Alpine Tourism

- **If the current trajectory of climate change continues, the Australian ski industry will change dramatically by 2050:**
  - **Ski seasons will be 44 days shorter (-42%) in a mid emission scenario and 55 days shorter (-52%) in a high emission scenario.**
  - **There will be no snow reliable ski areas left in Australia in any emission senario.**
  - **The additional snowmaking infrastructure, water, and energy required will place significant ecological and economic costs on alpine resorts that may make their operation economically unviable.**
  - **Fewer resorts are expected to make up Australia's snow tourism industry, with some resorts at risk of closing without successful adaptation.**
- **The SkiSim2 results highlight that long (and most likely economically viable) ski seasons are still possible with effective mitigation that keeps our global emissions trajectory within a low emission scenario, particularly for higher altitude resorts.**
- **Year-round tourism and diversification of winter tourism are the two adaptation options most likely to be successful long-term, but current offerings are ad-hoc and disjointed.**

Climate change is threatening the economic viability of alpine tourism globally, with ski tourism in Canada[12], the United States[3], Europe[45], China[6], Japan[7], South Korea[8], New Zealand[9], and Australia[10] impacted by warmer temperatures and reduced snow depths. Australia's alpine winter tourism industry has been labelled the "canary in the coalmine", as it is globally one of the first and most visibly impacted industries from climate change[11]. This means how Australia experiences climate change and the response by Australian alpine resorts, communities, and governments will provide valuable learnings to the rest of the world: either as a leader in climate adaptation and mitigation, or as a lesson in what not to do.

Table 2.1 summarises Australia's alpine resorts. The primary summer activities column lists only the main activities directly offered by the resorts. Although Charlotte Pass and Perisher don't offer any activities directly, there are popular walking trails and running events that occur in both locations during summer.

Tasmania has one commercial alpine resort, Ben Lomond, which is small, with limited elevation, limited variability of terrain, and highly variable snow. Ben Lomond has been included in the overview of Australian alpine resorts and in the snowmaking section, as a feasibility study into Ben Lomond Alpine Resort's snowmaking has recently been released and Ben Lomond is included in the SkiSim2 modelling. However, most literature focuses on the mainland Australian Alps. As such, the impacts of climate change on the Tasmania Alps have been predominantly excluded from this report, although the mitigation and adaptation principles may still be relevant.

Resort	Base Elevation (m)	Highest Lifted Point (m)	Skiable Terrain (ha)	Winter Visitor Numbers	Ski Lifts	Primary Summer Activities
VIC Alpine Resorts						
Mt Hotham	**1,450**[12]	**1,845**[13]	**320**[14]	**129,000**[15]	**Yes**	Hiking, Road cycling, 4WD
Falls Creek	**1,500**[16]	**1,780**[17]	**4,50**[18]	**139,000**[19]	**Yes**	Mountain Biking (shuttle accessed), Road Cycling, Hiking
Mt Buller	**1,375**[20]	**1,780**[21]	**340**[22]	**293,000**[23]	**Yes**	Mountain Biking (shuttle accessed), Road Cycling, Hiking
Mt Stirling*	**1,234**[24]	**1,749**[25]	**68km** Cross Country Trails[26]	**6,000**[27]	**No** (Nordic/ cross country skiing)	Mountain Biking (shuttle accessed), Hiking, Flying Fox
Mt Baw Baw	**1,460**[28]	**1,564**[29]	**35**[30]	**53,000**[31]	**Yes**	Mountain Biking (shuttle accessed), Road Cycling, Hiking
Lake Mountain*	**1,340**[32]	**1,480**[33]	**37km** Cross Country Trails[34]	**92,000**[35]	**No** (Nordic/ cross country skiing)	Mountain Biking (shuttle accessed), Hiking, Flying Fox
NSW Alpine Resorts						
Perisher	**1,605**[36]	**2,034**[37]	**1,245**[38]	**No Data**	**Yes**	**Nil**
Thredbo	**1,365**[39]	**2,037**[40]	**480**[41]	**No Data**	**Yes**	Mountain Biking (lift accessed), Hiking (lift accessed), Bobsled
Charlotte Pass	**1,760**[42]	**1,955**[43]	**50**[44]	**No Data**	**Yes**	**Nil**
Mt Selwyn	**1,492**[45]	**1,614**[46]	**45**[47]	**No Data**	**Yes**	**Nil**
TAS Alpine Resorts						
Ben Lomond	**1,470**[48]	**1,570**[49]	**29**[50]	**18,000**[51]	**Yes**	Mountain Biking, Hiking

Table 2.1

Note: The winter visitor numbers for VIC alpine resorts are an average from 2007-2021.
*Nordic/cross-country resorts: figure for the highest lifted point is the summit elevation and for the base elevation is the village elevation.

Snow Tourism

Australia's ski resorts have experienced significant decreases in natural snow since the 1950s[52]. The minimum snow depth required for downhill skiing and snowboarding is generally considered to be 30cm[53] and a minimum of 60 days maintaining this snow depth is considered necessary for an economically viable season in Australia[54] (although this does not comprehensively account for ticket demand and prices, increased operational costs for snowmaking, and stakeholder willingness to adapt[55]). There is a direct correlation between natural snow depth and visitor days at Australian alpine resorts[56]. A survey conducted in 2010 found that 90% of skiers surveyed at Perisher said they would ski less often (69%), not at all (5%), or overseas (16%) if the next five years had low natural snow[57].

The alpine tourism industry has several climate adaptation response options, some of which the industry is already implementing. The primary adaptation response is snowmaking, which refers to artificially turning water into snow using technology. Pickering and Buckley (2010)[58] predicted that most Australian ski resorts would be economically unviable by 2020 if they were to rely on natural snowfall alone. Efficient snowmaking is therefore a critical climate adaptation strategy for ski resorts, with all resorts in Australia except Mt Stirling using some level of snowmaking to improve the quality and length of the snow season. However, the longevity of snowmaking to maintain the economic viability of ski resorts is limited for two reasons. Firstly, the climatic conditions required to technically produce snow are projected to decrease under climate change[59]. Secondly, there are significant water and electricity costs associated with snowmaking and these will increase as progressively more technically produced snow is required in the future[60].

There are three main types of snowmaking machines used in Australia: air-water guns / lance snow guns, fan guns, and snow factories. The characteristics of each are outlined in Table 2.2.

Both lance guns and fan guns require sub-zero wet bulb temperatures[65]. Due to climate change, there will be fewer nights and hours per night that are hours per night that are sufficiently cold and dry for snowmaking. Figure 2.1 indicates the number of suitable snowmaking nights under climate change for the NSW resorts. Given that Snow Factories can produce snow at much warmer temperatures there is little technical limit on the capacity to produce snow, even in a warming climate. Rather, the constraints posed are the acceptable level of water extraction, energy availability, and cost[66].

Lance guns

- Requires wet-bulb temperatures of less than -2.5°C
- Moderately energy efficient
- Relatively portable
- Can direct snow onto specific runs
- Requires compressed air and pumped water

Fan guns

- Requires wet-bulb temperatures of less than -2.5°C
- Most energy efficient
- Relatively portable
- Can produce snow at more marginal temperatures than lances
- Only requires pumped water

Snow factories

- Can make snow at any temperature up to 35°C
- Least energy efficient
- Not as portable
- Produce relatively small amounts of snow. Designed for small areas, not entire slopes
- Expensive and requires significant infrastructure

Table 2.2: Most common snowmaking technology in Australia

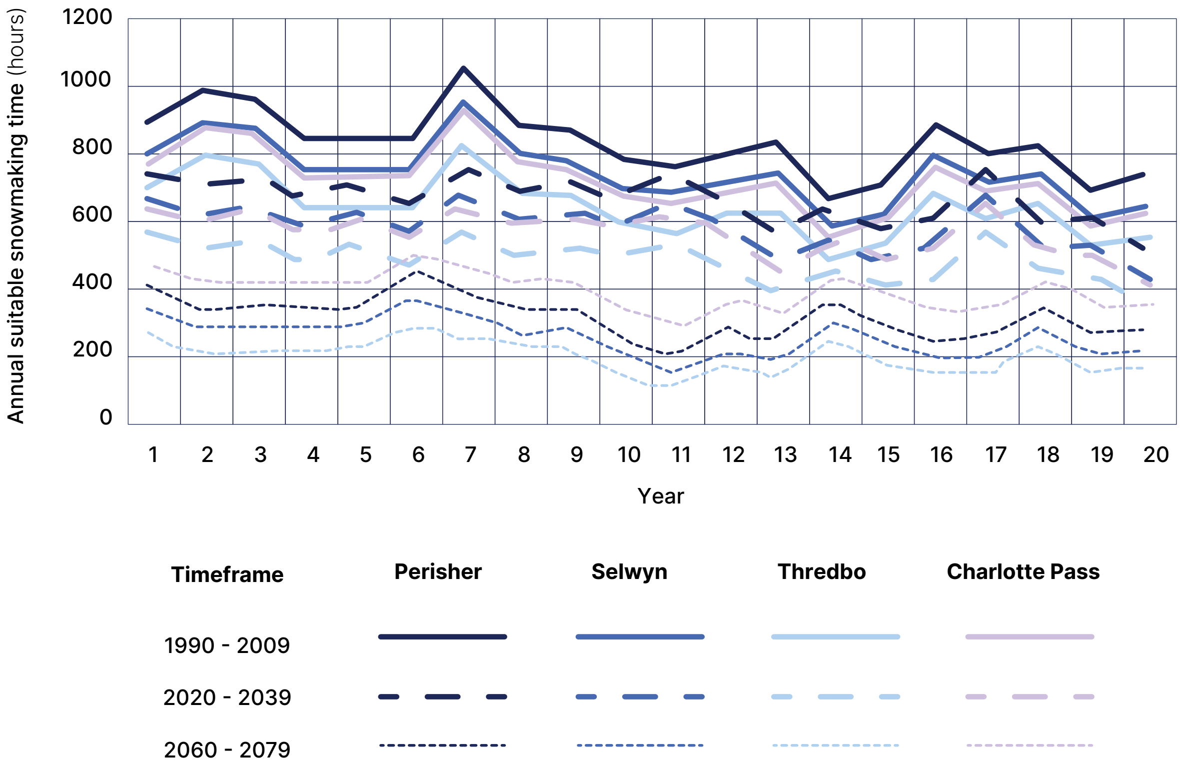

Figure 2.1: Interannual variability of suitable snowmaking for the -1°C threshold at NSW alpine resorts. Source: Adapted from Climate change impacts in the NSW and ACT Alpine Region – snowmaking[67].

Snow-reliability and economic viability

Snow reliability is defined as at least 100 days with a snow depth of at least 30cm in 70% of all winter seasons[68]. While this was originally used as a metric of economic viability for overseas ski resorts, it is no longer considered a robust economic indicator, particularly for Australia. A 60-70 day threshold has been used as an indicator for economic viability for Australian ski resorts in academic literature[69] and by the Alpine Resorts Co-ordinating Council (ARCC)[70]. However, both the 100-day "rule" for international ski resorts and the 60-70 day "rule" for Australia cannot comprehensively account for ticket demand and prices, the amount of snow required, or operation costs (including increased costs from additional snowmaking)[71]. A report by the Tasmania government of snowmaking feasibility at Ben Lomond Alpine Resort considered a 6-8 week season (42 – 56 days) to be the minimum length required for the resort's economic viability[72].

The Ben Lomond snowmaking feasibility study[73] found that under a mid emission (RCP4.5) scenario, the number of snowmaking days per year would reduce by 54% by 2050 and 66% by 2070, years with greater than 10 snowmaking days will become extremely rare after 2030, and after 2060 no years will have more than 10 snowmaking days.

The study concluded that expanding snowmaking to guarantee a 6-8 week season was economically unviable given these climate change projections and availability of affordable water and energy[74]. It should be noted that the private operator of Ben Lomond believes future operation to be economically viable and intends to continue. Feasibility studies of a similar level have not completed for NSW or VIC alpine resorts, however this report summarises what snowmaking information is available for these mainland resorts and the SkiSim2 model includes snowmaking conditions in projecting season length and calculates the amount of technically produced snow required to maintain a 100-day season.

Projections 2024: "SkiSim2" model on the impacts of climate change on Australian Alpine and Nordic commercial ski areas

This research applies the "SkiSim2" ski season simulation model with an integrated snowmaking module, originally developed by Scott, McBoyle, and Mills in 2003[75] and further enhanced by Steiger in 2010[76].

The "SkiSim2" model has been applied to ski markets around the world, including North America[77], Europe[78], Scandinavia[79], and China[80]. The modelling undertaken specifically for this report applied the SkiSim2 model to the Australian ski industry, including alpine resorts and Nordic (cross-country) resorts, for a low emission (RCP 2.6), mid emission (RCP 4.5, SSP 2-4.5) and high emission (RCP 8.5, SSP 5-8.5) scenario. Importantly, the model specifies the minimum snow depth required for skiing and accounts for resorts' capacity to technically produce snow, making it more realistic than studies which measure any level of snow cover, or which do not account for snowmaking (e.g., Mitterwallner et al. 2024[81]). The SkiSim2 projections indicate future season length (days), with fully incorporated snowmaking, and the amount of technically produced snow required to maintain a 100-day ski season at each resort if temperature-independent snowmaking was feasible.

Parameter	Value
Temperature threshold for snowfall	1°C
Temperature threshold for rain	3°C
Minimum degree-day factor (on Jun 21)	1mm/°C
Maximum degree-day factor (on Dec 21)	5mm/°C
Snow depth required for a skiable day (alpine ski area)	30cm
Snow depth required for a skiable day (nordic ski area)	15cm
Density of snowpack	400 kg/m³
Temperature threshold for snowmaking	-2°C
Snowmaking season start	May 1
Snowmaking season end	Sept 30
Snowmaking capacity	10cm/day

Table 2.3: SkiSim2 model parameters

Methods

The SkiSim2 model uses daily temperature and precipitation to simulate snowfalls, snow depth, and snowmaking. On days with a maximum temperature below 1°C, 100% of precipitation occurs as snow, above 3°C 100% of precipitation occurs as rain, and between 1°C and 3°C the snow-rain ratio is calculated linearly. The snow melt rate is set to a minimum of 1 mm snow water equivalent per 1°C daily mean temperature on June 21 and a maximum of 5 mm on December 21. This represents the increased radiation resulting from more daylight hours and therefore the increased snow melt before and after June 21. A day is considered skiable if the snow depth is at or above 30cm for alpine resorts and 15cm for Nordic/cross country resorts. Snowmaking is considered active between May 1 and September 30. Technical snow will be produced at 10cm/day if temperatures are below the threshold of -2°C and if additional snow is needed to maintain the season until the scheduled season closing. Table 2.3 outlines the SkiSim2 model parameters and for further details refer to Steiger 2010[82].

Six weather stations (Table 2.4) were chosen based on completeness of data, the length of the time series, and the proximity to a ski area. To model snow depth at different altitudes in the ski area, temperature and precipitation are extrapolated from the altitude of the weather station.

To consider the ability of ski areas with a greater vertical range to prolong their ski season in the higher elevations of their terrain, "critical altitude" for each resort is used. The season length at the critical altitude represents the maximum season length that is possible with partial opening of the highest terrain, being the lowest point of the upper-half (if such an area exists), or the base station if not. For example, Thredbo could choose to operate the upper-part of the ski area starting from Merritts Mountain House at 1670m. The projections for Thredbo's season length therefore use an elevation of 1670m rather than 1365m (Thredbo village elevation). Table 2.5 shows the altitudinal range of all analysed ski areas and at which altitude the results were analysed.

Parameter	Altitude (m)	Latitude	Longitude
Khancoban	339.3	-36.2304	148.1405
Launceston airport	166.9	-41.5492	147.2144
Mount Baw Baw	1561	-37.8383	146.2747
Mount Buller	1707	-37.145	146.4394
Mount Hotham	1849	-36.9767	147.1342
Thredbo	1957	-36.4917	148.2859

Table 2.4: SkiSim2 weather stations

Ski Area	Type of ski area	Minimum altitude (masl)	Maximun altitude (masl)	Critical altitude* (masl)	Description of critical altitude
Selwyn	Alpine	1492	1614	1540	The village is at 1540m, this is the central area.
Mt Buller	Alpine	1375	1780	1600	Mount Buller Alpine Village is at 1600m. Seven ski lifts start at or above that altitude.
Falls Creek	Alpine	1500	1780	1620	The Halley's Comet Quad Chair can serve as a shuttle for the lifts on the Southern side starting at 1620m.
Hotham	Alpine	1450	1845	1730	The village is at the top of the ski area. Two lifts (Big D Express and Summit Quad) start at/above 1730m.
Thredbo	Alpine	1365	2037	1670	Partial operation is possible starting from Merritts Mountain House at 1670m. Then the cruiser chairlift and Sponard's and Anton's T-bar are also accessible (going back with the cablecar).
Perisher	Alpine	1605	2034	1720	Perisher Village (central part of the ski area) is at 1720m.
Ben Lomond	Alpine	1470	1570	1470	n.a
Mt Baw Baw	Alpine	1460	1564	1460	n.a
Charlotte Pass	Alpine	1760	1955	1765	n.a
Mt Stirling	Nordic	1234	1749	1500	The Mt. Stirling Alpine Winter Camp is located at an altitude of 1500m
Lake Mountain	Nordic	1340	1480	1340	n.a

Table 2.5: Altitudinal range of analysed ski areas

Projected temperature and precipitation

Projected temperature increases for the Australian Alps and Ben Lomond area (Tasmania) for June-October in the 2030s range between 0.5 - 0.9°C across all scenarios. In the 2050s temperatures increase by 0.9 – 1.1°C in the low emission scenario, by 1.2 – 1.5°C in the mid emission scenario, and by 1.7-2.1° in the high emission scenarios. In the 2080s temperatures increase by 0.8 – 1.0°C in the low emission scenario, 1.5-2.1°C in the mid emission scenario, and between 3.0-3.8°C in the high emission scenarios. Figure 2.2 details the temperature increases at each of the six weather stations.

Projected precipitation changes for June-October in the 2030s range between -4% and 0% (+1% and +5% in Tasmania) across all scenarios. In the 2050s, precipitation declines between -2% and -11% (+2 to +6% in Tasmania) for all scenarios. In the 2080s, precipitation changes between -5% to +7% (-1% in Tasmania) in a low emission scenario, between 3% and -10% (+2 to +9% for Tasmania) in a mid emission scenario, and declines by -10% to -20% (+3 to +7% for Tasmania) in a high emission scenario. Figure 2.3 details the precipitation changes at each of the six weather stations.

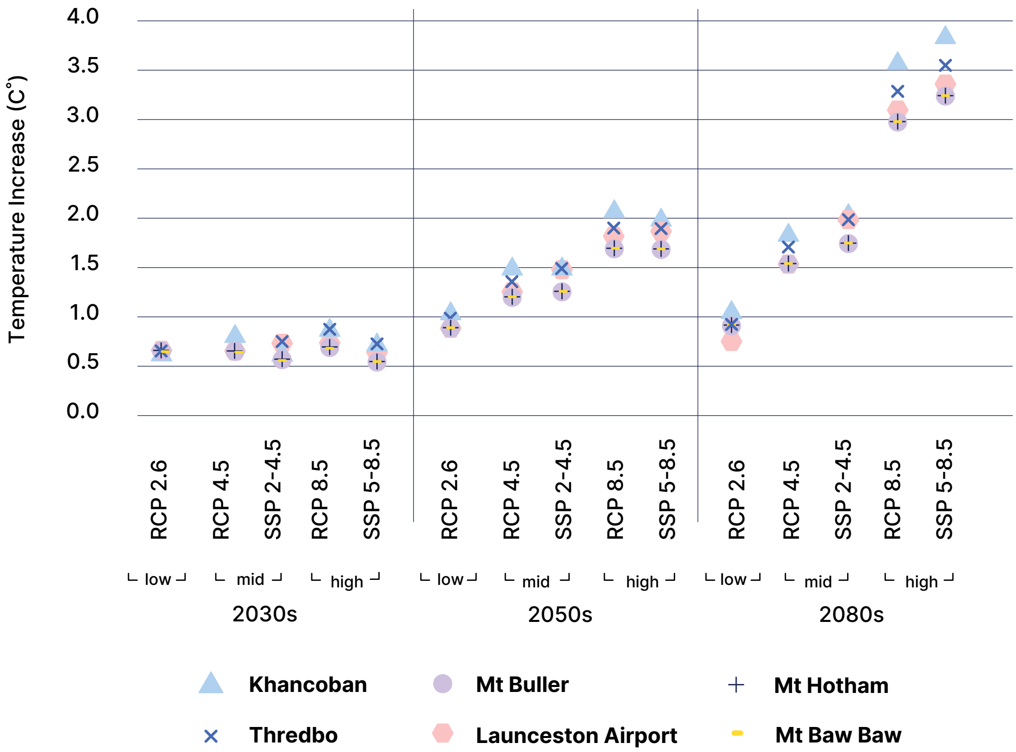

Figure 2.2 Projected temperature increase at each of the weather stations

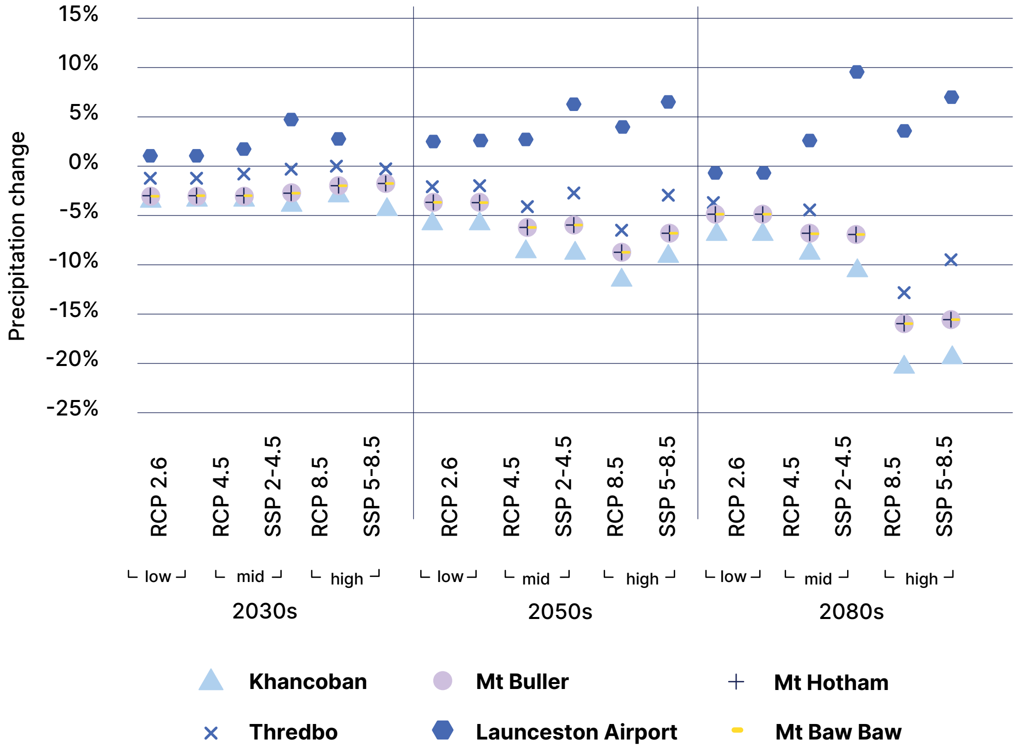

Figure 2.3 Projected precipitation change at each of the weather stations

Results: Projected ski season length

In the reference period (1981-2010), the average season length in Australian ski areas is 105 days at the critical altitude. A comparison with the reported season length of 116 days in the period 2015-2023 (excluding the COVID seasons 2020 and 2021) shows that the SkiSim2 projections sightly underestimate the current ski season length. A potential reason for this is due to wind-induced losses from precipitation gauges in the Snowy Mountains that were used to source snow depth data[83]. Another explanation is that the model assumptions do not fully reflect the operating realities of Australian resorts. For example, the 30cm snow depth threshold model requirement is an international standard and was supported by an Australian resort as an appropriate depth for the safe operation of snow groomers. However, ski area managers may still choose to operate below the 30cm snow depth threshold, particularly in snow-scarce and short seasons like 2023. It is also technically possible to produce snow at slightly higher temperatures than used in this model if air humidity is low, although this typically results in higher snowmaking costs and lower snow quality. Temperature independent snowmaking, such as snow factories, which can produce snow at up to 35°C, is not captured by this model given the expense associated with using snow factories over a large area.

Figure 2.4 shows the projected season lengths across all Australian ski resorts, including Nordic/cross country. Across Australian downhill ski resorts (excluding Nordic/cross country resorts) (Figure 2.5) season length including snowmaking will decline by 16-18 days (-15% to -17%) by the 2030s. In the 2050s, ski seasons will be 28 days shorter (-27%) in the low emission scenario, 44 days shorter (-42%) in the mid emission scenario (SSP245) and 55 days shorter (-52%) in the high emission scenario (SSP585). In the 2080s, the ski season will be 25 days shorter (-24%) in a low emission scenario, 61 days shorter (-58%) in a mid emission scenario and completely vanish (1 remaining skiable day) in a high emission scenario.

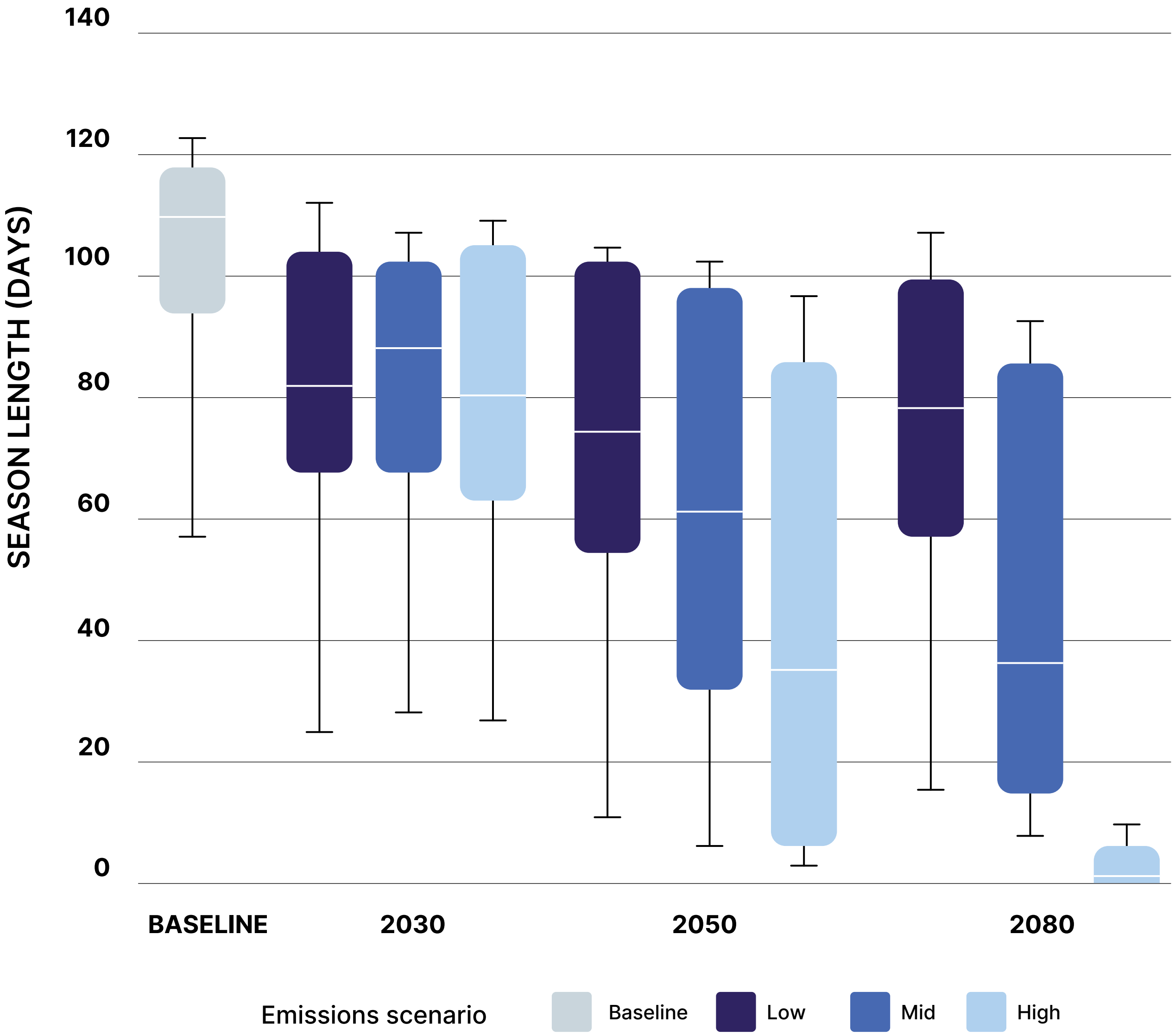

Figure 2.4: Projected season lengths for all Australian ski resorts (including Nordic/cross country resorts) using RCP2.6, RCP4.5 and RCP8.5. The figure depicts the median (solid horizontal line), the lower (25%) quartile, and the higher (75%) quartile of results in all analyzed ski areas. The vertical lines represent ski areas with the shortest and longest ski seasons.

Snow reliability is defined as at least 100-days with a snow depth of at least 30cm in 70% of all winter seasons[84]. In the reference period (1981-2020), six out of nine analysed ski areas are snow-reliable. By the 2030s, only two to three ski areas will remain snow-reliable and no ski area will be snow-reliable from the 2050s in any emission scenario.

The projected ski season length for each individual ski resort under different climate change scenarios is summarised in Table 2.6 and illustrated in Figures 2.6 and 2.7. Ski season length (days), including snowmaking, is provided for the baseline (average season length from 1981-2010), in a low emission scenario (RCP 2.6), mid emission scenario (RCP 4.5 and SSP 2-4.5) and a high emission scenario (RCP 8.5 and SSP 5-8.5).

Importantly, the above season lengths are calculated using the critical altitude for each ski resort, meaning that to achieve the projected number of days, some resorts will have to only partially open for some of the season. This means that for part of the season some resorts may only have 1-2 lifts and 1-2 T-bars opening.

This modelling assumes that ski resorts (except for Nordic resorts) already have snowmaking infrastructure in place over all the groomed slopes at or above the critical altitude. While most resorts now have extensive snowmaking infrastructure (Table 2.7), this is not the case for all resorts, meaning investment in further snowmaking infrastructure will be required. Snowmaking also requires significant water and electricity. For example, Thredbo already uses an average of 243,000[85]cubic metres of water and Mt Buller uses 210,000 - 250,000[86] cubic metres of water per year for snowmaking. The additional snowmaking infrastructure, water, and energy required to meet these projections will place significant ecological and economic costs on alpine resorts that may make their operation economically unviable.

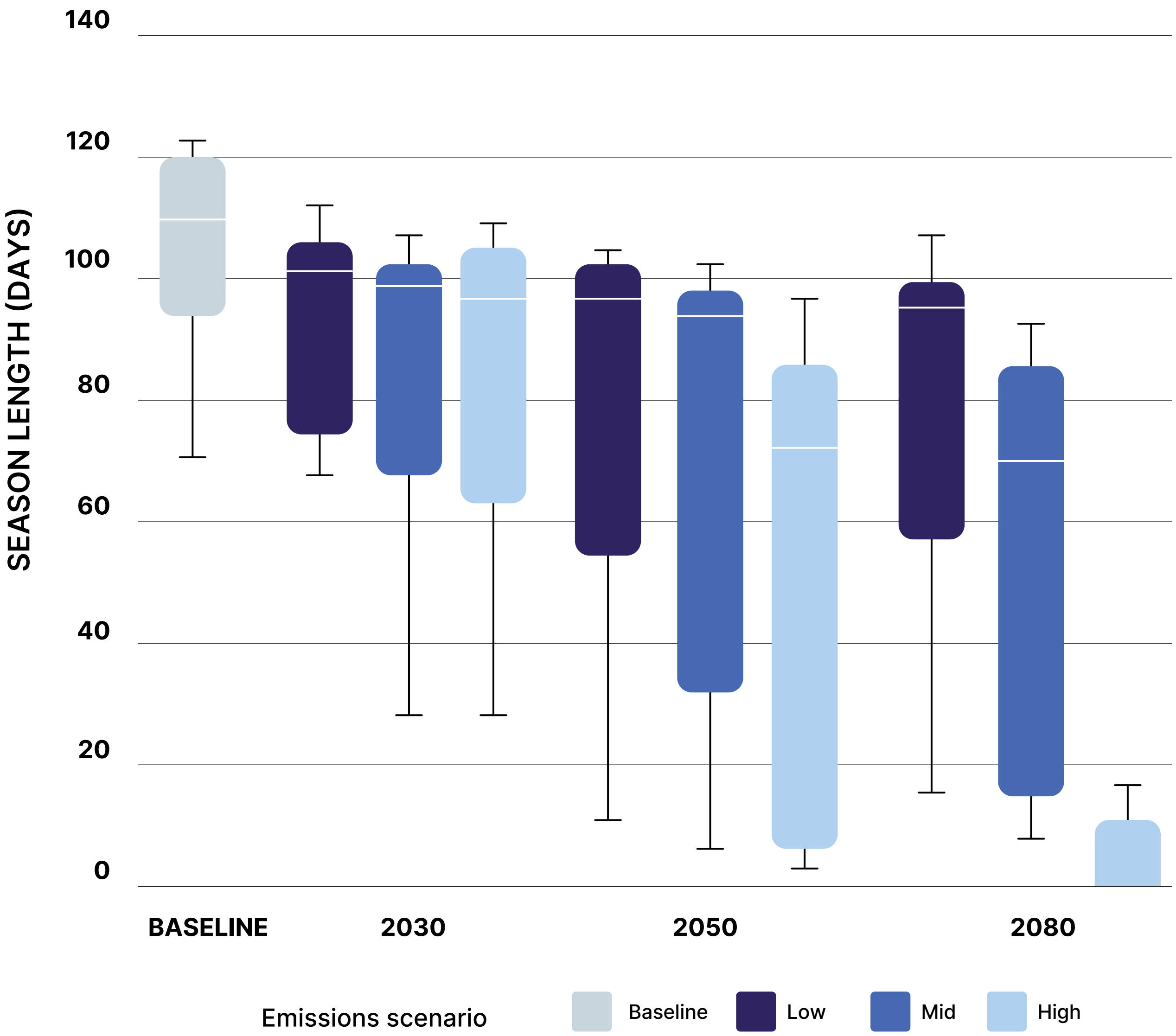

Figure 2.5: Projected season lengths for Australian downhill ski resorts (excluding Nordic/cross country resorts) using RCP2.6, RCP4.5 and RCP8.5). The figure depicts the median (solid horizontal line), the lower (25%) quartile, and the higher (75%) quartile of results. The vertical lines represent ski areas with the shortest and longest ski seasons.

	Baseline	Low Emission Scenario			Mid emission Scenario			High Emission Scenario		
Year	1981-2010	2030	2050	2080	2030	2050	2080	2030	2050	2080
VIC ALPINE RESORTS										
Mt Hotham	123	113	105	107	109-113	99-102	94-96	110	95-96	7-18
Falls Creek	109	101	95	96	99-102	97-91	58-75	98-101	74	0
Mt Buller	93	83	70	79	89	47-58	17-29	80-85	26-28	0
Mt Stirling*	92	70	57	67	76-74	44-60	25-33	65-76	29-35	2-5
Mt Baw Baw	70	23	11	16	29-29	5	0-2	28-32	1-3	0
Lake Mountain*	59	36	24	27	32-34	14-17	6-11	35-38	8-11	1
Average	91	71	60	65	74	49-56	33-41	69-74	39-41	2-4
NSW ALPINE RESORTS										
Perisher	117	105	101	99	103-104	91-96	77-87	106	84-86	0-5
Thredbo	111	101	96	95	99-103	85-92	63-81	101-102	70-73	0-1
Charlotte Pass	122	108	103	102	107-111	92-97	85-93	108-111	88-89	4-12
Mt Selwyn	97	68	51	53	68-74	25-28	3-8	64-74	3-8	0
Average	112	96	88	87	94-98	73-78	57-67	95-98	62-63	1-5
TAS ALPINE RESORTS										
Ben Lomond	109	82	62	74	79-83	19-33	1-11	76-85	2	0
NATIONAL										
Average	112	96	88	87	94-98	73-78	57-67	95-98	62-63	1-5

Table 2.6: Projected season lengths for each individual Australian ski resort. The range shown indicates the slight difference between RCP scenarios and SSP scenarios (RCP first number; SSP second number; where there is only one number RCP and SSP are the same). Averages have been rounded to the nearest whole day.
* Nordic (cross country) resorts, with no or limited snowmaking capacity but a minimum snow-depth requirement of only 15cm.

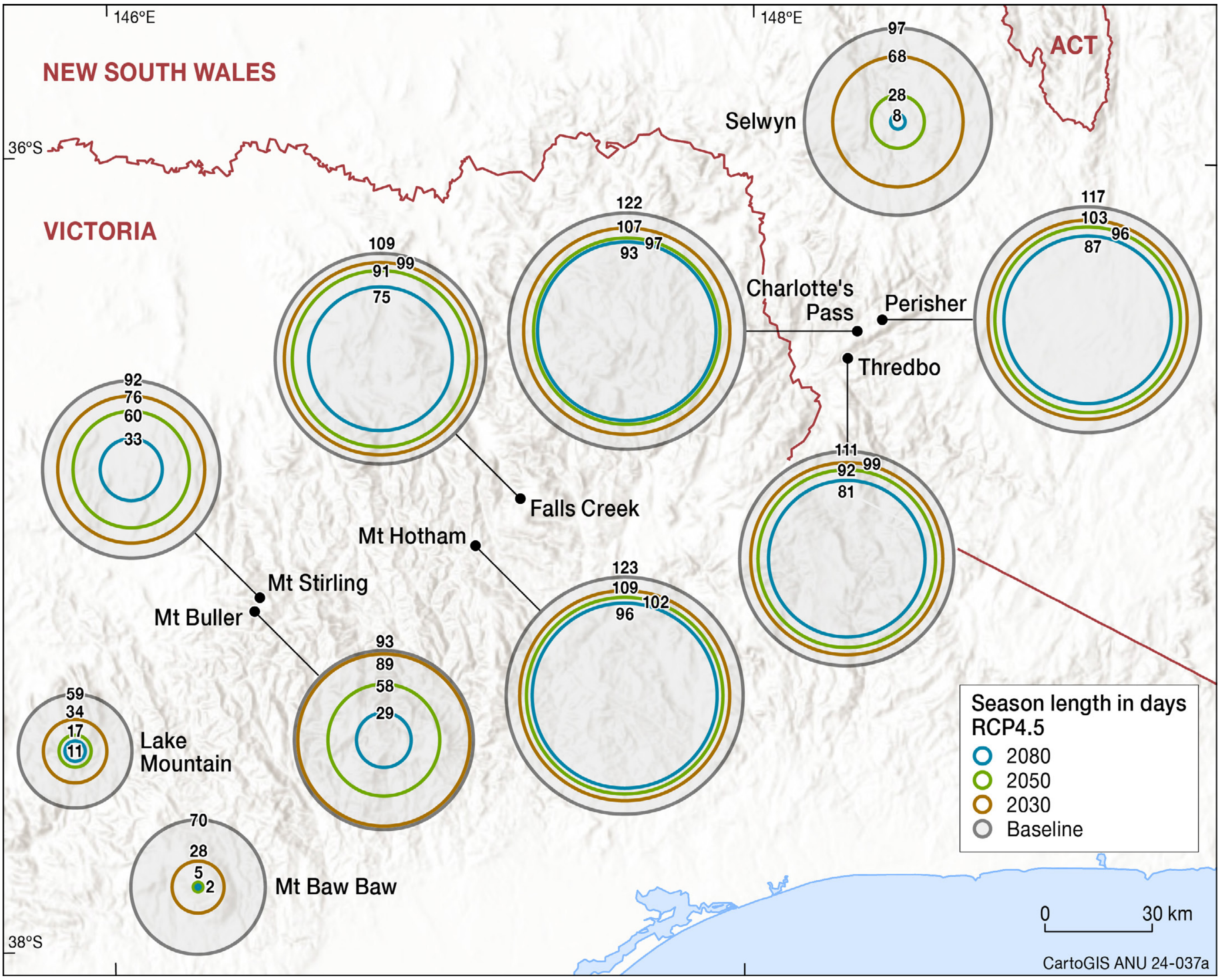

Figure 2.6: Projected season lengths for Australian Alpine resorts in a mid emission scenario (RCP4.5). The size of the circles corresponds to season length (larger circles = longer seasons).

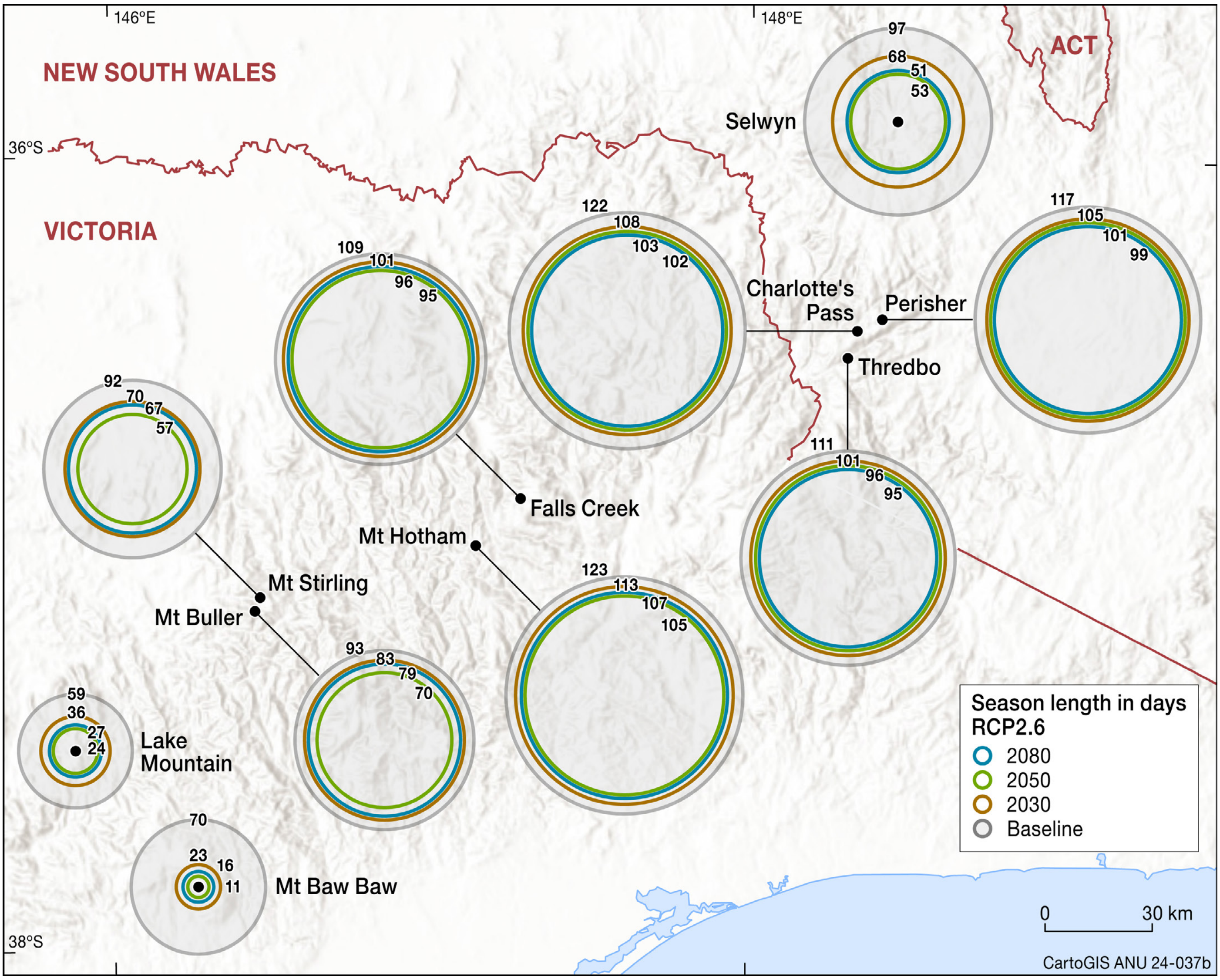

Figure 2.7: Projected season lengths for Australian Alpine resorts in a low emission scenario (RCP2.6). The size of the circles corresponds to season length (larger circles = longer seasons).

Technically produced snow required to maintain a 100-day season

These results show the amount of technically produced snow that would be required to maintain a 100-day ski season, assuming that temperature-independent snowmaking is available for the entire ski area. As such, these results do not account for the snowmaking temperature threshold and the impacts of climate change on reducing available snowmaking hours.

The amount of technically produced snow required to maintain a 100-day ski season will increase by 20-24% in the 2030s, 71-98% in the 2050s, and 115-237% in the 2080s (Figure 2.8). The cost for ski resorts to operate will dramatically increase as a result, given the energy requirements of temperature-independent snowmaking, water, and snowmaking infrastructure. Temperature-independent snowmaking also requires a significant number of snow groomers, personnel, and time to distribute the snow from central snow factories across the entire ski slope, putting greater pressure on resort economic viability.

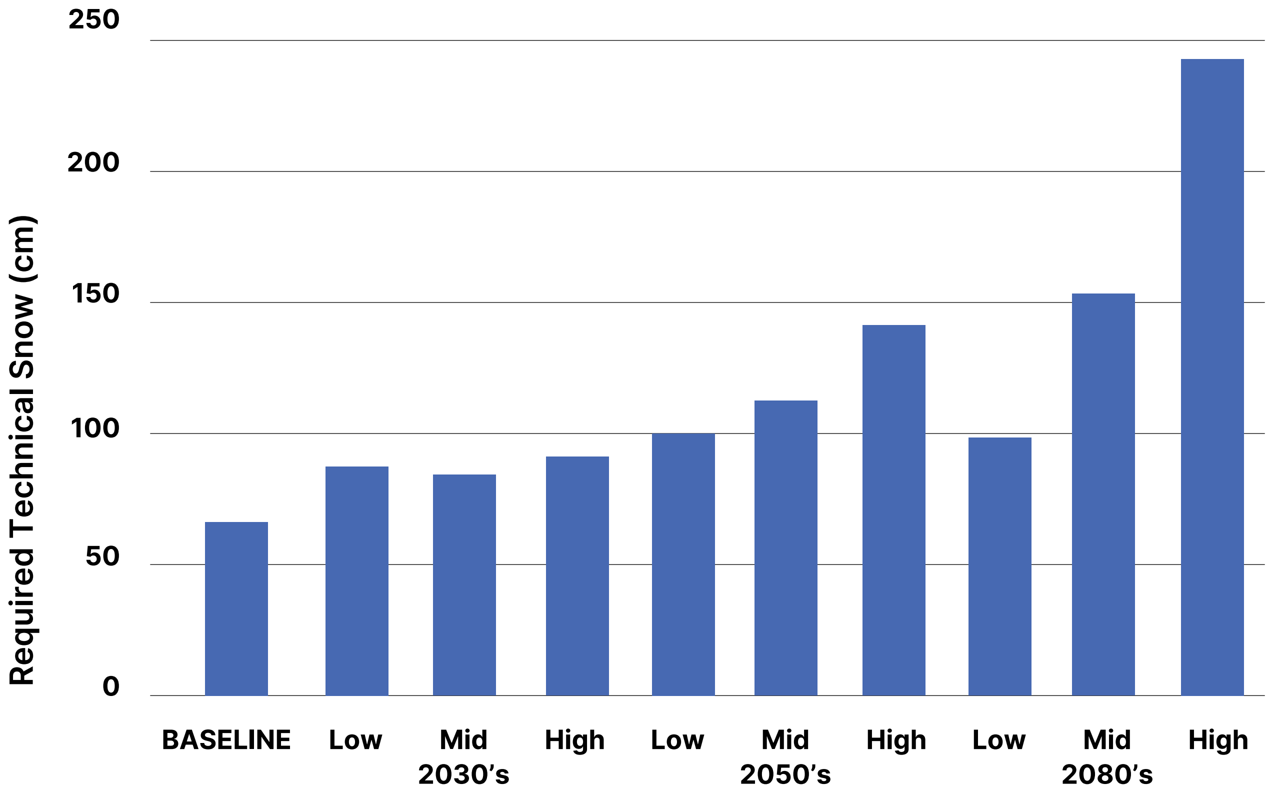

Figure 2.8: Technically producd snow required to maintain a 100 day season.

Snow tourism adaptation options

This section more closely examines Australian alpine resort's snowmaking operations and explores other adaptation adjusting the physical landscape through slope development or moving to higher altitudes, winter diversification, and transitioning to all-year tourism or summer (green season) tourism.

Snowmaking

Snowmaking has been critised as maladaptive because of its extensive water and energy use. A study by Scott et al. (2022)[88] argued that snowmaking could fall anywhere on a continuum between maladaptive or a successful and sustainable adaptation strategy, depending on how snowmaking operations were conducted (Figure 2.9).

Snowmaking that increases greenhouse gas (GHG) emissions or results in unsustainable water extraction is one of the greatest maladaptation risks to Australian alpine resorts. While some resorts have invested in renewable energy, others are either connected to the state electricity grid, which in 2023 had a renewable power percentage of 18.96%[90], or are powered by diesel or LPG generators. Table 2.7 outlines the snowmaking capacity of each Australian alpine resort, including access to water and energy, and the SkiSim2 results for increased snowmaking requirements in a mid emission scenario. While all resorts can employ snowmaking as a short-term solution to climate change, it is only financially realistic for higher-altitude resorts with sufficient water and energy supplies[91].

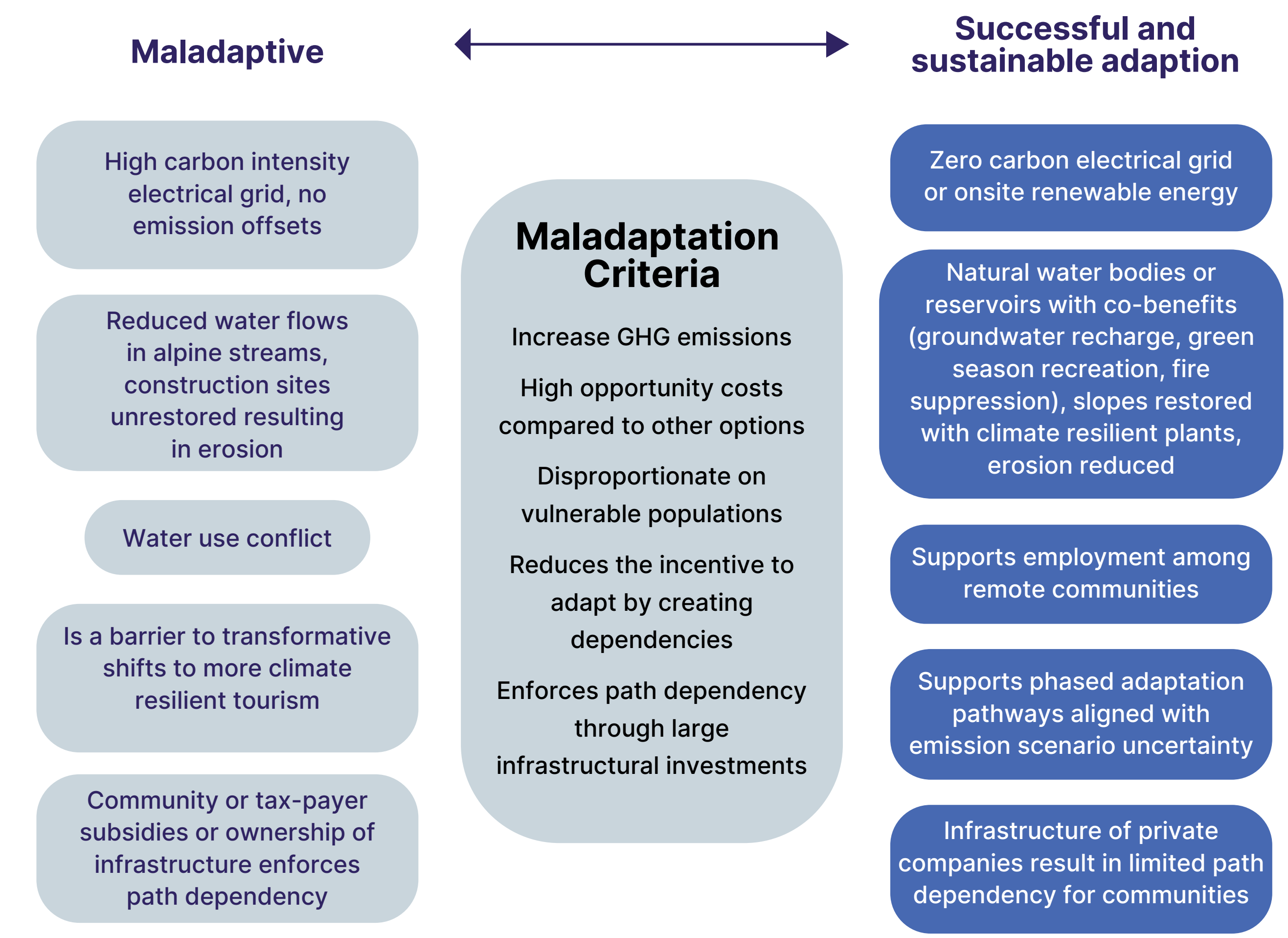

Figure 2.9: Snowmaking maladaptation continuum adapted from Scott et al. 2022 [89].

Resort	Snowmaking Equipment	Snowmaking Terrain	Water use	Electricity Use	Snowmaking increase to maintain 100 day season*
Mt Hotham	112 Snowguns[92]	38ha (10.31% of skiable terrain)[93]	Amount: 124,000 cubic metres per year (5 year average) for snowmaking[94]. Source: Private reservoir owned by ARV (29,000 cubic metres) plus nearby creek[95]	Partnered with Red Energy, which is certified carbon neutral[96], although Mt Hotham does not own any renewable energy itself[97]	2030: 11 – 7% 2050: 30 – 43% 2080: 75 – 113%
Falls Creek	No data	110ha (25% of skiable terrain)[98]	Amount: Average annual water diversion between 2016/17 and 2018/19 was 167,000 cubic metres for all resort operations[99]. Source: Rocky Valley Lake (28,000 megalitre capacity)[100]	Partnered with Red Energy, which is certified carbon neutral[101], although Falls Creek does not own any renewable energy itself[102]	2030: 26 – 24% 2050: 82 – 83% 2080: 132 – 117%
Mt Buller	350 Snowguns and five snow factories[103]	78ha (26% of skiable terrain)[104]	Amount: 210,000 - 250,000 cubic metres per year for snowmaking[105] Source: Two reservoirs filled from the Boggy Creek catchment (capacity 170,000 cubic metre capacity)[106]	Connected to State electricity grid plus a 40KW solar panel system[107,108]	2030: 39 – 35% 2050: 103 – 129% 2080: 194 – 219%
Mt Stirling	Nil	Nil	Nil	All power is provided by renewable energy in the form of a micro-hydro facility[109]. Not connected to the grid	2030: 106 – 91% 2050: 202 – 220% 2080: 300 – 326%
Mt Baw Baw	1 Snow factory (owned by ARV)[110]	12ha (40% of skiable terrain)	Amount: No data Source: Two 400,000 L storage tanks filled from Dam Valley water catchment[111]	Not connected to the grid. Three LPG fuelled generators. A solar and battery hybrid system powers the Mt Baw Baw Ski School[122]	2030: 39 – 30% 2050: 88 – 85% 2080: 112 – 131%
Lake Mountain	1 Snow factory (owned by ARV)[113]	25848 cubic metres	Amount: No data Source: Three storage tanks filled from the Taggerty River[114]	Not connected to the grid. Resort is powered by a 96.8kWp solar PV system[115] and diesel generators[116]	2030: 32 – 26% 2050: 75 – 70% 2080: 94 – 109%

Table 2.7: Snowmaking capacity of Australia alpine resorts. Note that the content is based off a mix of open source information and communication with some ski resorts. Changes in resort snowmaking capabilities or energy and water use not made available through open source or direct communication are not reflected.
*A mid emission scenario was chosen to illustrate approximate snowmaking increases in the future as a moderate scenario. The percentage increase is relative to the baseline (1981-2010). The range shown indicates the slight difference between RCP scenarios and SSPs scenarios (RCP first number; SSPs second number; where there is only one number RCP and SSP are the same).
† Nordic (cross country) resorts, with a minimum snow-depth requirement of only 15cm.

Resort	Snowmaking Equipment	Snowmaking Terrain	Water use	Electricity Use	Snowmaking increase to maintain 100 day season*
Perisher	236 Snowguns[117]	53ha (4.29% of skiable terrain)[118]	Amount: No data. Source: A Snowy Hydro aqueduct and Wraggs creek[120]	Partnered with Red Energy, which is certified carbon neutral[9121] and Perisher installed 88 solar panels on Bullocks Flat Skitude Terminal in 2019[122]	2030: 26 – 9% 2050: 92 – 99% 2080: 121 – 175%
Thredbo	337 lance guns 19 tower fans 8 mobile fans 185 manual pits[123]	120ha (25% of skiable terrain)[98]	Amount: 243,000 cubic m (5 year average) for snowmaking[125]. Source: The Thredbo River	Amount: 3,957.78 seasonal GWh (5 year average)[126] All resort operations powered by renewable energy through a power purchasing agreement with Red Energy[127,128]. Thredbo does not own any renewable energy except solar panels on the Thredbo Leisure Centre[129]	2030: 38 – 14% 2050: 104 – 124% 2080: 138 – 183%
Charlotte Pass	7 snow guns[130]	No data	Data unavailable - possibly Charlotte Pass Dam and/or Spencers Creek	Data unclear, but suggests that Charlotte Pass has no renewable energy[131]	2030: 19 – 5% 2050: 72 – 82% 2080: 97 – 153%
Mt Selwyn	27 snow guns[132]	35ha (77.78% of skiable terrain)[133]	Amount: No data. Source: Three Mile Dam[134]	No renewable energy[135]. Connected to the state grid	2030: 21 – 18% 2050: 42% 2080: 54 – 59%
Ben Lomond	4 snow guns[136]	No data	Amount: Average 500 snowmaking hours per season with a maximum of 45,000 litres per hour[137] Source: 0.9ML dam supplied by Big Ben Creek. Water could be pumped from the Ford River with appropriate infrastructure, albeit with other challenges[138]	Not connected to the grid. Diesel generators[139].	2030: 27 – 25% 2050: 49 - 56% 2080: 60 – 75%

For resorts which have not invested in renewable energy, snowmaking is maladaptive. If resorts are perceived to be intensive producers of greenhouse gases, this may affect the social acceptability of snow tourism. A member of the Australian Alpine Resorts Management Board (ARMB) argued "You cannot use carbon polluting technologies to enhance snowmaking in response to climate change"[141]. Not only might this impact revenue from visitors, but several ski resorts have received government support in the form of public infrastructure investments and payments to help resorts meet shortfalls in operating revenue[142]. Perceptions of resort unsustainability may put pressure on the government to withdraw support, despite climate change impacts likely to make the need for such support grow[143]. Resorts must therefore make a trade-off between short term gains and long term reputational risk.

While there are short term costs to investing in renewable energy, long term, local renewable energy can increase resilience by reducing reliability on long distance infrastructure, reducing reputational risk, and contributing to national and global emissions reduction efforts. However, high country terrain can be unconducive to renewable infrastructure and many resorts do not own the land they operate on, limiting their ability to invest in renewable energy. As a result, some resorts rely on state and national investment in renewable energy or purchasing power agreements with electricity companies, such as Red Energy, to support renewable energy uptake.

For snowmaking to be a successful adaptation strategy better understanding of visitor perceptions and preferences is needed. A study of VIC resorts in 2016[144] found that visitation was most responsive to snow depth (natural snow and snowmaking) at the higher altitude resorts and that the rate of change in visitor numbers is consistently higher for natural snow areas compared to snowmaking areas. This VIC study found that visitors' decisions are still strongly influenced by natural snow, but that such perceptions could be changed with greater awareness of the effectiveness of snowmaking. Conducting an updated study of visitor perceptions and behaviour for the 2025 snow season across both NSW and VIC would provide insights as to whether snowmaking will be a successful adaptation strategy for a future where a greater proportion of technically produced snow is needed.

Snowmaking as an adaptation option also has social implications. Resorts are likely to increase visitor costs to offset increased operational costs associated with snowmaking. Skiing is already a recreation directed towards higher income demographics[145], and access by lower and middle income individuals and households is increasingly limited. If alpine resorts are forced to price visitation at a level sufficient to offset increased snowmaking costs, it may transform resort skiing and snowboarding into a recreation that completely excludes lower-and-middle-income Australians. Exclusion based on income may also happen if domestic alpine resorts close and Australians need to travel overseas for snow tourism, adding travel costs to already inflated ticket prices. Although, some overseas snow destinations, such as Japan, are already comparably expensive to a domestic trip. Snow sports being inaccessible to most Australians based on income may be an unacceptable social outcome, in which case discussions around trade-offs and values need to occur.

Adjusting the physical landscape: landscaping, slope development and moving to higher altitudes

Adjusting the physical landscape to incorporate higher terrain or by re-grading slopes are both adaptation options for alpine resorts. However, there are significant economic and ecological costs to both options.

Most alpine resorts already have lifts running to the highest point either in or immediately adjacent to the resort boundaries, and there are currently no proposals for resorts to incorporate additional terrain. Historically however, NSW ski resorts have advocated for development on the Main Range (1957 to 1965), with previous proposals including a gondola on the Main Range's western face[146]. In 2002, Falls Creek released the Rocky Knolls and Damsite Ski Field Development Plan[147], which proposed expansion onto Mt McKay; critical habitat for the endangered Mountain Pygmy Possum[148]. While expansion to Mt McKay may provide reliable natural snow for the short-term, the peak (1849m)[149] is only 69m higher than the current summit of the Falls Creek resort area, and may rely on snowmaking in the near-future. These proposals were rejected on the basis that significant ecological damage would occur and degradation of the water catchment could have economic implications for hydroelectricity and the Murray-Darling Basin[150]. Such trade-off decisions will remain relevant over the next few decades, with increasing competition for higher ground in the Alps.

Landscaping and slope grading is another option being explored by ski resorts. Slope grading involves breaking rocks and ground levelling to create smoother ski runs. This requires less snow for operation, which increases snowmaking efficacy and means reduced levels of natural snowfalls can still result in viable operation. Unfortunately, slope grading disturbs or destroys vegetation including habitat for (threatened) native animals, increases the risk of erosion[151], and decreases slope stability[152]. The 1988 landslide at Mt Hotham was likely the result of slope grading and over-clearing[153], and similar causes are suspected of the 2010 landslides at Mt Hotham, Mt Buller, and Falls Creek[154]. Thus, Scott, Knowles and Steiger (2022)[155] have labelled slope grading as maladaptive and recommend it is avoided or minimised.

Diversification of winter revenue

Non-skiers represent an important market at overseas alpine resorts[156]. For example, a 2007 study found one out of four visitors in French winter alpine resorts does not ski[157]. There is no publicly available data on whether this trend is occurring in Australia and further research is required. If non-skiers are a significant or growing proportion of the market, then there are adaptation options to invest in winter hiking and snow shoeing, spas, music events, and other entertainment.

Backcountry skiing and snowshoeing will have much greater longevity than resort skiing, as higher-elevation areas such as the Main Range will retain natural snow for far longer than any of the alpine resorts[158]. Tourism operators are already capitalising on backcountry skiing; Snowy Mountains Backcountry operates gear hire and tour guiding out of Guthega[159], and Thredbo and Falls Creek resorts offer backcountry and snowshoeing tours[160]. These alternative winter activities could be expanded by resorts, although will generate less revenue than downhill snow sports, given its reduced reliance on infrastructure and narrower appeal.

Expanding backcountry activities will require ecological trade-offs, and further research should determine what the carrying-capacity of future backcountry locations (such as the Main Range) will be. Education about “Leave no trace” practices for high country environments will influence this carrying capacity. Another constraint on expanded backcountry activities will be the increased pressure on emergency services and rescue resources. If backcountry activities increase, whether as an individual or resort response to climate change, it is likely both NSW and VIC will need to increase the personnel and resources available to perform rescues.

Year-round tourism or summer tourism

The Australian Alps is the most seasonal tourism location in Australia. In 2013, non-snow-based tourism revenue was worth only approximately 30% of winter revenue. A decade later, the alpine tourism market is still geared towards winter and over half of all visitation occurs during the peak snow period of just 12 weeks[161]. This extends to surrounding towns’ visitor economy, where average winter spend significantly outperforms summer. Climate change projections indicate that a transition to year-round tourism is needed if alpine resorts are to support regional economies and maintain values of nature-based recreation in the future. However, summer or “green season” tourism has its own climate change risks and needs to be balanced with ecological impacts.

Transitions by some overseas alpine resorts to year-round tourism have been highly successful. Even eight years ago, Whistler Mountain Bike Park (Canada), achieved $46 million in visitor spending directly attributable to mountain biking, supported 389 jobs, and generated $75.9 million in economic activity for British Columbia[162]. The town of Derby in Tasmania turned around its decline after tin mining operations ended by investing in mountain biking[163], attracting 45,000 riders per year and resulting in new businesses, accommodation, and community services[164].

Australian alpine resorts are already transitioning; Thredbo has the only lift-accessed mountain biking in the country and Falls Creek, Mt Buller, Mt Baw Baw, and Lake Mountain all offer shuttle-accessed mountain biking. More women and families are participating in mountain biking[165], bringing it closer to the family-holiday that skiing often is. Although there is a risk of saturating the mountain biking market, mountain biking participation has increased more than 100% in the last five years, and growth is expected to continue[166]. Other possible summer offerings for resorts include hiking, road cycling, fishing, trail running, bird and wildlife viewing, camping and glamping, horse riding, four-wheel driving, kayaking, canoeing, and rafting, many of which are already being offered. Within the bounds of their lease agreements, resorts could also build facilities for summer activities, such as golf courses, tennis courts, zip lines, swimming pools, bobsled tracks, and alpine coasters, with attention to avoiding an unacceptable level of ecological impact.

One opportunity arising from climate change is that the Australian Alps will become a haven from heatwaves and urban heat islands. Heatwaves are projected to last longer and occur more frequently in the rest of NSW and VIC . While the Australian alps will experience increased temperatures, they will remain relatively cool compared to non-alpine areas (Figure 2.10).

Despite these opportunities, there are several challenges for resorts to overcome in a year-round tourism transition. Firstly, climate change projections indicate the region will experience more severe and more frequent bushfires and storms[169], which have the potential to damage infrastructure, reduce operation days of the resort, and threaten lives. High winds associated with even mild storms may reduce operation of lift-accessed activities such as mountain biking and hiking, as resorts are often forced to put lifts on hold for safety reasons. Although annual precipitation will decrease, extreme rainfall events will increase, with such events risking damage to hiking trails, mountain bike trails, road access, and resort infrastructure.

Without snow, the alpine resorts lose their unique selling point and need to compete with established tourism destinations on the coast, in national parks, and in towns and cities. A transition to year-round tourism requires a critical mass of product prior to opening and a commitment of retail operators to operate during the summer. Green season offering across the Australian Alps resorts is currently limited, ad hoc, and disjointed[170]. A report commissioned by the Alpine Resorts Coordinating Council (ARCC) into green season offerings at Victorian resorts found that awareness was a challenge, as Australians often did not consider summer Victorian alps trips due to the perception that summer holidays should be at a beach or pool, concerns a holiday would be reliant on good weather, and uncertainty over what activities were available[171]. However, some positives were that people considered it a relatively cheap holiday that could be easily reached via car rather than plane and was in a location of stunning natural beauty[172].

There have been several unsuccessful attempts to increase summer tourism in Australian alpine resorts. ARCC comments that “efforts to expand the offerings of the green season have yielded low economic returns and these will continue to be more economically challenging than snow-based activities for the foreseeable future”[173]. Alpine resorts have very different conditions and characteristics, making summer tourism more achievable for some rather than others. For example, Mt Hotham attempted four different summer activity offerings, including an Onsen retreat and spa, chairlift accessed mountain biking, scenic chairlift rides, and a tube park, all of which are now discontinued[174]. Some reasons for these failures included that mountain biking required onsite medical facilities due to the number of injuries and caused erosion, and the resort struggled to maintain staffing numbers outside the winter period[175]. Other resorts may be constrained in their capacity to offer summer tourism activities due to the conditions of their lease, which may prevent the development of mountain biking or hiking trails, or the expense of development approvals.

Nevertheless, efforts to increase green season resort offerings are underway. In NSW, the Snowy Mountains Special Activation Precinct Master Plan seeks to “establish Australia’s alpine capital as a resilient year-round tourism destination”[176]. Unfortunately, there is limited collaboration across state borders. Collaboration across NSW and VIC, with national parks, local, and state government, could achieve a critical mass of activities. Coordination will also mean that alpine resorts can specialise in different activities to avoid direct competition across all resorts. Events are already playing a huge role in attracting summer visitation, including mountain bike, road cycling, trail running, and adventure racing events, and coordination may increase their success.

Ultimately, the success of year-round tourism and winter diversification depends on the coordination and quality of these offerings, and the behavioural adaptive capacity of visitors. It is essential that extensive collaboration occurs to ensure that any ecological trade-offs are acceptable and that summer tourism investments have the best chance of a sustainable and economically viable outcome.

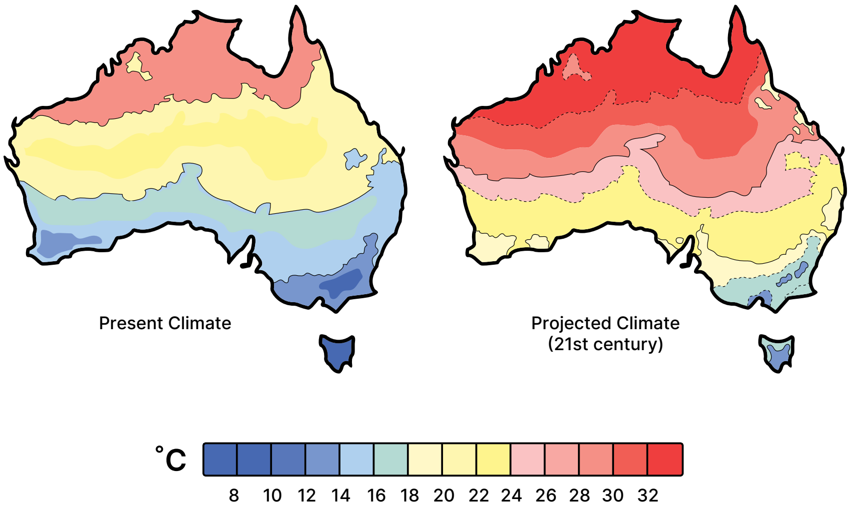

Figure 2.10 Mean annual temperature for the present climate (left) and projected climate in the late 21st century (right)[168].

Mergers and ski resort conglomeration

Mergers and resort conglomerates are behavioural adaptations that have been adopted by many alpine resorts globally. These forms of cooperation mean resorts can share equipment, personnel, and expertise, while reducing market competition and costs[177]. Resorts offering a season pass covering multiple resorts in the region, such as in the Canadian Rockies, is a common form of mergers and cooperation. Vail Resorts (Vail) have implemented this in Australia, where an EpicPass provides season access to Perisher, Falls Creek, Mt Hotham (all Vail-owned), and many overseas resorts[178]. The Ikon Pass[179] and Mountain Collective Pass[180] provide season or limited access respectively to many overseas destinations, but differ from the EpicPass in that they only provide 2-7 day passes for Thredbo (Ikon) and Mt Buller (Ikon and Mountain Collective).

Alpine resort conglomeration has mostly occurred in North America, with large corporations buying multiple ski locations across the continent or internationally. This business model is proving to be an effective adaptation strategy financially. When poor conditions occur at some resorts, the financial impact can be spread across the organisation, and above-average economic performance at another resort can offset losses. Conversely, companies with an alpine resort in only one location are more vulnerable to poor conditions. Vail owns Perisher, Falls Creek and Mt Hotham in Australia, giving these resorts a competitive advantage over other Australian resorts, as Vail can continue to operate these resorts over years with poor conditions and offset the losses with its 38 overseas ski resorts[181]. This is particularly effective as Vail's other resorts are located in the United States, Canada, and Switzerland, and these countries will experience less severe climate change impacts for longer than Australia. While this may mean Perisher, Falls Creek, and Mt Hotham will outlast other Australian resorts, it is also possible Vail will close or sell its Australian resorts to focus on North American and European ones, which are still experiencing their own climate change crisis[183].

One adaptation option would be for Australian resorts to merge, conglomerate, or more informally cooperate. Unfortunately, Australian ski resorts tend to experience poor conditions simultaneously, given their close proximity (Figure 1.1 and 1.2), negating one of the main benefits of merging. Resorts not currently owned by Vail forming a conglomerate or merger with overseas alpine resorts, such as in New Zealand or Japan, could have benefits for both parties; the Australian resort increases adaptive capacity by being able to offset poor seasons, while the international resort gets access to the Australian market.

Mergers and conglomerations do not reduce greenhouse gas emissions, nor do they improve snow quantity, quality, or snowmaking conditions. However, they may ensure the economic viability of alpine resorts and allow them to continue operating in good snow years where they otherwise would have closed. It should be noted that monopolies and oligopolies are also known for creating undesirable economic outcomes for consumers[184]. There is therefore a risk that merging or conglomerating could result in resorts becoming more expensive and even less accessible to lower- and middle-income Australians, thereby exacerbating social equality concerns.

Summary

Skiing in Australia is already relatively short compared to many other markets globally and the number of ski areas with a substantial ski season will decline rapidly in the coming decades. Mt Buller, Mt Baw Baw, Mt Stirling (Nordic), Lake Mountain (Nordic), Mt Selwyn, and Ben Lomond are Australia's ski resorts most vulnerable to climate change. Visitors of smaller ski resorts tend to have a greater tolerance for poor-quality snow, as a larger proportion of visitors are families, with higher interest in snow play, tobogganing, and beginner slopes, which require less snow. With sufficient support from these groups, smaller, low-elevation resorts may continue operating for longer. However, as indicated by the SkiSim2 projections, these resorts are unlikely to be economically viable past the next few decades if they continue to rely predominantly on winter downhill skiing.

These vulnerable ski resorts play an important part of the region's economy, culture, and identity (see Section 3: Regional communities). These resorts need to further invest in adaptation measures, such as summer tourism and winter diversification, to preserve Australian values of outdoor-based recreation in the alps, health and wellbeing, and to continue supporting regional towns. There are opportunities to be seized when adapting to climate change; as Australia warms, the Alps will provide a haven of cool temperatures in Summer. Seizing these opportunities requires proactive decision-making and collaboration across governments, communities, businesses, and recreational users.

The Australian alpine industry is different to the international alpine industry, where snow cover is more extensive, the ski season is longer, and visitor preferences and expectations differ.

Further research into Australian visitor perceptions and preferences would improve the ability to predict short and medium term responses to declining snow and increased snowmaking. Some areas of inquiry would be:

- How many winter visitors are non-skiers and how could winter diversification cater to these visitors?
- What would make the Australian alps a more attractive summer destination (first-time research for NSW resorts)?
- How do visitors respond to changes in natural snow depth and snowmaking (update of Victorian resorts since 2016 and first-time research for NSW resorts)?
- How is backcountry skiing projected to increase and what is the carrying capacity of the Australian Alps backcountry areas?

The SkiSim2 results highlight that long (and most likely economically viable) ski seasons are still possible with effective mitigation that keeps our global emissions trajectory within a low emission scenario, particularly for higher altitude resorts. It is therefore critical that governments take drastic action to mitigate climate change. For resorts particularly vulnerable to climate change, planned adaptation needs to occur soon, so that Australian governments and communities can support a transition that preserves jobs, economic activity, regional towns, and other values.

Recommendations

- Investment in year-round tourism and diversification of winter tourism should occur. These options need to be balanced with ecological values and the carrying capacity for each needs to be determined.
- Extensive collaboration about adaptation options needs to occur between natural resource managers, the alpine resorts, and the community to ensure that ecological trade-offs are acceptable and that adaptation options have the best chance of a sustainable and economically viable outcome.
- Further investment in renewable energy for snowmaking operations needs to occur, at a resort and/or state levels.

Image. Daygin Prescott

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