ACRP – Calls for Proposals

Publizierbarer Endbericht

gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	CCSBD-AT
Langtitel:	Climate Change Impacts on Skier Behaviour and Spatial Distribution of Skiers in Austria
Zitiervorschlag:	Steiger, R., Posch, E., Pons, M., Vilella, M. (2018): Climate Change Impacts on Skier Behaviour and Spatial Distribution of Skiers in Austria. Austrian Climate Research Program 7 (Project B464728, final report)
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	Partner 1: Sustainability Observatory of Andorra (OBSA), Andorra
Schlagwörter:	Wintertourismus, agentenbasiertes Modell, choice-based conjoint, Beschneiung
Projektgesamtkosten:	191.388,40 €
Fördersumme:	176.071,00 €
Klimafonds-Nr:	KR14AC7K11929, B464728

Allgemeines zum Projekt	
Erstellt am:	17.01.2018

B) Projektübersicht

1 Kurzfassung

Der Wintertourismus wurde wiederholt als eine der am stärksten vom Klimawandel betroffenen Branchen identifiziert und gilt zugleich als eine der am wenigsten vorbereiteten (Scott et al, 2012). Massenwintertourismus hat positiv zur wirtschaftlichen Entwicklung vieler ländlicher Alpenregionen, die von sinkender Wettbewerbsfähigkeit der Landwirtschaft und weniger attraktiven Standortfaktoren für die Industrie gekennzeichnet sind, beigetragen (Bätzing, 2005). Das künftige Entwicklungspotenzial des Wintertourismus, mit Skifahren als dem wichtigsten Produkt, ist daher von großer Bedeutung für die Entwicklung von ländlichen Räumen. Die vorhandene wissenschaftliche Literatur zu diesem Thema weist zwei bedeutende Limitationen auf: die Nicht-Berücksichtigung der technischen Beschneiung und eine fehlende integrative Betrachtung von angebots- und nachfrageseitiger Auswirkungen und Anpassungen (Steiger et al., 2017).

Das übergeordnete Ziel dieses Projektes ist daher, mögliche klimawandelinduzierte Verhaltensänderungen von Skifahrern in Österreich zu untersuchen, sowie die räumliche Verteilung der Skifahrer unter vergangenen und künftigen Klimabedingungen zu simulieren. Daraus ergeben sich folgende Unterziele: 1) Die Integration von individuellen Beschneiungskapazitäten und Saisonzeiten der Skigebiete in ein Skisaisonmodell; 2) Die Untersuchung von Präferenzen bei der Destinationswahl, insbesondere bei Schneemangelverhältnissen, sowie eine Differenzierung nach Skifahrersegmenten um potenzielle Unterschiede bei der Destinationswahl und den Anpassungen identifizieren zu können; 3) Die Verbesserung eines bestehenden agenten-basierten Modells zur Simulation der (Um-)Verteilung von Skifahrern ausgehend von ihrem Wohnort unter Berücksichtigung unterschiedlicher segmentspezifischer Präferenzen; 4) Die Integration von angebots- und nachfrageseitiger Klimawandelanpassung; 5) Die Entwicklung von Analyse von potenziellen Entwicklungspfaden der Österreichischen Skigebietsbranche.

Ein Hauptbestandteil des Projektes war eine in der Saison 2015/16 durchgeführte deutschsprachige Gästebefragung in 53 österreichischen Skigebieten, sowie Online um nicht Skifahrer in Österreich sondern auch potenzielle Skifahrer befragen zu können. In der Befragungskampagne wurde ein choice-based conjoint Experiment durchgeführt zur Identifizierung der Destinationswahlpräferenzen von Tages- wie auch Urlaubsgästen. Das wichtigste Entscheidungskriterium ist demnach für Tagesgäste die aktuelle Naturschneelage, gefolgt von Anreisezeit und Liftpasspreisen. Für Urlaubsgäste waren es die Schneebedingungen während des letzten Besuchs, sowie Schneesicherheit und Liftpasspreise. Überraschenderweise war die Skigebietsgröße das unwichtigste Kriterium bei den Tagesgästen, und bei den Urlaubsgästen nur auf Rang 4. Eine Segmentierung der Befragten nach Destinationspräferenzen ergab sechs Gruppen für die Tagesgäste und sieben für Urlaubsgäste mit signifikant unterschiedlichen Präferenzen.

Modellergebnisse der Skisaisonsimulation mittels SkiSim3 zeigen eine Verkürzung der durchschnittlichen Skisaison auch unter Berücksichtigung der technischen Beschneiung. Unter der Annahme, dass die Beschneiungskapazitäten künftig gleich bleiben, verkürzt sich die Saison um 9 (2030er) bis 28 Tage (2080er) im RCP 4.5 Szenario, und um 11-72 Tage im RCP 8.5 Szenario. Dies bei steigendem Beschneiungsaufwand, von 22-43% im RCP 4.5 und 26-45% im RCP 8.5, wobei die zu hohen Temperaturen in den 2080ern größere Steigerungswerte verhindern. Wenn die Beschneiungskapazitäten auf 10 cm pro Tag und 100% der Pistenfläche erweitert würde, könnten Verluste der Betriebstage bis in die 2030er (RCP 8.5) bzw. 2050er (RCP 4.5) verhindert werden. Die verschneite Wassermenge würde dann im Mittel um 67-105% (RCP 4.5) bzw. 73-129% (RCP 8.5) steigen. Im 2080er RCP 8.5 Szenario wären auch mit gesteigerter Kapazität nur noch 31% der Skigebiete schneesicher. Dies zeigt die Grenzen der heutigen Beschneiungstechnologie bis Ende des Jahrhunderts auf.

Die Simulationen des agenten-basierten Modells zeigen auf nationaler Ebene einen nur leichten Rückgang der Skifahrernachfrage (Ersteintritte) zumindest bis in die 2050er. In den 2080ern sinkt die Nachfrage um 20-60%, je nach Entwicklungspfad. Es zeigt sich jedoch schon in den 2030ern eine deutliche räumliche Umverteilung der Nachfrage um mehr als +/-50%. Potenzielle Zuwächse könnten Regionen wie das südliche Vorarlberg (Montafon, Arlberg), der Westen Tirols, Pinzgau, Pongau sowie in einzelnen Entwicklungspfaden auch Kärnten auftreten auf Kosten aller anderen Regionen. Die Simulation zeigt auch, dass kleine (<50 km Piste) und mittelgroße (51-100 km) Skigebiete weitaus häufiger mit Nachfragerückgängen rechnen müssen als große Skigebiete.

Wenn Skigebiete mit einem hohen klimatische Risiko nicht mehr von Privatunternehmern betrieben werden können, müsste die öffentliche Hand in diese Skigebiete investieren und diese betreiben, damit das Angebot aufrechterhalten werden kann. Der Klimawandel wird die nötigen Investitions- und Betriebskosten weiter in die Höhe treiben, wodurch sich vielerorts Fragen nach der Sinnhaftigkeit derartiger Investitionen und öffentlicher Beteiligungen wie auch nach der klimatischen Eignung dieser Standorte stellen werden. Die Politik steht daher vor der großen Herausforderung eine nachhaltige Regionalentwicklung zu fördern die zugleich im Einklang mit regionalen und nationalen Klimawandelanpassungs- und Vermeidungsstrategien stehen.

2 Executive Summary

Winter tourism has been repeatedly identified as one of the sectors being highly affected by climate change and at the same time being one of the least prepared for climate change impacts (Scott et al. 2012). Mass winter tourism has contributed to the positive economic development of many rural alpine areas which suffer from declining agricultural competitiveness and less favourable location factors with regard to industry (Bätzing, 2005). Thus the future development potential of winter tourism – and ski tourism as the most important winter product – is of utmost relevance to the development of rural areas. The existing literature on climate change impacts on the ski tourism industry is characterized by two important limitations: the omission of snowmaking and a missing integrative assessment of supply-side and demand-side impacts and consequences (Steiger et al., 2017).

Therefore the overall objective of this project is to assess potential behavioural adaptation of skiers due to climate change and to model the spatial distribution of skiers in Austria under past and future climatic conditions, including snowmaking and operational decisions in Austrian ski areas. The resulting aims of the project are 1) to better assess individual snowmaking capacity and seasonal opening; 2) to investigate skiers' destination choice preferences in general and in particular concerning lack-of-snow situations. And to differentiate between skier segments to account for potential differences in destination choice and behaviour; 3) to improve an existing agent-based model by enabling the simulation of (re-) distribution of skiers based on the agent's place of residence and by differentiating between skier segments; 4) to integrate supply-side and demand-side modelling to analyse the integrated effects of supply- and demand-side adaptations to climate change impacts; 5) to develop and analyse potential development paths of the Austrian ski industry.

In order to define rules for the agent-based model, a survey with German speaking skiers was conducted during the 2015/16 winter season in 53 Austrian ski resorts and Online to include current skiers in Austria as well as the potential market. A choice based conjoint experiment was at the core of the survey focusing on the destination choice processes of day-visitors and overnight guests. Survey results showed that the most important destination attribute for day-trippers is 'current natural snow conditions' followed by 'travel time' and 'lift ticket price'. For overnight guests, 'snow conditions during last visit' is the most important attribute, followed by 'snow reliability' and 'lift ticket price'. Surprisingly, ski area size was the least important attribute for day-trippers and only ranked 4th for overnight guests. Segmenting the respondents by destination choice preferences revealed six distinct groups for day-trippers and seven for overnight guests.

Ski season modelling results show that the average ski season will be shortened significantly in the next decades even when including snowmaking. Assuming that snowmaking capacities remain unchanged, the average ski season is shortened by 9-28 days (2030s/2080s) in the RCP 4.5 scenario and by 11-72 days in the RCP 8.5 scenario. If snowmaking capacity is increased to 10 cm per day in all ski resorts, then losses of operation days could be prevented until the 2050s in the low emission scenario but only until the 2030s in the high emission scenario. If current snowmaking capacity is unchanged, snow production needs to be increased by 22-43% in RCP 4.5 until the 2080s and by 26-45% in RCP 8.5 until the 2050s, with reduced increase in the 2080s due to too high temperatures not allowing a higher required snow production. If snowmaking coverage is increased to 100% of skiing terrain and if all ski areas improve their capacity to 10cm/day, snow production will increase by 67-105% in RCP 4.5 and by 73-129% in RCP 8.5. Considering that despite these increases only 31% of ski areas will still be snow reliable in the RCP 8.5 2080s, the suitability of snowmaking for ski areas to ensure a viable ski season is limited in the long-term.

Agent-based model results show moderate losses of skier visits until the 2050s on a national level. In the 2080s skier visits are projected to decline between 20-60%, depending on the ski industry development path. Nevertheless, regional redistribution of demand is remarkable (more than +/- 50% skier visits) already in the 2030s scenario with potential increases of demand in southern Vorarlberg, Western Tyrol, Pinzgau, Pongau and in some DPs also Carinthia at the expense of the other regions. Simulation results also showed that small (up to 50 km ski slopes) and medium sized ski areas (51-100 km ski slopes) are more negatively affected than large ski areas.

If high risk ski areas are not operated by private companies anymore, public authorities have to invest into these ski areas and to operate it in order to maintain that offer, or otherwise these ski areas will terminate their operation. Climate change will increase investment and operating costs. As soon as public authorities engage in non-profitable ski areas, questions on the suitability both from a market but also from a climate perspective will arise. Thus policy is challenged to provide a sustainable regional development strategy that is also compatible with national and regional climate change adaptation and mitigation strategy.

3 Background and project aims

Tourism is an important economic sector in many alpine areas of the world (Becken & Hay, 2007). It was repeatedly identified as one of the sectors being highly affected by climate change and at the same time being one of the least prepared for climate change impacts (Scott et al., 2012). Mass winter tourism has contributed to the positive economic development of many rural alpine areas which suffer from declining agricultural competitiveness and less favourable location factors with regard to industry (Bätzing, 2005). Thus the future development potential of winter tourism – and ski tourism as the most important winter product – is of utmost relevance to the development of rural areas.

In a literature review conducted in spring 2017, 119 publications dealing with climate change impacts on the ski tourism industry in 27 countries were critically reviewed (Steiger et al., 2017). The omission of snowmaking in many studies as well as a missing integrative assessment of supply-side and demand-side impacts and consequences were identified as important limitations of the existing literature.

The motivation for this project stems both from the challenges that climate change causes for the Austrian winter tourism industry as well as from the limitations of the existing international impact assessment literature. Ski tourism is of high relevance for mountain tourism destinations in Austria (Arbesser et al., 2010) and impacts of climate change on this market are also of interest outside of Austria as it is the third biggest market in the world for skiing tourism (ranked 3rd in terms of skier visits; Vanat, 2014). A series of snow-poor winter seasons in the 2000s (e.g. 2006-07) and extraordinary warm and snow-poor seasons from 2013-14 to 2016-17 ensures a high public and political interest in the consequences of climate change on the Austrian ski tourism industry. On the other hand, it became visible in the last years that ski resort performance differed considerably, and while ski resorts with up-to-date snowmaking facilities were able to operate almost as usual, it was reported that especially day-trippers stayed away (ORF, 2016). Summarizing, the winters during the project period coincidentally confirmed the need for investigating both the ski resorts' ability to provide a sufficiently long ski season and skiers' behavioural adaptation to extraordinary warm and snow-poor periods of the winter season.

The scientific motivation for this project is based on the need for improvement of methods to better represent climate change impacts on the ski season and on demand behaviour in existing models and to combine these models to be able to assess the integrated effect of supply and demand-side adaptations on the spatial distribution of skiers.

The overall objective of this project is to assess potential behavioural adaptations of skiers due to climate change and to model the spatial distribution of skiers in Austria under past and future climatic conditions.

The resulting aims of the project are

- To better assess the opening, ending and length of the ski season by improving an existing ski season simulation model (SkiSim); by taking into account different operational strategies (season dates) and snowmaking capacities of ski areas; and by using regionalized CMIP5 simulations with two representative emission paths (RCP 4.5 and 8.5).
- To investigate skiers' destination choice preferences in general and in particular concerning lack-of-snow situations; and to differentiate between skier segments to account for potential differences in destination choice and behaviour
- To improve an existing agent-based model by enabling the simulation of (re-) distribution of skiers based on the agent's place of residence; and by differentiating between skier segments.
- To integrate supply-side (SkiSim) and demand-side modelling (agent-based model) to analyse the integrated effects of supply- and demand-side adaptations to climate change impacts
- To develop and analyse potential development paths of the Austrian ski industry

4 Project content and results

Austria is the third biggest ski destination in the world in terms of skier visits, after the US and France and has the highest number of skiers visits per capita (Vanat, 2014). Thus skiing tourism is not only important for the regional economy of tourism intense municipalities and valleys, but also for tourism intense provinces like Tyrol or Salzburg. We included 208 ski areas in this study, a ski area being defined as an entity of ski lifts interlinked with other lifts and/or ski slopes. Therefore we define a ski area from the customer's point of view and not from the business view where in some cases interlinked ski areas are a conglomerate of several independent companies. Despite some renowned extra-large ski areas, the majority of Austrian ski areas is rather small with less than 20 km of ski slopes, or a lift capacity of less than 8000 persons/hour (Table 1). Half of the ski areas' base stations are located below 1000m, and the top stations are below 1900m. To account for the fact that ski areas with large vertical differences are able to have a longer ski season in the upper half of the ski area, we defined a 'critical altitude' where the snow depth threshold of 30 cm determining ski operation is analysed. Considering the altitude of natural snow reliability defined in an OECD study as currently being at 1050m in the East and

1200m in the West and increasing by 150m per 1°C warming (Abegg et al., 2007), it is obvious that many ski areas are potentially threatened by climate change. A fast diffusion of snowmaking facilities was the ski industry's answer to a series of snow deficient winter seasons at the end of the 1980s and in the 1990s. Currently about 67% of ski slopes in Austria are equipped with snowmaking (APCC, 2014) and the majority of ski areas has a share of at least 80% (Table 1).

Table 1: Overview characteristics of 208 analysed Austrian ski areas

	Base elevation (masl)	Peak elevation (masl)	Critical Elevation (masl)	Share of ski slopes with snowmaking (%)	Size (km of ski slopes)	Lift capacity (persons/hour)
Min	545	1050	600	0	2.5	800
1st quartile	828	1550	1100	50	10	4,765
Median	1000	1886	1400	80	19	7,838
3rd quartile	1300	2200	1600	91	35	14,310
Max	2736	3440	2900	100	284	146,550

WP 1 Project Management

The objectives of this WP were to establish an efficient project management and a successful dissemination strategy. It includes the coordination of scientific advance, stakeholder/partner workshops, milestones, dates, payment, publications, and reporting; as well as the transportation of new methods, data and results relevant for the scientific community, practitioners, partners, and the public.

In order to ensure an efficient communication with our project partner OBSA, a joint platform was established, where protocols were stored and documents containing e.g. the discussion on linking the two models as well as a project plan were updated regularly. Besides several skype calls, three joint project workshops were held: Two as a side-event of conferences where the team from Innsbruck and the Andorran partner participated to reduce travel costs and emissions, and one workshop in Innsbruck in October 2016. The Andorran project partners also participated in one stakeholder workshop to ensure that the live presentation of the integrated agent-based model worked and also to witness the discussion with tourism stakeholders. Information for the public was integrated in the work group homepage of 'Alpine Tourism Geography' (ATG) (https://geographie.uibk.ac.at/blog/atg/de/projekte/).

Project results were presented at 10 conferences; two conference papers and three journal papers were published so far. As the integrated methods approach required some feedback-loops between the agent-based model, SkiSim and the analysis of the guest survey, it was decided to publish these results-oriented papers at the end of the project when all analyses are finished. This is planned for winter-summer 2018.

Reports aiming at the general public and/or tourism stakeholders include a summary of the three stakeholder workshops, a documentation of results of the ski area manager survey and a detailed report on methodology and results of the skier survey conducted during the 2015/16 winter season.

Two press releases were initiated via the public relations department of the University of Innsbruck followed by several press inquiries. Additionally, summaries of the skier survey were published in tourism practitioner magazines.

WP 2: Model development, setup and coupling

The objectives of this WP were to setup and enhance the ski season simulation model and the agent-based model and to couple these models.

SkiSim development (milestone 2.1)

In order to overcome major limitations of previous assessments of climate change impacts on the ski industry (Steiger et al., 2017), we improved the 'SkiSim2' model, a physically-based snow model including operational decisions and snowmaking. In this model, daily snow depth is calculated for each 100m elevation band of a ski area based on temperature and precipitation (for model details see Steiger, 2010). The SkiSim2 model (Steiger & Stötter, 2013) was improved in several aspects: Slope orientation was included by applying a correction factor for the degree-day factor of +/-50% for south/north oriented slopes (Hottelet et al., 1993). Thus, snow depth simulations are available for three aspect classes (north, south and west/east) of each 100m elevation band per ski area. Operational decisions in the model were enhanced as well: six categories of season closing dates (Table 2) were identified from a comprehensive data set of snow reports from 2002/03 to 2015/16 (provided by Bergfex.at). As a result, the amount of produced snow required to reach the scheduled season closing date is more realistic in the improved model than in previous applications.

Snowmaking capacity differs quite considerably between ski areas, both the share of ski slopes covered with snowmaking as well as the capacity of daily snow production (defined as cm/day). The first was derived from an internet platform (at.skiinfo.com), the second was calibrated by comparing modelled season closing dates with the closing dates in the snow reports. Consequently, the resulting improved model is titled 'SkiSim3'.

Table 2: SkiSim3 parameters

Parameter	Values
Snowmaking season dates	Nov 1 – Mar 31 (glacier ski areas: Sept 1 – Mar 31)
Temperature limit for snowmaking	-2°C
Snow depth required for ski operation	30 cm
Density of a groomed ski slope	400 kg/m³ (Fauve et al. 2002)
Daily snowmaking capacity	1-10 cm (calibrated for each ski area)
Scheduled season closing	six different categories: Mar 19, Mar 30, Apr 9, Apr 20, May 1, May 15

The performance of SkiSim3 was evaluated by comparing modelled versus observed season starts and closings (derived from the snow reports). In SkiSim3 a ski area is considered open if at least 30 cm of total snowpack (natural and produced snow) is available at the critical elevation of the ski area. The critical elevation was defined for each ski area based on ski maps and topographic maps and represents the lowest point of the upper half of the ski area if such an upper part exists. By that, we consider the fact that many ski areas with sufficient vertical difference can be operated without having snow down to the lowest base station. As illustrated in Table 1, average critical elevation is considerably higher than average base elevation and thus climate change impacts are expected to be less than when analysing the base stations of ski areas.

A ski area is only considered open if the day is within the season dates derived from the snow reports. Note that some ski areas do not open before mid-December even if snow depth would allow an earlier opening, because demand is too low in this location and/or an earlier planned season opening is considered too risky because average climatic conditions do not allow an earlier opening in all of the years. Many ski areas also terminate ski operation in spring despite sufficient snow depth, because skiing demand is falling rapidly in mid-late March.

Climate change scenarios of the ÖKS15 project (Chimani et al., 2016) were used to represent possible climate futures in Austria in the 21st century. Thirteen climate projections were available based on combinations of six regional models (EUROCORDEX; Jacob et al., 2014) and five global circulation models (CMIP5; Taylor et al., 2011). The projections' spatial resolution is 12.5km and two emission pathways (RCP 4.5 and 8.5) were available. In order to limit the complexity of results presentation, we only present results for the ensemble mean of the 13 climate projections for the 2030s (2021-2050), 2050s (2041-2070) and the 2080s (2071-2100).

Projected warming in the winter season (December-February) averaged over our 56 used climate stations is higher for minimum temperature than for maximum temperature with 1.3-2.6°C in RCP4.5 and 1.4-4.7°C in RCP 8.5 compared to 1.1-2.2°C and 1.1-4.1°C for maximum temperature (Figure 1). Winter precipitation is projected to increase by 8-13% (RCP 4.5) and 11-20% (RCP 8.5).

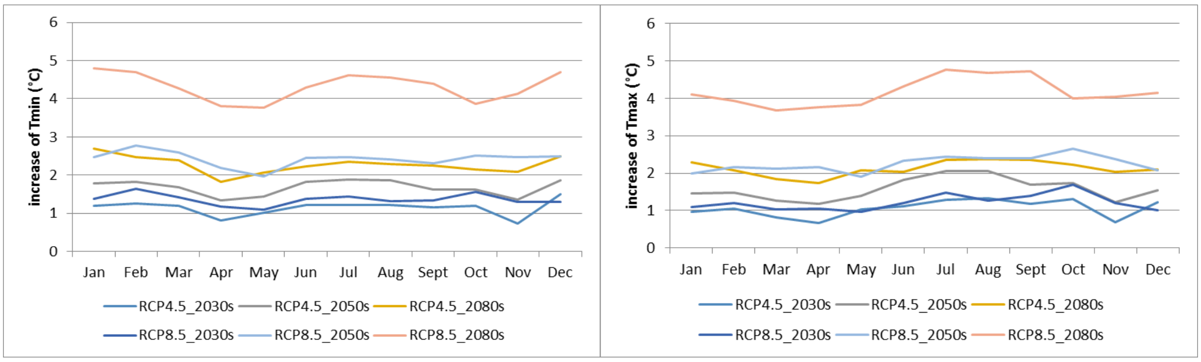

Figure 1: Projected temperature increase of the Ensemble mean averaged over all used locations

ABM development (milestone 2.2)

The agent-based model (ABM) has been further developed to be able to distribute skiers from their place of residence to ski areas (in the former version skiers were assigned to ski areas based on empirical data). The second enhancement implemented is different rules for skier segments, considering that different types of skiers are likely to react differently to conditions with a lack of snow.

Agents in the ABM are skiers with a certain number of skiing days per season derived for each segment from the skier survey. In order to calculate the number of agents and skiing days being available in the simulation, several data sources were used. In order to estimate the number of overnight-agents we used overnight statistics of all municipalities within a 15km distance to a ski area. From our survey we retrieved the average number of skiing days during day-trips and holidays in Austria. It turned out that this differs significantly between places of residence. Therefore, we divided Germany and Austria in three greater regions (GR) to account for these regional differences that also correlate with distance to ski areas. The GR were defined as follows: DE1-Southern Bavaria, DE2-Northern Bavaria and Baden-Wurttemberg and DE3-the rest; AT1-Vorarlberg, Tyrol, Salzburg, Carinthia, AT2-Styria, Upper Austria, AT3 – Lower Austria, Vienna, Burgenland. Switzerland was defined as another region (with values from AT1) and remaining tourists were considered as agents with characteristics identical to DE3. Skiing days during day-trips and holidays consumed by agents are then calculated per region:

$SV_{hol(GR)} = OS_{(GR)} * f, \quad SV_{day(GR)} = SV_{hol(GR)} * share_{SD\_hol(GR)}$

Where SV is the sum of skier visits per GR, OS is the number of overnight stays, f is a scaling factor, $share_{SD\_hol}$ is the share of skiing days during holidays as stated is the survey. The scaling factor is required as not every overnight stay leads to a skiing day, because not all winter tourists ski and not all tourists ski every day of their holiday. A factor of 0.8 turned out to work best comparing resulting total skier days and official data for Austria (MANOVA) with an overestimation of 1% between 2003/04-2005/06, but also an overestimation of 17% in 2006/07. This is due to the fact that in this extraordinary season, skiers might have had less skiing days than usual due to a lack of snow which is not represented in our survey data, but which is accounted for later in the ABM simulation.

The number of agents per GR are calculated as follows:

$A_{hol(GR)} = SV_{hol(GR)} / SD_{hol(GR)}$

Within the GR, agents are distributed to NUTS3 regions based on the population share of each NUTS3 region to total population of that GR.

At the beginning of the simulation, agents are created at each origin location (NUTS3 regions) and a set of specific factors (behaviour preferences), as well as a skier days calendar (when they ski), is assigned depending on their origin and cluster (type of skier profile). During the simulation, agents combine their preference factors with resorts' conditions (both in the actual simulation day and in previous visits to resort assuming some memory) and select a preferred resort. Biggest difference between overnight guests and day trippers occurs in this step, as not only characteristics of resorts and agent preferences are evaluated, but also maximum capacity of resorts to allocate skiers is considered every day. An agent is not hosted if the occupancy of a resort reaches 40% of total lift capacity; however, overnight guests have an extra overnight capacity value that prevents for hotel overbooking situation. Some agents may not find an attractive resort to visit, and are tracked into an unhosted group.

All attributes contained in the choice based conjoint model (CBC) were operationalized in the ABM (Table 3). Seasonal distribution of skier days was based on data from four ski areas available from a preceding research project (CC-Snow2).

Table 3: Operationalization of destination attributes and levels in the ABM

Day-trippers			Overnight guests	
Attribute	**Operationalization**		**Attribute**	**Operationalization**
Travel time	Origin (NUTS3) / destination (ski area) matrix		Total length of ski slopes	Retrieved from at.skiinfo.com
Km of open slopes	SkiSim3 – daily values		Snow reliability	SkiSim3 low/medium/high risk
Current natural snow conditions	At base elev.	If SP_nat ≥ 10 cm at Alt_min	Additional non-snow activities	Threshold: 10.000 beds
	Only at higher elev.	If SP_nat ≥ 10 cm at Alt_mean		
	No natural snow	If SP_nat < 10 cm at Alt_mean		
Lift ticket price	Retrieved from at.skiinfo.com		Lift ticket price	Retrieved from at.skiinfo.com
Number of skiers during last visit	Threshold for good/bad: 20% of lift capacity		Same as for day-trippers	
Snow conditions during last visit	Threshold for good/bad: 50% of skiing terrain open		Same as for day-trippers	

Model coupling (milestone 2.3)

SkiSim output is adapted to the format and type of information that is required by the ABM: available skiable terrain and 'winter atmosphere' (natural snow in the entire ski area, natural snow only in the upper half of the ski area, no natural snow) on a daily basis for each ski area. These values are used by the ABM to define the characteristics of each ski resort on a daily basis resulting in a segment-specific attractiveness score for each ski resort.

WP 3: Secondary data collection and analysis

The objective of this work package was to obtain empirical data of winter sport tourists and ski area managers in Austria. This provides the basis for sensitivity analyses of demand to snow conditions in WP 4.

Ski area manager survey (milestones 3.2-3.3)

An online survey was sent to all Austrian ski companies (n=207) to retrieve information required for assessing current snowmaking as well as information on demand (e.g. the share of one-day and multi-day lift tickets sold per season to estimate the number of day-trippers and holiday guests). 65 ski areas from seven provinces filled out the online questionnaire after the winter season 2015/16.

Responding ski areas with snowmaking are currently covering 70% of their slopes with snowmaking facilities. One third (34%) of ski areas has a high capacity, being able to finish base-layer snowmaking within five days, another quarter (26%) needs 6-9 days and 40% need 10-15 days to provide a resistant snow base for skiing. Most ski areas are planning to expand their snowmaking capacities in the next three years (86%), about half of these plan 'significant improvements', the other half only 'smaller improvements'.

In the sample, 40% of lift tickets are day tickets, 40% are multi-day tickets and 20% are season passes. Here, a clear dependency on size can be seen: Small ski areas have a considerable higher share of season pass holders than larger ski areas, multi-day tickets have a higher share with increasing ski area size. Note that the above mentioned shares do not represent the share of ticket types in Austria, as the individual shares need to be weighted by skier days per ski area. But, results already indicate that different behaviour of day trippers, overnight guests and locals are likely to affect smaller ski areas differently than larger ski areas.

Tourist survey (milestones 3.1, 3.4, 3.5)

A choice based conjoint experiment (CBC) was at the core of the survey in German language conducted with winter sport guests in 53 ski areas throughout Austria during the winter season 2015/16. Additionally, an online survey was conducted also including potential skiers in Austria. A final sample of 3,673 respondents could be achieved. A CBC experiment is an advanced survey method to reveal preferences between different hypothetical choice scenarios as well as trade-offs (Pröbstl-Haider et al., 2016). The CBC model is rooted in Random Utility Theory, which proposes that choices and alternatives have certain utilities and can be modelled as a function of the alternatives' attributes (McFadden, 1974; Train, 2009). A random utility model (RUT) consists of an observable, deterministic utility component as well as an unobservable random component (McFadden, 1974). According to RUT, individuals will choose the best option of all alternatives with the highest overall utility (Louviere et al., 2000; Louviere et al., 2010). The overall utility of an individual's choice (U_{in}) consists of explainable (V_{in}) and random/unexplainable components (ε_{in}) (Louviere et al., 2010):

$$U_{in} = V_{in} + \varepsilon_{in}$$

From a set of possible alternatives (C_n), an individual will choose the option with the highest utility, thus the probability (P) of choosing an option (i) over all other options (j) can be expressed as:

$$P \langle i|C_n \rangle = P \, (V_i + \varepsilon_i > V_i + \varepsilon_j ; \forall j \in C)$$

To calculate the final probabilities of one alternative from a set of other alternatives, a logit model is applied:

$$\frac{\exp(V_i)}{\sum_{j \in C} \exp(V_{i)}}$$

The idea of choice experiments is to analyse individuals' repeated choices made in hypothetical scenarios. The hypothetical scenarios consist of numerous alternatives, also called choice sets, with combinations of different attributes and attribute levels. The observation of repeated choices reveals certain preferences of the individuals, showing the overall importance of each single attribute compared to the other attributes presented in the choice task. This allows estimations about the relevance of different attribute levels in comparison to other attribute levels. Choice data were analysed with Sawtooth Software to estimate the overall probability of an individual's choice.

The focus of the choice based conjoint experiment was on the destination choice processes of day-visitors and overnight guests. In the online survey, respondents were asked to make eight choices between hypothetical combinations of destination profiles described by a set of attributes. The six attributes consisted of two or three levels each and were based on an extensive literature review (e.g. Konu et al., 2011; Joppe et al., 2013; Bédiová & Ryglová, 2015; Dawson et al., 2011; Dawson & Scott, 2010; Dawson et al., 2013; Behringer et al., 2000; Godfrey, 1999; Matzler et al., 2008; Gilbert & Hudson, 2000; Won et al., 2008). The respondents were asked to choose one or none of the options. Attributes for the choice based conjoint differ for day-visitors and overnight guests (see Figure 2). The results were analysed with Sawtooth Software. Using Bayesian hierarchical modelling, the part-worth utilities for the different levels of the attributes were estimated and a latent-class analysis performed.

Comparisons with national survey data point to a good quality of the sample in terms of its representativeness of the population. Still, limitations exist because of the internet-based survey design restricting the survey to participants with internet access.

In the sample, females account for 45%, males for 55% (n=3673). Almost 44% of the surveyed people are under 35 years old, about 46% are between 35 and 54 years, and about 10% are older than 55. Their place of residence includes

Austria (24%), Germany (66%), Switzerland (3%) and other countries (5%). The free disposable household income of most respondents (43%) lies between 2000-4999€. Skiers account for 86% of the persons interviewed, snowboarders account for 13% and 1% consider themselves as other snow related winter sport tourists.

The most important destination attribute for day-trippers is 'current natural snow conditions' followed by 'travel time', 'lift ticket price' and 'snow conditions during last visit' (Figure 2). For overnight guests, 'snow conditions during last visit' is the most important attribute, followed by 'snow reliability' and 'lift ticket price'. Surprisingly, ski area size was the least important attribute for day-trippers and only ranked 4th for overnight guests. Figure 2 shows the part-worth utilities of each attribute level. The more positive (negative) this value is, the more (less) likely a destination with that attribute level will be chosen. Travel time for example has a positive impact on destination choice as long as it is below 2 hours driving time, whereas a travel time of 3 hours has a serious negative impact on destination choice (Figure 2).

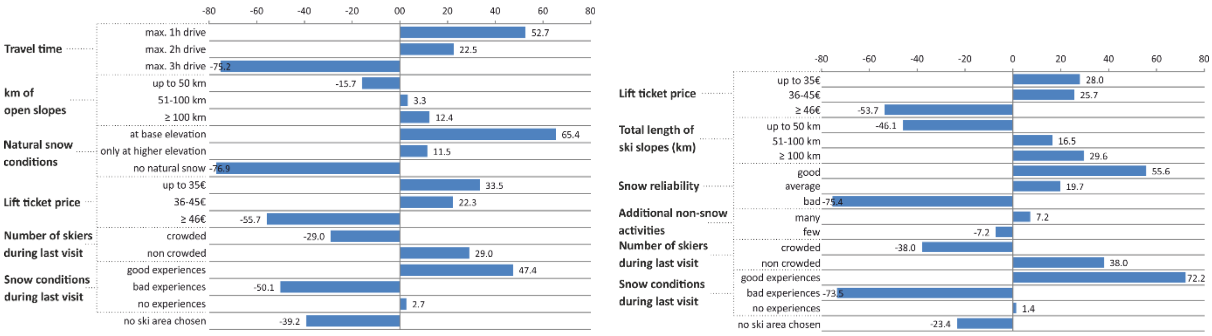

Figure 2: Destination attributes and levels with part-worth utilities for day-trippers (left) and overnight guests (right)

There are different ways to analyse data from choice experiments. A latent class analysis is a segmentation method based on the individual part-worth utilities. It was conducted in order to identify groups of significantly differing destination choice preferences to be included in the agent-based model. The basic assumption of latent class models is that similar choice patterns of individuals will be highly correlated (Aldrich et al., 2007). The latent class analysis is separating the sample based on similar homogenous choice structures within each group, but which differ to other groups. Each respondent is then given a probability to belonging to a certain group (Langen, 2012):

$$\mathrm{P}\,\langle n|C_s\rangle \;=\; \frac{\exp(\alpha\,\lambda_s \mathrm{Z}_n)}{\sum_{s=1}^{S}\exp(\alpha\,\lambda_s \mathrm{Z}_n)}$$

The Akaike Information Criterion (AIK) and Bayesian Information Criterion (BIC) were then used to determine the number of sub-groups to consider (Landauer et al., 2012). To allow heterogeneity between individual respondents, part-worth utilities are calculated separately for each sub-group. We identified six different sub-groups for day-trippers and seven for overnight guests (Figure 3, Table 4).

The result of the latent class analysis shows that it is important to consider differences in tourists' destination choice preferences. Group 6 of the day-trippers for example weights short travel distances much more than all other destination attributes. Thus, a longer travel time can hardly be compensated by other destination attributes. In group 4 the snow conditions during the last visit dominate over all other attributes. By elaborating dominant destination attributes and socio-demographic characteristics, each group was assigned a meaningful name (Table 4). A more detailed description can be found in the report on the skier survey (https://geographie.uibk.ac.at/blog/atg/wp-content/uploads/sites/4/2017/11/Endbericht_Befragung_Juni2017_Web.pdf).

Table 4: Groups resulting from latent class analysis

Day-trippers			Overnight guests		
Group	**Name**	**Number (sample share)**	**Group**	**Name**	**Number (sample share)**
DT1	Price-sensitive beginners	n=164 (13%)	OG1	Old hands	n=300 (16%)
DT2	Time- and price-sensitive epicures	n=165 (13%)	OG2	Experienced enthusiasts	n=302 (16%)
DT3	Demanding expert skiers	n=237 (19%)	OG3	Supply-oriented beginners	n=113 (6%)
DT4	Supply-oriented occasional skiers	n=147 (12%)	OG4	Tranquillity-seeking expert skiers	n=289 (15%)
DT5	Sportive maniacs	n=276 (22%)	OG5	Young maniacs	n=252 (13%)
DT6	Price-sensitive enthusiasts	n=285 (22%)	OG6	Demanding snow freaks	n=271 (14%)
			OG7	Price-sensitive epicures	n=349 (19%)

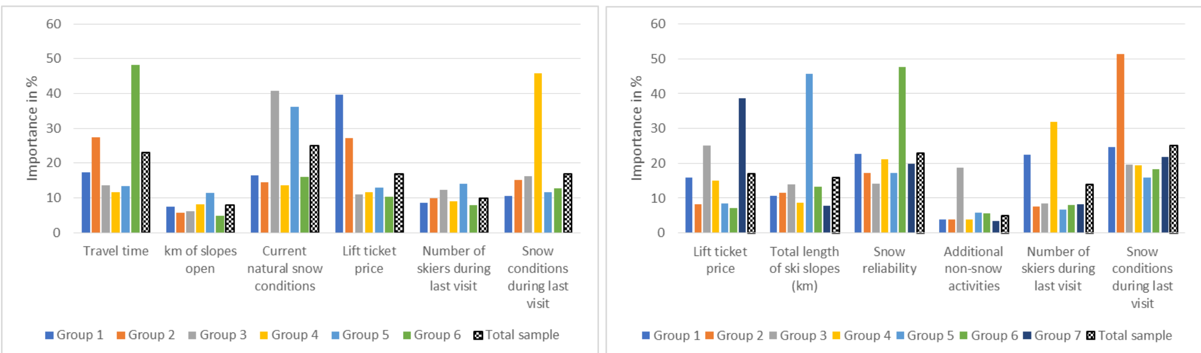

Figure 3: Importance of destination attributes per group for day-trippers (left) and overnight guests (right)

WP 4: Model testing, application and interpretation

The objective of this work package was the calibration/validation of the coupled model and subsequently performing two model runs. Model run 1 with climate change as the only external stressor, model run 2 where climate change is combined with alternative development paths defined by ski area managers in three regional workshops (see WP 5).

Model calibration / validation (milestone 4.1)

SkiSim3

Considering the climatological and operational conditions, the season start of 208 modelled ski areas is at average 3.4 days later than reported in the 2002/03-2009/10 period, with the extreme warm 2006/07 season showing the highest bias of 5.3 days. The modelled season end is 2.4 days earlier than observed, with 2006/07 again being the season with the highest deviation of 8.2 days. The greater model bias in the extreme warm season can be explained by the desperate situation in many ski areas forcing operators to open with less than 30 cm of snow depth, to organize large scale snow transports with trucks or helicopters and to concentrate snowmaking on fewer slopes (Steiger, 2011); such extraordinary measures are not captured in the model's operational decision rules.

Climatological data for the baseline period (1981-2010) for 56 weather stations was obtained from the central meteorological office of Austria (ZAMG), including daily values of minimum and maximum temperature, precipitation, snow depth and snow-fall. Proximity to ski areas and a complete data set were important selection criteria.

Coupled SkiSim3-ABM model

In order to validate the ABM simulation, two data sources were used. First, simulated skier visits on the province level were compared against real skier visits published in the annual report of the Austrian Cableway Association. Second, annual statistics of cableways ("Eisenbahnstatistik, 2. Teil Seilbahnen") were used. In that statistic, skier visits on draglifts are not included and consequently do not represent 100% of real skier visits. Nevertheless, it is still the best publicly available data source.

We used three winter seasons from 2004/05 to 2006/07 to test the performance of the ABM. The winter season 2004/05 represents a climatically normal season with December and January being close to the 30 year average and February being cooler than normal. The 2005/06 season represents a cool season with winter months being 1.5-2.5°C cooler than normal, depending on the region. The 2006/07 was the warmest season ever recorded with a 3°C deviation from the climate mean.

Model performance was promising on a province level and consistent in the three investigated seasons (Table 5). Differentiating between ski area size as defined in our CBC experiment reveals a systematic overestimation of small and underestimation of large ski areas (Table 6). Concerning lift ticket prices, the model (slightly) overestimated skier visits in cheap (mid-priced) ski areas and underestimated skier visits in high-priced ski areas (Table 6). This might point to a potential stated-real preferences bias (and/or perception-behaviour gap) in our survey.

Table 5: Deviation of simulated skier visits from reported skier visits on the province level

	Season		
Province	**2004/05**	**2005/06**	**2006/07**
Vorarlberg	-1%	0%	0%
Tyrol	0%	-1%	2%
Salzburg	-3%	-3%	-4%
Carinthia	2%	2%	2%
Styria	2%	1%	1%
Upper Austria	0%	0%	-1%
Lower Austria	0%	0%	0%

Table 6: Deviation of simulated skier visits from reported skier visits per ski area size and lift ticket price category

	Ski area size			Lift ticket price		
Season	**≤ 50 km**	**51-100 km**	**> 100 km**	**≤ 35 €**	**36-45 €**	**> 45 €**
2004/05	9%	3%	-11%	4%	12%	-16%
2005/06	10%	3%	-12%	4%	12%	-17%
2006/07	6%	5%	-11%	1%	14%	-16%

Result analysis (milestones 4.2-4.3)

SkiSim 3

The modelled average ski season length of 80 days only considering natural snow (A in Table 7) is already low in the reference period (1981-2010). This less than three months natural ski season can be explained with the high number of ski areas at lower altitude in Austria (**Fehler! Verweisquelle konnte nicht gefunden werden.**) and the fact that we analysed the ski season at the critical altitude and not the mean altitude of the ski areas. On the other hand, ski areas in Austria already adapted to that with a high share of ski runs equipped with snowmaking facilities (**Fehler! Verweisquelle konnte nicht gefunden werden.**). Average ski season length including current snowmaking capacities (B in Table 7) is 53 days longer, or when only considering the usual skiing period in each resort the season is extended by 35 days to a total of 115 days (D in Table 7).

The average ski season will be shortened significantly in the next decades even when including snowmaking. Assuming that snowmaking capacities remain unchanged, the ski season is shortened by 9-28 days in the RCP 4.5 scenario and by 11-72 days in the RCP 8.5 scenario (B in Table 7). If snowmaking capacity is increased to 10 cm per day in all ski resorts, then losses of operation days could be prevented until the 2050s in the low emission scenario but only until the 2030s in the high emission scenario (C in Table 7).

Ski season reductions are somewhat smaller when excluding the weeks with skiing potential that are not used by the ski resorts today due to too low demand on the market. Focusing on the operational relevant period of the winter season derived from the snow reports for each ski area, losses are 7-17 days in the low emission scenario and 7-70 days in the high emission scenario (D in Table 7). When also considering improvements of snowmaking capacity (E in Table 7), losses can be limited to 3-8 days in a low emission future and to 3-36 days in a high emission future.

Table 7: Modelled ski season length

		RCP 4.5			RCP 8.5		
Ski season length	**1981-2010**	**2030s**	**2050s**	**2080s**	**2030s**	**2050s**	**2080s**
(A) with natural snow only	80	64	56	45	63	44	19
(B) potential with current snowmaking	138	129	122	110	127	108	66
(C) potential with improved snowmaking (10cm/day)	146	140	135	126	137	124	90
(D) operational relevant ski season with current snowmaking	115	108	105	98	108	98	55
(E) operational relevant ski season and improved snowmaking (10 cm/day)	117	112	111	107	112	106	79

In order to assess the climatic risk for snow reliability of ski areas, two indicators were used: the 100-day rule (e.g. Abegg, 1996; Steiger & Abegg, 2013), i.e. the probability within a 30 year period to provide a ski season of at least 100 days; and the Christmas indicator (e.g. Scott et al., 2008), i.e. the probability within a 30 year period to provide continuous ski operation during the 2-week Christmas-New Years holiday. If both indicators are fulfilled in ≥ 90 % of years, it is considered a 'low risk' ski area. If one indicator is below 70% probability, it is considered a 'high risk' ski area. In all other cases, it is considered a 'medium risk' ski area. This classification is further used in the alternative development paths. In the reference period, 16% of ski areas are considered as 'high risk' (

Table 8). If all ski areas increased snowmaking coverage to 100% of terrain and capacity to 10cm/day, only 3% would be in the high risk category. This alleviating effect of investments in snowmaking continues almost in all future scenarios except the 2080s RCP 8.5 scenario. Even with snowmaking investments, 37% of all ski areas are in the high risk category in the RCP 8.5 2050s scenario. An improvement of snowmaking coverage and capacity is required in all scenarios as soon as the 2030s in order to reduce climate change impacts. From the 2050s onwards, differences between the RCP 4.5 and 8.5 become remarkable. Thus climate change mitigation is in the interest of the ski industry, but the effects are minor before the 2050s. Apart from high risk ski areas, the share of medium risk ski areas also increases considerably. Though 'medium risk' is not necessarily equal to unprofitability, it nevertheless marks the increasing share of ski areas with deteriorating climatic conditions.

Table 8: Risk categories of Austrian ski resorts based on snow reliability indicators

Snowmaking coverage & capacity	Risk category	1981-2010	RCP 4.5			RCP 8.5		
			2030s	2050s	2080s	2030s	2050s	2080s
Status Quo	Low risk	59%	25%	17%	8%	26%	8%	2%
	Medium risk	25%	41%	34%	27%	37%	24%	3%
	High risk	16%	35%	49%	65%	37%	69%	95%
Advanced (100% coverage, 10cm/day)	Low risk	87%	51%	38%	24%	56%	23%	4%
	Medium risk	11%	38%	42%	43%	35%	41%	10%
	High risk	3%	12%	20%	34%	10%	37%	86%

A warmer climate means an increasing share of rain events during the winter season and more energy available for snow melt. Consequently, more snow needs to be produced in the future to ensure continuous ski operation until the scheduled season closing. But, rising temperatures also reduce the available time for snow production.

If current capacity is unchanged, snow production needs to be increased by 22-43% in RCP 4.5 and by 26-45% in RCP 8.5 until the 2050s, with reduced increase in the 2080s due to too high temperatures. These increases are directly correlated with results on season length indicators, meaning that although season length is shortening and less ski areas remain snow reliable, snowmaking needs to be increased in order to reach these season length values. If snowmaking coverage is increased to 100% of skiing terrain and if all ski areas improve their capacity to 10cm/day, snow production will increase by 67-105% in RCP 4.5 and by 73-129% in RCP 8.5 (Table 9). Considering that, despite these increases, only 31% of ski areas will still be snow reliable (100-days rule, see Table 8), the suitability of snowmaking for ski areas to ensure a viable ski season is limited.

Table 9: Change of produced snow

	RCP 4.5			RCP 8.5		
Snowmaking capacity	**2030s**	**2050s**	**2080s**	**2030s**	**2050s**	**2080s**
Status quo	22%	32%	43%	26%	45%	40%
Current capacity, 100% coverage	37%	56%	79%	41%	76%	70%
Improved capacity	28%	42%	57%	33%	60%	73%
Improved capacity & 100% coverage	67%	85%	105%	73%	110%	129%

Agent-based model

As a result of the stakeholder workshops (see WP5), three alternative development pathways (DP) were defined and operationalized in the ABM. The resulting four development paths are described in WP 5.

Simulated skier visits on a national level remain relatively stable until the RCP 4.5 2050s and RCP 8.5 2080s (Table 10). In the 2080s RCP 4.5 and 2050s RCP 8.5 scenario, losses are still less than 10%. Bigger losses of 20-60% (depending on DP) only occur in the RCP 8.5 2080s scenario. As expected, losses in DP 2 and 4 are higher than in the other DPs, as in the former high risk ski areas are considered to be permanently closed. The early losses in DP 3 and 4 despite higher snowmaking capacities can be explained by assumed higher lift ticket prices and a resulting lower attractiveness of ski areas that entered a higher price category.

Table 10: Change of skier visits on a national level for different ski industry development paths

Ski industry development path	RCP 4.5			RCP 8.5		
	2030	**2050**	**2080**	**2030**	**2050**	**2080**
DP 1	0.4%	0.1%	-0.8%	0.3%	-0.8%	-20.4%
DP 2	-0.9%	-2.7%	-6.5%	-1.3%	-7.5%	-59.2%
DP 3	-2.9%	-3.2%	-4.3%	-3.0%	-4.2%	-19.9%
DP 4	-3.5%	-4.3%	-9.2%	-3.4%	-7.0%	-44.8%

Despite rather small changes at the national level, considerable changes can be seen when differentiating by ski area size (Figure 4). While in DP 1 mainly small ski areas lose skier visits for the benefit of large ski areas and in some scenarios also for medium sized ski areas. A possible explanation is the - in the average - worse current snowmaking capacity of small ski areas due to financial constraints. This pattern intensifies in DP 2 where mostly small ski areas are considered to be permanently closed due to too unreliable climatic conditions. In DP 3 the biggest losers are medium sized ski areas in all scenarios. In the simulation these ski areas are disadvantaged as the price increase of € 5 shifts many medium sized ski areas from the medium- to high-price category considerably reducing attractiveness compared to the baseline. Small ski areas also lose attractiveness if they move from the low- to the medium-price category, but the difference in part-worth utilities is bigger in the former case (Figure 2). Another remarkable effect in DP 3 is that large ski areas achieve a growth of skier visits even in the RCP 8.5 2080s scenario due to higher snowmaking capacity and also continuing operation of high risk ski areas. DP 4 is similar to DP 3 with higher losses for small ski areas compared to DP 3 and less pronounced losses for medium sized ski areas.

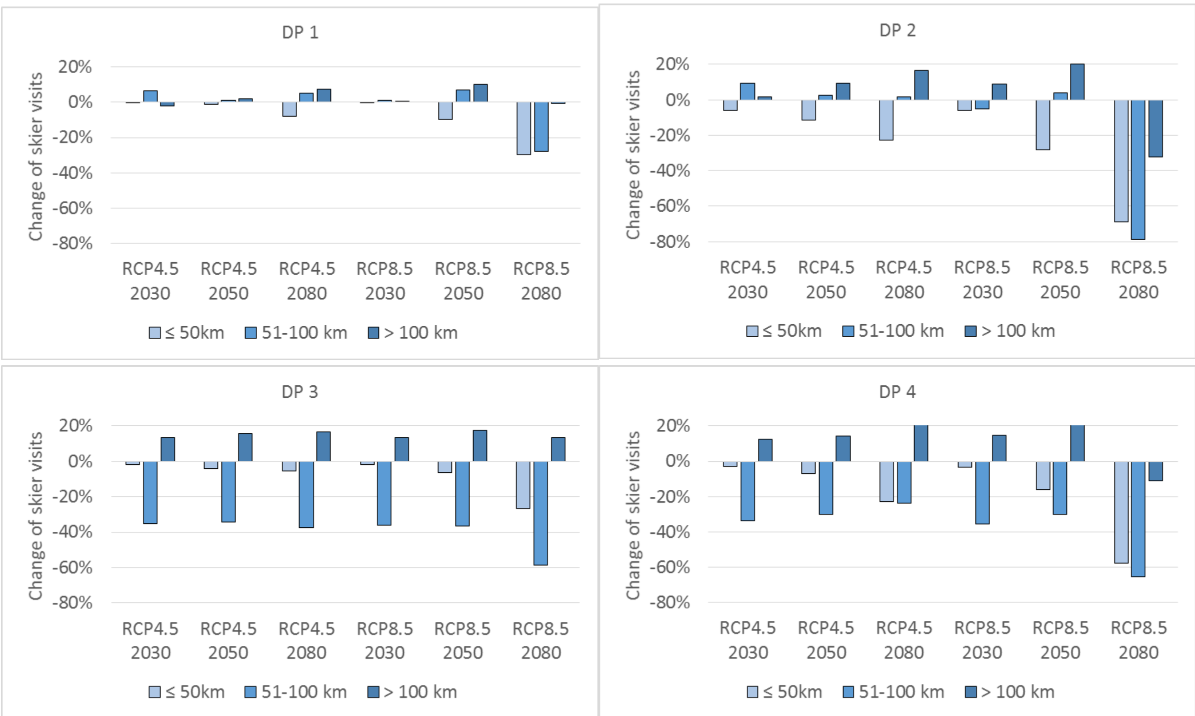

Figure 4: Change of skier visits aggregated per ski area size for different ski industry development paths

Analysing the results on a regional (district) level reveals further details and complexity of climate change impacts on spatial distribution of skiers (Figure 5). Considerable differences exist within provinces, e.g. more negative impacts in Northern Vorarlberg (e.g. Bregenzerwald) but positive impacts in the South (Montafon, Arlberg), or negative impacts in the East of Tyrol opposed to positive impacts in the West. Regional diverse patterns in the different development paths are visible as well. Assuming that high risk ski areas drop out of the market (DP 2 and 4), northern Vorarlberg, Eastern Tyrol, Northern Salzburg, Eastern Styria and the Alps south of Vienna are more negatively affected than in DP 1 and 3. But, Carinthia and East Tyrol as well as the South-West of Styria show an increase of skier visits compared to DP 2 and 4. If snowmaking capacity is increased (DP 3 and 4), skier visits in many districts of Carinthia are projected to decline. One possible explanation is that current snowmaking capacity is generally higher in Carinthia than in other regions, not least to the fact that natural snow availability is more variable south of the main alpine divide. If snowmaking capacity is increased in all ski areas in Austria, ski areas in Carinthia lose their competitive advantage in the simulation.

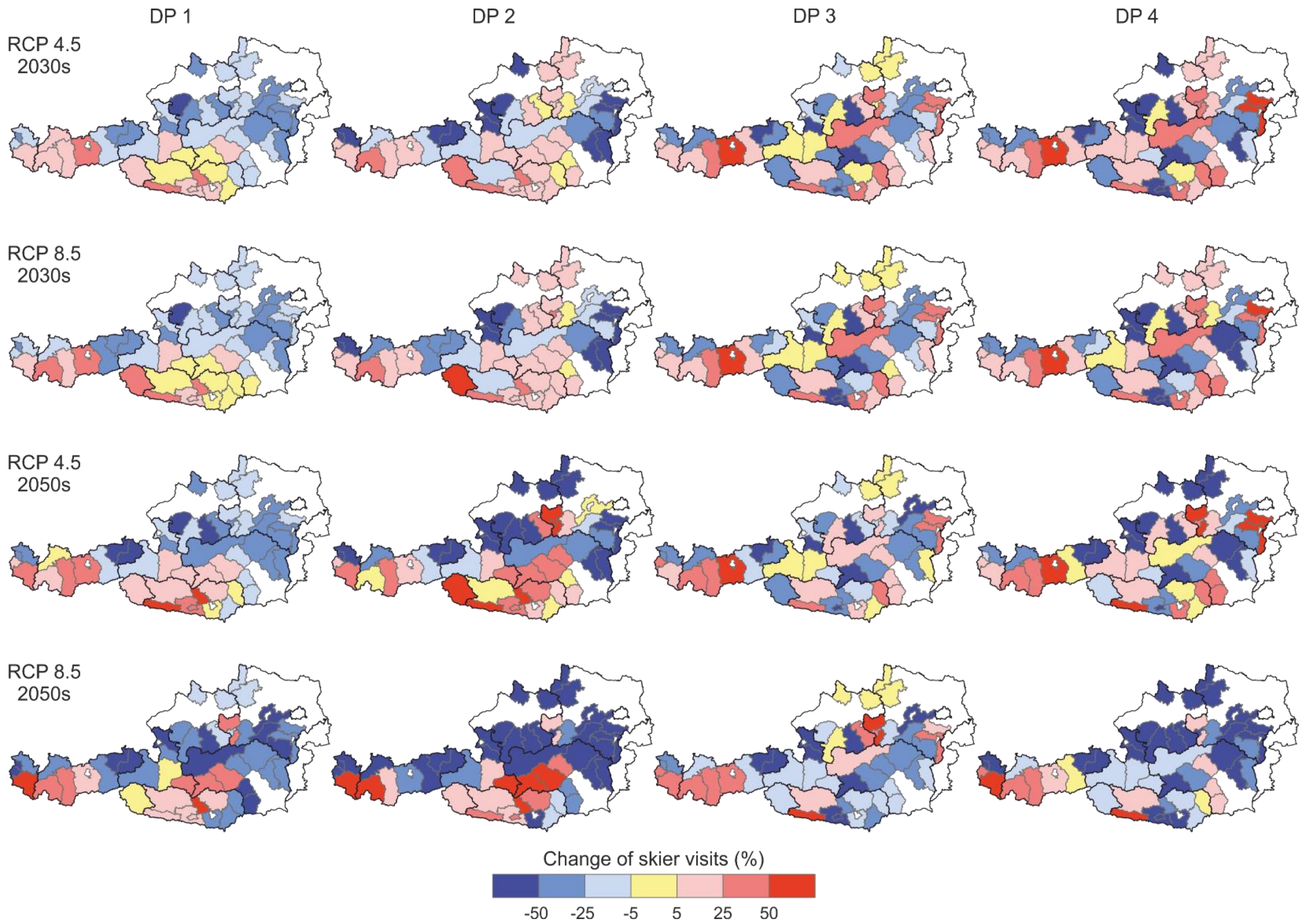

Figure 5: Change of skier visits on a district level with different ski industry development paths

WP 5: Scenario planning

The objective of this work package was to present and discuss model results with ski area managers and public authorities in three regional workshops. In these workshops potential development paths of the ski industry were jointly elaborated and defined by participating stakeholders.

Development paths of the ski industry (milestone 5.1)

Three stakeholder workshops were organized in Innsbruck (04.10.2016, 16 participants), Schladming (06.10.2016, 25 participants) and Dornbirn (10.10.2016, 18 participants). The results of the skier survey were presented and discussed. The identified low importance of ski area size surprised the participants, but in all three workshops it was argued that size is more than the mere total length of ski slopes and might also be representative for service quality, comfort (e.g. ski lifts) or professional snowmaking in real life destination choice. Furthermore, the participants agreed that bigger ski areas usually have a higher marketing budget and therefore are better visible on the market.

The high relevance of past experiences with snow conditions raised interest and participants noticed that this is of importance but often overlooked by tourism stakeholders. The segmentation of skiers was identified as an important message for marketing as still too few ski areas try to specialize on certain tourist segments which would be particularly important for smaller ski areas.

The most important drivers of ski tourism development in the upcoming decades named and scored by the participants were 'a lack of younger skiers' (score: 28), 'snow reliability and climate change' (24), and 'costs of skiing' (7). Although the lack of young skiers, or demographic change in other terms, was identified as the most important driver, we decided not to include it in the ABM as more knowledge is required: The conducted segmentation is not based on age and the resulting segments do not show a significant difference in age groups. Therefore, preferences differing by age cannot be included by changing the share of segments towards older aged segments. Furthermore, even if another segmentation by age was conducted, it remains unknown whether age-specific preferences would persist ('cohort effect') or if preferences would change with age. This represents an important knowledge gap and opportunity for further future research.

We decided to differentiate snow reliability and climate change according to the discussion with tourism stakeholders and to include the cost of skiing in the alternative scenarios in model run 2. It was argued that if climatic conditions deteriorate it is almost sure that all ski areas would aim at increasing snowmaking capacity and terrain covered by snowmaking. The role of public authorities was discussed as well, as currently non-profitable ski areas are often taken over and operated by municipalities and/or necessary investments are (co-)financed by public authorities.

Decision rules for model run 2 (milestone 5.2)

The chosen ski industry development paths are the following:

DP 1: No change except climatic conditions (model run1 as described in the proposal).

DP 2: It is assumed that high risk ski areas (see SkiSim3 results section) remain permanently closed as climatic conditions are too unreliable.

DP 3: All ski areas increase their snowmaking capacity to 10cm/day and 100% of skiing terrain is covered by snowmaking. Due to increasing investment and operating costs, lift ticket prices are increased by € 5 and consequently some ski areas move into a higher lift ticket price category. If a ski area is already in the highest price category (more than 45 €), the price remains unchanged as the part worth utilities of higher prices are unknown. All ski areas are in operation despite the fact that some might have unprofitably short ski seasons. It is assumed that public authorities enable the continuation of these ski areas.

DP 4: As DP 3, but high risk ski areas are closed permanently, assuming that neither private nor public authorities engage in high risk ski areas.

5 Conclusions

In the following, conclusions of project results for each objective are presented:

Objective 1: To better assess ski season simulation by improving an existing model

The SkiSim model was improved by including slope aspect and also by including ski area-specific snowmaking capacity and season dates. Direct comparison with previous climate change impact assessments of ski tourism in Austria (e.g. Steiger & Abegg, 2013; Steiger & Stötter, 2013) is not possible as different climate scenarios and model parameters were used. Previous studies for example assumed a uniform snowmaking capacity of 10cm/day. Our results show that snow reliability is considerably lower when using empirically derived ski area-specific snowmaking capacity (from 1-10 cm/day). The share of high risk ski areas for example with empirically derived snowmaking capacity is 49-69% in the 2050s (RCP 4.5, 8.5 respectively); whereas for advanced snowmaking capacity (10 cm/day), 20-37% of ski areas are in the climatic high risk category in the 2050s.

Our results also show that a projected shortening of the ski season is considerably different when analysing the potential ski season or only the part of the ski season that is relevant from an operation perspective. Modelled potential season length (Nov-Apr) declines from 138 days including snowmaking with current capacity to 122 (RCP 4.5) and 108 (RCP 8.5) in the 2050s. The touristic relevant period of the winter half year though (ski area-specific and ranging from early November and mid-December to mid-March and early May) shows smaller declines from 115 to 105 (RCP 4.5) and 98 (RCP 8.5). This points to the fact that many studies may have overestimated climate change impacts.

Objective 2: To investigate skiers' destination choice preferences and to differentiate between skier segments

The representative skier survey conducted in the 2015/16 winter season revealed a high importance of natural snow conditions and travel distance for day-trippers as well as experiences with past snow conditions. For overnight guests, snow reliability and experiences with past snow conditions were the most important destination attributes. A surprising result was the low importance of ski area size. This is on the one hand in contrast to market research studies (e.g. MANOVA) which point to a high importance of this attribute. Unfortunately, these studies are not available except some excerpts of public presentations that are not sufficient for verification of applied methods and conducted results. On the other hand, another survey also using a CBC came to similar results concerning the low importance of ski area size (Pröbstl-Haider et al. 2017).

A latent-class analysis revealed large differences in destination choice preferences between tourist segments (both for day-trippers and overnight guests). For example, while snow reliability is the most important destination attribute for the "demanding snow freaks" (14% of the sample), it is e.g. lift ticket price for the "price sensitive epicures" (19%) or the degree of crowding for the 'Tranquillity-seeking expert skiers' (15%).

This finding supports the aim to include different segments in the agent-based model. Participants in the stakeholder workshops echoed the need for customer segmentation in market research and an urgent need for specialization towards specific user groups particularly for small to medium sized resorts.

Objective 3: To improve an existing agent-based model by enabling the simulation of (re-) distribution of skiers based on the agent's place of residence; and by differentiating between different skier segments

Previous ABM applications of ski tourism assigned skier agents to destinations based on e.g. overnight statistics or skier visit data (e.g. Pons et al., 2014; Soboll & Dingeldey, 2012) and the agent was only reallocated to another ski area if the pre-assigned ski area was closed in a future scenario due to a lack of snow. In CCSBD-AT agents are allocated to places of residence based on NUTS3 regions and are distributed during the simulation based on destination preferences and segment-specific attractiveness scores of each ski area. On the one hand this increases model complexity and potential model bias as not all relevant destination attributes may have been captured in the survey and not all attributes (as e.g. image) can be operationalized in the ABM. On the other hand it increases the accuracy of spatial redistribution of agents in case of a lack of snow as compared to applications where the agents are reallocated to other ski areas based on the nearest neighbour principle (e.g. Pons et al. 2014) neglecting places of residence, travel distances and other important destination attributes.

Our ABM reproduces the distribution of skier visits on a province level very well, whereas aggregated per ski area size and lift ticket price category, the ABM overestimates skier visits in small and cheap ski areas. But, this is not so much an inaccuracy of the ABM itself but might rather indicate a potential stated vs. real preferences bias and/or attitude-behaviour gap of respondents in the skier survey.

Objective 4: To integrate supply-side and demand-side modelling (agent-based model) to analyse the integrated effects of supply- and demand-side adaptations to climate change impacts

Model results show a modest decline of skier visits on the national level (-0.8% in the RCP 8.5 2050s to -20.4% in the 2080s) compared to modelled average shortening of the ski season. One important reason is that ski area size and thus relative market share of the ski areas is neglected in average season length changes. This suggests that supply-side focused analyses of climate change impacts on the ski industry (e.g. Hendrikx et al., 2012; Steiger & Abegg, 2013; Wobus et al., 2017) have a tendency to overestimate impacts in markets with very diverse ski area sizes and vulnerability to climate change – as it is the case for Austria, but also for other market as e.g. the US (Steiger et al., 2017).

Analysing the ABM results aggregated on ski area size revealed losses of skier visits for small and medium sized ski areas to the benefit of larger ski areas. Beside that systematic redistribution of skiers we also identified a very pronounced spatial redistribution with losses and gains of more than 50% on a district level already in the 2030s scenarios. Extrapolating the status quo of snowmaking capacity and coverage, northern districts of Vorarlberg, districts east of Innsbruck and most parts Styria, Upper and Lower Austria face serious declines of skier visits whereas districts in southern Vorarlberg, Western Tyrol and Carinthia might experience considerable gains of skier visits.

Objective 5: To develop and analyse potential development paths of the Austrian ski industry

We defined four development paths of the ski industry based on discussions during three stakeholder workshops with representatives of ski areas and destinations.

When assuming that high risk ski areas are closed permanently, losses of skier visits on the national level are higher than in the status quo path, with ~7% losses in the RCP 8.5 2050s and 45-60% losses in the RCP 8.5 2080s scenario. As the share of high risk ski areas is higher for small and cheap resorts, a permanent closure of these resorts significantly reduces the available number of small and cheap resorts being important destination attributes for some skier segments. Consequently, an increasing number of agents remain unallocated due to missing alternative ski areas. Second, as many of these ski areas are located in day-trip distance to population centres such as Munich, Graz, Linz or Vienna, a closure results in a loss of day-trippers for the entire system.

On a district level, differences of spatial skier distribution become visible between different development paths. If high risk ski areas exited the market, Carinthia and East Tyrol and in some scenarios also the South-West of Styria, attract more skier visits than in the other two development paths.

For the ski industry our CBC results suggest that also smaller and medium sized ski areas are attractive ski destinations, provided that they are competitive with larger ski areas in the other important destination attributes, e.g. snow conditions, snow reliability, travel distance or lift ticket price. The development path with the least negative climate change impact on demand on a national level is DP 1, i.e. maintaining the status quo of snowmaking capacity and lift ticket prices. Though an increase of snowmaking capacity reduces the number of high risk ski areas, it also reduces the number of skier visits due to increasing lift ticket prices.

Concerning the exit of high risk ski areas and the significant spatial redistribution of demand, the role of the public sector will become even more important than today. If high risk ski areas are not operated by private companies anymore, public authorities have to invest into these ski areas and to operate it in order to maintain that offer. Climate change will increase investment and operating costs. As soon as public authorities engage in non-profitable ski areas, questions on the suitability both from a market but also from a climate perspective will arise. Thus policy is challenged to provide a sustainable regional development strategy that is also compatible with national and regional climate change adaptation and mitigation strategy.

The project provided the opportunity to collect important data and to develop the coupled ski season/agent-based model as well as to work interdisciplinary. The successful application of the integrated model motivated the project team to continue the further development of the ABM and also to again team up in future calls for project proposals.

C) Project details

6 Methodology

In CCSBD-AT an interdisciplinary approach was a key prerequisite to investigate the research questions and to face the complexity of climate change impacts on winter tourism. Relevant destination choice attributes had to be included in the survey, but at the same time it had to be ensured that these attributes are either publicly available or that these can be modelled and operationalized in the ski season simulation model SkiSim3 and in the agent-based model. The ski industry development paths defined in stakeholder workshops had to be 'translated' to adjustable variables in SkiSim3 and the ABM.

Segment-specific destination choice preferences identified in the survey were implemented in the ABM (Figure 6). Information on the daily status of the ski areas (e.g. size of open terrain, natural snow conditions as defined in the CBC) were generated in SkiSim3 and exported to the ABM (Figure 6).

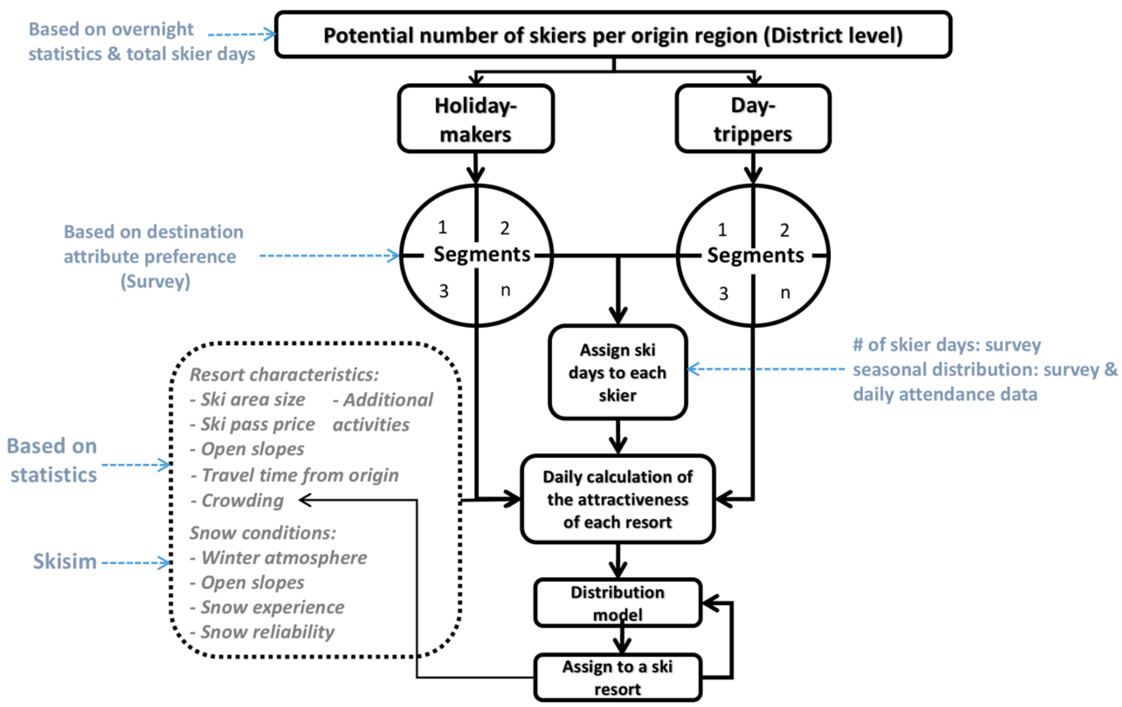

Figure 6: ABM Model flowchart

7 Work- and time schedule

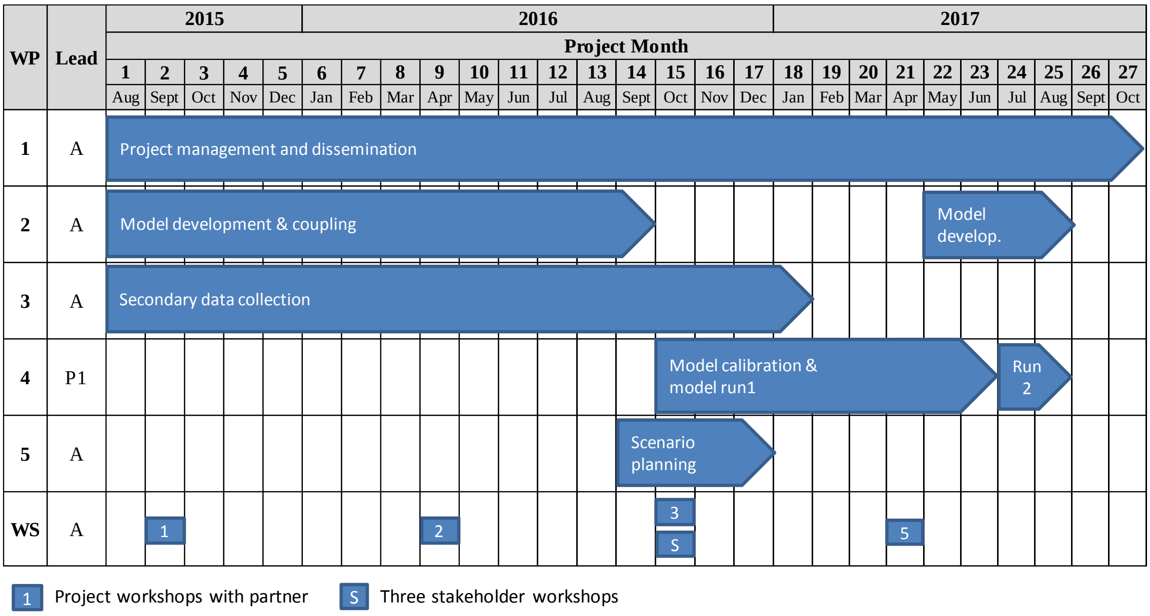

Figure 7: Project work plan

8 Publications und Dissemination activities

Oral presentations

- Steiger, R. (2016): Mainstreaming ABM in tourism research: opportunities and barriers. ABM meets tourism workshop, 18-20.01.2016, Wageningen, Netherlands.
- Steiger, R. (2016): Das Risiko Klimawandel minimieren – Sind Zusammenschlüsse das geeignete Mittel dazu? Bergumwelt 2016, 15.03.2016, Saalfelden, Austria.
- Steiger, R.; Posch, E. (2016): Verhalten und räumliche Verteilung von Wintersportlern in schneearmen Zeiten. Klimatag 2016, 06.-08.04.2016, Graz, Austria.
- Steiger, R. (2016): Limitations of modeling snow in ski resorts. EGU 2016, 17.-22.04.2016, Vienna, Austria.
- Posch, E.; Steiger, R. (2016): Perception and behaviour of ski tourists and consequences for sustainability of skiing tourism. International Conference on Global Tourism and Sustainability, 14.-16.10.2016, Lagos, Portugal.
- Steiger, R.; Posch, E.; Pons-Pons, M.; Vilella, M. (2016): Winter tourists' preferences for destination choice in times of snow deficiency. Consumer Behaviour in Tourism Symposium (CBTS) 2016, 14.-17.12.2016, Bruneck, Italy.
- Steiger, R.; Posch, E.; Pons-Pons, M.; Vilella, M. (2017): Climate Change Impacts on Skier Behaviour and Spatial Distribution of Skiers in Austria. Klimatag 2017, 22.-24.05.2017, Vienna, Austria.
- Steiger, R.; Posch, E.; Pons-Pons, M.; Vilella, M. (2017): No natural snow, no skiing (holi)day? Winter tourists' preferences for destination choice in times of snow deficiency. International Conference of the Society for Skiing Safety (ISSS 2017), 17.04.-22.04.2017, Innsbruck, Austria.
- Posch, E.; Steiger, R.; Pons-Pons, M.; Vilella, M. (2017): Auswirkungen schneearmer Winter auf die wintertouristische Nachfrage in Österreich. Jahrestagung Arbeitskreis für Tourismusforschung, 14.-16.06.2017, Wergenstein, Switzerland.
- Pons-Pons, M.; Posch, E.; Steiger, R.; Vilella, M. (2017): Climate sensitivity of skier behavior and spatial distribution of skiers in Austria. The 1st Workshop on the Future of Winter Tourism (FWT2017), 03.-05.04.2017, Rovaniemi, Finland.

Academic Publications

- Posch, E.; Steiger, R. (2016): Perception and behaviour of ski tourists and consequences for sustainability of skiing tourism. In: Lira, S.; Mano, A.; Pinheiro, C.; Amoeda, R.: Tourism 2016. Proceedings of the International Conference on Global Tourism and Sustainability, p. 305-314.
- Pons-Pons, M.; Posch, E.; Steiger, R.; Vilella, M. (2017): Climate sensitivity of skier behavior and spatial distribution of skiers in Austria. The 1st Workshop on the Future of Winter Tourism (FWT2017), 03.-05.04.2017, Rovaniemi, Finland, p. 141-152.
- Johnson, P.; Nicholls, S.; Student, J.; Amelung, B.; Baggio, R.; Balbi, S.; Boavida-Portugal, I.; de Jong, E.; Hofstede, G.J.; Lamers, M.; Pons, M.; Steiger, R. (2017): Easing the adoption of agent-based modelling (ABM) in tourism research. Current Issues in Tourism, 20(8), p. 801–808.
- Amelung, B.; Student, J.; Nicholls, S.; Lamers, M.; Baggio, R.; Boavida-Portugal, I.; Johnson, P.; de Jong, E.; Hofstede, G.J.; Pons, M.; Steiger, R.; Balbi, S. (2016). The value of agent-based modelling for assessing tourism–environment interactions in the Anthropocene. Current Opinion in Environmental Sustainability, 23, p. 46–53.
- Steiger, R.; Scott, D.; Abegg, B.; Pons, M.; Aall, C. (2017): A critical review of climate change risk for ski tourism. Current Issues in Tourism, p. 1–37.

Publications to the broader audience

- Kennst du deinen Gast? FF 51-52, 2016, p. 26-29.
- Klimawandel ist nicht Ende des Skisports, aber großer Kostentreiber. Mountain Manager 6/2016, p. 2-3.
- Studie: Auch Chancen für kleine Skigebiete. University Innsbruck press release, 05.12.2016.
- CCSBD-AT: Climate Change Impacts on Skier Behaviour and Spatial Distribution of Skiers in Austria. ACRP in essence, 2017, p.
- Wie wirkt sich der Klimawandel auf Verhalten und Verteilung der Schneesportler aus? Mountain Manager 2017.
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