature and precipitation data. As a degree-day model, SNOWREG summarizes the energy transfer process using only air temperature as reference input variable (Kleindienst 2000). The model has been further developed and improved in the CC-Snow project with respect to interpolation, radiation correction and calibration capabilities. A simulation, calibration and validation process has been implemented that provides possibilities to calibrate the snow model with snow depth measurements from snow gauges (point based) and snowmaps derived from MODIS and Landsat satellite data (spatially distributed).

For modelling future snow conditions the calibrated SNOWREG model will be forced with daily temperature and precipitation input data derived from climate scenarios. For these future climate conditions, where no observed snow data exists, the local-scale snow model AMUNDSEN will be used to provide both snow distribution information at selected sites as well as snow depth data. Thus, the local snow model will replace point-based snow depth data as well as satellite-based snow cover maps with (future) simulation results, and thus enhance SNOWREG with prognostic capabilities. The model will be applied for the entire regions of Tyrol and Styria for both the historical calibration period, as well as for the future scenario period. In CC-Snow II, it is envisaged to implement a module for artificial snow production into SNOWREG to allow the derivation of additional information such as water and energy demand in different ski regions.

By means of a set of indicators that were jointly defined at the beginning of the project the conditions of future natural snow, and of artificial snow production are described (see Figure 2).

These indicators are either directly inferred from the regional-/local-scale climate data, or computed by means of the snow models at the two different scales. The list of indicators includes: ski season length (opening and closing dates, without snowmaking, under current and under future snowmaking technology), snowmaking hours, white landscape, daily fresh snow and urban snow conditions. The indicator "ski season length" is shown for the period 1961–1990 and the C4I model run together with the change in the ski season length for the scenario period (2021–2050) in Figure 2. As the shown in the illustration, this realisation of the A1B scenario leads to a shortening of the ski season of up to –60 days in the skiing areas of the Schladming region.

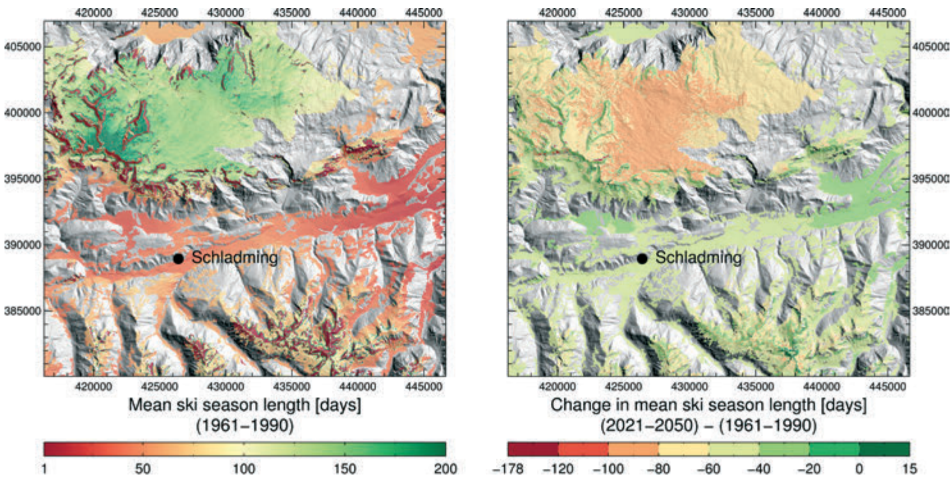

Figure 2: Indicator "ski season length" for natural snow conditions and the historical time period 1961–1990 as calculated on the basis of the C4I model run by the local-scale snow model AMUNDSEN for the case study site Schladming (left) and change in the ski season length calculated by subtracting the mean ski season length 1961–1990 from the mean ski season length 2021–2050. Forested areas are masked (grey shades of the underlying DEM).

4 Effects on regional winter tourism structure

The concept of two scales of analysis based on the output of the two snow models is applied for research questions on structure and processes within the tourism industry. On the regional level (provinces Tyrol and Styria), a cluster analysis of tourism destinations (based on statistical data) is conducted to identify: (i) the relevance of tourism for the regional economy (e.g. employees in the accommodation sector), (ii) the seasonal focus of the destination (e.g. the share of overnight stays in winter/summer), (iii) the internationalization of the destination (e.g. the share of foreign visitors), and (iv) the amount, the size and the snow reliability (with/without snowmaking) of ski areas within each destination. Tourism destinations have shown different development dynamics in the past. It is likely that the future development will be influenced by climate change and will again differ between certain types of destinations. It is the aim of our investigations in CC-Snow to identify the relevant factors for different past development paths in the two regions to be able to create scenarios for potential future developments.

The snow reliability classification system for ski areas is based on two indicators: Abegg's (1996) "100-days indicator" and Scott et al.'s (2008) "Christmas indicator". The first indicator represents a critical economic threshold considering the length of the ski season. It is assumed that at least 100 operation days (= days with snow depth ≥ 30 cm) are required in 7 out of 10 winter seasons for a profitable ski business, which was confirmed by ski area managers in Europe (Abegg 1996) and Northern America (Scott et al. 2003). Though this indicator is suitable for a quick analysis of the ski areas' climate sensitivity, the uneven distribution of demand within the winter season (i.e. higher demand in the peak season and lower demand in the off-season) remains unconsidered. Therefore, the Christmas indicator gives information on the reliability for skiing within the Christmas/new year period accounting for about 30% of winter revenues in Tyrol (Steiger 2010). Abegg (1996) and Scott et al. (2008) applied these indicators for the mean altitude of the ski areas only. However, most of the ski areas in the research area have altitudinal differences of several hundreds of meters and are able to open the upper parts of the ski area although skiing might not yet be possible at lower elevations. Therefore, Steiger and Trawöger (2011) combined the two indicators with the skiing terrain and formed a snow reliability classification scheme that will be used for the cluster analysis conducted in CC-Snow.

On the local scale (case studies Kitzbuehel and Schladming), the main objective is to get a deeper understanding of spatial differences of vulnerability within a destination following two research questions: (i) how does the regional tourism structure react on variable snow conditions?, and (ii) what are the stakeholders' perceptions and strategies regarding winters with scarce snow conditions? An empirical regional analysis is conducted in order to reveal the spatial organisation of tourism within the case study regions. Therefore, a basic data set will be elaborated which contains and maps socio-economic data, tourism infrastructure information as well as standard tourism indicators on the basis of a regional statistics raster with 500 m spatial resolution. These data will then be complemented with local snow modelling data to assess the effects of scarce snow conditions on different accommodation classes as well as different locations in the past. The main criterium thereby is the degree of capacity utilization. By an analogue-year approach (e. g. Scott 2006; Steiger 2011a, 2011b), these reactions will be projected into the future using the snow modelling output, which is based on our climate scenarios. The end result will be a map of regional vulnerability, answering the question of "who" is affected (accommodation classes) and "where" the vulnerable areas are (core or periphery). Another research question addresses the interaction between snow conditions, daily number of skiers and capacity utilization in the accommodation sector to identify to what extent the performance of the accommodation sector contributes to the daily number of skiers and vice versa.

With this insight in spatial vulnerability, the (re)search for causes and reasons follows. Using a regional "laboratory analysis", based on a purposive sample of interviews of stakeholders in the accommodation sector, the perception of climate change and existing adaptation strategies to meet winters with scarce snow conditions will be analyzed. This research step finally tries to dissolve the mismatch between long-term oriented climate change research (climate oriented) and short-term thinking/planning of tourism stakeholders (weather oriented).

5 Economic effects

Increased utilization of snowmaking reduces the exposure of ski areas towards natural snow conditions, but at the same time it is important to take into account its economic efficiency. For such an analysis, the costs of artificial snow production need to be compared to its immediate economic benefits, namely the additional demand owing to the continuance of skiing in times of adverse natural snow conditions. The profitability of snowmaking heavily depends on the development of future climate conditions, changes in costs and visitor numbers. Hence, it is crucial for an overall economic evaluation to understand the underlying climatic and economic uncertainties.

Snowmaking as an adaptation strategy to climate change impacts on the ski tourism industry is already taken into consideration in several studies (e. g. Scott et al. 2003; Scott & McBoyle 2007; Hennessy et al. 2008; Steiger 2010). In these studies the snowmaking potentials under future climate conditions and the impacts on ski season length have been determined, whereas a detailed analysis of the costs and benefits of snowmaking has not been taken into account. Gonseth (2008) first analyzed the effects of additional investment in snowmaking on the economic indicator EBITDA (Earnings before Interest, Taxes, Depreciation and Amortization) of Swiss ski operator companies. The results show that the partial effect of snowmaking investments on EBITDA is positive but tends to decrease for higher levels of investments. However, projections of future snow conditions based on climate and snow modelling are not considered in this econometric analysis. Teich et al. (2007) carried out a regional input-output analysis of the economy of Davos (Switzerland). The change in ski tourism demand due to the production of artificial snow is considered by means of three different scenarios, where different assumptions are made with respect to the change in visitor numbers. Input data concerning the investment and operating costs of artificial snowmaking are based on data from literature: Investment costs of CHF 8,000,000 per km ski run and operating costs from CHF 30,000 to 50,000 per km ski run are applied to the current length of ski runs covered with artificial snow. Hence, the input-output analysis is based on simplified assumptions to investment and operating costs and does not consider future climate and snow conditions on the basis of sophisticated climate and snow models.

Our economic study in CC-Snow addresses the gap of knowledge concerning the economic profitability of prospective snowmaking requirements under future climate scenarios. We will therefore carry out a detailed analysis of snowmaking costs and revenues under current and future climate conditions for the two case study sites Kitzbuehel and Schladming using dynamic investment models. The annuity method is applied which presents an appropriate investment decision criterion. Using the results of the detailed cost-revenue analysis for the case study sites as well as additional climatic indicators (from the regional snow model SNOWREG) and operational indicators we make an attempt to expand the scope of analysis to all ski areas in the two provinces Styria and Tyrol. Furthermore, we will conduct an econometric analysis of how snowmaking investments changed ski ticket prices in previous years, as the positive effects of snowmaking on snow reliability could be offset in the longer term by the effects of higher prices for skiing, possibly resulting in lower demand.

The starting point of all economic calculations is the daily demand for artificial snow that determines the requirements for additional snowmaking investments and additional operating costs. The demand for artificial snow on the local scale of the two case study sites Kitzbuehel and Schladming will be provided by the local-scale snow model AMUNDSEN. Besides natural snow conditions the demand for artificial snow is also determined by the scheduled ski season length. A long ski period from November until the Easter holidays usually requires a higher amount of snowmaking to assure a continuous ski operation until the scheduled end of the ski season. Whereas a shorter ski period reduces the costs of artificial snow production but in turn leads to a potential loss of the Easter business. Hence, depending on the ski season length ski area operators choose different strategies of snowmaking.

The operating costs of snowmaking basically depend on the required duration and practices of snowmaking and the development of the input prices. Apart from the required volume of artificial snow the type of snowmaking technology and the prevailing weather conditions are crucial in determining the hours of snowmaking since the efficiency of the technology depends on the ambient temperature and humidity. In addition, the investment costs of snowmaking facilities vary with respect to the technology and the number of required snowmaking units.

The immediate economic benefits of snowmaking arise from additional individual skier days and therefore increased revenues. On the one hand the number of individual skier days depends on the ski operating days, i. e. the number of skiable days in the ski season and the share of open ski runs respectively. On the other hand it is influenced by the ski ticket prices. But there is also a link back from the number of skiers to the ticket prices. Many ski area operators offer lower ticket prices in the off-season and some even give a discount when ski runs are partly unavailable. Therefore, among other reasons (i. e. holiday effects), this requires to incorporate the unequal distribution of skiers throughout the season. Furthermore, the prevailing weather conditions directly influence daily visitor numbers. In order to examine these effects a detailed econometric analysis of tourism demand will be conducted for the two case study regions. Besides snow conditions, which nowadays mainly depend on technological and operational decisions relating to the artificial snow production, direct (e. g. rainfall, temperature) and indirect (e. g. white landscape) weather effects are considered in the demand models. The results of the ski tourism demand models enter the cost-revenue analysis of artificial snowmaking and enable the determination of the additional revenues of ski ticket sales through artificial snow production.

6 Stakeholder participation

CC-Snow addresses research questions, which are highly relevant for society. Stakeholders from the two case study regions of Kitzbuehel (Tyrol) and Schladming (Styria) have been integrated in the beginning of the project for a *joint system development* process in order to (i) discuss facets of the models, (ii) develop the key indicators, (iii) obtain qualitative and quantitative data from the ski lift companies, tourism and regional development (e. g. snowmaking practices, business reports, statistics) and (iv) to establish a network for collaborative research to apply the interdisciplinary scenario tool which is developed in CC-Snow. The two groups of stakeholders comprise the the cable car companies, communities, tourism managers, and regional planners. With its participatory approach, CC-Snow aims at overcoming the gap between knowledge production in academia and practices of enterprises and regions struggling with climate change in Austria. First experiences show the importance of the involvement of representatives from the regions and the widespread information provision in the case study regions. Stakeholders from different sectors (e. g. regional development, companies, politics) have contributed to the abovementioned tasks (i–iii). The multi-perspective approach allows to capture a series of highly relevant aspects for the research project, following the goals of the series of ACRP calls. These aspects range from concrete information on specific practices to insights into socially and politically highly sensitive issues, which nobody could grasp from an outsider perspective. Though a general interest in potential impacts of climate change on winter tourism, a number of constraints can be detected in both regions that have to be dealt with. In the case of Kitzbuehel one obstacle is that the destination is often referred to as a typical loser of climate change due to its relatively low altitude and international name recognition. Stakeholders fear that a scientific project on climate change might turn out to produce bad publicity. In Schladming representatives of all fields are short in time due to the preparation for the world championship in 2013. However, the collaboration with stakeholders from the case study regions proved to be of high importance even in the first project phase. Creating mutual understanding, shared aims and adequate participatory settings are continuous tasks during all phases of CC-Snow, complementing and enriching the interdisciplinary integration process.

7 Concept of integration

The scenario tool developed in the framework of CC-Snow is composed out of various interconnected model components that represent the different (sub-)disciplines in CC-Snow, exchanging information via strictly defined interfaces. The aim of this approach is to get results that are more than just the sum of all model results by developing interfaces to couple our models and methods in the framework of a holistic interdisciplinary workflow. Climate data for past and potential future climate conditions serves as input for both the local-scale snow model AMUNDSEN applied to the two case study regions and the regional scale snow model SNOWREG applied to the provinces of Tyrol and Styria. While the concept model SNOWREG is calibrated on the basis of remote sensing data and measured snow depths for an accurate simulation of past snow conditions, calibration data in the scenario period is provided by the physically based, local-scale snow model AMUNDSEN.

Subsequent to the snow simulations, the concept of a two-scale analysis is continued in the economy and tourism sector. Model results from AMUNDSEN and SNOWREG (e.g. season length, resource use of snowmaking, daily weather variables) are used in the cost-revenue analysis of artificial snow production and validated with real costs and skier visit data provided by the ski lift companies of both case study sites. Results from the tourism demand models, the cost-revenue analysis and simulated snow indicators are combined with high resolution tourism data on the local scale to identify differing impacts and sensitivities for a destination. The transformation of the detailed case study results to the regional level is based on the cluster analysis of tourism destinations and model results from SNOWREG.

In return, the results on the regional scale serve as input for a subsequent cluster analysis using future simulations (e.g. season length, tourism demand). The result of this integration process is a scenario tool with a number of sub-models that are capable of simulating the impacts of climate change on the Austrian tourism industry on the local as well as on the regional scale. In order to exemplify this interdisciplinary approach in CC-Snow, an exemplary "storyline" of interaction has commonly been developed. It shows the different feedbacks between the (sub-)disciplines in CC-Snow and allows for illustrating the path of the climate change signal through the different models and disciplines. The storyline is shortly described in the following (the pictured reactions to changing climate conditions at this stage are merely 'best guess' assumptions and are not directly based on model results): Comparing simulations for a reference period (1971–2000) to those for a scenario period (2021–2050), an average climate change scenario like that provided by the METNO model run (RCM: HIRHAM, GCM: HadCM3Q0) projects a temperature increase of approximately 1.7 °C combined with an increase in precipitation of 3% for the area of Styria in the winter season. As a reaction to these climatic changes, the snow models AMUNDSEN and SnowReg compute a decrease in the ski season length from 120 days in the reference period to 110 days in the scenario period for the higher elevated parts of the Schladming ski area. This shortening of the ski season goes together with a decrease in snow making hours of −10% in the winter season. Tourists respond differently to these changing conditions depending on the type of tourism destination, with decreases in demand ranging from –10% (cluster characterized by large ski areas and a highly diversified tourism product portfolio) to −30% (cluster characterized by small to medium sized ski areas with strong focus on skiing). Parallel to this development, a decrease in capacity utilization is observed that varies for different locations and classes of accomodation units with values of −2,5% and −5% for private accomodations and four star hotels respectively, up to values of −35% in case of two star hotels. A cost-revenue analysis of artificial snow production reveals that it is economically sensible to compensate for these effects by rising the annual operating costs for artificial snow production in the skiing areas from € 5,000,000 (reference period) to € 10,000,000 (scenario period) not considering inflation. These rises in costs manifest in an increase in ski ticket prices from € 43 (reference period) to € 60 (scenario period), again without consideration of inflation.

Based on the results of this exemplary storyline, stakeholders will be enabled to define and simulate a number of future development pathways, altering parameters (e. g. climate scenarios, energy prices, snowmaking practices) in order to test different adaptation strategies. The resulting coupled modelling approach therefore represents a tool to jointly develop the most sustainable adaptation strategies to cope with the effects of climate change in Austria's skiing business.

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