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Impacts of climate change on mountain tourism: a review

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ABSTRACT
Mountain landscapes and communities are highly sensitive and vulnerable to climate change. Tourism in mountain regions is highly dependent on natural resources and attractions which are very sensitive to climatic changes. This systematic review analyzing 276 papers, provides a comprehensive analysis of scientific literature dealing with climate change impacts on mountain tourism. While the impacts on the snow season are predominantly negative, impacts to summer season activities range from positive to negative. Contradictory results and lack of research in some regions and tourism activities means the overall impact is far from clear. We identified seven key knowledge gaps: underrepresentation of studies for South America and Africa, lack of appropriate data and indicators, an all-season perspective and investigation of opportunities, economic and socio-political consequences for mountain communities, the need for better science communication, and a lack of studies addressing liability and regulatory risks. Increasing our multidisciplinary understanding of potential climate impacts on mountain tourism and engaging stakeholders to prepare for the projected changes will help local populations in mountain communities create applicable and effective climate adaptation strategies.

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climate change; tourism; mountain regions; systematic review; adaptation

Introduction

Climate change is widely acknowledged as having profound effects on the mountain cryosphere which will impact local, regional, and global resources. Mountain ecosystems provide essential livelihoods, food security, well-being and cultural identity, yet are facing increasing climate hazards that create significant adaptation challenges (Masson-Delmotte et al., 2021). Defined and typified by the IPCC (Hock et al., 2019 as landscapes with high elevation and steep topography, as well as cold temperatures and remoteness, high mountain regions are highly sensitive to climate change. Similar to amplified warming in polar regions, low temperatures in alpine areas are particularly sensitive to radiative forcing (Ohmura, 2012), which means any increase in atmospheric humidity due to increasing temperatures will drive disproportionately larger warming (Chen et al., 2014). Moreover, as the vertical temperature gradient reduces (Held & Soden, 2006) and the cooling effect of aerosols diminishes (Zeng et al., 2015), warming can be enhanced at

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higher elevations. Further, as snow cover declines with warming, absorption of solar radiation (i.e., snow-albedo feedback) increases, which leads to a rise in surface air temperatures and further snowmelt (Scherrer et al., 2012).

Over 671 million people live in high mountain regions (approximately 10% of the global population) (Jones & O'Neill, 2016) which are highly vulnerable to climate change (Carey et al., 2017; Rasul & Molden, 2019). These mountain communities, particularly within developing countries, face barriers that limit their ability to cope with climatic impacts due to lower incomes and restricted opportunities to diversify local livelihoods (McDowell et al., 2013). Historically, high mountain communities access production zones at different elevations for both agricultural yields and pastoral livelihoods, but cryosphere changes are influencing mobility and migration by altering resources (e.g., availability of freshwater influenced by snow and glacier melt) and increasing exposure to hazards (e.g., snow avalanches, landslides, rock falls, rain-on-snow floods) (Hock et al., 2019). To provide supplementary income, wage labor migration has subsequently increased, with returns to agricultural labor declining as household members impacted by climate change seek employment opportunities in urban or lowland areas (e.g., Parveen et al., 2015). Given the often remote and rugged location of mountain communities, outdoor recreation and tourism can provide an opportunity to aid economic diversification, generating employment and income for residents while simultaneously supporting local cross-sector industries that collectively help combat local population losses (Keller, 2018).

Mountain tourism has the advantage of attracting diverse year-round visitors through a range of activities, including mountaineering, hiking, biking, and snow sports (skiing, snowboarding, sledding) (Romeo et al., 2021). Interestingly, the unique factors that limit opportunities for economic development in high mountains is what attracts visitors to these regions (e.g., nature, wilderness, topography, remoteness, climate conditions). As a labor intensive sector with several links across the economic value chain, investments in tourism-related facilities (e.g., transportation infrastructure, restaurants, hotels, spas, sports facilities) can valorize mountain resources by attracting visitors to mountain destinations (Keller, 2018). However, given that mountain tourism facilities and activities rely on alpine climate, topography, scenery and seasonal cycles, climate change is and will continue to impact both current and future tourism development in mountain regions with associated impacts on the quality of life for residents in tourism-dependent mountain communities (Scott et al., 2012b).

Previous reviews of the existing literature provide a global overview (e.g., Scott et al., 2012b; Becken, 2013; Scott, 2021), regional analysis (e.g., Hall & Saarinen, 2021; Pröbstl-Haider et al., 2021; Steiger et al., 2021) activity-specific insights (e.g., skiing Gilaberte-Burdalo et al., 2014; Steiger et al., 2019) or bibliometric analyses to identify key contributors, collaboration networks and subject areas (e.g., Fang et al., 2018; Scott & Gössling, 2022). This literature concludes that climate change will lead to temporal and geographic shifts in tourism demand, and environmental change affecting natural resources relevant for tourism and destination competitiveness (Scott et al., 2012a). The growth of scientific literature is making tourism more prominent within the IPCC reports (Scott et al., 2016) and leading to broader, more diverse and multidisciplinary research. However, to our knowledge, there is no global review on climate change impacts focusing on mountain tourism with its variety of tourism activities in both the summer and winter season.

Using a systematic literature review, this paper demonstrates the existing state of knowledge on how climate change has and may impact mountain tourism destinations over a range of climate futures. In doing so this paper also highlights the gaps in our understanding of mountain tourism within a changing climate and suggests regions, topics and methodologies which may help the sector and stakeholders prepare and plan for the impending impacts of climate change.

Method

Our search strategy identified papers in the Web of Science Core Collection using the search terms "climat* chang*" and "touris*" plus specific keywords for geographical regions, mountain

Figure 1. Number of papers found and finally included.

ranges, or mountain tourism activities within the fields Topic, Title, Abstract, Keywords Plus, and Author Keywords. All searches specifically addressed mountain tourism, either via including the word "mountain*" for geographical regions, the name of a mountain range, or the name of a mountain-based tourism activity like trekking or skiing. The deadline for inclusion was November 30, 2021.

We scanned titles and abstracts, and where necessary the full text of 794 papers (Figure 1), to decide whether to include or exclude each paper based on three criteria: (1) Articles focused on mountain tourism or tourism in a mountain region. (2) Articles related to climate change and tourism. This means papers were excluded, that, for example, tried to explain how climate change *and* tourism development affect a certain region, but without investigating interrelationships between the two topics. (3) Articles that included empirical or theoretical findings on the issue. Consequently, editorial papers were excluded. With the search terms, only a small selection of papers discussed climate change mitigation in mountain tourism, which were excluded as it is not the focus of this paper.

Results

The 276 reviewed publications on climate change and mountain tourism fell into three strands of literature with 151 (54%) focusing on the winter season, 82 (30%) on the summer season and 43 articles (16%) that include all tourism seasons. Figure 2 demonstrates the three fields displayed similarly low numbers of articles until 2005. After 2005, the number of winter season publications grew quickly, with more than seven papers published annually between 2005 and 2015, on average. Simultaneously, the average number of summer season papers published was only slightly above three. After 2015, summer season publications started to catch up with an average of almost nine yearly publications. The mean publication number for the winter season at the same time was just over 11. In the last three years, similar publication numbers were observed for both seasons. The yearly number of all-season publications remained constant throughout the entire time period, with a slight decrease since 2017.

Table 1 and Table 2 (Appendix) illustrate the articles' geographical distribution. Articles were localized according to the regions and destinations researched, with articles featuring multiple countries counting for each of the countries. When counting the papers per continent, most multiple-country papers were assigned to one of the continents, except a dozen that were counted separately as "Multiple Continents", see Table 1.[1] By far the largest number of publications focused on Europe with 155 out of 276 papers (56%). Within Europe, the most represented country in our review was Austria with 50 references, followed by Germany (27) and Switzerland (22). North America followed Europe in publication output, wherein 30 papers examined the United States and 21 investigated Canadian mountain contexts. Thus, the US ranked as the second-most featured country after Austria. Australia - Oceania and Asia have been covered by a substantial number of papers (28 and 26 papers respectively). In Asia, the most researched country was Nepal (10), followed by China (9). In Australia – Oceania, 20 papers studied Australia and

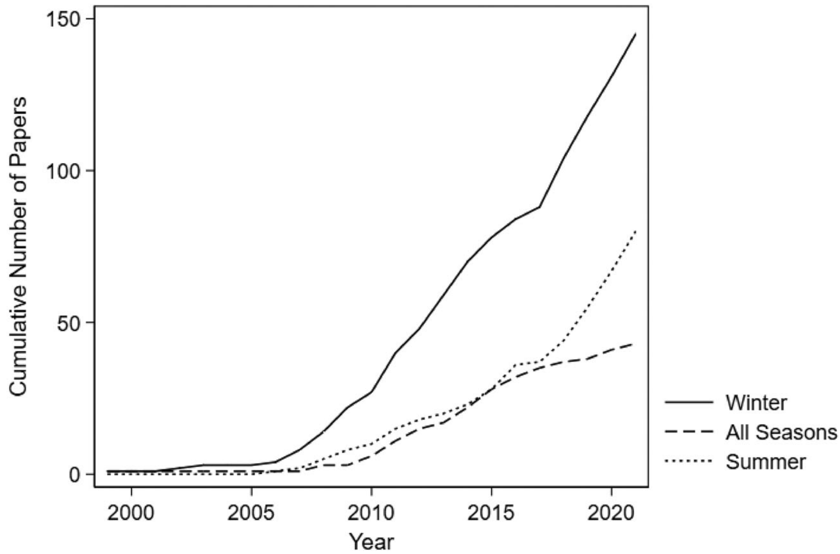

Figure 2. Cumulative number of papers, development by year, n = 276 (Winter n = 151, All Seasons n = 43, Summer n = 82), papers included until Nov 2021.

Table 1. Number of papers by continents.

Continent	n	share
Asia	26	9%
Africa	3	1%
Europe	155	56%
South America	7	3%
North America	44	16%
Australia - Oceania	28	10%
Multiple Continents	13	5%
Total	276	100%

13 New Zealand. South America and Africa have both been underrepresented in the literature about climate change and mountain tourism, even though a third of the 50 most mountainous countries are in Africa and seven of them are in South America, the same number as in well-studied Europe (Central Intelligence Agency, 2011). This highlights a key regional knowledge gap that needs to be filled.

Table 3 shows 68% of reviewed articles used some type of quantitative method, while 22% used a qualitative method and 10% a mixture of qualitative and quantitative methods. Within the qualitative research, many different methods were used, ranging from a historical event analysis to ethnography to a method focusing on social relations. Only two qualitative methods appeared in more than five of the reviewed papers: interviews and focus groups. Regarding quantitative methods, econometric models using regressions with secondary data were used most often, followed by surveys and climate data analysis. The latter are studies where indicators were produced that investigated climate suitability for tourism.

Throughout the literature, three major themes emerged across publications, geographic region, and methodology including: (1) the weather-mountain tourism nexus, (2) impacts of climate change on mountain tourism, and (3) climate change adaptation in mountain tourism destinations. The detailed results, analysis and discussion for each of these themes follows, including a comparison between winter and summer mountain tourism activities and destinations, and sub-focus areas within each major theme.

Table 3. Number of papers by method.

Method Category	n	share	Method	n	share
Quantitative	188	68%	Agent-Based Models	6	2%
			Analogue Approach	6	2%
			Choice Experiment	9	3%
			Climate Data Analysis	61	22%
			Econometric Analysis	45	16%
			Survey	49	18%
			Other/Multiple	12	4%
Qualitative	60	22%	Literature Review	11	4%
			Focus Groups	6	2%
			Interviews	22	8%
			Other/Multiple	21	8%
Mixed Methods	28	10%	Mixed Methods	28	10%
Total	276	100%	Total	276	100%

The weather Mountain tourism nexus

Mountain tourism is among the most weather sensitive forms of tourism (Kubokawa et al., 2014). Weather can be both an enabling and limiting factor for leisure activities (Scott & Lemieux, 2010), since specific climatic conditions provide the basis for some activities and attractions (e.g. snow for skiing, glaciers as attractive landscape feature). Furthermore, one or more weather variable may influence tourist comfort during some mountain tourism activities thereby potentially affecting visitor numbers (de Freitas, 2003). Climate change will alter the probability of required or comfortable weather conditions and thus also affect destinations' suitability for specific activities, forms of tourism and consequently tourist behavior (Scott et al., 2012a).

For mountain destinations in summer, rain was found to be the most important climatic factor in the European Alps, Canada and New Zealand, followed by sunshine duration (Scott et al., 2008b; Steiger et al., 2016). Conversely, mountain tourism in Sweden and different mountain national parks in the US are mostly influenced by temperature (Scott et al., 2007a; Scott et al., 2008b; Buckley & Foushee, 2012; Smith et al., 2018). The review finds that the ideal temperature for green season mountain tourism ranges from 20.5 °C (Scott et al. (2008b) to 25 °C (Steiger et al. (2016), with Smith et al. (2018) noting a decline in tourism numbers above 25 °C. This range is one to six degrees lower than for beach tourism. On Mount Ainos in Greece, these ideal biometeorological conditions in summer occur predominantly in the lower mountain below 1300 m and in the mornings and evenings (Maniatis et al., 2020). With impending climate change it may be important to research which regions, including altitudes and temporal variance, may move outside of those ideal temperature ranges and conversely which regions may begin to experience these biometeorological conditions, and the resulting shifts in tourist patterns.

Understanding changing tourist patterns may include multiple factors both in terms of climate impact and tourist behavior as for example, exceptional droughts were found to severely impact visitor spending in the northern Rocky Mountains (Jedd et al., 2018). Weather conditions can also induce short-term or spontaneous decisions to travel, or to change travel plans. In Germany's Bavarian Alps, good weather conditions and short-term forecasts increase the number of short trips in summer and fall while long trips are extended when bad weather conditions occur (Bausch et al., 2021). Extraordinary hot weather, especially in urban heat islands, represents a potential for increased demand for cool stays in the mountains at higher altitude. For Switzerland, Serquet and Rebetez (2011) revealed a significant correlation between hot temperatures at lower elevations and overnight stays in mountain resorts. It is unclear from this review, whether these weather-travel behaviour correlations in summer mountain tourism environments are transferable beyond the area and context of each study because there lacks replication.

Results demonstrated a clear trend in winter mountain tourism wherein the most dominant weather influence is snow availability. Natural snow depth was found to have a statistically significant positive impact on overnight stays (Töglhofer et al., 2011; Falk, 2013b; Falk & Lin, 2021), on visitation in ski areas (Shih et al., 2009; Falk, 2015; Falk & Vieru, 2017) and also affected the cancellation ratio in sports competition events such as cross-country skiing (Falk & Hagsten, 2017). However, the magnitude of the effect was site-specific (Shih et al., 2009) for example, this relationship was found to be not significant (Falk, 2010), or negative (Töglhofer et al., 2011) in Austria's high-elevation resorts. This can be explained by these resorts' relative competitive advantage over competitors due to usually better snow conditions, especially in snow-scarce winter seasons. Whereas in Australia, demand declined by 38% in a winter representative of a low emission future in the 2050s (Pickering, 2011) and in the US, Canada and Austria, total demand in ski areas in a winter representative of a high emission future in the 2050s declined by 10-11% (Dawson et al., 2009; Steiger, 2011; Rutty et al., 2017). In the latter studies, demand losses were higher in low altitude and small sized ski areas. However, a shift of booked holidays away from mountain to other destinations could not be detected for Austrian travelers (Falk & Hagsten, 2018).

Snow depth was also found to affect ski area profitability, with differing implications depending on the destination, place of origin, tourist demographics, and the timing of snowfall. At one end of the spectrum reduced snowfall has led to the closure of predominantly small ski areas in New England (Beaudin & Huang, 2014). At the other end, no significant correlation between natural snow depth and lift ticket price was found for a case study ski area in Serbia (Joksimovic et al., 2021). While snow reliability of ski areas highly correlated with the share of high-altitude ski slopes (e.g. $r^2=0.74$ in France) (Francois et al., 2014), high elevation ski areas had a higher profit rate: in Austria, ski areas with a maximum elevation above 2300 m had a four percentage point higher profit rate and the debt-to-capital ratio was largest for ski areas between 1350 and 1700 m (Falk & Steiger, 2018). Nevertheless, ski area size (in terms of ski slope length) had the greatest effect on profitability (Moreno-Gene et al., 2018; Falk & Steiger, 2020; Moreno-Gene et al., 2020). This suggests that higher elevation ski areas are not only less exposed to climate change impacts but might also have a higher (financial) capacity to adapt to climate change. Snow conditions in the source market can positively affect skier visits, a phenomenon termed the 'backyard effect' (Hamilton et al., 2007). Overnight stays by domestic tourists were found to be more sensitive to fluctuations in snow depth than by foreign tourists (Falk, 2013b), and tourists from neighboring countries were more sensitive than tourists from more distant source markets (Falk & Vieru, 2019). From a temporal perspective, snow was more important for lift ticket sales early in the season (November, December) (Falk & Hagsten, 2016).

The positive relationship between natural snow and tourism demand has declined in magnitude over time though, as shown for tourist accommodations (Töglhofer et al., 2011; Falk & Lin, 2018a, 2021), skier visits (Falk & Lin, 2018b) and athletes' cancellations at sports events (Falk & Hagsten, 2017). In Austria, early snowmaking adoption has led to a significantly lower business failure risk (Falk, 2013a). Evidence for France shows that in small to medium-sized ski areas, investments in snowmaking were significantly higher after extraordinary snow scarce winters, while this effect was not visible for larger ski areas (Berard-Chenu et al., 2021). The positive effect of snowmaking on ski visits was found to differ depending on elevation: while skier visits in higher elevation ski areas benefited from snowmaking, in lower elevation ski areas (<1770 m weighted average of all ski lifts) this effect was only significant in snow-poor winter seasons (Falk & Vanat, 2016). The benefit of using snowmaking was quantified in a study with a sample of Swiss ski areas, where demand in ski areas with 30% of ski slopes covered with snowmaking was less sensitive (by 39%) to natural snow depth than ski areas without snowmaking (Gonseth, 2013). Conversely, an analysis for Spain revealed that the share of ski slopes equipped with snowmaking does not have a significant influence on profits, suggesting that the benefit of more reliable and longer seasons is countered by high investment and operating costs of snowmaking facilities (Moreno-Gene et al., 2020).

Besides snow, temperature also affects winter tourism. Shih and Nicholls (2012) found that a higher maximum daily temperature positively affected tourism traffic and that this effect was even more pronounced in winter than in other seasons. Conversely, cooler temperatures, more snow and poorer air quality in the city lead to increased travel to two canyons in Colorado (Zhang & Smith, 2018). In summer glacier skiing, higher temperatures (represented by the wind-chill factor combining temperature and wind speed) had a positive impact on skier visits (Mayer et al., 2018). However, overly high temperatures can also have the opposite effect, as shown for skier visits in Norway (Malasevska et al., 2017; Malasevska & Haugom, 2019). A plausible reason for this reverse effect is that snow conditions deteriorate with higher temperatures and might thus negatively affect visitor experiences. This suggests there is a possible temperature threshold for winter mountain tourism or ideal temperature range for winter mountain tourists which has not yet been studied as it has for summer (Scott et al., 2008b; Steiger et al., 2016; Smith et al. (2018) and would similarly be valuable to identify which regions or temporal patterns may shift towards or away from as climate change accelerates.

Impacts of climate change on Mountain tourism

Summer season

As climate change accelerates, tourism practitioners often assume warmer weather and longer summer seasons will result in a simple shift to increases in summer mountain activities (Hadwen et al., 2011; Walters & Ruhanen, 2015; Gilani et al., 2018). Some studies, particularly across Europe demonstrated this summer tourism season extension (Endler & Matzarakis, 2011b; Marshall et al., 2018; Pröbstl-Haider et al., 2021). However, this review of existing climate research focused on nature-based tourism in mountain regions across the world, including but not limited to, hiking and trekking, climbing, biking, bird and wildlife viewing, and camping, demonstrates that the impacts are wide-ranging, multifaceted and non-uniform in terms of both impact type and severity.

The major themes identified in the literature for summer tourism in mountain environments are shifting seasonality, climate attractiveness, and resulting visitation; accessibility and hazards; landscape attractiveness and biodiversity; and adaptation and engagement.

Seasonality, climatic attractiveness & resulting visitation

Climatic conditions for tourism in the summer seasons are likely to improve in some mountain destinations while negatively impact others. Two German destinations showcase how the positive effect is pronounced in higher mountains as heat stress is not an issue and cold stress is reduced (Endler et al., 2010; Endler & Matzarakis, 2011b; Miszuk et al., 2016). Another potentially positive effect of temperature changes noted in mountains was the extension of the summer season into spring and autumn (Endler & Matzarakis, 2011c; Matzarakis et al., 2012b; Marshall et al., 2018; Pröbstl-Haider et al., 2021). Conversely, in the Nepalese Mt. Everest region 72% of interviewed households thought that changing weather patterns resulting from global warming will hurt the tourism business in the long run (Poudyal et al., 2021), although short-term impacts on tourism were perceived as positive (Anup & Parajuli, 2015). Liu et al. (2021a) used GPS data from hikers to model the relationship between hikers and weather, and projected these patterns onto future climate scenarios. When applying the RCP 4.5 scenario, they estimated the hiking duration to drop over seven percent by 2050. This negative effect became even larger under RCP 8.5 scenarios. Buckley and Foushee (2012) also found shifts in peak attendance in some US National Parks that were attributed to climatic changes.

A substantial future rise in summer overnight stays is expected for mountain destinations in a North-Italian destination in the RCP 4.5 scenario based on demand modelling. This effect could even become larger, when accounting for socioeconomic trends (Cavallaro et al., 2017). Pröbstl-Haider et al. (2015) also suggested implementing those findings when advertising for destinations in the European Alps, as many potential tourists still view these mountains as rainy and cold. Similarly, Scott et al. (2007a) modeled climate change in Canada's Waterton Lakes National Park which demonstrated an increase in annual visitation up to 36% by the 2050s. Coupling the modeling with a visitor survey, Scott et al. (2007a) found that environmental change would have minimal influence on visitation based on high and low carbon climate scenarios up to 2050. However, by 2080 under RCP8.5, 19% of survey respondents felt they would no longer visit and 37% would visit less, suggesting extreme climate change will have a severely negative impact on summer mountain tourism in this region.

Mountain areas could also gain attractiveness in providing heat escapes from nearby cities experiencing extreme heat days with global warming. Using surveys, focus groups, workshops, and a theory of planned behavior (TPB) model, two articles from Austria found that the escaping behavior from heat waves into refreshing mountainous areas is likely to increase (Juschten et al., 2019a) and that the intention to visit such destinations is mainly influenced by a combination of social and subjective norms (Juschten et al., 2019b). In Iran, where the mountainous regions at the Zayandehroud River route already provide a heat escape for tourists today, this possibility is threatened by climate change (Yazdanpanah et al., 2016).

Tourism infrastructure, accessibility, and natural hazards

Key summer attractions in mountain tourism destinations are already affected by increasing risk of natural hazards and altered accessibility, both consequences of global warming. In Portugal's Madeira Island, unique hiking paths on water canals have been closed due to safety reasons related to more frequent heavy rain events which as main attractions to the island, might lead to fewer visitors (Fernandes, 2016). In the alpine, glacier retreat and melting permafrost is steepening ice and rock slopes and destabilizing moraines. As a result, the risk for debris flow, rock falls, ice collapses, and glacier lake outburst floods increase and more debris is accumulating on the glacier surface (Purdie et al., 2015; Mourey et al., 2019; Correas-Gonzalez et al., 2020). These hazards have increased the risk for tourists participating in activities such as climbing and mountaineering and have the potential to damage and destroy important tourism infrastructure such as trails and access roads (Nyaupane & Chhetri, 2009; Hoy et al., 2016; Tuladhar et al., 2021). This is confirmed by a visitor survey which showed that landslides are considered the most threatening consequence of climate change in mountain destinations (Liu et al., 2021b). Pröbstl-Haider et al. (2016), while analyzing risk perceptions of Austrian summer tourists, found that glacial retreat and related natural hazards like rock fall will increase risks for tourists, particularly for experienced mountaineers who are more willing to take risks in the first place.

Glacier accessibility is affected as well, according to mountaineers in France and tourism stakeholders in New Zealand, as climate change increases route difficulty on and to the glacier (Moreau, 2010; Purdie et al., 2020). Mourey et al. (2019) found that more than two thirds of the access routes to high mountain huts in France were impacted by glacier shrinkage and about one third were affected by permafrost degradation or periglacial processes. Changes in glacier formation and resulting poorer accessibility has been shown to decrease visitor numbers as many are not willing to visit glaciers with increased walking times or the necessity to use commercial transportation means (Welling et al., 2020). On the other hand, glacier shrinkage also opens up new routes for trekking and hiking, as shown for the tropical Andes (Vuille et al., 2018). The climatic concerns for visitor safety and accessibility are multifaceted and linked, and reduction of some risks (e.g. melting glaciers opening up non-glacial travel routes) may exacerbate other risks (e.g. permafrost melt, landslide and debris flow), suggesting research is required on a case by case basis.

Biodiversity and landscape attractiveness

Rapid temperature increases and snow cover declines due to climate change have phenological, temporal, and geographic impacts to flora and fauna in alpine ecosystems (Theurillat & Guisan, 2001). These interrelated changes emphasize the linked climate and biodiversity crises that directly impact summer nature-based activities in mountain destinations. Climate change affecting alpine species ranges, habitats and behavior, for example invasive species, is resulting in increasingly unfamiliar ecological contexts within which tourism operates (Knowles, 2019). Arnberger et al. (2018) and Weber et al. (2019) highlighted how ecological integrity is important to tourists and tourism operators. However, Buckley and Foushee (2012) and Sato et al. (2013) noted that recreation ecology impact research is currently not sufficient nor keeping pace with increases in summer usage (Ballantyne et al., 2014), the introduction of new high impact activities such as all-terrain vehicles or with mountain resorts developing four-season activities (Morrison & Pickering, 2013a; Walters & Ruhanen, 2015; Gilani et al., 2018). For example, the results from Ballantyne et al. (2014) showed that with increasing temperatures and declining snow cover across the Australian Alps there may be colonization by competitive vegetative species that may be impacted negatively by hiking trails and requisite trampling. In some regions in Japan, biodiversity concerns were found to be more important than the climate crisis, when asking conservationists (Chakraborty, 2020a).

Tourism and climate change both increase pressure on already stressed water systems in mountain areas across the world ranging from the Al Jabal Al Akhdar Resort in Oman (Al-Kalbani et al., 2016), the Himalaya-Hindu Kush region (McDowell et al., 2013; Sherpa et al., 2019; Muller et al., 2020), the Andes (Bury et al., 2011; Chevallier et al., 2011) and the Rocky Mountain region (Pederson et al., 2006). The most significant threat noted in these cases is that (foreign) tourists have high water demands, that existing water sources can hardly supply. In contrast with the above examples which demonstrated that used resources like water and air will be harmed by climate change, Schmude et al. (2021) found that climate change will have no negative influence on the natural resources necessary for nature-based alpine health tourism attractions including healing tunnels and thermal water sources. This suggests the impact of climate induced natural resources used by tourism might differ for various types of tourist activity and the ecology within which tourism exists.

Beyond the impact to biodiversity and use of natural resources, nature as a tourism asset is at risk to climate change. Arnberger et al. (2018) survey results demonstrated that visitors across the USA and Germany prefer healthy and mature forests while two studies (Cahyanto et al., 2018; Perry et al., 2018a) in the Appalachian Mountains of North America noted that climate induced outbreaks of pine beetle will have negative implications for hiking and other nature-based activities. Similarly, Inglis and Vukomanovic (2020) modelling climate impacts on aspen distribution found that aspens are expected to decrease overall yet increase in low elevation areas and areas visible from scenic byways which may hold implications for hiking, biking and other scenic nature viewing tourism patterns. As forest fire risks increase due to climate induced drought and extreme temperatures, some mountain tourism infrastructure will be in greater direct fire risk, while mountain tourist experiences may be indirectly impacted by smoke inhibiting tourist health or views and vistas or access closure to areas for safety concerns (Sanders & Laing, 2009). In Annapurna (Nepal), tourism operators were concerned that reduced snow cover will decrease landscape attractiveness (Konchar et al., 2015), an issue also confirmed by residents in Tibet (Wang & Qin, 2015).

For glacier tourism, the review found contradicting impacts of climate change. While Salim et al. (2021a) detected solely negative impacts of glacial retreat on tourism at the Mer de Glace in France, Purdie (2013) found that Tasman Glaciers melting led to the increasing size of a proglacial lake that is opening up more opportunities for summer tourism. A concept that might further increase the willingness to visit glaciers is *Last Chance Tourism* wherein visitors are keen to visit the glaciers before they are gone (Stewart et al., 2016). A study on glacier tourism on Yulong Snow Mountain in China found that visitor numbers have increased substantially despite a marked glacier retreat (Wang et al., 2020). However, it was not clear if this can be attributed to last chance tourism or to tourism development. Last chance tourism motivations are currently not among the most important motives for visiting glacier areas when studying TripAdvisor comments and conducting interviews among visitors (Lemieux et al., 2018; Salim & Ravanel, 2020; Abrahams et al., 2022).

Two studies assessed how well glacier visitors are aware of climate change. They came to the conclusion that tourists know a lot about the impacts of climate change on glaciers but are often not able to identify them in the landscape (Moreau, 2010; Garavaglia et al., 2012). Conversely, Groulx et al. (2017) found that fewer tourists find glacier landscapes attractive when they show impacts of climate change. Many glacier sites also try to educate people about the impacts of climate change, examples are the Mimisbrunnr Climate Park in Norway, the Stubai Glacier in Austria, and the Route of Climate Change in Peru's Huascarán National Park (Vistad et al., 2016; Rasmussen, 2019; Carver & Tweed, 2021). Another interesting finding in glacier tourism was the cognitive dissonance of tourists that "know they contribute to climate change and agree with natural conservation but travel long distances to see glaciers" (Salim & Ravanel, 2020, p.15). This is carried to the extreme when aircraft flights are used to see glaciers in New Zealand because walking access has become more difficult due to climate change (Stewart et al., 2016; Purdie et al., 2020). Research from Jasper National Park in Canadafurthermore showed, that many glacier visitors were not willing to offset their journey's carbon footprint (Groulx et al., 2019). Vander Naald (2020) asked visitors of Mendenhall Glacier in Alaska in a choice experiment how much they would be willing to pay for shrinkage mitigation measures. Implementing the measures would result in best-case degradation of 0.15 m^3 per year. Conversely to Groulx et al. (2019), they found that tourists are willing to pay over $600 per year for such a purpose.

Winter season

Impacts on winter tourism are expected to be predominantly negative for snow-based forms of tourism (Steiger et al., 2019), whereas for non-snow- and ice-dependent activities, climate change may as well hold some potential by reducing cold stress (Matzarakis et al., 2012b; Nizic & Grdic, 2018). As snow and ice provide the physical basis for important winter activities, key themes of the literature included the climate change impacts on these resources, the potential demand response or reduced quality and potential interrelationships between supply and demand-side reactions.

Physical impacts

The first climate change assessments for mountain winter tourism were published for ski tourism in the 1980s in Canada, followed by other major ski tourism markets (e.g. US, Austria, Switzerland) in the 1990s (Steiger et al., 2019). These so-called 1st generation impact studies (Steiger et al., 2019) showed that climate change will pose a serious threat to ski tourism in the 21st century due to shortening ski seasons and deteriorating snow reliability of ski areas (e.g., Breiling & Charamza, 1999). An increasing societal and economic relevance of the topic due to snow scarce winters and existing limitations of 1st generation studies, e.g. inappropriate indicators, too coarse temporal and spatial resolution of input data and results, and the omission of snowmaking (Steiger et al., 2019), provided the ground for a broad range of innovations.

Snowmaking, a technology to balance variability of natural snow availability and to improve season planning (Steiger & Mayer, 2008) was first incorporated in climate change assessments with the SkiSim model developed and applied in Canada (Scott et al., 2003) and marks the emergence of 2nd generation studies. Other applications that used different methodologies to include snowmaking followed in Austria (Mayer et al., 2007) and Australia (Hennessy et al., 2008). In some studies the climatic suitability for snowmaking to reach the minimum required snow depth is analysed but not integrated in the snow model and thus does not consider technically produced snow melt (Hennessy et al., 2008; Rixen et al., 2011; Hendrikx & Hreinsson, 2012; Demiroglu et al., 2016). One of the most applied models SkiSim 2.0 (Steiger, 2010) used a standard set of output indicators, allowing comparison of the vulnerability across and within different ski markets. For example, (Scott et al., 2015; Scott et al., 2019b) investigated the suitability of former host locations of the Winter Olympic Games and Paralympic Winter Games finding that 13 of 21 locations of the Winter Olympic Games and 10 of 21 locations of the Paralympic Games are projected to remain snow reliable until the 2050s. Applications in Scandinavia revealed that higher snow reliability in Norway (Scott et al., 2019a) and Sweden (Rice et al., 2021) compared to the European Alps might provide a competitive advantage for the later part of the 21st century. However, additional factors such as accessibility and limited winter daylight at high latitudes represent obstacles for realizing this potential climatic advantage (Demiroglu et al., 2020).

Several innovations have been introduced in 2nd generation studies in the last two decades and can be summarized in three categories. 1) Snow model improvement and better skiing terrain representation, e.g. ski slope grooming (Scott et al., 2003), slope aspect (Spandre et al., 2019a; Steiger & Scott, 2020), considering the difference between natural and man-made snow properties (Spandre et al., 2019b), and detailed simulation of single snow guns in the model (Damm et al., 2014). 2) New output indicators to better address the industry's information needs, concerning changing snow reliable skiing terrain (Steiger & Trawöger, 2011; Scott et al., 2019c), probability of operations during economically important Christmas holidays (Dawson & Scott, 2007), crowding (Scott et al., 2021), inter-seasonal variability (Scott et al., 2020a; Willibald et al., 2021) and including weather comfort as an additional factor (Berghammer & Schmude, 2014; Demiroglu et al., 2021). For a recent review and discussion of indicators for ski tourism see Abegg et al. (2021). A recently published visualization app covering Europe (Morin et al., 2021) included several indicators for the public and potential end-users. Such climate services improve the database for this sector's adaptation. 3) Integrating additional external factors in climate change risk assessments, such as regional dependence on ski tourism (Steiger & Scott, 2020), or the integrated effect of demographic and climate change (Steiger, 2012; Witting & Schmude, 2019).

Climate change is also considered as important location factor for emerging markets, such as China, where numerous new ski areas are planned to stimulate demand (Fang et al., 2021). Here, potential new ski destinations are evaluated based on climate change impacts on snow availability in combination with factors such as distance to populations centers, accessibility and vegetation coverage (Deng et al., 2021).

Despite different methodologies used, common findings of 2nd generation studies can be summarized as follows (Steiger et al., 2019): when including snowmaking, climate change impacts are considerably smaller than assessments where only natural snow is included (Steiger & Abegg, 2013; Scott et al., 2019a). However, resource use (water, energy) for snowmaking will considerably increase (e.g. Scott et al., 2007b; Steiger & Stötter, 2013). Limited water availability and potential water-use conflicts have already been recognized (Pickering & Buckley, 2010; Hoogendoorn et al., 2021) and were addressed by two studies on the catchment scale (Vanham et al., 2009; Gerbaux et al., 2020). Analysis of water losses (7-35%) during snowmaking due to wind drift and sublimation (Grunewald & Wolfsperger, 2019) suggest that climate change impact assessments likely underestimated snowmaking water demand as water losses have so far not been considered in those assessments. In many (but not all) ski markets, skiing will still be possible with snowmaking at the end of the 21st century in a high emission future (Steiger et al., 2019). However, climatic limits will be exceeded at locations where temperatures become too warm to produce snow and water resources limit snowmaking capacity (Schmidt et al., 2012;

Pons et al., 2015). Financial and climatic limitations will shape competition in an already highly competitive environment and will ultimately lead to a complex set of relative winners and losers (Scott et al., 2020b), reducing the number and spatial distribution of ski areas within ski markets. Relative vulnerability, i.e. skiing condition evaluation in comparison to competing markets, needs to be considered when assessing the ski tourism industry's viability (Hopkins et al., 2013).

Despite the progress made in the last two decades to represent more complex environmental conditions in models and more appropriate output indicators required by the tourism industry, studies limited to the 1st generation lens are still published (Uhlmann et al., 2009; Sauter et al., 2010; Hendrikx et al., 2013; Campos Rodrigues et al., 2018; Chin et al., 2018; Joly & Ungureanu, 2018). Other approaches such as tourism indices (e.g. TCI, Noome & Fitchett, 2019), the weather suitability index (Miszuk et al., 2016) and the PET (Endler & Matzarakis, 2011a, 2011c; Matzarakis et al., 2012a) are unable to quantify the potential impact on the industry and do not consider snowmaking as option to reduce climate risks.

For activities other than downhill skiing, only few assessments of climate change's physical impacts exist. Tervo-Kankare et al. (2013) find that a snow landscape is very important for tourists in Rovaniemi (Finland) and the majority would not visit the place in the absence of snow. Therefore, rebranding the destination may be necessary in the future. For snowmobiling, conditions are projected to decline, especially as snowmaking is not considered feasible for this activity (Scott et al., 2008a; Tercek & Rodman, 2016). Cross-country skiing, dog sledding, ice sports and reindeer activities were found to be negatively affected by high temperatures and lack of snow (Tervo, 2008; Schrot et al., 2019). However, in high latitude regions, snow-related tourism enterprises perceived extreme events such as cold spells and strong winds as a greater challenge than warming (Tervo, 2008).

Demand-side impacts

Snow reliability (including snowmaking) was found to be the most important factor for choice of a ski destination (Steiger et al., 2020), although the importance seems to decrease with older respondents (Bischof et al., 2017; Wölfle et al., 2018). Despite the fact that tourism demand's dependence on natural snow has decreased according to revealed preference studies (see Ch. 3.1), it is still a factor that can lead to dissatisfaction (Bausch et al., 2019). Yet, tourists lowered their expectations when informed about unfavorable conditions leading to more positive attitudes toward the destination (Scholl-Grissemann et al., 2020). When faced with unwanted weather/snow conditions, winter tourists' capacity to adapt is diverse as they can substitute spatially, i.e. ski at a different place with sufficient snow, temporally, i.e. ski when there is snow, or substitute the activity (Landauer et al., 2009; Dawson & Scott, 2010; Dawson et al., 2011). A survey with German tourists found that willingness to adapt travel behavior to unfavorable weather conditions is higher for winter (73% of respondents) than for summer tourists (54%) (Schwirplies & Ziegler, 2017). .

In case of lack of snow, ski tourists tend to book later to evaluate the actual snow conditions (Pröbstl et al., 2008) and favor spatial substitution (Unbehaun et al., 2008; Cocolas et al., 2016), or temporal substitution (Pickering et al., 2010; Rutty et al., 2015a). A reason for differing substitution types in these studies might be the availability of substitutes within acceptable travel distance in the investigated markets (Austria, Eastern Canada, Australia). Activity substitution was the least preferred option in most studies (Steiger et al., 2019), however, it was found that overnight guests were more likely to switch to different activities than day guests (Witting et al., 2021). The type of substitution behavior also differed depending on skills, with expert skiers choosing spatial substitution more often and beginner skiers more likely to stop skiing altogether (Rutty et al., 2015a; Cholakova & Dogramadjeva, 2019). Furthermore, the total number of skiing days per season is also likely to decline: if the usual ski area was permanently closed, 43% of respondents in a study in Canada would halve their number of skiing days, and another 35% would cut it by 75% (Rutty et al., 2015a). In Austria, a demand simulation based on choice experiments revealed that if substitute ski areas exist in a market, ski areas with bad snow conditions are simulated to lose up to 60% of demand. However, demand losses depend on the duration of such situations, i.e. if limited to the beginning and end of the season, losses would be around 18% (Steiger et al., 2020).

Spatial substitution not only impacts individual businesses but can potentially affect tourism receipts in a regional economy as well if substitutes in other states are chosen. For Eastern Canada, Rutty et al. (2015b) revealed potentially 11-15% of respondents were willing to switch from the Ontario market to New York state or Québec. For Australia, Pickering et al. (2010) showed that 16% of respondents would ski overseas in case of a lack of snow, suggesting a substantial increase of emissions related to this type of holiday. Conversely, for summer skiers in Norway spatial substitution with summer ski centers in other parts of the world was least favored (Demiroglu et al., 2018). Skiers were found to neglect the connection between skiing mobility and climate change while at the same time acknowledging that climate change is a major environmental concern (Stoddart, 2011). A study with skiers investigating the mediating role of five predictors between climate change knowledge and behavior intention found that self-efficacy has the strongest effect (Chen et al., 2020). This raises important questions on future carbon footprint of this activity.

Second home-owners are a particularly important demand group, as their perception and behavior has the potential to affect real estate prices. In a survey this group stated they would use their property less often or to even sell the property if the ski area was to close (Dawson & Scott, 2013). Furthermore, second home-owners might also be affected by natural hazards that are likely to increase due to climate change. Their potential responses, namely relocate, return or adapt also hold the potential for economic impacts for tourism destinations (Adie, 2020).

For cross-country skiing, literature on demand behavior showed that adaptation behavior differs from alpine ski tourists. In a discrete choice experiment conducted with cross-country skiers in Austria, the majority of respondents (55%) would switch to alternative activities in case of a lack of snow while 18% would accept neither alternative activities nor snowmaking (Landauer et al., 2012). The results of the choice experiment were also used in a decision support tool to simulate the impact of possible adaptation strategies on the destination (Pröbstl-Haider & Haider, 2013). Comparing the most-favored adaptation options between Finish and Austrian cross-country skiers, Austrians were more willing to pay for the activity (to finance snowmaking) while Finish skiers were more likely to accept ski tunnels (Landauer et al., 2014). In a study in Finland, differing sensitivity of cross-country skiers was related to motivation. While participants interested in socializing were more likely to give up this activity when poor snow conditions exist, participants with motives related to nature and landscape as well as the fitness-oriented group were more likely to travel farther and use artificial snow tracks (Landauer et al., 2009). Snowmobilers are already adjusting their behavior, as shown by a study where 31% of respondents stated that they have reduced their amount of snowmobiling (Perry et al., 2018b). Snowmobilers' sensitivity to climate change impact was found to be higher for local users than for non-locals, while for the latter group, diverse tracks are most important (Xiao et al., 2020). These results suggest that different winter mountain tourist stakeholders will likely respond differently and thus require context-, activity- and demographic-specific adaptation strategies.

Combined impacts

The identification and quantification of tourists' sensitivity to weather allowed researchers to estimate potential future demand for winter tourism. A study for South Tyrol (Italy) projected losses between 13% (RCP 4.5) to 18% (RCP 8.5) in the 2050s (Cavallaro et al., 2017) which roughly corresponds to a warming of 2 °C. Conversely, climate change might also increase ski tourism revenues as shown for Switzerland using a general equilibrium model. When considering that snow availability is also diminishing in competing markets, this positive value represents a relative competitive advantage despite declining snow availability (Gonseth & Vielle, 2019). A scenario analysis combining a regional input-output model and a model for tourist behavior for Davos, a Swiss destination, showed that snowmaking would save up to 10% of the regional factor income in snow scarce winter seasons (Pütz et al., 2011). Using the travel cost method, Chapagain et al. (2018) estimated that skier visits and related net economic benefits decline by 8% in a 2060 A1B scenario. A regression for lift ticket sales also including snowmaking conditions in a Slovakian ski resort showed losses in a similar range between 6% (+1 °C) to 19% (3.2 °C) (Demiroglu et al., 2015).

Several studies applied agent-based models (ABM) to investigate the integrated effect of modeled physical impacts and adaptive demand-side behavior revealed by surveys on skiing markets or ski resorts. In an application covering parts of Switzerland, Austria and Germany, the assumptions on water utilization determine ski tourism demand (Soboll & Schmude, 2011; Soboll & Dingeldey, 2012). If water utilization was maximized, demand in virtually all ski tourism regions is projected to increase (more than 60%), whereas if water utilization was limited to the current level, a more complex picture emerges with both declines (< −60%) and increases (>60%). Other ABMs were used for Andorra (Pons et al., 2012), the Pyrenees (Pons et al., 2014) and Ontario/Canada (Scott et al., 2020b). In the last two cases, a decoupling of season length and demand change was found at some ski areas, concluding that shortening ski seasons do not necessarily reduce demand and revenues for ski areas that hold a competitive advantage (e.g. proximity to urban markets, still better snow reliability than competitors), but rather this could lead to more frequent situations of overcrowding (Scott et al., 2020b). In an ABM conducted for a destination in the Italian Dolomites, ski season modeling results were combined with tourism adaptation strategies, demand scenarios and competition scenarios to contribute to the discussion of potential climate change adaptation paths in stakeholder workshops (Balbi et al., 2013; Bonzanigo et al., 2016).

For cross-country skiing, a demand model combining survey data and snow projections showed that participation rate and participation days could decline up to 36% and 39% respectively in a high emission (A2) 2051-2080 scenario (Pouta et al., 2009). Respondents living in an urban environment, with lower socioeconomic status and female participants were found to be more vulnerable to climate change, as they have less resources and agency to adapt. Consequently, these groups will lose access to snow sports earlier than other groups revealing a social inequity of impacts.

Summer season type activities might hold potential for future winter seasons. Regression models for Croatian and Romanian mountain regions showed that higher temperatures during winter would lead to higher tourist numbers (Surugiu et al., 2011; Grdic & Nihe, 2016; Nizic & Grdic, 2018). Less frequent snow conditions could ultimately lead to visitation increases as shown for the Yellowstone national park, as accessibility with conventional automobiles will improve in the winter season and over-snow vehicles are no longer required (Tercek & Rodman, 2016).

Climate change adaptation

The climate change impacts on mountain tourism identified in the international literature call for immediate action of the industry to increase the tourism system's resilience and preparedness. An increasing frequency of extreme weather both in the summer and winter seasons highlight the type and magnitude of impacts the tourism system will experience more often in the future, which illustrates the need for adaptation. The tourism industry also needs to anticipate that legislation might increase the pressure to adapt, as exemplified by the French Mountain Act stating the "construction of new tourism units of any type and size must take into account the vulnerability of mountain areas to climate change" (Joye, 2018, p.249).

Several social network analyses investigated mountain tourism systems' resilience. In a case study of an eco-tourism destination in Peru, it was found that ties of the community to local organizations was rather weak, suggesting that more effort is needed to improve the resilience towards climate change (Gabriel-Campos et al., 2021). In Switzerland, Luthe et al. (2012) and Wyss et al. (2015) identified a high level of cooperative activity that fosters innovation, whereas uneven distribution of power was a clear weakness. Therefore, in a follow-up study the question "how should power be distributed?", or "how should governance be designed for addressing climate change?", was investigated (Luthe & Wyss, 2016). The authors compared the resilience of the current governance system consisting of three independent municipalities with a proposed regional destination management organization uniting all stakeholders. While adaptation to abrupt changes were found to be more effective at the municipal scale, gradual climate changes were better dealt with at the regional governance scale, i.e. the DMO level in this case.

Structural barriers complicate adaptation processes and cannot be easily overcome (Wyss, 2013). Important barriers to be addressed are a lack of quality information on climate change impacts, how stakeholders perceive leadership, the sector's adaptive capacity and the economic feasibility of adaptation strategies (Roman et al., 2010; Matasci et al., 2014). In a two-stage process with tourism stakeholders, Becken et al. (2015) derived climate indicators that stakeholders perceived as important and then presented regional maps showing these indicators' projected changes to the same stakeholders to stimulate discussion on adaptation strategies. Juhola and Kruse (2015) used a framework with five determinants to assess various tourism regions' adaptive capacity to climate change: knowledge and awareness, technology, infrastructure, institutions, and economic resources. Tourism policy- and decision-makers evaluated 15 indicators based on these five determinants for alpine tourism regions providing the status quo and starting point for improving adaptive capacity. In a study in Switzerland, a multi-risk assessment was conducted, using a scenario method identifying potential minimum and maximum climate change impacts on snow reliability, permafrost, glaciers, landscape and natural hazards and resulting impacts for nine destinations (Müller & Weber, 2008).

Summer season

Research across the globe highlights the need for stakeholders in summer mountain tourism to adapt to the rapid changes they are facing now and will face in the future with large-scale (Ritter et al., 2010; Roman et al., 2011) yet localized responses (Cahyanto et al., 2018). Studying summer mountain tourism stakeholders' perceptions of climate change, (Furunes & Mykletun, 2012; Stewart et al., 2016; Welling & Abegg, 2021) demonstrated how stakeholders have high adaptive capacity yet some, especially in Europe, continue to turn a blind eye to climate change threats to their business. Still current adaptations do not meet the scale of the global climate change impacts on summer mountain built and natural tourism infrastructure (Ritter et al., 2010), which are what draw tourists to many alpine regions in the first place (Chakraborty, 2019, 2020b). For summer glacier tourism, those measures included the change of itineraries (Purdie et al., 2020; Salim et al., 2021b; Salim et al., 2021a), activity diversification (Furunes & Mykletun, 2012; Salim et al., 2021b; Welling & Abegg, 2021) and placement of new safety equipment (Salim et al., 2021a). Another measure highlighted was the installation of blankets to mitigate glacier shrinkage (Chakraborty, 2019; Wei et al., 2019; Salim et al., 2021b), which is a strategy tourists are not really fond of (Vander Naald, 2020). Glaciers that have been used as winter ski areas increasingly try to build new summer attractions in response to climate change induced winter losses (Carver & Tweed, 2021). An interesting example is the now vanished Chacaltaya glacier in the Bolivian Andes. Despite no longer existing, this former ski area has multifunctional infrastructure and nature on site which still attracts many tourists (Kaenzig et al., 2016).

Scholars proposed a coordinated management approach including engaging tourism stakeholders to contribute more effectively to trans-regional and cross-sector climate responses (Ritter et al., 2010; Chakraborty, 2019, 2020b). The need for this wide perspective could be seen in the vulnerable mountain areas of the Himalaya-Hindu Kush region, where tougher farming conditions related to climate change sometimes force mountain dwellers to shift from agriculture to tourism activities which came with both tradeoffs and co-benefits (Wang & Cao, 2015; Merrey et al., 2018; Dilshad et al., 2019). Another agricultural aspect noted was the loss of traditional farming techniques that are a tourist attraction in some regions (Al-Kalbani et al., 2016). Noting the increasing complexity and interactions as climate impacts ecological integrity in areas where nature-based mountain tourism exists, Espiner and Becken (2014), Stewart et al. (2016) and Roman et al. (2011) suggested utilizing multidisciplinary methods and socio-ecological systems perspective to integrate climate change impacts with biodiversity and ecological vulnerabilities to identify and strengthen adaptive capacity in mountain tourism destinations.

Recommendations ranged from creating tourism attractions in northern or higher elevation areas, altering or lengthening seasons and introducing new activities (Perry et al., 2018a; Mourey et al., 2020) to decreasing usage and downscaling large-scale tourism (Wyborn, 2009; Chakraborty, 2019). Cahyanto et al. (2018) further suggested management strategies need to be more localized to accommodate variance in environmental change risk perceptions by visitors. This aligned with a case study in the Mont Blanc region (Salim et al., 2019) where guides have increasingly diversified their activities in Mont Blanc's Chamonix destination, while guests are more flexible in the Courmayeur region. Weber et al. (2019) encouraged prioritizing educational material rather than commercialized tourism to ensure biodiversity and conservation outcomes aren't compromised through changing environments and increasing tourism visitation. Chakraborty (2019, 2020a) and Weber et al. (2019) also encouraged better interpretive and educational material to engage tourists in the environmental change and adaptation of local destinations. Since glaciers are often used for educational purposes (Vistad et al., 2016; Rasmussen, 2019; Carver & Tweed, 2021) their losses and the loss of infrastructure necessary to access them (Nyaupane & Chhetri, 2009; Hoy et al., 2016; Tuladhar et al., 2021) could make climate interpretation and education increasingly difficult. These papers further suggested policymakers and protected area managers engage in climate change adaptation planning.

Archie (2014) added that mountain communities are key stakeholders in effective adaptation planning, over half of local community member participants stated they are affected by decisions made on nearby public lands and parks. Using a similar methodology Chakraborty (2019, 2020a) found similar results that local community members were highly aware and concerned about the threats environmental change poses for the region's biotic and abiotic elements. In the Mt. Everest region in Nepal, tourists also contribute to climate change awareness among locals (Poudyal et al., 2021).

Winter season

Ski tourism stakeholders did not perceive adapting to climate change as a top priority (Wolfsegger et al., 2008; Hoy & Matschullat, 2009; Heuchele et al., 2014). Although they perceived climate change as real (Morrison & Pickering, 2013b; Knowles, 2019) and awareness was found to be increasing (Trawöger, 2014), they often perceived climate change only as a threat of the far future and for others (Hopkins, 2015; Thimm et al., 2019). Ski industry representatives also reported that climate change is a negatively connoted topic (Kundzewicz et al., 2008) and therefore is not addressed publicly by the industry (Trawöger, 2014). Nevertheless, it must be noted that most of these studies are dated and probably misrepresent the current perception of tourism stakeholders.

Potential adaptation measures included four-season tourism (Bicknell & Mcmanus, 2006; Ghaderi et al., 2014) and snow-independent alternatives in the winter season (Siegrist & Gessner, 2011), such as hiking, nordic walking or biking (Hoy et al., 2011). However, Bausch and Gartner (2020) noted winter (i.e. snowy) landscapes are still a basic requirement even for activities that are not dependent on snow . Other options included maintaining the current product, a shift to higher terrain, subsidies, fatalism, i.e. not adapting at all and/or cancelling ski tourism (Elsasser & Burki, 2002). Varley and Medway (2011) investigated the impacts of infrastructure on the mountain landscape, tourists' desires and how they perceived the scenery on the mountain in Cairngorm, Scotland. These findings were then used to assess the feasibility of the ecosophic tourism (i.e. tourism in ecological equilibrium) as a climate change adaptation option. Weather derivatives were proposed as a strategy to transfer part of the weather risk to counterparties (Bank & Wiesner, 2011; Sileo, 2012; Ballotta et al., 2020). Though such derivatives can limit the financial impacts of weather variability, its attractiveness might be reduced by climate change and associated higher premiums. The common strategy though was to maintain the current business model status quo (Hill et al., 2010), mainly with snowmaking (Bicknell & Mcmanus, 2006; Haanpää et al., 2015).

Stakeholder groups have diverse perceptions of snowmaking as an adaptation strategy. Hopkins (2014) noted that ski industry representatives rated snowmaking's environmental and social sustainability less important than the local population and tourists'. In a study in Switzerland identified three different stakeholder 'perspective groups' holding different opinions regarding snowmaking (Moser and Baulcomb, 2020). However, agreement was found on the following statements: not every ski area should invest in snowmaking; resorts should not solely rely on snowmaking as an adaptive strategy; no single source of income could financially replace the ski tourism business; snowmaking should not be allowed to impact water allocation to other sectors; and snowmaking under summer-like conditions cannot be justified and snow farming should be evaluated as an alternative method.

To act proactively, Hopkins and Maclean (2014) suggested that decision-makers require more or better knowledge. However, Knowles (2019) demonstrated that it is not a lack of knowledge or understanding, but rather a short term profit focus, fear of bad press, lack of money, and lack of buy in from other stakeholders that hinders implementation of long term climate strategies. Furthermore, awareness about potential climate change impacts influences the extent of adaptation measures taken by entrepreneurs (Hoffmann et al., 2009). Dannevig et al. (2021) used six determinants to assess the adaptive capacity of ski tourism in Norway: physical situation, technology, networks and collaboration, economic resources, and innovative ability. Their analysis was used at a stakeholder workshop to discuss adaptation options and barriers to adaptation.

Conducting a media analysis, Knowles and Scott (2021) concluded that four dominant frames are used in the media when reporting climate change impacts on the ski tourism industry (disaster, settled science, economic, unsettled science) and that it often fails to refer to credible research contributing to slower climate responsiveness. To improve the information basis, Helgenberger (2011) proposed the development of a joint climate information management system, ideally led by strong local actors such as cable car operators.

Discussion & conclusion

This review paper provides a state of knowledge overview of the impact of climate change on mountain tourism and potential adaptations for changing conditions. Despite the rich body of literature on this topic, seven key knowledge gaps can be identified (Figure 3):

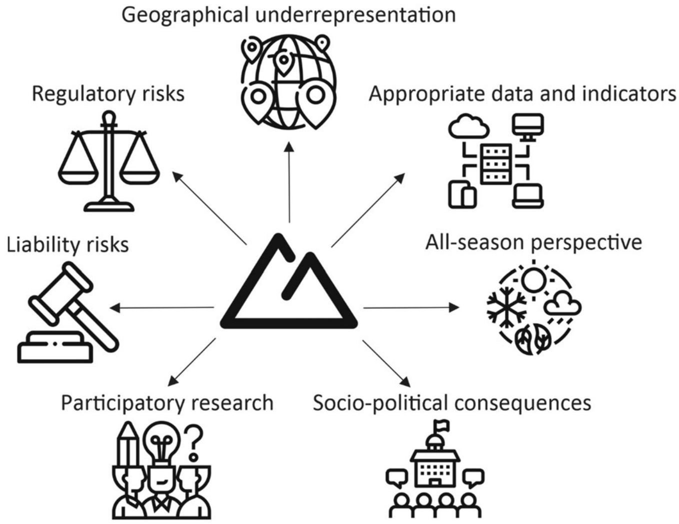

Figure 3. Key knowledge gaps identified in the literature.

All sources for icons in Figure 3 are taken from www.flaticon.com. Authors of icons: Bombasticon Studio (mountain), wanicon (geographical underrepresentation) catkuro (appropriate data and indicators), GOWI (a-all-season perspective), noomtah (socio-political consequences), Eucalyp (participatory research), Freepik (liability risks), monkik (regulatory risks).

1. Geographical underrepresentation: Africa (1%) and South America (3%) are fundamentally underrepresented. This is especially concerning as tourism development is often used as a strategy to reduce geographical economic disparities in rural mountain communities. In contrast to mature markets like Europe or North America, new tourism destinations are still being established in Africa and South America highlighting the necessity to understand tourism's multifaceted socio-ecological impacts in alpine regions before any development begins and if deemed appropriate, the opportunity to design a climate-resilient tourism industry from the start. In comparison to Europe (56% of reviewed articles), the North American continent is considerably less represented by peer-reviewed literature (16%). This is surprising considering that many mountain communities are dependent on the highly developed tourism industry, a lot of capital is bound in tourism infrastructure and real estate, and attractiveness of tourism destinations will be affected by changing reliability (Scott et al., 2012b).
2. Appropriate data and indicators are important to better estimate the social, environmental and economic impact of climate change (Scott et al., 2012a). This research requires weather data that is representative of weather/climate conditions at the researched area which is not available in sufficient quality, quantity or degree of detail for climate change and tourism research. Especially in mountain regions, this is often a challenge: first, mountain topography leads to more complex small-scale climatic features, resulting in more climatic heterogeneity of mountain regions. Second, as mountain regions are often less densely populated and accessible, the station network is often less dense as well. Gridded weather/climate data provide an alternative to station data, if data is suitable in terms of spatial resolution and accuracy for assessing weather conditions relevant for touristic purposes.

   Demand data from official statistics (e.g. overnight stays) is usually available only in coarse temporal resolution (seasonal or monthly values). However, the majority of tourist trips, which are influenced by weather one way or the other, lasts for a few days to a few weeks. This means that potential demand reactions regarding weather takes place on a shorter time scale than official tourism statistics provide. Demand reactions to weather can be more directly investigated with daily visitation demand data, e.g. in ski areas or mountain bike parks. However, such proprietary performance data are not freely available (Steiger et al., 2019).

3. All-season perspective: Only few studies investigate the net-impacts of climate change on tourism with an all-season perspective to provide a knowledge base for proper adaptation of this sector. The majority of papers deal with winter tourism (54%). One reason for this might be that winter mountain tourism is more capital-intensive than summer tourism (e.g. ski lifts, snowmaking, etc.) and therefore the perceived need for research might be higher. Another key reason is that the climate change impacts are more visible, e.g. ski areas are closed due to a lack of snow and therefore the destination's main attraction is not available. In the summer season, climate change mainly impacts thermal comfort which is more subjective, or aspects that are locally specific, e.g. accessibility, natural hazards, biodiversity which cannot be extrapolated to other contexts. The contradictory results and lack of research in some regions and tourism activities means the effect of climate change on summer mountain tourism visitation is far from clear. Furthermore, expected impacts for summer are both positive and negative, whereas for winter expected impacts are mainly negative, suggesting that perceived urgency to gain knowledge might be higher for winter. Strengthening and extending the summer season is often mentioned as a climate change "opportunity" and represents a potential adaptation to deteriorating winter conditions. However, an increase in summer tourism could also be harmful to fragile mountain environments that are already stressed by skiing tourism in winter. In addition, the carrying capacity of summer tourism destinations could be reached soon if tourists start to substitute their beach holidays with mountain vacation due to increased temperatures. Therefore, more studies that consider the entire tourism year and system are required to investigate what may constitute a "climate opportunity".
4. Socio-political consequences: Potential economic implications of climate change on tourism will have socio-political consequences, e.g. public services such as hospitals in rural areas, or local supply. This is almost entirely neglected in the reviewed literature, therefore we suggest a systems perspective that is context/site specific is needed to properly address the challenges and opportunities of climate change and its interrelations between different actors and sub-systems, such as the political ecology lens (Knowles, 2019). This includes the integration of local conservation, societal and cultural goals into climate change adaptation.
5. Participatory research: The mountain tourism industry's revealed lack of pro-active behavior to adapt to climate change calls for an increase in participatory research and science communication. Although lack of knowledge is often mentioned by stakeholders as a barrier to adapt, the fabrication of uncertainty is also often used to justify non-action (Gössling & Scott, 2018). Participatory research reduces barriers, includes a wide range of tourism stakeholders, gives stakeholders agency to direct research to suit their needs and thus creates more applicable research.
6. Liability risks are not considered by recent research. These risks arise from an increasing public awareness of climate change and action (or lack of action), increasing environmental, social, and governance (ESG) needs for the financial market and pressure from the local population. If not properly considered and addressed, potential consequences could include more difficulty financing tourism projects, a compromised image of the industry with declining public support and visitation to the tourism destination.
7. Regulatory risks need to be anticipated and analyzed, including the regulatory risks related to potential adaptation strategies as for example water supply restrictions can limit the availability of water for snowmaking, or increasing prices for natural resources and/or tourism destinations due to changing supply and demand may change the guest mix or reduce tourist numbers in destinations.

The diversity of methods used in the reviewed literature is promising however, some climatic output indicators need to have a more clear connection to tourism (Abegg et al., 2021) e.g. how does a changing climate comfort (measured by e.g. TCI or PET) affect tourism demand in specific regions with specialized tourism offers and activities? More importantly, researchers and practitioners need to consider and better understand potential adaptation behavior both by the supply and demand side. Substitution behavior of tourists has become more prominent in ski tourism research, but there is a clear lack of such studies for other forms of tourism, especially in the green season. Supply side adaptation includes technical solutions (e.g. snowmaking, air condition), dynamic pricing strategies (e.g. weather dependent ticket prices) or altered tourism products. Such adaptation processes need to be considered to better estimate potential climate change risks for tourism destinations.

With revealed preference data (used in e.g. econometric models) demand reactions to past weather/climate conditions can be investigated. Although econometric models project potential future tourism demand based on climate data, the suitability of such models deteriorates the more the future climate develops beyond the past bandwidth (Greene, 2012). One advantage of revealed preference data is that the result of climate change impact and adaptation by supply and demand side is integrated in the data. However, it is not possible to disentangle the effect of specific adaptation measures and a challenge of stated preference data is the underlying stated versus real behavior gap (Steiger et al., 2019). In particular for the climate change tourism context, respondents in a survey may not be able to accurately understand or anticipate how a change of natural resources (e.g. loss of glacier, or average 2 °C warmer conditions when hiking) would affect their behavior. One approach could be to display different scenarios more realistically in stated preference studies. For example, virtual reality goggles could enable research on how landscape changes induced by global warming are perceived or valued by tourists. Furthermore, for activities where climate-induced changes of natural resources are not critical to perform the activity, habituation effects to a changing environment might occur as well.

Most of the qualitative work in this review relies on interviews and focus groups with contemporary tourism stakeholders. Nevertheless, climate change is a long-term phenomenon and therefore looking at longer time periods would perfectly complement quantitative research in regions where there is climate data available. For regions that lack climate data, as mentioned above, qualitatively assessing a longer time period would allow to find long-term effects of climate change on tourism in those regions. Potential methods for such analyses include interviews with retired tourism stakeholders, the analysis of historic newspapers, prose, and grey literature, and the analysis and interpretation of historic photographs.

Mountain regions across the world continue to face rapidly accelerating warming, creating new and distinct challenges for their rare alpine habitats, endemic species, and small remote communities. Considering these rare, raw and remote environments are what draw tourists to the mountains to begin with, the tourism industry and all its stakeholders have a vested interest in being agents for positive change. As ecosystems naturally adapt to the climate, tourism systems will require new knowledge and strategies to adapt alongside nature, dealing with changing water availability, seasonality of species, weather, and hazards. Again, considering the formidable stature of mountains is a key tourist attraction, a response that aligns with the natural setting and not only mitigates negative impact to natural resources, views and vistas or nature-based tourism assets but uses these as nature-based climate adaptations may see an advantage in drawing new tourists to destinations. Still, considering the direct impact of tourism on mountain environments, destinations may want to investigate their tourism carrying capacity within their specific socio-ecological contexts. Furthermore, the global scale nature of climate change and IPCC directed requirements in the next 30 years make it clear that continued growth of tourism does not align with a decarbonized economy. Therefore, in looking forward in research and practice, we must look for ways that ensure mountain tourism gets better but not bigger, and continues to serve the needs of the local communities and ecosystems upon which it is built.

Disclosure statement

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Notes

1. Please note that papers were only counted once each for Table 1, whereas papers featuring multiple countries were counted once for each of the featured countries in Table 3 in the Appendix, therefore the total numbers are different.

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Appendix

Table 2. Number of papers per Country.

Country	Nr of Papers
Andorra	2
Argentina	1
Australia	20
Austria	50
Bangladesh	1
Bhutan	1
Bolivia	2
Bosnia and Herzegovina	1
Bulgaria	1
Canada	21
Chile	1
China	9
Croatia	2
Ecuador	1
Finland	8
France	21
Germany	27
Greece	2
Iceland	1
India	1
Iran	1
Italy	13
Japan	5
Lesotho	2
Nepal	10
New Zealand	13
Norway	10
Oman	1
Pakistan	1
Peru	5
Portugal	1
Romania	1
Russia	2
Sierra Leone	1
Serbia	1
Slovakia	1
Slovenia	1
Spain	4
Sweden	7
Switzerland	22
Taiwan	1
Turkey	2
United Kingdom	4
United States	30
Sum	312

*Note: This total is higher than the number of reviewed papers (276), as papers investigating multiple countries were assigned to all of these countries and thus counted more than once.