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Introduction

- 1 Snow-based tourism is one of the most exposed activities to climate change (Gilaberte-Búrdalo *et al.*, 2017; Campos *et al.* 2018; Steiger *et al.*, 2019). With rising temperatures, the future viability of winter tourist resorts and especially those at lower altitudes will need the development of alternatives able to compensate for likely decline in ski and other activities based on snow (Scott and McBoyle, 2007). In this paper we focus on the Spanish Catalan Pyrenees as one area particularly exposed to the effects of climate change on the snow cover and therefore on the ski tourist industry. Several studies (Pons *et al.*, 2015; Fraguell *et al.*, 2017) point that most Spanish Catalan ski resorts will be affected by reductions in the snowpack which could lead to the closure of some of them and to a deep reconfiguration of the current business model for most of them. During the last decades, all resorts have opted for the installation of facilities to produce artificial snow, despite high economic, energy and environmental costs. Thus far artificial snow production has generally helped to ensure the viability of ski resorts by limiting the impacts of dry winters. However, its effectiveness may be substantially curtailed under higher average temperatures as those foreseen for the Pyrenees during the next decades. Ski resorts therefore will need to adapt to a changing climate and this adaptation necessarily involves transforming resorts towards promoting activities not dependent on snow. Ski will always remain an option, climate conditions permitting,

but, likely, it may not suffice to ensure the economic viability of these resorts which are seen as fundamental for the socioeconomic survival of mountain areas. The objective of the paper is to assess how Spanish Catalan ski resorts are responding to the challenges both of insufficient natural snow covers and to longer term trends that could threaten the overall viability of resorts. Adaptation actions to confront these challenges, snow making and the transition from ski resorts to mountain resorts, pose both risks and opportunities that will be assessed.

The adaptation of winter tourism to climate change

- 2 The scientific literature on impacts and adaptation to climate change in the tourist sector and particularly in winter tourism has increased considerably in recent years and continues to expand (Barrios and Ibañez, 2013; Kajan and Saarinen, 2013; Arendt *et al.*, 2014; Dogru *et al.*, 2019). As one of the most exposed tourist modalities, snow-based tourism has received special attention (see, for example, Trawöger, 2014; Bonzanigo *et al.*, 2016). Adaptation in the form of snow making facilities is now widespread but depending on altitude, orientation, and water and energy availability and prices, it may become unfit to guarantee the opening of ski resorts during a sufficient number of days to avoid losses (Damm *et al.*, 2017). In sum, increasing temperatures would force to produce snow under unfavorable conditions and therefore at greater costs (Damm *et al.*, 2014; Spandre *et al.*, 2015). One of the key issues appears to be the increase in average temperatures. High emissions scenarios leading to temperature increases above 2°C could cause losses of up to 73 percent for the global ski sector towards midcentury (Scott *et al.*, 2019). Given the uncertainties surrounding the viability of snowmaking, ski resorts are exploring other forms of adaptation (Bourdeau, 2009). The recreational and aesthetic (both natural and cultural) values of mountain areas represent opportunities for attracting visitors to resorts all year round as was already observed at least twenty years ago (Rautenberg, 1998; Bryden and Munro, 2000; Desmichel, 2000). New resources have been added to tourist packages of mountain areas, both those that before were not considered as part of the package (heritage in its multiple manifestations, architectural, gastronomical, religious, etc.) and those created specifically for the package (hiking and mountain bike trails, mountain races, etc.).
- 3 While diversification is in itself a potentially sound strategy to adapt to changing climate conditions it also involves changes in the business models of ski resorts involving increasing competition with other providers of the similar products and services as well as more atomized and fragmented revenues possibly smaller than those of ski. At any rate, diversification has contributed to the expansion of a business model interested in off season activities. Still, snow continues to be the main resource of these resorts with all the uncertainties that this creates.

Snow tourism in Catalonia

- 4 In Spain and Catalonia, references on the impact of climate change on tourism show a certain bias towards summer tourism which is not surprising given the critical importance of the sector for the Spanish and Spanish Catalan economies. However, there are a number of contributions focusing explicitly on snow-based tourism (March *et al.*, 2014). Moreover, the three reports on Climate Change and its impacts in Spanish

Catalonia have always included a chapter on tourism (Saurí and Llurdés, 2005 and 2010; Fraguell *et al.*, 2017).

- 5 Catalonia currently has 10 Alpine ski resorts, all of them located in the Pyrenees (Fig. 1). Ski has become in recent years a key sector in the livelihood of the Pyrenees providing about 11,500 jobs (2,500 direct and 9,000 indirect) and some 350 million euros per year of revenue. In most resorts skiers come from Catalonia. However, in Baqueira Beret, Spanish skiers, especially from Madrid and the Basque Country, are dominant (Cmbsport, 2017). The business association Hosteltur (2014) estimated that every euro spent in a forfait produces six euros in related activities. However, only a few Alpine ski resorts are clearly profitable and several of them have been turned to the public sector after bankruptcy declarations. Resorts under public ownership generate around 250 direct jobs in the winter season and 223 million euros annually which represents more than 20 percent of the total economic output of the areas in which these resorts are located (UPF Sports Lab, 2018).

Fig. 1. Location and importance (in forfaits sold) of Spanish Catalan Alpine ski resorts

Source: D. Saurí, J. C. Llurdés

- 6 Although these may seem rather modest figures, in the context of the Pyrenees they represent critical magnitudes. In 1990 and for the first time, two million ski forfaits were sold in the Spanish Catalan Pyrenees. This figure has oscillated in the past two decades. In the 2005-2006 season a record of 2.2 million forfaits was reached. In contrast, the season 2011-2012 (1.728.900 forfaits) was rather poor of little snow and the coincidence with the height of the economic crisis that has affected Catalonia and Spain since 2008. The 2017-2018 seasons set a new record of 2.3 million forfaits sold again after an excellent winter in snow terms and the improvement in the economy. Averages for the last decade give a figure slightly below two million forfaits sold annually (Fig. 2). Baqueira Beret and Masella have always been the two more active resorts (41 and 20.5 percent, respectively, of forfaits sold in the 2017-2018 season); next comes La Molina (15 percent) connected to Masella, while the rest adds up the remaining 23.5 percent. When comparing these figures with the development of non-

snow related activities, the first two resorts do not show much leverage in relation with the rest. Therefore, an interesting question appears regarding the contribution of ski to the general development of mountain areas (Lasanta *et al.*, 2007): whether larger resorts have an advantage over smaller resorts in terms of incorporating effectively these activities to their benefit and to the benefit of surrounding areas, or, on the contrary, smaller resorts could manage a more effective adaptation than larger resorts in terms of new activities.

Fig. 2: Number of forfeits sold (2011-2018). Spanish Catalan Alpine ski resorts

Source: D. Sauri, J. C. Llurdés

- 7 Climatic conditions in the Spanish Catalan Pyrenees are responsible of important uncertainties regarding skiing. First, almost all Spanish Catalan resorts have minimal snow packs below 1900-2000 m of altitude and forecasts question the future viability for ski in those areas. Second, climatic variability, accentuated by the latitudinal factor and also by Mediterranean influences, has a clear impact on the number of ski days (Pons *et al.*, 2015). Finally, the nearby resorts of Andorra and Southern France, most of them with a North orientation and currently very accessible from Barcelona and other Spanish Catalan cities, have become formidable competitors attracting more and more skiers.
- 8 Alpine skiing in Catalonia has to face more challenges. First, and also an issue for the Spanish and European ski resorts, is a stalemate market which remains stable despite the increase in the number of ski areas, the dissemination of new, snow-based modalities, better weather forecasts and accessibility, improvements in services provided, etc. (Catalan Federation of Winter Sports, 2012; Vanat, 2019). To all this, Spanish Catalan resorts must add their relative small size which not only limits the number of domestic customers but makes difficult the capture of foreign skiers. Another potentially important problem, common to many ski resorts of the developed world, is the aging of the population. For some managers, this may become a challenge for the future as important as climate change (Saurí and Llurdés, 2005).

Impacts of future climate scenarios in snow tourism in Catalonia

- 9 Assessments of global climate change in recent years have continued to expand and deepen our knowledge on this phenomenon and its impacts. Major advances have been made regarding the downscaling of projected temperature, precipitation and other climate variables. Reports exist for Europe (European Environment Agency, 2017) and the Mediterranean region (Cramer *et al.*, 2019). Regarding the Pyrenees, we must mention the climate scenarios of the Meteorological Service of Catalonia (2012), the Third Report on Climate Change in Catalonia (Martín-Vide, 2017), several studies from the Observatory for the Sustainability of Andorra (OBSA) and the last report from the Observatory of Climate Change of the Pyrenees (OPCC) (2018).
- 10 Regionalized projections of temperature and precipitation in Catalonia for the present century are available from the Catalan Meteorological Service (Meteocat). Models and projections have been downscaled to three main sub-regions in Catalonia: the Pyrenees, the central lands and the coastal areas. Regarding temperature, projected average increase oscillates between 0.9 °C and 2 °C for 2050. Increase is expected to be the norm for the whole of Catalonia but would be especially significant in the Pyrenees during summer. Precipitation, on the other hand, appears to be more elusive and projections offer a disparity of results. However, most models show a decline of 6.8 percent for the whole of Catalonia for 2050 in comparison with current values. All models and projections are based on scenarios of moderate increases in emissions of greenhouse gases. Scenarios based on growing emissions give increases of average temperature up to 4 °C. In all cases and for Catalonia, the Pyrenees appears to be the area where the effects of climate change would be more acute (Catalan Office for Climate Change, 2012).
- 11 Critical factors for the presence of natural snow are altitudes (maximum and minimum) of ski trails in each resort and, even more important, the orientation. In this sense, Western resorts and especially Baqueira enjoy relatively high altitudes while Eastern resorts are located at lower elevations. Furthermore, the northwestern orientation of Baqueira gives this resort a privileged location because it exposes ski slopes to the more humid Atlantic conditions while the rest of resorts depend on the Mediterranean-influenced drier conditions. Pons *et al.* (2015) estimated the effects of temperature increase on the viability of ski resorts in the Pyrenees. These authors considered three scenarios: current conditions, an increase of 2 °C in average temperature, and an increase of 4 °C in average temperature. Furthermore, they simulated impacts for a scenario of just naturally occurring snow and for another scenario involving the production of artificial snow. Natural viability was defined as a minimum snow cover of 30 cm for a minimum of 100 days per season whereas technical viability was defined as the achievement of the same conditions using artificial snow. The results are devastating for the Spanish Catalan ski sector since only one resort (Baqueira Beret) would be viable in any of the scenarios. Even with snowmaking, three resorts would not be viable under the +2 °C (Fig. 3).

Fig. 3: Natural and technical viability of the Spanish Catalan Alpine ski resorts (scenarios + 2 °C and + 4 °C)

Source: D. Sauri, J. C. Llurdés Based on Pons *et al.* (2015).

- 12 The impacts of unfavorable climate scenarios are well perceived by residents of towns and villages near the ski resorts whose livelihoods depend to an important extent on snow-based activities. In a survey contrasting the perceptions of impacts by climate change in areas of winter and summer tourism in Catalonia, it was found that, in general terms, residents in the Pyrenees were more aware and expressed more concern for these impacts than residents in coastal areas regarding jobs, future tourist development and even water availability (March *et al.*, 2014).

Adaptation strategies in Catalan Alpine ski resorts

Snowmaking

- 13 One of the most recurrent strategies to compensate for the natural variability of snow in the Alpine resorts of the Spanish Catalan Pyrenees has been the increase in snowmaking capacity during the last decades and especially since the disastrous winter of 1988-89 (table 1 and Fig. 4a i 4b).

Table 1: Main background data of Spanish Catalan Alpine ski resorts (2009-2019)

Resort	Min altitude Max altitude (m)	Length of ski trails (km)		Number of ski trails		Number of snow making devices		Ski trails with artificial snow (km)		Skiers / hour	
		2009	2019	2009	2019	2009	2019	2009	2019	2009	2019
Baqueira-Beret	1.500-2.610	108	162	69	115	549	710	39	41	56.403	61.024
Boí-Taüll	2.020-2.750	45	45	52	43	205	205	20,2	20,2	19.690	15.770
Esport Esquí	1.500-2.500	23	25	22	22	104	163	10,6	15	9.140	7.320
La Molina	1.700-2.445	60	71	52	68	440	512	27	42	25.500	29.450
Masella	1.600-2.535	68	74	64	72	418	574	33	53	12.160	14.740
Port-Ainé	1.650-2.440	32	27	22	25	90	126	12	12	11.850	10.810
Port del Comte	1.700-2.400	40	50	36	39	240	256	20	20	15.460	16.060
Tavascan	1.750-2.250	5	6	5	7	0	0	n.a.	n.a.	1.200	5.850
Vall de Núria	1.965-2.250	7,6	7,6	11	11	85	88	6,6	6,6	4.560	4.560
Vallter 2000	1.960-2.535	19,9	14,8	14	13	77	88	9	9	7.200	9.622
Total / Average	1.734-2.453	408,5	482,4	347	415	2.208	2.722	177,4	218,8	163.163	175.206

Source: compiled with data from Sauri and Llurdés (2005, 2010) and www.infonieve.es/estaciones-esqui

Fig. 4a and 4b: Main background data of Spanish Catalan Alpine ski resorts (2009-2019)

Source: compiled with data from Saurí and Llurdés (2005, 2010) and www.infonieve.es/estaciones-esqui

- 14 In 2009 Spanish Catalan resorts operated 2,208 snow making devices; in 2019 this number had risen to 2,722 (23.2% increase). Snowmaking has permitted the expansion in the number of ski trails with artificial snow from 347 (2009) to 415 (2019) and of their total length as well as of the skiable area (+ 19% increase). A special mention should be made to Baqueira-Beret: during the last decade, this resort increased the number and length of ski trails with artificial snow (66 and 50 percent respectively) and the number of snow making devices (29.3%), resulting in an increase of 8.8 percent in the number of skiers per hour. In the 2017-2018 season, Baqueira Beret concentrated 40 percent of skiers of Spanish Catalan resorts (41 percent of the total on average since 2010). Baqueira is the largest winter resort in Spain and, probably, one of the few viable resorts for the whole Pyrenees under a warmer climate.
- 15 Snowmaking has been labelled as a “maladaptation” action since it may create important economic and environmental problems (Barnett and O’Neil, 2010). Proponents of snowmaking defend that the amount of water used is small (the equivalent to one day consumption for a city such as Barcelona). Moreover, as a non-

consumptive activity, more than 80 percent of the water used is returned to the environment while environmental regulations for rivers are scrupulously respected. As to energy, comparisons with the consumption of other tourist modalities (for instance, airplanes transporting tourists to Caribbean destinations) also yields favorable outcomes. Opponents to snowmaking defend that large amounts of water are needed to produce snow and that, although a non-consumptive use, water for snowmaking may be returned to the environment in different quality conditions and to different basins thus disrupting natural flows. The other major source of concern is energy as it is argued that electricity for snowmaking may represent over 50 percent of total electricity consumption by Spanish Catalan ski resorts. In this sense, water shortages and mounting energy costs could jeopardize snowmaking even in the absence of temperature increase.

Diversification and transition towards mountain resorts

- 16 A more fundamental adaptation strategy, especially in the mid and long term, would be to pursue a transition from seasonal ski resorts to all year mountain resorts. This is not a new strategy since before the current preoccupation with climate change, many ski resorts were already seeking for off season alternatives, either by promoting sports tourism (Dienot and Theiller, 1999), rural tourism (Cànoves *et al.*, 2004) or landscape and cultural heritage (Métailié and Rodríguez, 2011). That is, in addition to maintaining and expanding the range of snow-based activities, resorts would have to search for forms of sport and leisure not dependent on snow but that can still take advantage of the environmental attractiveness of mountain areas. In the case of the Spanish Catalan Pyrenees, this strategy has shown some progress although very unevenly (table 2). Around 2005, most resorts placed efforts on other adaptation measures such as the increase in snowmaking capacity; the expansion of ski tracks; the purchase of climate insurance and the reorganization of the business model towards the creation of larger and more competitive companies. In 2010, non-snow related activities had gained a greater presence (Saurí and Llurdés, 2010). In the last decade the overall number of these activities expanded from 42 to 69, the most popular being hiking trails (offered by all resorts) and mountain biking probably because they require little specific infrastructure, are largely compatible, and can use resorts as starting and ending points. A second group of activities is mostly oriented towards families with children involving adventure circuits, playgrounds, some water sports, and horseback and pony excursions. The most recent additions fall within the field of nature and heritage discoveries involving visits and sightseeing of nearby areas with environmental or cultural values (Fraguell *et al.*, 2017). This is a very important question given the fact that any strategy aimed at promoting off season activities should be developed within a global assessment of the area where the resort is located.

Table 2. No-winter activities in Spanish Catalan Alpine ski resorts (2019)

Resort	2010	2015	2019																						Total
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Baqueira-B	2	7																							6
Boí-Taüll	4	3																							4
Espot Esquí	0	1																							9
La Molina	13	12																							13
Masella	1	3																							7
Port-Ainé	0	4																							6
Port Comte	6	6																							7
Tavascan	1	3																							5
Vall de Núria	8	9																							7
Valldet 2000	7	5																							5
Total	42	53	4	2	2	10	1	3	1	3	6	5	3	3	3	5	3	1	3	1	3	3	2	2	69

1. Horse riding and ponies / 2. Boating / 3. Archery / 4. Hiking / 5. Segway / 6. Tubbies / 7. Spa / 8. Wildlife observation / 9. Mountain biking / 10. Fishing and water sports / 11. Observatory / 12. Heritage / 13. Chairlift / 14. Adventure circuits; amusement areas / 15. Mountaineering, rock climbing / 16. Nordic walking / 17. Quads, karts / 18. Frisbee golf / 19. Virtual racing, trail running, / 20. 4-wheel drive tours / 21. Road cycling / 22. Paintball

Source: compiled from the websites of ski resorts webpages (accessed February 2019).

- 17 Despite an increasing interest, resorts still show some reluctance to explore more fully possibilities for intensifying the transition especially when compared to the continuous interest in diversifying and reinforcing snow-related activities considered after all, key to the business: more ski tracks, new snow-based sports, inclusive circuits of the number of tracks, riders, more aggressive price policies, nocturnal and inclusive circuits, joint forfeits between resorts, accessibility and weather information improvements, implementation of Information and Communication Technology (ICT), etc. (Cristobal-Fransi *et al.*, 2018). Secondly, ski resorts may have to confront competition by the many small and medium businesses present in the nearby areas specializing in the same products and, at the eyes of potential customers, might be handicapped by their association with ski. Finally, and at least in the short term, for some resorts it is only profitable to remain open in winter since a weekend of a good ski season may attract the same volume of visitors as in the whole summer season.
- 18 Developing off season activities involves the consideration of at least two important caveats: first, the fact that some of these activities could be affected by climate change as well, and second, that certain activities may cause significant environmental impacts. In the first case, climate change may deteriorate flora, fauna and mountain landscapes to the point of making unattractive activities such as hiking, fishing, nature observation, etc. As to impacts, activities such as mountain bike trails could induce soil erosion, losses of flora and fauna and landscape impoverishment.

Discussion and conclusions

- The impact of climate change on the snow-based tourist sector in Catalonia is likely to be significant given the high exposure to increasing temperatures and decreasing precipitation. In this sense, tourism based on snow may be the “canary in the coalmine” acting as an early warning of a full range of potential impacts that would affect later on beach and other tourist modalities. That said, climate change needs to be considered in the context of the many more challenges affecting the Spanish Catalan ski sector, especially the relatively small sizes of resorts, the lack of a critical mass of skiers, the growing competition by resorts in Andorra and France or the costly investments in renovating and updating resorts. Financially the situation of the sector

is extremely problematic: the ownership of six of the ten resorts has been passed to the regional government of Catalonia through a subsidiary company, another resort is owned by a local council, while the remaining three are private. Between 2007 and 2016, public resorts suffered losses above 60 million euros (Fraguell *et al.*, 2017). This model is subject to criticism under the argument that spending public money on ruinous activities is unfair to other potential sectors also in need. And yet, for many, there is no alternative to ski and people in the Pyrenees do not want the closure of any resort. Put simply, from this perspective ski has to continue no matter the losses because otherwise the Pyrenees would be decimated in economic and demographic terms. It is possible that this argument responds to the generally accepted idea that ski resorts have created wealth, thus contributing to stop or at least attenuate migration processes. But this tends to hide a far more complex reality with negative consequences such as loss of local capacity to manage the territory, excessive weight of the service sector in comparison with agrarian and forestry activities, and the perennial dependence on climate (García, 2012). As said before, the current development model is economically unsustainable with or without climate change. In contrast, other arguments point that positive effects of ski resorts are limited to the nearest municipalities and do not extend much beyond these (Lasanta *et al.*, 2007). As to the privately owned resorts they are all profitable and, one of them, Baqueira Beret, may be able not only to resist both socioeconomic pressures and growing climate constraints but also capture a larger portion of the ski business in Catalonia and Spain (Campos *et al.*, 2018).

- 20 Under these climatic constraints, a sufficient length of the snow cover needed for skiing cannot be guaranteed alone with natural conditions in almost all resorts. Therefore, all have opted for introducing snowmaking facilities, which can be seen as a form of adaptation. To a greater or lesser degree (more so those located in the Eastern Pyrenees) all resorts are now dependent on snowmaking but for increase of temperature above 2 °C even snowmaking will not be enough and only the Baqueira Beret resorts (the Westernmost resort in the central Pyrenees) will be able to survive. Still the most likely consequence of climate change will not be the complete disappearance or even a significant decrease of ski in the Pyrenees but rather the territorial redistribution from Eastern to Western resorts.
- 21 In front of this challenge another, more comprehensive but equally challenging adaptation strategy for ski resorts would be to undergo a transition towards their transformation into mountain resorts able to break the snow dependency and offer other activities all year round. This transition faces however important challenges and difficult tradeoffs, especially whether or not alternative activities will be able to compensate for the loss of skiers. This is why it is so important to attempt to maintain skiing as much as possible even acknowledging the impacts of snowmaking. The crucial question therefore is whether ski must continue to be the main tourist activity of the Pyrenees or rather must become secondary to other activities. Even if the answer points towards this second option, any change in the tourist business model must include climate change as well and also the possibility that the new model creates its own set of negative environmental impacts.
- 22 Hence sustainable and perhaps not so sustainable measures will have to be applied to ensure as much as possible snow although, at any rate, ski seasons would probably be shorter and increasingly unmanageable from an economic point of view. Thus ski will

not disappear from the Spanish Catalan Pyrenees in the next decades but unless a renovated productive base (based or not on tourism) consolidates, the socioeconomic future of this area, with a few exceptions, appears rather bleak.

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ABSTRACTS

Ski tourism in Catalonia has long been a fundamental socioeconomic asset for the Pyrenees region. However, in recent years some studies increasingly warn about the dubious future viability of most ski resorts as a result of climate change, and recommend the implementation of adaptation strategies for seasons in which snow maybe absent or insufficient. In this context, the article analyzes the evolution of the most common adaptation strategies to increasingly problematic ski seasons: on the one hand, the installation of snowmaking facilities and, on the other, the diversification of the main tourist product, skiing, towards other, snow-independent leisure activities. In Spanish Catalan resorts we observe that snowmaking is widespread but that, according to some scenarios, could not ensure the future viability of most resorts. The transformation of the ski resorts in mountain resorts represents in principle a more reliable

adaptation measure although it has still to prove its potential on two critical questions: the impacts of climate change on new activities and the environmental consequences of the same activities.

INDEX

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