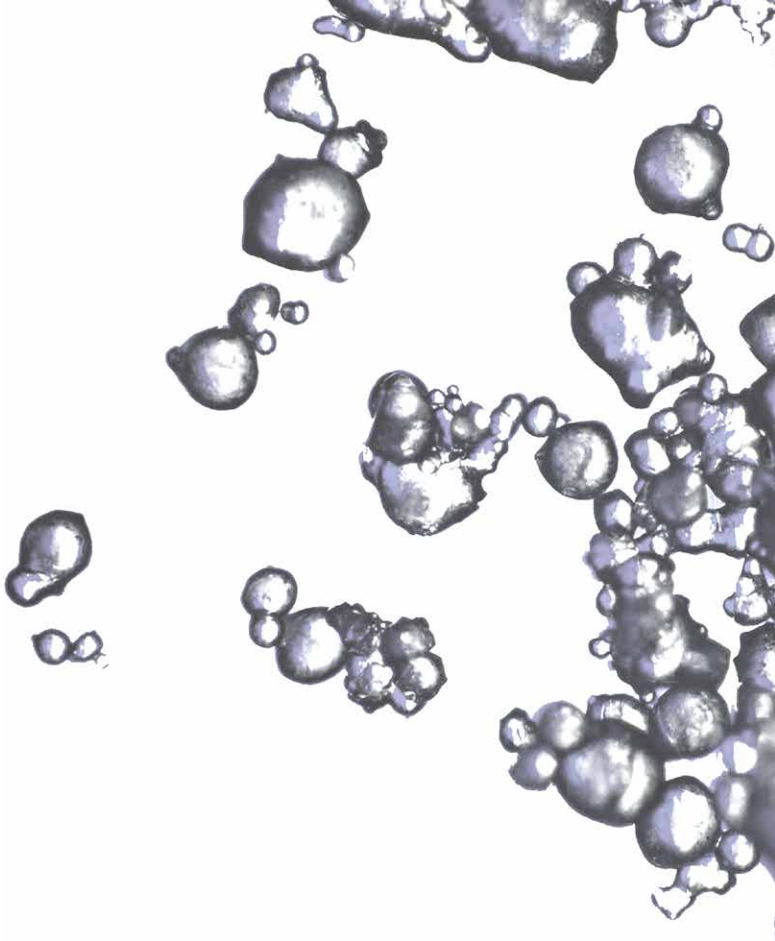
CIPRA



Artificial Snowmaking in the Alps

Follow-up to the report ‘Der gekaufte Winter' (The bought winter) by Axel Doering and Sylvia Hamberger



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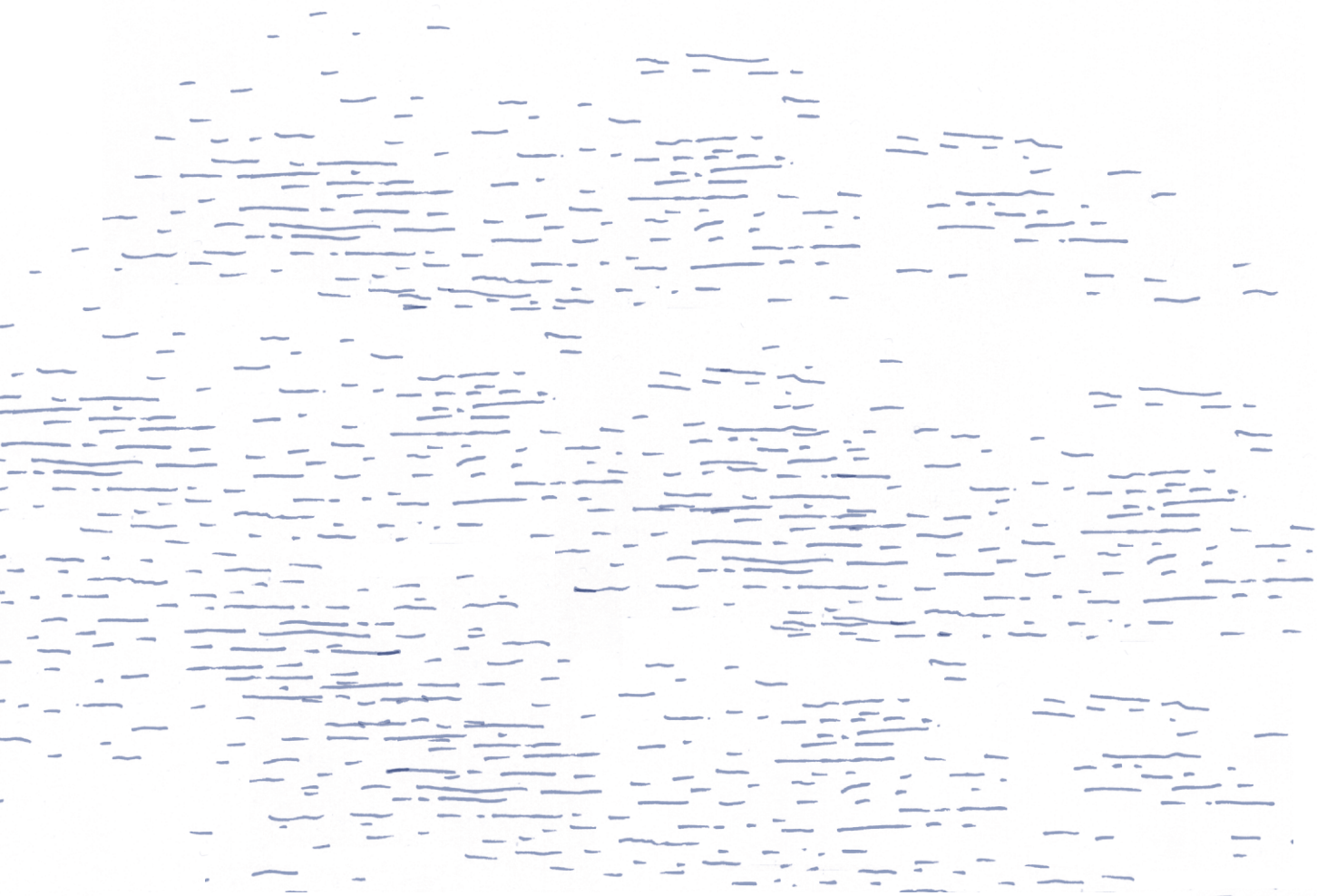
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« We believe that we can buy back the winter we have lost through our high energy use by consuming even more energy.»

Axel Döring,
Co-author of the study 'Der gekaufte Winter' (2015) and President of CIPRA Germany

1 Introduction

Hardly any image shapes our idea of a winter holiday in the Alps as strongly as immaculately groomed, snow-white pistes against a blue sky. That this image is now industrially manufactured across large parts of the Alps is rarely considered. Since the first installations in the 1960s and 1970s, artificial snowmaking has evolved from a technical niche into a mainstay of Alpine winter tourism. What was once intended to supplement natural snow has become a basic prerequisite for operations in many ski areas: without artificial snow, economically reliable ski operations can now barely be maintained across large parts of the Alps.

This has also shifted the relationship between people and mountains. In the past, people adapted to the conditions nature provided; today, nature is increasingly being adapted to the abilities of skiers – with levelled slopes, straightened pistes and a snow cover that no longer falls from the sky, but is produced at the push of a button. This change comes at a price: piste grooming, snowmaking infrastructure and the ongoing operation of the installations require an ever-growing input of water, energy, land and money. This also causes noise and considerable environmental impacts.

Just how large this input actually is turns out to be surprisingly difficult to quantify. As early as 2015, the authors of the predecessor report ‘Der gekaufte Winter’ (‘The Bought Winter’) noted that it was almost impossible to obtain up-to-date figures for most Alpine countries (Hamberger & Doering 2015). More than a decade later, little has changed: ski areas readily publish their kilometres of piste, but information on the area covered by snowmaking, or on water and energy consumption, remains the exception. To this day there is no uniform, Alps-wide survey method. Nevertheless, this report attempts to draw as accurate as possible a picture on the basis of the best available studies, extrapolations and surveys. At the same time, it makes transparent where the data reach their limits. How this was approached, and the caveats with which the figures should be read, are explained in the chapter ‘Snowmaking data’.

However patchy the figures remain in detail, the trend they reveal is unambiguous: the resource consumption of snowmaking has been growing for decades – considerably faster than public awareness and political regulation have so far kept pace with. In 2004, CIPRA International put the area in the Alps equipped for snowmaking at around 23,800 hectares, with a stated water consumption of 95 million cubic metres. This is equivalent to the annual water consumption of a city of 1.5 million inhabitants (CIPRA International 2004). By the end of 2014, Hamberger and Doering already estimated the area covered by snowmaking at a minimum of

70,000 hectares. The extrapolation in this report likewise arrives at no less than 62,000 hectares. Since it is based in part on outdated national figures, and conservative assumptions or minimum values were used wherever there was uncertainty, the actual area is likely to be considerably larger. It can therefore be assumed that the true figure is substantially higher. Areas for storage reservoirs and ancillary facilities are not even included (see chapter 'Snowmaking data'). Water demand has also doubled since the early 2000s: at that time, the hydrologist Carmen de Jong estimated it at around 95 million m^3 per year; according to extrapolations, it now stands at around 190 million m^3 per season (Keiser 2007; see chapter 'Water consumption').

CIPRA's 2004 background report had already identified the core of the problem, which has lost none of its relevance: it was inconsistent, it argued, to use actual and impending global heating as an argument for opening up the high mountains and building snowmaking installations, while at the same time clinging at all costs to winter tourism in its conventional form (CIPRA International 2004). The report 'Der gekaufte Winter' by Hamberger and Doering (2015) subsequently described the machinery of the ski and snowmaking industry behind this in all its facets.

This report now takes stock of the figures, data and facts on snowmaking across the entire Alpine region and sheds light on the ecological, economic and legal dimensions of this development. In doing so, CIPRA adopts a critical perspective grounded in nature conservation, without condemning winter sports as such. The aim is a balanced assessment of the tourism economy, adaptation to climate change and ecological carrying capacity – as a sound basis for discussion for policymakers, the media and the interested public.

The climate crisis in the Alps

In the Alpine region, climate change has long ceased to be an abstract question for the future. Not as much snow, melting glaciers, thawing permafrost, increasing heat and changing natural hazards show that the natural conditions of the Alpine region are changing fundamentally – and faster than in most other regions of the world.

The Alps are warming twice as fast as the global average. In Switzerland, the mean annual temperature in the period 1991–2020 was already around 2.0 °C above the pre-industrial level (1871–1900); worldwide, the figure for the same period was about 0.9 °C. In the record year of 2024, Switzerland was as much as 2.9 °C above the pre-industrial mean (MeteoSwiss/ETH Zurich 2025). For Austria, the Climate Status Report 2025 shows warming of around 3.1 °C compared with 1850–1900 (smoothed trend value; Stangl et al. 2026). Europe as a whole is the fastest-warming continent (Copernicus/WMO 2026).

The consequences in the high mountains are impossible to overlook: Swiss glaciers have lost around a quarter of their volume since 2015; 2022 and 2023 saw the greatest losses ever measured, and more than 1,000 small glaciers have already disappeared completely (GLAMOS 2025). The last remnant of the Triglav Glacier in Slovenia melted in 2026. Permafrost is also warming: 2024 was a new record year,

with temperatures at a depth of ten metres rising by up to 0.8 °C within a decade (PERMOS 2025) – with consequences for the stability of slopes and of infrastructure such as cable car pylons and mountain stations.

Changes in the snow line and snow cover

The proportion of precipitation falling as snow is declining – even at higher altitudes; several independent measurement series show this trend. At 76 Swiss measuring stations, the proportion of snowfall days among all precipitation days is decreasing markedly, most strongly at low altitudes (Serquet et al. 2011). Since 1970, the number of snowfall days at 2,000 metres has fallen by around 20%, and below 800 metres it has roughly halved (NCCS 2025). Directly linked to this is the rise of the zero-degree line: in Switzerland, it lay at about 420 metres in winter around 1900, but already at around 900 metres on average for 1991–2020 (MeteoSwiss/ETH Zurich 2025). Snow cover in the Swiss Alps now lasts a good five weeks (38 days) less than in 1970 (Klein et al. 2016); in Austria, according to Olefs et al. 2020, the duration of snow cover has fallen by 42 days since 1960.

The duration of snow cover in the Alps is now around 36 days below the average of the past 600 years (Carrer et al. 2023). Snowfall itself has also decreased: between 1920 and 2020 it fell by 34% at 46 stations in the Alpine region, and by almost half in the south-western Alps – with a marked acceleration since 1980 (Bozzoli et al. 2024).

Impact on skiing

Since the 1960s, artificial snowmaking has been regarded as the technical answer to absent or unreliable snowfall; today it is a prerequisite for economically predictable ski operations across large parts of the Alps, but under greatly changed conditions.

Snow conditions are changing. As the climate warms, conditions on the pistes themselves are changing too. Winter starts later and ends earlier, and the snow is becoming less abundant and wetter. Rain increasingly falls up to medium altitudes and softens the snow cover; if frosty nights follow, the pistes ice over. For skiers this means more frequent slushy, wet conditions in the afternoon and hard, icy pistes in the morning. The image of the ‘white ribbon’ – a narrow strip of artificial-snow piste in a green or brown landscape – has long been the norm at lower altitudes.

The risk of injury is greater on hard artificial snow. Artificial snow is considerably denser and harder than natural snow (see section ‘Artificial snow vs natural snow’). The Innsbruck sports physicians Gerhard Ruedl and Martin Burtscher point out that artificial snow is often hard and icy, encourages high skiing speeds and is associated with long braking distances; at 50 km/h the kinetic energy is 25 times as high as at 10 km/h – making falls and, above all, collisions correspondingly serious (Ruedl & Burtscher 2026). In addition, in winters with little snow, operations are concentrated on a few, often narrow, pistes covered with artificial snow. According to the survey by the Ski Accident Evaluation Unit (ASU), the collision risk for skiers

in the 2024-25 season reached its highest level since records began in 1979-80 (Stiftung Sicherheit im Skisport 2025) – although the statistics do not show whether, and to what extent, this is linked to piste conditions. A direct comparative study of injuries on artificial and natural snow is still lacking.

Artificial snow also comes up against physical limits. It can only be produced at sufficiently low temperatures and low humidity. If it is too warm, even the most powerful snowmaking system is of no help. The winter of 2022-23 demonstrated this vividly: even in high-altitude ski areas such as Sölden (Austria) and Zermatt (Switzerland), artificial snow could not guarantee the opening of the pistes, and in Lenzerheide (Switzerland) more than a hundred helicopter flights carrying snow were unable to prevent the pistes from melting away (de Jong 2023). At the same time, the time windows for snowmaking are shrinking: in Austria, the number of hours with suitable snowmaking conditions between 1961 and 2020 has declined by around 26% compared with 1961–1990 (Olefs et al. 2020).

Glacier ski areas are particularly affected. To counter ongoing glacier retreat, snow is sometimes even removed from the glacier's accumulation zone and transported by diesel-powered piste bashers onto artificially extended access ramps between the valley station and the retreating glacier tongue – a practice that harms not only the glaciers themselves but also the sensitive glacier forefield (de Jong 2023).

Climate change is transforming ski tourism as a whole. Operations are increasingly concentrated in large, mostly high-altitude areas: worldwide, around 73% of all skier days are accounted for by large ski areas (<100,000 skiers per year), which make up only 13% of all areas. 69% of all ski areas are small (up to four lifts) and record just 18% of skier days. The Alps account for around 39% of all skier days worldwide (Vanat 2025). Smaller and lower-lying areas are giving up: in France, around 186 ski areas have closed since 1951, mostly very small ones (Metral 2025); in Italy, Legambiente counted as many as 273 permanently decommissioned lift facilities in 2026, with a further 231 kept alive with public money despite their doubtful future (Legambiente 2026). At the same time, prices are rising, see Table 1: despite some strong winters, the number of skier days in the major Alpine countries remains below the peak values of the late 2000s – in Austria, for example, at 50.1 million (2023-24) compared with 56.9 million in the 2008-09 season – and, according to Vanat, demographic change and a stagnating middle class offer little prospect of growth (Vanat 2025).

Country	Ski area	Day pass 2016-17	Day pass 2026-27
Germany	Garmisch-Classic	42 €	72 €
France	Les 3 Vallées	60 €	84,20 €
Italy	Dolomiti Superski	57 €	89 €
Liechtenstein	Malbun	47 CHF	55 CHF
Austria	Ski Arlberg	52 €	85 €
Austria	Sölden	52 €	84,50 €
Switzerland	Zermatt	79 CHF	ab 89 -120 CHF
Slovenia	Kranjska Gora	31,50 €	50 €
Slovenia	Krvavec	32 €	43 € (advance purchase)

Table 1: Prices of adult day passes (high season) in selected ski areas of the Alpine countries, 2016-17 and 2026-27. Sources: 2026-27 operators' price lists (Bayerische Zugspitzbahn, Les 3 Vallées, Dolomiti Superski, Bergbahnen Malbun, Ski Arlberg, Zermatt Bergbahnen, RTC Žičnice Kranjska Gora) and Urlaubshamster (2026); 2016-17 operators' prices according to alpinforum.com (2016), www.bergbahnen.li (archived 4 January 2016).

Many ski areas nevertheless respond with growth – more kilometres of piste, larger linked areas, more snowmaking. A survey of 1,413 Alpine skiing holidaymakers calls this strategy into question: winter guests are looking for more than a 'high-performance ski area', namely a variety of activities to suit their abilities and preferences. The authors of the study conclude that ski areas should rethink their strategies geared towards growth and ever more technical snowmaking, develop offers covering the entire winter experience, differentiate prices by target group and factor daily fluctuations in snow and weather, as well as climate and demographic change, into their planning (Bausch, Ortanderl & Pröbstl-Haider 2024; see box 'Rethinking growth orientation').

Projections

All current climate projections point to these trends continuing and intensifying.

In an ever larger share of ski areas, winter precipitation is falling as rain rather than snow. By 2050, the winter zero-degree line in Switzerland is likely to rise by a further 300 metres or so under a medium emissions scenario (RCP4.5) (Schweizer Tourismus-Verband 2024, Klimaszenarien Winter 2050 für die Schweiz). Without effective climate action, it will rise by 400 to 650 metres by the middle of the century and by 700 to 1,050 metres by the end of the century – reaching approximately 1,500 to 1,900 metres (NCCS/CH2018). In a world 3 °C warmer, it would be around 550 metres higher in winter than today (MeteoSwiss/ETH Zurich 2025).

Natural snow cover is declining sharply. Projections for natural snow cover are correspondingly stark. The Swiss climate scenarios 'Klima CH2025' predict a decline in snow amount (snow water equivalent) at altitudes between 1,000 and 1,500 metres of around 51% compared with 1991–2020 at 1.5 °C of global warming,

and of 78% at 3 °C; between 1,500 and 2,000 metres the figures would be 19% and 63% respectively (MeteoSwiss/ETH Zurich 2025). By 2050, snow cover below 1,500 metres is likely to decrease by 25 to 35%, and above 2,000 metres by about 20% (Schweizer Tourismus-Verband 2024). Without climate action, around 50% less snow is to be expected below 1,000 metres by 2060, and more than 80% less by 2100 (NCCS/CH2018; Climate scenarios for Switzerland).

Even with snowmaking, operations during the economically important Christmas and New Year period will become less certain. In Austria, 84% of ski areas used to be able to guarantee them. If current snowmaking capacities and terrain coverage remain unchanged, snow production will have to increase by 22–26% in the 2030s and by 32–45% in the 2050s (Steiger & Scott 2020).

Snow availability (Snow Supply Risk)

The stronger global warming turns out to be, the more artificial snow will be needed simply to keep ski operations going – with correspondingly rising water and energy demand (details in the chapter ‘Snowmaking data’). The Europe-wide study by François et al. (2023), led by Météo-France and Université Grenoble Alpes, modelled this for 2,234 ski areas in 28 European countries and developed its own indicator for the purpose, the ‘Snow Supply Risk’ (SSR).



2 Snowmaking basics

According to the common definition, a ski area is considered ‘snow-reliable’ if, in 7 out of 10 wint ers, a snow cover of around 30 to 50 cm lies on at least 100 days between 1 December and 15 April. Where natural snow is not sufficient for this, it is supplemented by technical snow (CIPRA International 2004; Abegg et al. 2013). The Swiss WSL Institute for Snow and Avalanche Research SLF names the following aims of technical snowmaking: securing ski operations for the whole season, with a view to opening the season on schedule and the Christmas business; ensuring an optimal range of pistes including runs down to the valley, connecting routes and snow parks; and covering hazards such as stream crossings, rocks or the turf (Wolfsperger et al. 2018).

A ‘snowmaking day’ is a day on which the daily mean wet-bulb temperature is below about –2 °C, so that the physical conditions for producing artificial snow are met (Hartl & Fischer 2015); local wind systems, cold-air pools in the valleys and solar radiation also play a role. Artificial snow is created when fine water droplets are ejected from the snow generator under high pressure and freeze in the air. For this, air temperature and relative humidity must be right: the drier the air, the warmer it may be. Both variables are combined in what is known as the wet-bulb temperature.

Infrastructure

A snowmaking system consists of much more than the visible snow generators. Water intakes and abstraction structures on streams, lakes or drinking-water springs supply the water. Pumping and compressor stations generate water pres-

Defining the terms: technical snow or artificial snow?
Artificial snow and technical snow generally mean the same thing: snow produced from water and air using snow guns or lances. The term ‘technical snow’ is intended to emphasise that no artificial material is being made, but that snow is formed physically. In everyday usage, technical snow is largely a rebranding of artificial snow. In technical language, the term can be useful because it describes a particular type of snow that differs from natural snow.

sure (around 12 to 60 bar depending on the device) and compressed air. Frost-proof pipes carry water, compressed air, electricity and data to hydrants, which are typically located every 50 to 100 metres along the pistes. A rule of thumb shows just how energy-intensive pumping the water alone is: a water pressure of 50 bar corresponds to a pumping head of around 500 metres (Wolfsperger et al. 2018).

Storage reservoirs are a central element. They buffer the water demand, which is concentrated in a few cold weeks in early and mid-winter, and in some cases hold several hundred thousand cubic metres. Before the water reaches the snow generators, it is usually cooled to about 1 to 4 °C in cooling towers, since the colder the water, the more efficiently snow can be produced (Wolfsperger et al. 2018);

Nobody knows exactly how many storage reservoirs there are in the Alpine region. Estimates put the figure at more than 1,200 reservoirs (de Jong 2023). National figures cite at least 459 reservoirs for Austria (2026) and, for Switzerland, at least 80 built and 18 planned (Iseli 2015). In the French Alps, 136 reservoirs with a combined storage volume of almost 7.3 million m^3 were counted in 2021 (Gerfand et al. 2025; de Gaillande 2026). The most recent reliable count comes from Italy: in 2026, Legambiente used satellite imagery to record 169 reservoirs with a combined surface area of around 1.99 million m^2, not including reservoirs under construction or in planning, or smaller storage facilities (Legambiente 2026).

Modern systems are controlled automatically on the basis of weather data. To distribute the snow precisely, snow depth is increasingly measured using satellite-based systems (Wolfsperger et al. 2018). Piste levelling, pipe trenches and reservoir construction require access roads for heavy goods vehicles that bring excavators and bulldozers even to high altitudes; the consequences for soil and water balance are discussed in the chapter ‘Impacts of snowmaking’.

Snowmaking systems and technology

All methods share the task of freezing water into ice and delivering it in a grain size typical of snow. Regardless of the technology, the same amount of energy is released as heat per kilogram of water (334 kJ). The methods differ in where this heat is dissipated (Wolfsperger et al. 2018). This is crucial, because water only freezes if this heat is continuously removed – and this is what determines whether snowmaking depends on the weather and how much energy it costs. If the cold ambient air absorbs the heat, freezing itself is ‘free’, but only works at sufficiently low temperatures. If a machine has to dissipate the heat, snow can be produced regardless of the weather; but then all of the freezing energy has to be supplied by electricity or a refrigerant. Weather-independent snow generators therefore consume around 3 to 60 times as much energy (ibid.).

- **Nozzle technology:** Water is atomised under high pressure (around 12–60 bar) into fine droplets 0.1 to 1 mm in diameter, giving it the largest possible surface area. As the droplets fly through the air, they cool, freeze and release their heat directly into the surrounding air. This only works if the air is cold and dry enough and the flight time is sufficient. The method is therefore weather-dependent, but requires compa-



Fan gun ('snow cannon') © Zefram_wikimedia



Snow lances © vwalakte_magnific

ratively little electricity – only for pumps, compressed air and, where applicable, fans, around 0.5 to 8.4 kWh per m³ of snow – and is the most widespread (ibid.).

- **Refrigeration technology:** A refrigeration unit – in principle like a fridge – extracts heat from the water and releases it via a cooling circuit. In flake-ice systems, water freezes on a cooled surface and is then crushed into ice granules; in vacuum-ice systems, part of the water evaporates under low pressure, extracting so much heat from the rest that it freezes. The method is weather-independent, but the coarse ice granules bond less well to form a firm piste, and at around 25 to 40 kWh per m³ of snow, the energy requirement is many times higher (ibid.).

- **Cryogenic technology:** A very cold refrigerant such as liquid nitrogen or liquid carbon dioxide is added directly to the water spray. It cools the droplets sharply and absorbs the heat of freezing as it evaporates. Because the refrigerant escapes into the air in the process and has to be constantly repurchased, the method is very expensive; it is now only rarely used, and only where very little snow is needed (ibid.).

The most common nozzle-technology devices are fan guns ('snow cannons') and snow lances. Both systems work with water pressure and compressed air. Fan guns distribute the droplets with a fan over a trajectory of 20 to 45 metres. This allows them to achieve high flow rates (up to around 100 m³ of snow per hour), but they need 3 to 11 times more energy per cubic metre of snow than lances. Snow lances are around ten metres tall, cheaper to buy, quieter and require less maintenance, but are more susceptible to wind; the most powerful manage up to 60 m³ per hour. Fan towers combine drop height and throw distance, thereby extending the time available for the droplets to freeze (Wolfsperger et al. 2018).

Energy requirements vary greatly and depend on the system, location and weather – and on whether pumps, cooling and compressed-air supply are included. Field trials and surveys in Sweden found a mean energy efficiency of 4.3 kWh per m³ of snow, with extreme values between 0.6 and 14 kWh – excluding pumping and water cooling (Wolfsperger et al. 2018). The technological trend is also clearly towards automation: satellite-based snow depth measurement in piste bashers (e.g. 'Snowsat') shows where how much snow lies and, according to operators, can reduce artificial snow production by up to 20% (swissinfo 2017). Permanently installed, fully

Technology	Principle	Energy requirement (kWh per m³ of snow, incl. pumping)	Special features
Snow lance (nozzle technology)	Atomisation at the end of a lance approx. 10 metres tall	approx. 0,5–1,3	inexpensive, quiet, susceptible to wind
Fan gun (nozzle technology)	Fan blows droplets 20–45 metres	approx. 1,4–8,4	high output, inefficient at marginal temperatures
Refrigeration technology (flake ice, vacuum ice)	Cooling circuit, ice granules are crushed	approx. 25–31 (corrected 36–40)	weather-independent, coarse ice, lower firmness
Cryogenic technology	Liquid nitrogen or CO_2	no data	very expensive (nitrogen over €500 per m³ of snow), only where demand is low

Table 2: Comparison of snowmaking technologies. Source: Wolfsperger, Rhyner & Schneebeli (2018), Table 1.5 and Section 1.6.2; values partly manufacturers' data and SLF field measurements.

automated snow generators and snowmaking towers are increasingly replacing older, mobile equipment. However, efficiency gains per cubic metre of snow are being eaten up by the expansion of the areas covered by snowmaking and the growing demand for snow in warmer winters (cf. Steiger & Scott 2020).
The same applies to water: theoretically, 1 m^3 of water yields around 2.5 m^3 of snow at a snow density of 400 kg/m^3. In practice, the snow-to-water ratio never exceeds about 2.2, because water is lost through wind, evaporation, sublimation and run-off. SLF field trials on snow lances found losses of 12 to 38%, and a study by Université Grenoble Alpes 10 to 50% (Spandre et al. 2017, cited in Wolfsperger et al. 2018). Carmen de Jong even assumes a loss of 40–60% through evaporation, wind drift and leaking pipes (de Jong 2020). The chapter 'Snowmaking data' therefore assumes a loss of around 30%.

Artificial snow and natural snow compared

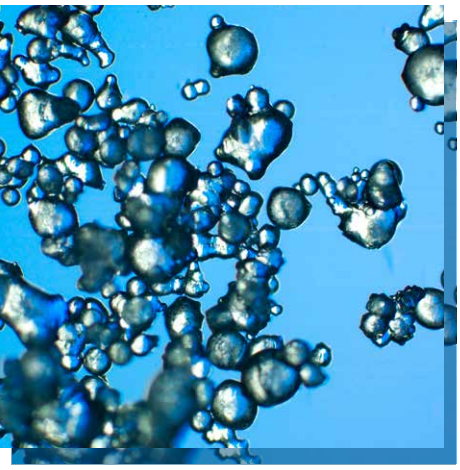
In physical terms, artificial snow is an industrial product. Natural snow crystals are hexagonal, highly individual in shape and trap a lot of air – which makes natural snow loose and light. Artificial snow, by contrast, freezes from the outside in to form small, round ice grains 0.02 to 2.0 mm in diameter. As a result, it is up to four times denser than freshly fallen natural snow, up to sixty times harder and contains significantly more water (de Jong 2011).



High-resolution image of natural snow
© Wilson Bentley, rawpixel.com

These properties are technically intended: artificial snow can bear loads and be skied on immediately, even before it has settled. Unlike natural snow, however, it provides hardly any thermal insulation for soils and overwintering organisms – an ecological function that the industrially manufactured product lacks (Hamberger & Doering 2015). For skiers, the hard, often icy surface also means higher speeds and a higher risk of injury (see section 'Development of skiing under climate change').

Snow density is ecologically relevant. Loose fresh snow is a good thermal insulator that protects soil and vegetation from frost. Dense piste snow conducts heat considerably better and offers less protection (Wolfsperger et al. 2018). In addition, snowmaking produces much more snow on pistes, which is reflected in a later melt-out date (ibid.). Depending on the system and the water, inputs of water and minerals are added. The consequences for vegetation, soil and water balance are set out in the chapter 'Ecological impacts'.



Artificial snow under the microscope
© Kenneht Libbrecht / Sicence Photo Library

In order to produce snow even at marginal temperatures, or to harden pistes at short notice, additives have been and are still being used – especially on competition pistes. The Soil Conservation Protocol of the Alpine Convention only permits chemical and biological additives for piste preparation if they have been proven to be environmentally compatible (Art. 14(2)). Table 3 shows the most common agents, their application, ecological risks and current legal status.

Additive	Effect / application	Ecological risk (incl. run-off & infiltration)	Legal status & current use
Snomax (ice nucleator, Pseudomonas syringae)	Added to snowmaking water; enables ice to form at approx. –3 °C instead of –9 to –4 °C.	Not a nitrogen compound. Ecologically relevant due to microbiological inputs: possible effects on alpine plants (laboratory tests show changes in growth). No chemical pollution of the soil, but input of ice-nucleating proteins from non-viable bacteria (Pseudomonas syringae, a widespread plant pathogen).	Banned in Germany & Austria (purity requirement for snowmaking water). Permitted in Switzerland, but banned in some cantons. Inconsistent internationally.
Road salt / pretzel salt (NaCl)	Spread on the piste to harden wet snow; salt extracts heat and promotes freezing. Typically 50–500 kg/ha per application; up to 2 t/ha/year.	No nitrogen. Ecological: soil salinisation, changes to soil chemistry, possible inhibition of sensitive plant species. Run-off via meltwater -> input into streams, but usually less ecological impact than nitrogen compounds.	Common at races (e.g. Garmisch World Ski Championships 2011: around 500 kg; Adelboden 2014: 2.8 t; 2023: around 500 kg). In Switzerland only permitted as a 'last resort' at competitions.
Ammonium nitrate (NH_4NO_3), urea ($CO(NH_2)_2$)	Nitrogen-based snow hardeners. Spread on the piste or applied dissolved in water. Products such as 'PTX 311' (pure urea) or 'PTX 312 Speedy' (composition unclear according to SLF).	Contain nitrogen. Ecological risks: nitrate leaching into groundwater, infiltration into the soil, promotion of nitrogen-loving species (nitrophiles). Risk of eutrophication of soils and water bodies. Nitrogen input alters alpine plant communities, favours grasses, displaces specialists.	Use at races documented: Lauberhorn 2007: around 1.4 t ammonium nitrate. Many bans relate only to snowmaking water, not to the piste itself; partly banned, partly tolerated.
Water injection (no additive)	Water is pressed into the piste under pressure and freezes inside -> very hard race piste.	No chemical input. Ecologically relevant only due to additional water demand. Run-off and infiltration as with normal snow.	Permitted everywhere. Standard on World Cup and Olympic pistes.

Table 3: Additives in snow production and piste preparation. Sources: Wolfsperger et al. (2018), p. 60; Wex et al. (2015); Blankenfeldt (2025); Schwörer et al. (2007), pp. ii–iv, 3–5, 14, 24–26; Rixen et al. (2003), p. 219; Bayerisches Landesamt für Umwelt (n.d.); Hamberger & Doering (2015), p. 22; Hauenstein AG (n.d.); BAFU (2010); Der Bund (2014); nau.ch (2023); NZZ (2007); swissinfo (2007); olympics.com (n.d.)

The use of additives across the Alpine region presents a mixed picture. The best-known snowmaking additive is Snomax, a powder made from killed bacteria (Pseudomonas syringae) that causes water droplets to freeze just below freezing point. In Germany it is banned under Art. 35 of the Bavarian Water Act; in Austria a 'purity requirement' applies, which Tyrol enshrined in law in 2018 after a court had previously allowed its use subject to conditions. For Italy and France, experts and industry associations describe its use as unusual or not permitted. In Switzerland, by contrast, Snomax has been approved since 1997 and is prohibited only in individual cantons, such as Bern. According to Seilbahnen Schweiz (Swiss Cable Cars), however, it is now hardly used there. The additive is difficult to detect in snow, which makes reliable monitoring difficult. The situation is different for competition pistes: here, operators also resort to methods for hardening the finished piste. The classic agent is table salt (NaCl), which is also sold as a ready-made product such as 'PTX 312'. The salt melts the snow surface, extracting heat from it in the process, and allows the resulting wet snow to refreeze. This makes the piste hard and race-ready for a short time. This is offset by an ecological risk: salt damages vegetation and soil, and the chlorides enter water bodies. According to the SLF (2007), quantities of up to 2,000 kg per hectare per year are possible. Salting remains common practice in ski racing. At the 2011 World Ski Championships in Garmisch-Partenkirchen, for example, around 500 kg was spread. In Switzerland, according to the FOEN's enforcement guidance, its use is only intended for competitions and only as a last resort.

A chemical-free alternative is water injection. Here, water is pressed 30 to 40 cm deep into the piste using injection bars, causing it to ice up from the inside. There is no chemical input, but there is additional water demand and an extremely hard, icy surface. The method is permitted everywhere and is now standard on World Cup pistes, for instance at the Lauberhorn.

Snowfarming

Artificial snow is stored over the summer in covered depots so that the season can start early. Examples: Kitzbühel/Resterkogel (around 25,000 m³ under sheeting and sawdust, loss approx. 10%, season start in early November), Davos (around 20,000 m³ under 40 cm of sawdust for a cross-country trail, approx. 20% loss), Ruhpolding (Chiemgau Arena, since 2004/05) and Livigno (snow-farming trail since 2024). For the 2014 Olympic Games in Sochi, 450,000 m³ was stored, of which around 140,000 m³ was lost to melting (cost approx. USD 11 million).
Sources: Kitzbühel: snowplaza.de 2025; Davos: SRF 2024; Ruhpolding: Traunsteiner Tagblatt 2020; Livigno: Fondoitalia 2024; Sochi: ORF 2013, Hamberger & Doering 2015.



Snowfarming in Livigno/IT © Fabio Borga/wikimedia

3 Snowmaking data

Obtaining reliable, up-to-date data on snowmaking that are comparable across the Alps is surprisingly difficult. The websites of ski area operators almost always provide information on kilometres of piste, but rarely on the area covered by snowmaking or on water and energy consumption. Even operators often find it difficult to quantify the share of snowmaking precisely: the weather, the width of groomed piste, which varies from day to day, and the strongly fluctuating share of natural snow all play a role. In addition, many pistes are now prepared for snowmaking – the pipes are already in the ground. Snow generators are deployed flexibly as required. ‘Equipped for snowmaking’ and ‘actually covered with artificial snow’ are therefore not the same thing. There is no uniform, Alps-wide survey method. Concrete, verified data for individual ski areas are in practice not publicly accessible. The few figures available often go back to old original sources that are cited again and again.

The following sections are therefore based on three types of source: firstly, comprehensive but older structural surveys (in particular Ringler/VZSB 2016-17 and the analysis of skiresort.info); secondly, the only larger, operator-based survey so far for an Alpine country – the survey of Austrian ski areas by Aigner, Mayer and Steiger (2026); and thirdly, scientific model calculations such as the Europe-wide study by François et al. (2023). Wherever possible, the Austrian survey is extrapolated to the entire Alpine region, as it currently offers by far the most solid data basis available. These projections are subject to uncertainty, but give a robust idea of the order of magnitude. As figures on snowmaking often differ depending on who publishes them – operators or environmental organisations – sources and assumptions are disclosed in each case.

Note on methodology: in what follows, country-specific figures are only shown where they are necessary to understand the overall calculation – for example as the basis for an Alps-wide extrapolation. Isolated facts relating to only one country have deliberately not been included.

Size of ski areas

The Alps cover a total area of 158,574 km² – roughly twice the size of Austria. According to an Alps-wide analysis by the Association for the Protection of the Mountain World (VzSB) from 2016-17, the total covered by ski areas is 5,593 km², which is about ten times the size of Lake Constance. The piste area actually used for skiing amounts to around 102,000 ha, making it almost twice the size of Lake Constance. It is distributed in roughly equal parts across Austria, France, Switzerland and Italy; Germany, Slovenia and Liechtenstein play a minor role across the Alps (Table 4).

Country	Mountain area	Ski area	Piste area	Share of piste area
Switzerland	25'482 km²	1'121 km²	22'439 ha	22 %
Austria	42'652 km²	135 km²	25'400 ha	25 %
Germany	4'252 km²	4'252 km²	3'700 ha	4 %
Italy	38'874 km²	1'234 km²	22'500 ha	22 %
France	30'128 km²	1'497 km²	26'500 ha	26 %
Liechtenstein	103 km²	3 km²	138 ha	<1 %
Slovenia	17'083 km²	95 km²	1'200 ha	1 %
Total	158'574 km²	5'593 km²	101'877 ha	100 %

Table 4: Size of ski areas in the Alps. Source: Ringler, A. / VzSB (2016-17).

In many places, data on piste areas are unavailable, outdated, poorly maintained or confidential. Analyses of satellite data as part of the study by François et al. (2023) in some cases show considerably smaller piste areas than the frequently cited VzSB figures. The number of ski areas also depends on how they are counted: Ringler (2016-17) recorded 1,681 ski areas including small individual lifts, while skiresort.info lists just over 1,100 ski areas for 2025. Robust analyses therefore require that piste areas and areas regularly covered by snowmaking are recorded up to date for each ski area and checked against satellite data.

According to data from skiresort.info, in 2025 there were more than 1,100 ski areas across the Alps with a combined total of more than 28,000 kilometres of piste. However, different measurement methods are used: ‘skied length’ (corresponding to the curved line of a ‘sporty skier’), ‘slope length’ (corresponding to a ‘diagonal straight run’) and ‘horizontal length’ (straight line measured by GPS). The most piste kilometres are found in France (around 8,400 km) and Austria (7,200 km) as well as Switzerland (around 7,200 km); Italy follows with just under 5,000 km.

Chart 1: Ski slope area in hectares

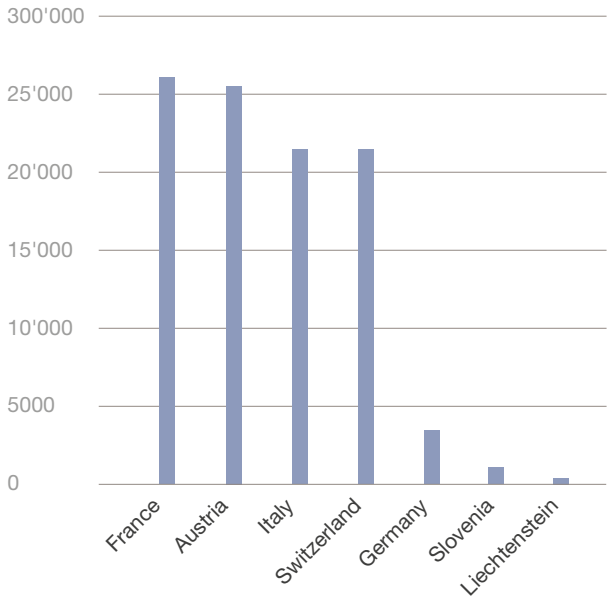


Chart 2: Number of ski resorts; proportion of area covered by artificial snow, by country

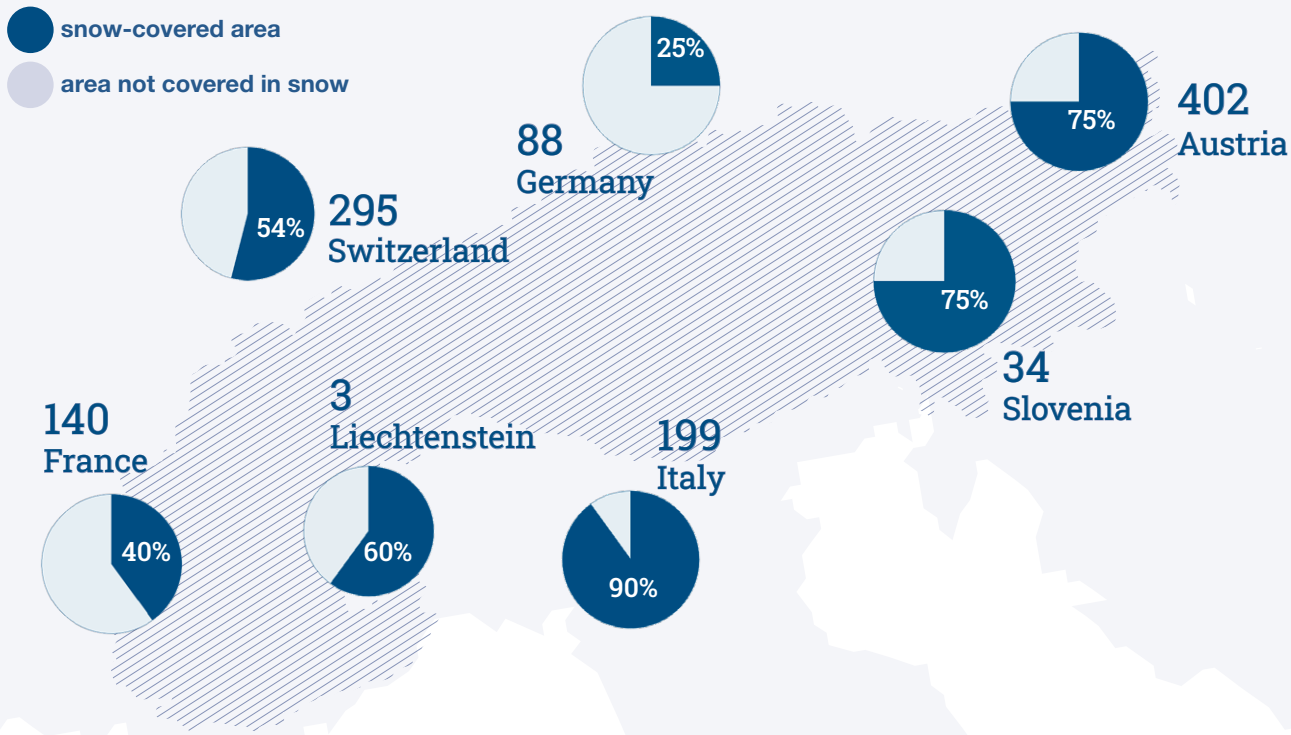


Chart 3: Share of ski areas by altitude (Alps-wide).

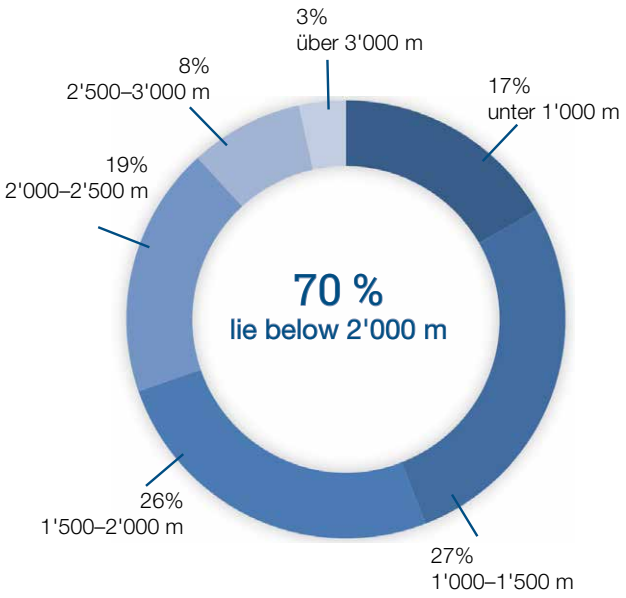
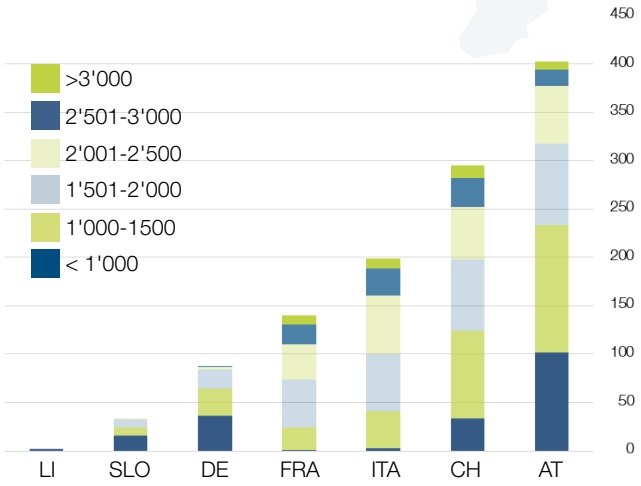


Chart 4: Distribution of ski areas by altitude and country.



Sources: Ringler/VZSB (2016/17); Aigner, Mayer & Steiger (2026); Marmotamaps (2026); skiresort.de

The altitude distribution is particularly revealing (Charts 3 and 4): 70% of all ski areas lie below 2,000 metres, 44% below 1,500 metres and a fifth (17%) even below 1,000 m. Only just over one in ten ski areas lies above 2,500 m.

If the altitude distribution is set against the development of the zero-degree line and the snow line (see chapter 'Climate change in the Alps'), the implications become clear: the winter zero-degree line in Switzerland is currently at around 900 to 1,000 metres on average and is likely to rise by a further 300 metres or so by 2050 and, without climate action, to 1,500 to 1,900 m by the end of the century. This means that a large proportion of ski areas below 1,500 m – almost half of all ski areas in the Alps – are moving into an altitude range in which winter precipitation increasingly falls as rain: natural snow cover will decline by a quarter to a third by the middle of the century, and by more than three quarters in a 3-degree world. At the same time, the time windows for snowmaking at these altitudes are becoming narrower, because it is less often cold enough.

Low- and mid-altitude areas in particular – many of them in Germany and Slovenia, but also in parts of Austria and Italy – are thus losing not only their natural snow but increasingly also the ability to replace it technically. In countries with predominantly low-lying ski areas, such as Germany and Slovenia, the question should be asked how much of a long-term future Alpine skiing still has there, and to what extent practising it justifies the resource consumption.

The Bavarian ski area at Kolbensattel in Oberammergau ceased ski operations in 2026. As early as 2016, the operators had invested €600,000 in a more powerful snowmaking system, but at an altitude of between about 850 and 1,270 metres, even that could no longer save the business.

Snowmaking area

The share of the total piste area actually covered by snowmaking – the so-called degree of snowmaking – can only be estimated for the Alps as a whole: there is no uniform survey method, and operators rarely provide reliable information. Our research in all Alpine countries did not yield any more recent data; there are no higher-level bodies requesting these data from operators. The following table summarises the best available estimate for each country:

Country	Piste area (Ringler/VZSB)	Piste area (corrected for Austria, Aigner et al.)	Share with snowmaking	Area with snowmaking
Switzerland	22'439 ha	22'439 ha	54 %	12'117 ha
Austria	25'400 ha	23'174 ha	75 %	17'381 ha
Germany	3'700 ha	3'700 ha	25 %	925 ha
Italy	22'500 ha	22'500 ha	90 %	20'250 ha
France	26'500 ha	26'500 ha	40 %	10'600 ha
Liechtenstein	138 ha	138 ha	60 %	83 ha
Slovenia	1'200 ha	1'200 ha	75 %	900 ha
Total	101'877 ha	99'651 ha	62 %	62'255 ha

Table 5: Estimate of areas covered by snowmaking in the Alps. Sources: Ringler/VZSB (2016-17); Aigner, Mayer & Steiger (2026); Marmotamaps (2026); skiresort.de

The shares for Switzerland (54%, Seilbahnen Schweiz 2024) and France (35–40%, Cour des comptes 2024) are backed by current industry and government data respectively; for Italy, Slovenia and Liechtenstein, only older or unofficial figures are available. For Austria, Aigner et al. (2026) found snowmaking coverage of between 58% and 100% of the piste area in the ski areas studied, with an average of 87% – considerably more than the 75% stated by the Austrian Economic Chamber. From a specialist perspective, the figure of 25% for the German Alpine region appears too low, but in the absence of public measurement data it cannot be quantified more precisely: for October 2022, the Bavarian state government reports around 920 ha of approved snowmaking area in the whole of Bavaria, of which around 750 ha are in Upper Bavaria and Swabia (Bayerischer Landtag 2023). As the resource estimates in this report are based on the figure of 25%, they should be read as a lower limit for Germany. Overall, at least 62,000 to 70,000 ha in the Alps are likely to be covered with artificial snow; it can be assumed that the actual figure is somewhat higher.

Water consumption

According to manufacturers, around 2.5 m^3 of snow can be produced from 1 m^3 of water. Scientific studies show, however, that considerable losses occur during production and processing – mainly through evaporation, sublimation (ice turning directly into water vapour) and wind drift: SLF measurements found losses of 7 to 35%, averaging 21% (Grünewald & Wolfsperger 2019). In their analysis, Aigner, Mayer and Steiger (2026) assume a water loss of around 30% and a snow density of 400 kg/m^3; this results in around 1.75 m^3 of snow per cubic metre of water. This more realistic figure is used in the projection below.

To meet the enormous demand for water, large storage reservoirs have for years been built into mountainsides and on high plateaus. Even the construction work causes massive interference with slope structures and the water balance, destroying wetlands, vegetation and alpine soils, which barely regenerate at high altitudes. The reservoirs are fed from natural water bodies – streams, rivers, lakes, bogs, meltwater and/or drinking-water springs. Some of the water evaporates in the reservoir itself, and more is lost during snowmaking; in intensive snowmaking phases, the water level falls so sharply that it has to be topped up by pumping several times a season. Storage reservoirs also sometimes alter the aesthetics of the mountain landscape dramatically: they are created in places where there would be no natural lakes – on ridges, for example – have no natural forms and are often visible from great distances. In some regions there is no longer any ‘off-piste’ – the experience of unspoilt landscape is severely impaired.

Data basis and methodology

Until now, practically all figures on the water demand for snowmaking have been based on rough estimates using assumptions that are often unrepresentative. One exception is the study by Aigner, Mayer and Steiger (2026, University of Innsbruck): for this work, operator data from Austrian ski areas were systematically requested for the first time. The response rate was 22%; however, the responding ski areas

account for around 34% of all ‘ski visits’ (skier days) in Austria. Using elaborate regression models, the results were then extrapolated to all Austrian ski areas. Despite the moderate response rate, the study is based on a representative volume of data and is currently regarded as the most robust source available for estimating water demand. Comparable analyses for other Alpine countries do not exist.
To make resource consumption tangible, it is related below to the individual skier day. According to the common definition (Vanat), a ‘ski visit’ is a visit by one person to a ski area for all or part of a day for the purpose of skiing, snowboarding or a comparable downhill activity; someone who skis for a week therefore counts as seven skier days. On average over six seasons (2014-15 to 2018-19 and 2022-23), there were around 52.5 million skier days per season in Austria. For the responding ski areas, water consumption averaged around 3,250 m³ per hectare of piste with snowmaking, corresponding to an average artificial snow depth of 57 cm; extrapolated to the whole of Austria, this gives around 2,750 to 3,000 m³ per hectare:

Indicator (Austria, Aigner et al. 2026)	Value
Skier days per season (avg. 2018-2023)	approx. 52,5 Mio.
Area with snowmaking	17'381 ha
Water consumption per skier day	930–1'020 l
Water consumption per hectare	2'749–3'002 m³
Total water consumption, Austria	48,8–53,6 miollion m³

Table 6: Indicators for water consumption in Austrian ski areas. Source: Aigner, Mayer & Steiger (2026).

Projection for the entire Alpine region

The most important reference value for water consumption is the area covered by snowmaking. Compared with other scientific studies, the Austrian figure of around 3,000 m³/ha is firmly in the middle range. As no comparable operator surveys are available for the other Alpine countries, this figure is applied below – with due caution – to Switzerland, France, Italy, Germany, Slovenia and Liechtenstein; the areas covered by snowmaking are taken from Table 2. The projection is subject to greater uncertainty, but gives a good idea of the order of magnitude:

Country	Area with snowmaking	Water consumption per season (extrapolated)
Switzerland	12'117 ha	36 million m³
Austria	17'381 ha	52 million m³
Germany	925 ha	3 million m³
Italy	20'250 ha	61 million m³
France	10'600 ha	32 million m³
Liechtenstein	83 ha	< 1 million m³
Slovenia	900 ha	3 million m³
Entire Alpine region	62'255 ha	187 million m³

Table 7: Extrapolation of water consumption for the entire Alpine region based on the Austrian indicators. Source: own projection based on Aigner, Mayer & Steiger (2026).

Conclusions from this projection:

- In the recent past, water consumption for snowmaking in the Alps is likely to have been around 190 million m³ per season.
- The area actually covered by snowmaking is likely to be larger than the just over 62,000 ha given in Table 2; accordingly, actual water consumption should also be assumed to be higher: based on the 70,000 ha estimated by Hamberger and Doering in 2015, it would be around 210 million m³ per season.
- For the Alpine region as a whole, this gives a water consumption of around 1,000 litres per skier day – roughly eight times the average daily per capita consumption in Germany of around 125 litres.
- This volume of water corresponds to around 1.7 m³ of artificial snow per skier day.

What do 1,000 litres per skier day mean?
That is roughly eight times what one person in Central Europe uses in their household each day (around 125 litres) – or about seven full bathtubs.
Extrapolated to around 190 million m³ per season, snowmaking in the Alps thus uses about as much water as four million people use in their households in a year.
At 3 °C of global warming and a snowmaking share of 75%, more than three times as much water would be needed according to François et al. (2023) – i.e. around 3,500 litres per skier day.

Dry summers, full storage reservoirs
'Swiss ski areas report full storage lakes and plan artificial snowmaking', reads an article on the Swiss news portal Blick. The full storage reservoirs for snowmaking are reported with eager anticipation – after this extremely dry summer, mind you, which dried up lakes and rivers. 'The Rhine, the lifeblood of the Swiss economy, is so dry that barges can hardly operate any more', it says. Nevertheless, there is delight that the storage reservoirs are full to the brim, so there is enough water for snowmaking. The reason given is the extreme snowmelt caused by the heat and severe thunderstorms. How nice that there is enough water for snowmaking – our rivers will presumably have to do without it if it is held back in the storage reservoirs.
Blick (30 August 2026)

Energy consumption

Snowmaking systems are among the least advantageous forms of electricity consumer. They run precisely in the winter months, when general energy demand is already high. In addition, climate change is shortening the time windows for snowmaking – more and more snow has to be produced in less and less time. As a result, snowmaking takes place not only during cheap base-load periods but

frequently also at expensive peak-load times, especially when natural snow and cold are in short supply. Total energy consumption depends on location, aspect, altitude, exposure to sun or shade, outside temperature and humidity, and on the technical components of the system. In addition to the snow generators themselves, total consumption also includes pumps, compressors, cooling systems, heating and control systems, and the data centres for fully automated snowmaking. Figures in the literature usually refer only to the snow generators and therefore tend to underestimate actual consumption.

Indicator (Austria, Aigner et al. 2026)	Value
Electricity requirement per hectare and cm of snow depth	257–305 kWh/ha/cm
Electricity requirement per hectare (at 57 cm snow depth)	14.600 - 17.400 kWh/ha
Total electricity consumption, Austria	260–309 GWh
Electricity consumption per skier day	5–6 kWh

Table 8: Electrical energy requirement for ski operations with artificial snow in Austria. Source: Aigner, Mayer & Steiger (2026).

Projection for the entire Alpine region

For the extrapolation to the entire Alpine region, the key factors besides the area covered by snowmaking (see Table 2) are above all the specific energy requirement per hectare and centimetre of snow depth. Here, however, it becomes apparent how different the results of various recent studies can be: Aigner et al. (2026) arrive at 281 kWh/ha/cm, whereas Knowles et al. (2024) find 634 kWh/ha/cm for Canada – more than double. Aigner et al. rely on real operator data (34% coverage for Austria), which suggests that this lower figure is more reliable; however, the difference shows how great the uncertainty surrounding this indicator still is.

Country	Area with snowmaking	Electricity requirement (based on Aigner et al.)	Electricity requirement (based on Knowles et al.)
Switzerland	12'117 ha	194 GWh	439 GWh
Austria	17'381 ha	278 GWh	629 GWh
Germany	925 ha	629 GWh	33 GWh
Italy	20'250 ha	324 GWh	733 GWh
France	10'600 ha	170 GWh	384 GWh
Liechtenstein	83 ha	1 GWh	3 GWh
Slovenia	900 ha	14 GWh	33 GWh
Total Alps	62'255 ha	997 GWh	2'253 GWh

Table 9: Estimate of the electrical energy requirement for ski operations with artificial snow in the entire Alpine region, reference snow depth 57 cm. Source: own projection based on Aigner, Mayer & Steiger (2026) and Knowles et al. (2024).

The projection for the entire Alpine region gives a total annual consumption of between around 1,000 and 2,250 GWh. That is equivalent to the electricity demand of an estimated 249,000 to over 560,000 households (at 4,000 kWh per household per year). The wide range is explained by the different methods: Aigner et al. rely on real operator data, Knowles et al. on literature, industry reports and modelling (SkiSim 2.0).

As early as 2013, Robert Steiger pointed out the dramatic increase in future energy demand in a study for the German Alpine Club. Since then, the climate crisis has hit the Alpine region in full, without political decision-makers having responded adequately.
François et al. (2023) also modelled how the climate crisis affects the energy demand of snowmaking – with the same basic pattern as for water: the greater the warming and the higher the required share of snowmaking, the disproportionately higher the energy consumption. If the factors determined for water demand (Table 6) are roughly applied to electricity demand, 4,000 to 9,000 GWh per season would be needed in future to make piste skiing possible on its current scale.

Conclusions from this projection:

- Snowmaking across the entire Alpine region is likely to require around 1,000 to 2,250 GWh of electricity per season – depending on whether the operator-based indicator of Aigner et al. (2026) or the modelled figure of Knowles et al. (2024) is used.
- In terms of skier days, that is 5 to 6 kWh per skier day in Austria (Aigner et al. 2026); across the Alps, depending on the indicator, the figure is around 5 to 12 kWh.
- The electricity is needed precisely in winter, when renewable electricity is already scarce. Even green electricity that goes into snow generators is no longer available for other purposes at this time.

What do 5 to 6 kWh per skier day mean?
That is roughly equivalent to the daily electricity consumption of a one-person household (around 4–6 kWh; Vattenfall n.d.) – or around 30 to 35 kilometres driven in an electric car.
Extrapolated to 2,250 GWh per season, the electricity used for snowmaking in the Alps could power around 900,000 electric cars for a year (at 15,000 km and 17 kWh per 100 km).
If temperatures continue to rise, based on a rough transfer of the factors from François et al. (2023), up to 9,000 GWh per season could be needed in future – as much as 2.25 million households consume in a year.

Data availability – Recommendations

As described at the outset, the data situation on snowmaking in the Alps is unsatisfactory. In the research for this chapter, enquiries to institutions, associations and experts have often led nowhere – with inadequate answers, referrals on the grounds of supposedly lacking responsibility, or even no response at all. Consumption data from individual ski area operators are practically nowhere publicly accessible and remain behind closed doors.
Yet a better data basis would long have been technically possible: with simple measuring equipment on the snow generators, radio transmission to a control centre and systematic analysis, the water and energy consumption of snowmaking could be recorded comprehensively. More than ten years ago, there already existed an

initiative by the Department of Geography at the University of Innsbruck (Tirol Atlas) which recorded data on piste area, degree of snowmaking, water consumption, number of snow generators and storage reservoirs – but only for Tyrol and as of 2012. To date, there is no comparable, up-to-date, Alps-wide project, even though the record heat and drought of summer 2026 and the increasing scarcity of drinking water make the issue more urgent than ever. Nevertheless, it seems to play only a minor role in politics.

Digital tools for a better data basis are already available but are still underused: the study by François et al. (2023) drew on, among other things, the MTMSI snow dataset of the Copernicus Climate Data Store, the digital ski map OpenSkiMap (based on OpenStreetMap), elevation and climate data from the European Environment Agency, the Copernicus European elevation model and regional datasets on global warming levels (SantanderMetGroup).

Such tools could be used to record snow depth in ski areas at high temporal and spatial resolution; comparison with the immediately adjacent areas without snowmaking would yield an index that describes the actual degree of snowmaking with sufficient accuracy – a neutral indicator independent of operators' data.

Recommendations for a better data basis

The data situation gives rise to the following recommendations (they are also included in the chapter 'Conclusions and recommendations'):Melde- und Messpflicht:

- Reporting and measurement obligation: ski area operators should be legally obliged to record their water and energy consumption for artificial snow production daily and report it to the competent authorities.
- Up-to-date area data: piste areas and areas regularly covered by snowmaking should be recorded up to date for each ski area by operators or municipalities, labelled digitally and checked against satellite data.
- Satellite-based monitoring: using existing data (Copernicus, OpenSkiMap, etc.), an index should be developed that describes the degree of snowmaking independently of operators' data.
- Alps-wide, independent monitoring project: following the example of the Tirol Atlas, an up-to-date, Alps-wide snowmaking monitoring system should be set up and publicly funded.
- Data access for science: universities and research institutes should be given access to operators' data so that realistic and neutral future scenarios become possible.
- Transparency: The data should be prepared in a comprehensible form and published in order to raise awareness of the issue among the public and policymakers.

Combined with satellite data on the area actually covered by snowmaking, this would create a robust, Alps-wide and neutral data basis – as a prerequisite for more realistic future scenarios and an objective political debate. The expertise for this exists at universities; what has been lacking so far is political will and funding.

4 Impacts of snowmaking

The previous chapters have shown how much snowmaking has grown. This chapter asks about the consequences: what does this use of resources mean for soils, plants, animals and waters in the Alps – and for the people who depend on an intact landscape just as much as on winter tourism?

Ecological impacts

Snowmaking has effects on several levels: through the artificial snow itself, through the construction of pipes and storage reservoirs, through piste preparation and operation, and through water abstraction, noise and light. The following sections summarise the current state of research.

Artificial snow

Artificial snow is denser, harder and wetter than natural snow (see Chapter II, 'Artificial snow vs natural snow'). Most of the ecological effects follow from this: There is more snow on pistes with snowmaking, and it lies for longer. Artificial snow can delay the start of the snow-free period by more than two weeks (Pintaldi et al. 2017). The growing season of the plants on the piste is correspondingly shorter. Whereas only individual critical spots were previously covered with artificial snow, today entire runs are usually covered with artificial snow from top to bottom – so ski operations continue even when hardly any natural snow falls.

Beneath the dense snow cover, gas exchange is also restricted, especially when ice layers form. Because soil organisms continue to respire, oxygen can become scarce at the soil surface (Pintaldi et al. 2017). In addition, meltwater from pistes with snowmaking contains on average more nutrient salts and ions. Although it is still of drinking-water quality, it can alter soil and vegetation over the long term (ibid.). For additives and snow hardeners, see Chapter II.

Infrastructure

The construction of snowmaking systems also has a profound impact on the landscape. Trenches are dug for water, compressed-air and power lines, and entire sections of terrain are reshaped for storage reservoirs – usually with heavy construction machinery. Pipe trenches at the edge of pistes are often located precisely

where the soil is particularly susceptible to erosion (Pintaldi et al. 2017). Snowmaking is also increasingly changing the shape of the landscape. To make pistes skiable even with small amounts of snow, uneven ground is levelled, boulder fields are filled in and vegetation structures are removed. Pistes optimised in this way need less snow and can be opened earlier. Particularly in the high mountains, these large-scale interventions often remain visible for generations because of the slow pace of natural succession.

Where soil is removed, levelled and reapplied, its properties change for decades: on levelled and revegetated pistes in the Monterosa ski area (Aosta Valley), the vegetation had largely recovered after around three decades, but the soil had not. It was less fertile, contained less organic carbon and was less stable than on undisturbed reference plots (Hudek et al. 2020). The largest structures are the storage reservoirs – and there are more and more of them. Estimates suggest there are already over 1,200 across the Alps (de Jong 2023). In Italy, Legambiente counted 142 reservoirs in 2023 and as many as 169 in 2026, with a combined water surface of around two million square metres. In the Aosta Valley alone, 14 reservoirs cover more than 87 hectares (Legambiente 2023). Many reservoirs hold over 100,000 m^3 and are often located in ecologically sensitive areas (Pintaldi et al. 2017). The new reservoir in Livigno, for example, holds around 210,000 m^3 (see section ‘Major sporting events’). To build them, slopes are excavated where wetlands used to be (see section ‘Flora and fauna’).

Competition for water

Chapter III shows how much water snowmaking needs. This section deals with the consequences on the ground. Some of the water is lost during snowmaking itself: the hydrologist Carmen de Jong puts losses through evaporation from storage reservoirs, pipe leakage, drift, wind transport and sublimation at up to 60% (de Jong 2013, cited in Hamberger & Doering 2015). SLF field measurements near Davos found losses of 7% to 35%, averaging 21%; the warmer the air, the higher the losses (Grünewald & Wolfsperger 2019). Model calculations for La Plagne assume around 10% evaporation (Morin et al. 2023). More decisive than the quantity is the timing: in the French Alps, 57% of abstractions fall in the winter low-flow period, when streams and rivers carry the least water anyway (Cognard et al. 2025). Storage reservoirs are supposed to ease this by collecting water outside the low-flow period. However, an analysis of 35 French ski areas over nine seasons shows the opposite: more storage capacity leads to more abstraction during the low-flow period. If reservoir volume increases by 1%, these abstractions rise by 0.28% in the short term and 0.4% in the long term (Cognard et al. 2025). If there is not enough water locally, it is brought in from neighbouring valleys, the valley floor, groundwater or hydropower reservoirs. This does not resolve the conflict but shifts it to other catchments – while glaciers and snow cover, as natural water stores, shrink under climate change.

Water conflicts in practice: current examples from the Alps

Switzerland, summer 2026 – full storage lakes, empty rivers: *'Swiss ski areas report full storage lakes' – in St. Moritz, Adelboden-Lenk and Zermatt, the snowmaking reservoirs were said to be 'completely full' thanks to thunderstorms and heavy snowmelt, securing snowmaking for the winter (Blick, 30 August 2026). At the same time, the Federal Office for the Environment reported low water levels of a kind that occur only once every 30 years or even less often at around a third of measuring stations; extremely low levels in Lake Constance, Lake Zurich and Lake Lucerne; and low groundwater and spring levels (BAFU, 23 September 2026); the Untersee reached its lowest level since records began, and freight shipping on the Rhine was severely restricted. At least 151 municipalities imposed water-use restrictions. Water held back in the mountains for snowmaking is missing from rivers and lakes in the valleys.*

Bavaria, September 2026 – groundwater at a record low: *82% of near-surface groundwater monitoring points and springs showed low levels, one in ten a new record low; Lake Starnberg reached its lowest water level since measurements began (LfU Bayern, situation report 25 September 2026). Nevertheless, groundwater may in some cases be used for snowmaking (de Jong 2023).*

South Tyrol – snowmaking ban and reservoir boom: *following the snowmaking ban in March 2023, the province once again declared a water emergency in July 2026 because the River Adige repeatedly fell below the guideline value of 80 m³/s (Dolomitenstadt, 21 July 2026). Water demand for snowmaking has risen from 6.1 million m³ (2012-13) to 8–10 million m³, and up to 12.6 million m³ has been approved; the umbrella organisation for nature and environmental protection warns of a 'storage reservoir boom' (DVN 2025).*

Kaunertal (Tyrol), 2026 – snowmaking versus hydropower: *snowmaking at the Kaunertal glacier ski area requires around 60,000 m³ of water, which according to the Tiroler Tageszeitung has been abstracted without a permit since the end of 2024; the energy supplier Tiwag is demanding compensation for lost electricity generation (TT, 4 August 2026).*

La Clusaz (Haute-Savoie) – court halts storage reservoir: *the planned Colombière reservoir (148,000 m³), two thirds of which was intended for artificial snow, was halted by an urgent ruling in 2022; in 2025, the Administrative Court of Grenoble definitively annulled the environmental permit because there was no overriding public interest (TA Grenoble, 25 October 2022 and 23 July 2025).*

Milano-Cortina 2026 Winter Olympics: *snowmaking at the competition venues required around 948,000 m³ of water (Il Fatto Quotidiano, 13 March 2026). In August 2026, Lake Maggiore and Lake Como were only around 5–6% full, and the Po was carrying a third of its usual flow (L'Espresso, 11 August 2026).*

Water conflicts over snowmaking are nothing new; ‘Der gekaufte Winter’ already documented numerous examples. The current cases in the box show that they are intensifying with climate change.

That snowmaking is reaching its limits in times of increasing water scarcity has long ceased to be merely the position of environmental organisations. The French Court of Audit concludes that artificial snow offers only ‘temporary, relative protection’ and puts a strain on water resources. It recommends tying public funding to adaptation plans (Cour des comptes 2024). In its assessment, the high public investment in snow production threatens to entrench dependence on skiing, leaving little room for alternatives (de Gaillande 2026). François et al. (2023) show that the water demand of snowmaking rises disproportionately with each further increment of warming. Legambiente criticises the fact that, in Italy, around 90% of public funding for mountain tourism goes into snow-dependent offers (Legambiente 2026). Carmen de Jong sums up: snowmaking bans will become necessary more frequently in future because of water scarcity, and the drought in South Tyrol ‘should awaken us to the fact that water is too precious to waste on winter tourism’ (de Jong 2023).

Several common claims made by the snowmaking industry about water use do not stand up to closer scrutiny. A recent compilation by the hydrologist Prof. Carmen de Jong (University of Strasbourg) contrasts widespread claims with the scientific evidence (de Jong 2024):

FACT CHECK ACCORDING TO CARMEN DE JONG:

‘100% of the water abstracted for snowmaking flows back into the water cycle.’
False. 30 to 60% evaporates or is lost along the way, and the water is often pumped up from another part of the catchment or from further down.

‘Only 0.5% of the water in the river catchment is abstracted for snowmaking.’
False. The figure must not be related to the entire catchment of a large river, but to the sub-catchment affected. In small headwater catchments in the mountains, 80 to 100% of the available water is abstracted.

‘Measured against annual run-off, abstractions are small and have no effect on the water balance.’
False. Abstractions must be related to seasonal, weekly and daily run-off, not to the annual average – and run-off is very low in winter.

‘Meltwater from artificial snow returns to the cycle with the same quality as meltwater from natural snow.’
False. Water from artificial snow is of considerably poorer quality than snow or rainwater: it contains bacteria, diesel residues, more minerals and salts, and has an excessive fertilising effect.

'Storage reservoirs are an environmentally friendly solution and ease water conflicts.'
False. Storage reservoirs exacerbate the problem: after they are built, demonstrably more water is abstracted from streams and rivers than before, and increasingly from drinking-water networks too. Refilling takes place precisely in the low-flow winter months. Conflicts between drinking water, agriculture and groundwater are increasing.

'Storage reservoirs are filled only by precipitation and snowmelt.'
False. Precipitation contributes at most 3 to 5%. There is never enough water on site, and the reservoirs are always oversized. The water comes from valley rivers, increasingly from groundwater, reservoirs and drinking-water networks, and is pumped up hundreds of metres in altitude.

'Storage reservoirs mainly serve other purposes such as drinking water, firefighting water or recreational use.'
False. Because permits and funding are hard to obtain for reservoirs used purely for snowmaking, other uses are cited – which are almost always unrealistic.

'No drinking water is abstracted for snowmaking.'
False. Around 30% of snowmaking water comes from drinking water – from drinking-water networks or from groundwater.

'The residual flow in streams is always maintained.'
Hardly verifiable: Most streams with abstractions have no gauging station and are monitored only sporadically – in summer – or not at all. In addition, residual flows have in some cases been lowered to allow greater abstraction for reservoirs, for example on the Gaisbergbach in Obergurgl (Tyrol).

Source: de Jong 2024 (own translation, abridged).

In South Tyrol, snowmaking ranks only fifth in the order of priority of water uses – after drinking water, agriculture, hydropower and industry. Nevertheless, storage reservoirs are increasingly fed from valley water or groundwater. In Malbun (Liechtenstein), a total of 80,415 m³ of water was used for snowmaking in the 2024-25 winter season: around 38,000 m³ from the Malbunbach and Guschgerbach streams and over 42,000 m³ from the Schneeflucht drinking-water reservoir – so more than half came from drinking-water reserves. The VU parliamentary group has therefore tabled a motion in the Landtag calling for a multi-purpose water reservoir to be examined in order to significantly reduce the share of drinking water (Vaterland 2026). Liechtenstein also publishes the snowmaking records for Malbun, including consumption data – an example of the transparency called for in the chapter 'Data availability' (LLV n.d.).

Noise and light

How loud snow generators are depends on the type of system (see Chapter II); older compressed-air guns reach up to 115 dB(A) – as loud as a pneumatic drill at close range. Ecologically, the timing is what matters most: snowmaking and grooming mostly take place at night. Noise and floodlights therefore extend into the rest periods of wildlife.

Galliformes such as the black grouse are particularly sensitive. A systematic review of 48 studies, mostly from the Alps, concludes that ski areas, with their lift cables and ski operations, certainly or very probably affect birds in most of the cases studied – especially galliformes. In addition to disturbance, this also includes collisions with lift cables (Brambilla & Roseo 2025).

Flora and fauna

The dense artificial snow cover has a direct effect on plants: oxygen can become scarce beneath it (see section ‘Artificial snow’), and the compacted piste snow protects the soil less well from frost (Pintaldi et al. 2017). If the snow lies around two weeks longer, the growing season is shortened. Early-flowering species become rarer, late-flowering ones are favoured, and there is less time for seed ripening (ibid.).

Nutrients also alter species composition. Artificial snow brings additional minerals into the area (see section ‘Artificial snow’), and snow hardeners increase the nutrient content and pH of the soil. This benefits nutrient-loving plants, which displace other species – diversity declines (Pintaldi et al. 2017). However, the effects are not equally great everywhere: a recent study from the southern Italian Alps found consistently higher soil pH on pistes, but no measurable differences in the activity of soil microorganisms compared with reference plots. The authors therefore call for longer-term and broader monitoring (Gebru et al. 2026).

Storage reservoirs are often built where there used to be wetlands or small lakes. They are hardly suitable as substitute habitats: a study of 136 storage reservoirs in the French Alps, 28 of them with biological surveys, found only sparse terrestrial vegetation on the banks and no aquatic plants at all; the fauna was species-poor and in some cases non-native. The researchers documented drowned mammals as well as stranded amphibians and dragonflies, and regard the design and operation of the reservoirs as ecological traps (Gerfand et al. 2025).

For wildlife there is also competition for space: ski areas overlap with the climate refugia of high-alpine bird species – i.e. the areas in which these species still find suitable conditions despite warming – and threaten them both now and in the future (Roseo et al. 2025).

Erosion

Levelled, compacted piste soils with poor root penetration absorb less water. It runs off over the surface, carrying soil with it (Pintaldi et al. 2017). Snowmaking intensifies this: because the dense piste snow melts later, more meltwater is released in a shorter time in spring (Morin et al. 2023). Freshly levelled areas, pipe trenches and slopes with storage reservoirs are particularly at risk, especially during heavy rainfall; the risk of landslides also increases here. The reservoirs themselves are often located in hazard zones: in the French Alps, around 20% are in avalanche-prone locations, one in two is exposed to debris flows and a quarter to a moderate to high geological hazard (Evette et al. 2011). If a dam breaks, settlements lower down are at risk. Courchevel shows how real the risk is: the La Loze reservoir, built on permafrost in 2020, is subsiding by around 15 cm a year; before it was emptied, a dam failure would have sent around 170,000 m³ of water towards the hamlet of Tania below (Le Monde 2026, cited in de Gaillande 2026).

Major sporting events

Hardly anything accelerates the expansion of snowmaking systems as much as major international winter sports events. Winter Olympics, World Ski Championships and World Cup races impose tight deadlines and complete snow reliability on host venues – requirements that FIS and the IOC set regardless of the actual local climatic conditions.

The costs are borne mainly by the public purse – municipalities, regions, the state – while the profits often remain with organising committees and federations. After the event, there is not infrequently a loss of attractiveness for 'normal' tourism: regular guests avoid the hustle and bustle during the event, and additional pistes remain as permanent interventions in the landscape

Example: Milano-Cortina 2026 Winter Olympics

For the Winter Games in the Italian Alps, which ended in February 2026, around 2.4 million m³ of artificial snow was produced; this required around 948,000 m³ of water (using the factor of 1.75 calculated in our report, this amount of artificial snow would actually require 1.3 million m³ of water), with 580,000 m³ for Livigno-Mottolino alone (Alpine Mag, 1 February 2026; Il Fatto Quotidiano, 13 March 2026). A new storage reservoir with a capacity of around 210,000 m³ was built for this purpose in Livigno, at an altitude of 2,530 metres. In Antholz/Anterselva, a 'SnowFactory' was also installed that can produce snow even at temperatures above freezing. The manufacturer TechnoAlpin received orders for snowmaking systems worth a total of €30 million for several Olympic venues (including Bormio, Livigno, Antholz and Tesero) (TechnoAlpin 2025).

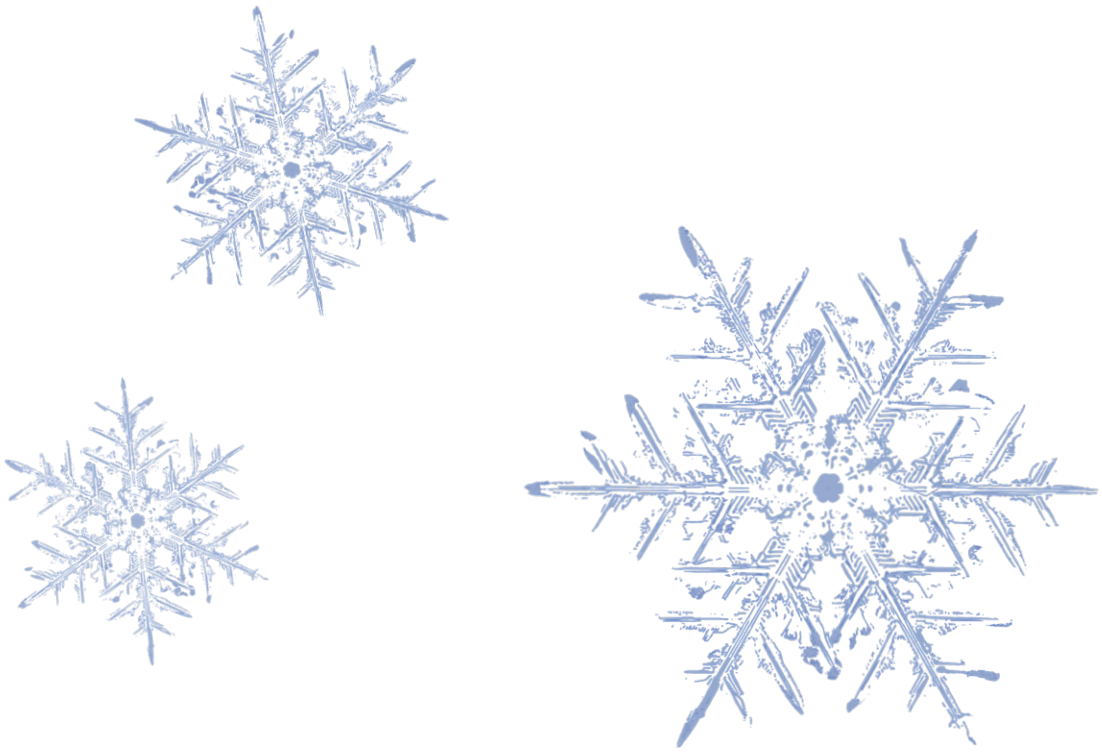
5 Economic Aspects

Economically, ski tourism based on snowmaking is caught in a dilemma: the fixed costs of investment and operation are rising steadily, while the number of skiers is stagnating or declining in several Alpine countries. In Austria, for example, the share of non-skiers in the population rose from 47 to 66 per cent between 1987 and 2011 (Zellmann 2011) – a structural decline in demand set against ever more elaborate and expensive snowmaking operations.
A key argument put forward by the cable car industry for investment in expansion and snowmaking is regional value creation. A study for the Upper Austrian cable car holding company concludes that every euro of revenue generated by the lifts triggers a fivefold revenue effect in accommodation, gastronomy, retail and other sectors (conos 2025).

These figures say little about how much value would be created even without intensive ski operations. Bausch et al. (2024) show that the Alpine winter holiday increasingly needs to be understood as a multifunctional experience in which skiing is combined with other activities, such as winter hiking, snowshoeing, wellness or social offerings. Moreover, depending on the ownership and corporate structure, not all of the tourism value creation remains in the region. Part of the revenue flows to external owners or companies outside the region. Locally, many of the jobs created are seasonal: of the roughly 17,100 employees of Austrian cable car companies, only around 7,650 are employed year-round (Fachverband der Seilbahnen 2023). Value creation in winter tourism therefore increasingly comes from a broad mix of offerings rather than from ski operations alone, which are becoming ever more expensive and resource-intensive in the face of the climate crisis.

Subsidies

In the Alpine countries, ski areas are mainly subsidised indirectly through investment in tourism infrastructure, especially cable cars and lift systems. Direct subsidies for snowmaking systems, by contrast, are only provided in isolated cases. In Bavaria, for example, snowmaking systems were supported under the cable car funding programme until the end of 2025; between 2009 and 2013, around €3.5 million in funding went to them. Since 2026, snowmaking systems have been excluded from funding there (Bayerisches Staatsministerium für Ernährung, Landwirtschaft, Forsten und Tourismus 2026; SI Magazin 2026). Snowmaking systems are not subsidised in South Tyrol either, although grants of up to 45% of investment costs are possible for certain cable car projects (Südtirol News 2017; SI Magazin 2026). In Switzerland, around CHF 439 million had flowed into tourism projects via the New Regional Policy by 2019, a large proportion of it into lift systems (Eidgenössische Finanzkontrolle 2022). France supports mountain regions through programmes such as the 'Plan Avenir Montagnes', for which a total of around €650 million has been made available (Banque des Territoires 2021). The distinction is not always clear-cut, as investment in the overall infrastructure of a ski area can also indirectly support ski operations based on snowmaking (Industriemagazin 2018; Eidgenössische Finanzkontrolle 2022). Overall, however, public money in ski tourism mainly supports the maintenance and modernisation of tourism infrastructure, while technical snow production is only rarely the subject of dedicated funding programmes.



6 Legal framework

The expansion of snowmaking does not take place in a legal vacuum. Several international, European and national regulations set the framework – even though their practical enforcement varies greatly from country to country. Given the diversity of legal provisions in the Alpine countries, however, this chapter cannot provide a complete overview. Instead, selected country and case examples are considered in order to highlight key legal issues and differences.

Alpine Convention

The Alpine Convention – an international treaty signed in Salzburg in 1991 by Germany, Austria, France, Italy, Slovenia, Switzerland, Liechtenstein, Monaco and the EU – forms the overarching framework for sustainable development in the Alpine region. Of particular relevance to snowmaking are the Tourism Protocol and the Soil Conservation Protocol, which have been ratified by all contracting parties except Switzerland (status of ratifications). Article 14(2) of the Tourism Protocol states: 'National legislation may authorise the production of snow during the respective local cold periods, in particular to secure exposed zones, if the respective local hydrological, climatic and ecological conditions allow.' However, this cannot be taken as a general justification for blanket snowmaking. According to Ennöckl (2022), artificially extending the ski season through snowmaking outside local cold periods contravenes the Tourism Protocol. In addition, the Soil Conservation Protocol permits chemical or biological additives for piste preparation only if they have been proven to be environmentally compatible (Art. 14(2)).

Environmental impact assessment

The question of environmental impact assessment (EIA) is also legally contentious. In Austria, an EIA is currently mandatory for the development of ski areas involving at least 20 ha of terrain modification and for new storage ponds of 275,000 m^3 or more. In protected areas, a case-by-case assessment is required from 10 ha or 125,000 m^3 respectively (UVP-G 2000, Annex 1 No. 12). In Switzerland, an EIA is mandatory for snowmaking systems with an area equipped for snowmaking of 5 ha or more (UVPV, Annex No. 60.4).

In the case of a planned storage reservoir in the Montafon (Austria), the lawyers commissioned by the provincial government concluded that the Austrian EIA provisions on snowmaking systems were to be interpreted in conformity with EU law (Bussjäger & Ennöckl 2019) and that the project should be subject to an EIA. No final judicial clarification was reached at the time, as the planning application was withdrawn. Independently of this, infringement proceedings by the European Commission against Austria are currently pending (INFR(2024)2012). They concern, among other things, those provisions in Austrian EIA law that govern the assessment of cumulative effects of different projects and which, in the European Commission's view, are inadequate.

The thresholds for an EIA in Bavaria are considerably higher than in Switzerland. Although snowmaking systems require a permit under Art. 35 of the Bavarian Water Act, since 1 August 2025 an EIA has only been required for an area with snowmaking of more than 20 ha (in protected areas: 10 ha) or if the system is located above 1,800 metres above sea level; previously, thresholds of 15 and 7.5 ha respectively applied (Third Bavarian Modernisation Act, GVBl. 2025 p. 254). The review of whether the new thresholds conform with EU law has not yet been completed.

South Tyrol shows a similar threshold problem with storage reservoirs: an environmental impact assessment is only mandatory from a storage volume of 100,000 m^3 – a figure that hardly any single reservoir reaches in practice. The South Tyrol Umbrella Organisation for Nature and Environmental Protection therefore calls for this threshold to be lowered significantly, for example to 5,000 m^3. Above this threshold, the permitting authority lies at provincial level (Dachverband für Natur- und Umweltschutz Südtirol 2025). In summary, because thresholds are very high, environmental impact assessments are only applied in exceptional cases, and an overall assessment of environmental impacts is therefore not carried out. Permit requirements under other legislation remain unaffected.

Water law provisions

At EU level, the Water Framework Directive (2000/60/EC, WFD) sets the goal of 'good status' for all waters by 2027 at the latest. This also applies to water abstraction for snowmaking, for example with regard to residual flows at abstraction structures. Under Art. 11, water abstractions require prior authorisation. At national level, water abstraction and discharge are subject to authorisation in implementation of the WFD. The Bavarian Water Act expressly stipulates that only water without additives may be used for snowmaking (Art. 35(3) BayWG). In South Tyrol, drinking water may not be used for new snowmaking systems (DVN 2025).

In Switzerland (not subject to EU law), the Waters Protection Act regulates water abstraction and minimum residual flows (Art. 29 ff. GSchG), which include permit requirements for snowmaking systems or storage ponds because of their effects on waters. In France, storage reservoirs are authorised under the Environmental Code (water law) and the mountain laws; in Auvergne-Rhône-Alpes, a regional doctrine on snowmaking under climate change (2019) additionally sets the framework. New projects must take multi-purpose use into account, abstractions are tied to minimum flows and prohibited under drought orders. Monitoring remains patchy: the water police and the French Office for Biodiversity (OFB) have too few staff for regular on-site inspections (de Gaillande 2026). The La Clusaz case shows how courts now assess snowmaking projects: in 2025, the Administrative Court of Grenoble annulled the permit for a storage reservoir because no compelling, overriding public interest justified the intervention (see box 'Water conflicts in practice'). In Liechtenstein, the government approved the Malbun snowmaking system in 2005, subject to conditions, after its environmental compatibility had been established; one of these is the annual submission of a snowmaking record with a water and energy balance, which is now publicly accessible (LLV n.d.). Water abstraction is regulated by the Waters Protection Act: when water is abstracted from watercourses, a minimum residual flow must remain; in principle, no water may be abstracted from small watercourses with a flow of less than 50 litres per second. Temporary exceptions are only permitted if ecological functionality is not impaired, no more than 20% of the mean flow is abstracted in total and abstraction does not take place during the low-flow period (GSchG Liechtenstein). The water rights to the Saminabach and its tributaries, including the Malbunbach, are also held by Liechtensteinische Kraftwerke (LKW).

Interventions in waters – for example through water abstraction or the potential introduction of pollutants – are in principle subject to authorisation, albeit to a different extent in each country. Where the effects on waters are more significant, operators often argue that there is an 'overriding' or 'paramount' public interest in maintaining a ski area that outweighs the protection of waters. Whether such an interest exists is increasingly the subject of administrative and judicial disputes.

7 Conclusions and calls to action

With the climate crisis, the effort required to achieve 'snow reliability' by means of artificial snow continues to grow – with rising demand for water, energy and land. Further investment in expanding snowmaking is therefore fundamentally at odds with climate protection and energy transition goals, while the growing trade in ski areas and purely capital-driven investment without regional ties should be viewed critically.

Scientific studies also show that winter holidaymakers today are not focused solely on piste skiing but make use of a wide range of other offers (Bausch, Ortanderl & Pröbstl-Haider 2024). This development should be harnessed to reduce economic dependence on skiing. The following key recommendations can be derived from these findings:

- Public funding should no longer be used for the operation and expansion of snowmaking systems. Instead, it should be channelled specifically into sustainable, climate-adapted and socially responsible tourism and winter sports offers.
- New construction and expansion of snowmaking systems in ecologically sensitive areas should be ruled out. A mandatory environmental impact assessment should be carried out for all projects, evaluating in particular the effects on water resources and energy consumption.
- Decommissioned snowmaking systems require a binding obligation to dismantle them and restore the land, in accordance with Art. 12(2) of the Tourism Protocol of the Alpine Convention. In addition, it must be clarified at an early stage whether facilities such as storage reservoirs are to continue in use, be renaturalised or be dismantled, while operators are still able to raise the necessary funds.
- The protocols of the Alpine Convention must be implemented consistently when permitting pistes and snowmaking systems. Particular weight should be given to Art. 14 of the Tourism Protocol, which governs the development of such infrastructure in a manner compatible with nature and the environment.
- Water abstraction and storage ponds may only be approved if they are compatible with the objectives of the EU Water Framework Directive. These include, in particular, the prohibition of deterioration and the maintenance or achievement of good status of waters in accordance with the respective national water legislation.
- Lower EIA thresholds for storage reservoirs and snowmaking systems and assess related projects as a single overall project, in order to capture significant interventions in waters, landscape and biodiversity in full and to prevent circumvention of the EIA obligation.
- Glacier ski areas are located in sensitive high-alpine environments that are changing particularly rapidly as a result of the climate crisis. Melting glacier tongues and newly emerging glacier forefields should therefore remain untouched. (cf. the 'Glacier Manifesto' signed in Milan in 2025 by more than 60 environmental organisations and research institutions)

Recommendations on data collection and monitoring:

- Ski area operators should be legally obliged to record water and energy consumption for artificial snow production daily and report this to the competent authorities.
- Piste areas and areas regularly covered by snowmaking should be continuously recorded digitally for every ski area and checked against satellite data.
- Development of a satellite-based index that records the extent of snowmaking independently of operators' data.
- Establishment of independent, Alps-wide monitoring of snowmaking, modelled on the Tirol Atlas and financed from public funds.
- Universities and research institutes should be granted access to relevant operational data, in particular data on water consumption, energy consumption, water abstraction and areas covered by snowmaking. The results of scientific analyses should be published transparently and in a generally comprehensible form.

For tourism, skiing, spatial planning and public safety, this means that future development cannot be geared solely towards growth and technical adaptation. What is needed instead is a long-term strategy that combines climate protection, climate adaptation, natural hazard prevention and the protection of Alpine ecosystems.

8 References

All sources cited in the report, in alphabetical order. Links last accessed in October 2026.

- Abegg, B. et al. (2013): Herausforderung Klimawandel – Chancen und Risiken für den Tourismus in Graubünden. Chur/Innsbruck. www.bbgr.ch/wp-content/uploads/2020/08/AWT_BBGR_Klimabericht%202013%20-%20definitiv_LOW.pdf
- Aigner, G., Mayer, M. & Steiger, R. (2026): Snowmaking in Austria: resource consumption and greenhouse gas emissions. Journal of Sustainable Tourism. doi.org/10.1080/09669582.2026.2656746
- Alpenkonvention (1991) und Durchführungsprotokolle, u. a. Protokoll «Tourismus», Art. 14, und Protokoll «Bodenschutz», Art. 14 (Stand der Ratifikationen). www.alpconv.org
- Alpenverein Südtirol (29.11.2021): AVS kritisiert Landesbeitrag für Seilbahnverbindung Tiers – Frommer Alm. alpenverein.it/landesbeitrag-seilbahnverbindung-tiers-frommer-alm/
- Alpine Mag (1.2.2026): The volume of artificial snow at the Winter Olympics in Milan Cortina comparable to the Great Pyramid of Giza. alpinemag.com/volume-artificial-snow-winter-olympics-milan-cortina-great-pyramid-giza/
- alpinforum.com (2016): Preisangaben der Skigebiete für die Saison 2016/17. www.alpinforum.com
- Banque des Territoires / Localtis (2021): Fonds Avenir montagnes : la répartition par massif (Juli 2021); Laurent Wauquiez lance un nouveau plan Montagne plus vert que blanc (16.9.2021). www.banquedesterritoires.fr/fonds-avenir-montagnes-la-repartition-par-massifs; www.banquedesterritoires.fr/laurent-wauquiez-lance-un-nouveau-plan-montagne-plus-vert-que-blanc
- Bausch, T., Ortanderl, F. & Pröbstl-Haider, U. (2024): Rethinking growth orientation: Do ski-resorts' strategies fit the profiles of today's alpine skiers? International Journal of Tourism Research 26(4), e2708. doi.org/10.1002/jtr.2708
- Bayerisches Landesamt für Umwelt (2026): Niedrigwasser-Lagebericht vom 25.9.2026. www.nid.bayern.de
- Bayerisches Landesamt für Umwelt (o. J.): Stickstoff-Deposition aus dem Niederschlag. www.lfu.bayern.de/luft/schadstoffe_luft/eutrophierung_versauerung/n_deposition/index.htm (Zugriff am 5.11.2026)
- Bayerisches Staatsministerium für Ernährung, Landwirtschaft, Forsten und Tourismus: Bekanntmachung vom 8.12.2025, BayMBl. 2026 Nr. 3; Pressemitteilung «Seilbahnförderung auch ab 2026» (14.1.2026). www.verkuendung-bayern.de/baymbl/2026-3/
- Bayerisches Wassergesetz (BayWG), Art. 35, i. d. F. des Dritten Modernisierungsgesetzes Bayern vom 25.7.2025. www.gesetze-bayern.de/Content/Document/BayWG-35
- Bergbahnen Malbun (2016): Preise Winter 2016/17. www.bergbahnen.li, Archivversion vom 4.1.2016. web.archive.org/web/20160104215810/http://www.bergbahnen.li/Bahnbetrieb/Preise.aspx
- Blankenfeldt, W. (2025): Eisbildende Bakterien. BIOspektrum 31 (1), 71. doi.org/10.1007/s12268-025-2390-3
- Blick (30.8.2026): Kommende Wintersaison – künstliche Beschneiung gesichert. www.blick.ch/wirtschaft/kommende-wintersaison-kuenstliche-beschneiung-gesichert/ny5k35m

- Bozzoli, M. et al. (2024): Long-term snowfall trends and variability in the Alps. International Journal of Climatology. doi.org/10.1002/joc.8597
- Brambilla, M. & Roseo, F. (2025): The impact of downhill skiing on Galliformes and other birds. Ecological Solutions and Evidence 6, e70030. doi.org/10.1002/2688-8319.70030
- Bundesamt für Umwelt BAFU (2007): Einsatz von Hilfsstoffen auf Skipisten.
- Bundesamt für Umwelt BAFU (2010): Verwendung von Schneehärtern. Merkblatt für Betreiber von Rennpisten und Veranstalter von Schneesportwettkämpfen. Umwelt-Vollzug UV-0731, Bern. www.bafu.admin.ch/dam/bafu/de/dokumente/chemikalien/uv-umwelt-vollzug/verwendung_von_schneehaerternfuerbetreibervonrennpistenundverans.pdf.download.pdf/verwendung_von_schneehaerternfuerbetreibervonrennpistenundverans.pdf
- Bundesamt für Umwelt BAFU (23.9.2026): Sommer 2026: Trockenheit und hohe Wassertemperaturen. www.bafu.admin.ch/de/sommer-2026-trockenheit-und-hohe-wassertemperaturen
- Bussjäger, P. & Ennöckl, D. (2019): Beschneiungsanlagen, Schigebiete und UVP-Pflichtigkeit in Österreich. Natur und Recht 41, 802–807. doi.org/10.1007/s10357-019-3595-3
- Carrer, M. et al. (2023): Recent waning snowpack in the Alps is unprecedented in the last six centuries. Nature Climate Change 13, 155–160. doi.org/10.1038/s41558-022-01575-3
- Conos (2025): Tourismus als Wirtschaftsmotor: Wertschöpfungsstudie von conos für die OÖ. Seilbahnholding www.conos.at/2025/02/06/tourismus-als-wirtschaftsmotor/
- CIPRA International (2004): Künstliche Beschneiung im Alpenraum – Ein Hintergrundbericht. Autor: Felix Hahn. Schaan. www.cipra.org/de/publikationen/2709
- Cognard, J., Berard-Chenu, L., Schaeffer, Y. & François, H. (2025): Snowmaking's slippery slope: The effect of mountain reservoirs on water demand. Ecological Economics 233, 108586. doi.org/10.1016/j.ecolecon.2025.108586
- Copernicus Climate Change Service (C3S)/ECMWF & WMO (2026): European State of the Climate 2025. climate.copernicus.eu/ESOTC/2025
- Cour des comptes (2024): Les stations de montagne face au changement climatique. Rapport public thématique, Paris, 6.2.2024. www.ccomptes.fr/fr/publications/les-stations-de-montagne-face-au-changement-climatique
- Dachverband für Natur- und Umweltschutz Südtirol (DVN) / CIPRA Südtirol (2025): Positionspapier Speicherbecken. Autor: Hanspeter Staffler. Bericht mit Link zum Positionspapier: www.suedtirolnews.it/politik/dachverband-warnt-vor-speicherbecken-boom-und-fordert-strengere-umweltpruefungen
- de Gaillande, A. (2026): Les retenues d'altitude – Gouvernance et avenir(s) dans un contexte de changement climatique. CIPRA France, Juli 2026 (dt. Übersetzung: Höhenspeicherbecken – Governance und deren Zukunft im Kontext des Klimawandels). Projektseite: www.cipra.org/fr/projets/gouvernance-retenues-altitude
- de Jong, C. (2011): Artificial Production of Snow. In: Encyclopedia of Snow, Ice and Glaciers. Springer. www.researchgate.net/publication/258565440_Artificial_Production_of_Snow
- de Jong, C. (2011, 2012, 2013): mehrere Arbeiten zu Wassernutzung, Biodiversität und Beschneiungsfolgen in den Alpen.
- de Jong, C. (2020): Umweltauswirkungen der Kunstschneeproduktion in den Skigebieten der Alpen. Geographische Rundschau 72 (6), S. 34–39.
- de Jong, C. (2023): Stellungnahme zur öffentlichen Anhörung «Wintersport und Tourismus im Zeichen des Klimawandels», Ausschuss für Tourismus, Deutscher Bundestag, 14. April 2023. Anlagenkonvolut zur Anhörung vom 19.4.2023: www.bundestag.de/resource/blob/989656/84b3610d67ed0bf4a8641e11597b872b/35-19-04-2023-Anlagenkonvolut.pdf
- de Jong, C. (2024): Water and Winter Tourism at the Limit: Artificial Snowmaking quo vadis? Common false declarations vs. scientific facts. Universität Strassburg.

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- Der Bund (Januar 2014): Salz streuen gegen die Wärme. www.derbund.ch/salz-streuen-gegen-die-waerme-220880175786
- Dolomitenstadt (21.7.2026). www.dolomitenstadt.at/2026/07/21/suedtirol-ruft-den-wassernotstand-aus/
- dpa (17.1.2020): Mega-Skigebiet: Seilbahnbetreiber in Österreich investieren Milliarden. Veröffentlicht auf weather.com. weather.com/de-DE/wissen/umwelt/news/2020-01-17-mega-skigebiet-seilbahnbetreiber-in-osterreich-investieren-milliarden
- Eidgenössische Finanzkontrolle (5.5.2022), zit. nach htr.ch. Prüfbericht zu den Tourismusinfrastrukturprojekten der Neuen Regionalpolitik (EFK-20028): www.efk.admin.ch/en/audit/tourism-infrastructure-projects-under-the-new-regional-policy-state-secretariat-for-economic-affairs/
- Ennöckl, D. (2022): Die Vorgaben des Tourismus-Protokolls der Alpenkonvention. In: Kuncio, P. & Schmid, S. (Hrsg.): Das Protokoll «Tourismus» der Alpenkonvention. Schriftenreihe zur Alpenkonvention, Bd. 6. CIPRA Österreich / Verlag Österreich, Wien. doi.org/10.33196/9783704689405
- Europäische Kommission (12.8.2021): State aid SA.63902 – Slovenia. ec.europa.eu/competition/elojade/isef/case_details.cfm?proc_code=3_SA_63902
- Evette, A., Peyras, L., François, H. & Gaucherand, S. (2011): Risques et impacts environnementaux des retenues d'altitude pour la production de neige de culture dans un contexte de changement climatique. Revue de Géographie Alpine / Journal of Alpine Research 99-4. doi.org/10.4000/rga.1471
- Fondoitalia (15.10.2024): Sci di fondo – Livigno, grazie allo snowfarming si scia già a fine ottobre: parte il conto alla rovescia per la 34ª Sgambeda. www.fondoitalia.it/2024/10/15/sci-di-fondo-livigno-grazie-allo-snowfarming-si-scia-gia-a-fine-ottobre-parte-il-conto-alla-rovescia-per-la-34a-sgambeda/
- François, H., Samacoïts, R., Bird, D. N., Köberl, J., Prettenthaler, F. & Morin, S. (2023): Climate change exacerbates snow-water-energy challenges for European ski tourism. Nature Climate Change. doi.org/10.1038/s41558-023-01759-5
- Gebru, Z. M., Casagrande Bacchiocchi, S., Fornasier, F., Assefa, S. & Wellstein, C. (2026): Impact of Ski-Piste Management on Soil Microbial Activity in the Southern Alps, Italy. Land 15 (10), 1915. doi.org/10.3390/land15101915
- Gerfand, B. et al. (2025): Ecological quality of snowmaking reservoirs in the Alps and management perspectives. Aquatic Sciences 87 (1), 9. doi.org/10.1007/s00027-024-01136-0
- Gewässerschutzgesetz (GSchG, Schweiz), SR 814.20. www.fedlex.admin.ch
- GLAMOS/WSL/SCNAT (2025): Medienmitteilung zur Gletscherbilanz 2025, 1.10.2025. scnat.ch/de/uuid/i/9d883a30-136c-55b8-8cde-a6b4c1851dee-Und_die_Schweizer_Gletscher_schmelzen_weiter
- Grünewald, T. & Wolfsperger, F. (2019): Water Losses During Technical Snow Production: Results From Field Experiments. Frontiers in Earth Science 7:78. doi.org/10.3389/feart.2019.00078
- Hamberger, S. & Doering, A. (2015): Der gekaufte Winter – Eine Bilanz der künstlichen Beschneiung in den Alpen. Gesellschaft für ökologische Forschung / BUND Naturschutz in Bayern. www.VzSB.de/media/docs/Der_gekaufte_Winter_-_8.12.2015.pdf
- Hartl, L. & Fischer, A. (2015): Beschneiungsklimatologie. Endbericht, Institut für Interdisziplinäre Gebirgsforschung der ÖAW, Innsbruck. doi.org/10.2312/Beschneiungsklimatologie_EB_2015
- Hauenstein AG (o. J.): Streusalz und seine zwei Wirkungen. Hauenstein AG, Rafz. www.hauenstein-rafz.ch/de/pflanzenwelt/sammelsurium/Streusalz-und-seine-zwei-Wirkungen.php (Zugriff am 5.11.2026)
- Hierneis, Friedl, Steinberger (2023): Schriftliche Anfrage der Abgeordneten (Bündnis 90/Die Grünen) «Kunstschneepisten und Naturschneepisten» vom 2.3.2023 mit Antwort des StMUV. Bayerischer Landtag, Drucksache 18/28586. Abrufbar über die Drucksachensuche: www.bayern.landtag.de
- Hudek, C., Barni, E., Stanchi, S., D'Amico, M., Pintaldi, E. & Freppaz, M. (2020): Mid and long-term ecological impacts of ski run construction on alpine ecosystems. Scientific Reports 10, 11654. doi.org/10.1038/s41598-020-67341-7

- Il Fatto Quotidiano (13.3.2026). www.ilfattoquotidiano.it/2026/03/13/olimpiadi-milano-cortina-consumo-acqua-neve-artificiale-notizie/8320362/
- Industriemagazin (15.11.2018). Österreichs Seilbahnbetreiber: 600 Millionen Euro für neue Anlagen. industriemagazin.at/a/oesterreichs-seilbahnbetreiber-600-millionen-euro-fuer-neue-anlagen
- Iseli, G. (2015): Künstliche Beschneiung in der Schweiz: Ausmass und Auswirkungen. Forschungsarbeit im Rahmen des Praktikums Nachhaltige Entwicklung, Universität Bern / Mountain Wilderness Schweiz. static.uni-graz.at/fileadmin/rewi-institute/Oeffentliches-Recht/Praxisprofessuren/Eisenberger-BlogSkigebiete/2015IseliKuenstlicheBeschneiung01.pdf
- Keiser, A. (2007): Schneekanonen – ein löchriger Wasserkreislauf. swissinfo, 20.4.2007. www.swissinfo.ch/ger/archiv-wissenschaft/schneekanonen-ein-loechriger-wasserkreislauf/1332284
- Klein, G., Vitasse, Y., Rixen, C., Marty, C. & Rebetez, M. (2016): Shorter snow cover duration since 1970 in the Swiss Alps due to earlier snowmelt more than to later snow onset. Climatic Change 139, 637–649. doi.org/10.1007/s10584-016-1806-y
- Knowles, N., Scott, D. & Steiger, R. (2024): Sustainability of snowmaking as climate change (mal) adaptation: an assessment of water, energy, and emissions in Canada's ski industry. Current Issues in Tourism 27(10), 1613–1630 (online 2023). doi.org/10.1080/13683500.2023.2214358
- Land Oberösterreich (2015): Programmdokument zur Förderung von Seilbahnunternehmen, gültig 1.7.2015–31.12.2021. Transparenzportal des Bundes. transparenzportal.gv.at/tdb/tp/leistung/1038777.html
- Legambiente (2023): Nevediversa 2023 – Il turismo invernale nell'era della crisi climatica. Rapporto di Legambiente. www.legambiente.it/wp-content/uploads/2021/11/Report-Nevediversa_2023.pdf
- Legambiente (2025, 2026): Nevediversa – Rapporto sul turismo invernale nell'era della crisi climatica. www.legambiente.it/attivita-scientifiche/nevediversa
- L'Espresso (11.8.2026). lespresso.it/c/sostenibilita/2026/8/11/po-acque-emergenza-siccita-livello-laghi/64025
- Liechtensteinische Landesverwaltung (LLV), Amt für Hochbau und Raumplanung (o. J.): Beschneiungsprotokolle Malbun. www.llv.li/de/landesverwaltung/amt-fuer-hochbau-und-raumplanung/baurecht-und-brandschutz/beschneiungsprotokolle-malbun (abgerufen 10/2026)
- Liechtensteinisches Landesgesetzblatt (2024): Finanzbeschluss vom 8. November 2024 über die Gewährung von Investitionskostenbeiträgen an die Bergbahnen Malbun Aktiengesellschaft für die Jahre 2025 bis 2028 und eines Beitrags zur Errichtung von Photovoltaik-Anlagen, LGBl. 2024 Nr. 479. www.gesetze.li/konso/pdf/2024479000
- Marmotamaps (2026): 7 Fakten zur künstlichen Beschneiung. Blogbeitrag (veröffentlicht November 2020). marmotamaps.com/de/blog/7-fakten-zu-kuenstlicher-beschneiung/
- Metral Pierre-Alexandre: La montagne désarmée, une analyse des trajectoires territoriales des stations de ski abandonnées françaises. Géographie. Université Grenoble Alpes [2020-..], 2025. Français. theses.hal.science/tel-05140065
- MeteoSchweiz/ETH Zürich/NCCS (2025): Klima CH2025 – Klimazukunft Schweiz. Bundesamt für Meteorologie und Klimatologie MeteoSchweiz, Zürich, 24 S. doi.org/10.18751/climate/scenarios/ch2025/brochure/1.0/de
- Morin, S., François, H., Réveillet, M. et al. (2023): Simulated hydrological effects of grooming and snowmaking in a ski resort on the local water balance. Hydrology and Earth System Sciences 27, 4257–4277. doi.org/10.5194/hess-27-4257-2023
- Nationale Skigebietsverbände: Seilbahnen Schweiz (SBS), Fachverband Seilbahnen Österreich (WKO), Domaines Skiables de France – jeweils aktuelle Jahresberichte/Statistiken. www.seilbahnen.org; www.wko.at/transport-verkehr/seilbahnen; www.domaines-skiables.fr

- Nau.ch (Januar 2023): Adelboden kämpft: 500 Kilo Salz sollen Chuenisbärgli-Rennen retten. www.nau.ch/sport/wintersport/adelboden-kampft-500-kilo-salz-sollen-chuenisbargli-rennen-retten-66386801
- NZZ (22.9.2007): Schneehärter häufig auch bei kleinen Anlässen. www.nzz.ch/schneehaerter_haeufig_auch_bei_kleinen_anlaessen-ld.434547
- olympics.com (o. J.): From snow crystals to World Cup courses – how snow shapes Alpine skiing. www.olympics.com/en/news/alpine-skiing-snow-piste-slopes-conditions-sofia-goggia
- NCCS (2018): CH2018 – Kernaussage «Schneearme Winter».
- NCCS (2025): Beobachtete Klimaentwicklung in der Schweiz. www.nccs.admin.ch/nccs/de/home/klimawandel-und-auswirkungen/schweizer-klimaszenarien/beobachtete-klimaentwicklung-in-der-schweiz.html
- Olefs, M., Koch, R., Schöner, W. & Marke, T. (2020): Changes in Snow Depth, Snow Cover Duration, and Potential Snowmaking Conditions in Austria, 1961–2020. Atmosphere 11(12), 1330. doi.org/10.3390/atmos11121330
- ORF (25.3.2013): Olympia: Sotschi bunkert jetzt schon Schnee für 2014. sport.ORF.at. sportv2.orf.at/stories/2173575/
- PERMOS/SCNAT (2025): Medienmitteilung Permafrost, 17.6.2025. www.geo.uzh.ch/de/news/2025/permos-2025.html
- Pintaldi, E., Hudek, C., Stanchi, S., Spiegelberger, T., Rivella, E. & Freppaz, M. (2017): Sustainable Soil Management in Ski Areas: Threats and Challenges. Sustainability 9 (11), 2150. doi.org/10.3390/su9112150
- Région Grand Est (2024): Adapter les stations de montagne au changement climatique. Dispositif régional, Strasbourg. www.grandest.fr/wp-content/uploads/2024/11/dispositif-soutien-a-ladaptation-des-stations-de-montagne-au-changement-climatique.pdf
- Regierung des Fürstentums Liechtenstein (2024): Bericht und Antrag betreffend die Gewährung von Investitionskostenbeiträgen an die Bergbahnen Malbun Aktiengesellschaft für die Jahre 2025 bis 2028 und eines Beitrags zur Errichtung von Photovoltaik-Anlagen, Nr. 116/2024. bua.regierung.li/BuA/default.aspx?nr=116&year=2024&erweitert=true
- Richtlinie 2000/60/EG (EU-Wasserrahmenrichtlinie). eur-lex.europa.eu/eli/dir/2000/60/oj
- Ringler, A. (2016/17): Skigebiete der Alpen: landschaftsökologische Bilanz, Perspektiven für die Renaturierung. Jahrbuch des Vereins zum Schutz der Bergwelt, 81./82. Jg., S. 29–130. www.alpenverein-muenchen-oberland.de/uploads/images/uuHCoiH52AGNNw69PiKtZw/ringler_VzSB_jb_2016_17_skigebiete_der_alpen_landschaftsoekologische_bilanz.pdf
- Rixen, C., Stoeckli, V. & Ammann, W. (2003): Does artificial snow production affect soil and vegetation of ski pistes? A review. Perspectives in Plant Ecology, Evolution and Systematics 5 (4), 219–230. doi.org/10.1078/1433-8319-00036
- www.slf.ch/fileadmin/user_upload/WSL/Projekte/kuenstliche_schneedecke/zusammenfassung_kunstschneeprojekt.pdf
- Roseo, F., Celada, C. & Brambilla, M. (2025): Ski resorts threaten climate refugia for high-elevation biodiversity under current and future conditions in the Alps. Biological Conservation 301, 110890. doi.org/10.1016/j.biocon.2024.110890
- Ruedl, G. & Burtscher, M. (2026): Collisions on ski slopes pose a high risk of injury – It's time to take action. Journal of Sport and Health Science 15, 101151. doi.org/10.1016/j.jshs.2026.101151
- Schweizer Tourismus-Verband (2024): Faktenblatt Klimaszenarien Winter 2050 für die Schweiz (erarbeitet von Seilbahnen Schweiz, November 2024). files.stv-fst.ch/staging/assets/downloads/kona_sbs_klimaszenarien-winter.pdf

- Schwörer, C., Rhyner, H., Rixen, C., Schneebeli, M. & Iten, B. (2007): Chemische Pistenpräparation – Grundlagenbericht. Eidg. Institut für Schnee- und Lawinenforschung SLF, Davos, im Auftrag des BAFU. vi, 69 S. www.newsd.admin.ch/newsd/message/attachments/10875.pdf
- Serquet, G., Marty, C., Dulex, J.-P. & Rebetez, M. (2011): Seasonal trends and temperature dependence of the snowfall/precipitation-day ratio in Switzerland. Geophysical Research Letters 38, L07703. doi.org/10.1029/2011GL046976
- SI Magazin – Seilbahnen International (19.1.2026): Bayern: Seilbahnförderung auch 2026, aber ohne Beschneiung; (9/2026): Südtirol: Neue Förderkriterien für Seilbahnen. www.simagazin.com/si-magazin/themen/seilbahn-technik/bayern-seilbahnfoerderung-auch-2026-aber-ohne-beschneiung/; www.simagazin.com/si-magazin/themen/management-tourismus/suedtirol-neue-foerderkriterien-fuer-seilbahnen/
- Siol.net (28.1.2023): Po 10 letih suše krepkih 80 milijonov evrov za slovenska smučišča. siol.net/sportal/rekreacija/po-11-letih-suse-krepkih-80-milijonov-evrov-za-slovenska-smucisca-597939
- Skiresort Service International GmbH: Datensammlung zu Skigebieten weltweit. www.skiresort.info
- SLF – WSL-Institut für Schnee- und Lawinenforschung (2026): Technischer Schnee. www.slf.ch/de/schnee/schneesport/schnee-und-ressourcenmanagement/technischer-schnee/
- snowplaza.de (30.10.2025): Ski fahren ab 7. November: Kitzbühel setzt auf innovative Schneespeicherung. www.snowplaza.de/weblog/ski-fahren-ab-november-kitzbuehel-setzt-auf-innovative-schneespeicherung/
- Spandre, P., François, H., Thibert, E., Morin, S. & George-Marcelpoil, E. (2017): Determination of snowmaking efficiency on a ski slope from observations and modelling of snowmaking events and seasonal snow accumulation. The Cryosphere 11, 891–909. doi.org/10.5194/tc-11-891-2017
- SRF (13.12.2024): Kren, A.: Snowfarming in Davos – Wie man dem Ski-Winter auf die Sprünge hilft. www.srf.ch/wissen/nachhaltigkeit/snowfarming-in-davos-wie-man-dem-ski-winter-auf-die-spruenge-hilft
- Stangl, M. et al. (2026): Klimastatusbericht Österreich 2025. CCCA/Klima- und Energiefonds, Wien. ccca.ac.at/wissenstransfer/klimastatusbericht-2025
- Steiger, R. (2013): Auswirkungen des Klimawandels auf Skigebiete im bayerischen Alpenraum. Im Auftrag des Deutschen Alpenvereins. Innsbruck. www.alpenverein.de/files/DAV-Beschneiungsstudie_21661.pdf
- Steiger, R. & Scott, D. (2020): Ski tourism in a warmer world: Increased adaptation and regional economic impacts in Austria. Tourism Management 77, 104032. doi.org/10.1016/j.tourman.2019.104032
- Stiftung Sicherheit im Skisport/ASU (2025): Unfallanalyse Saison 2024/25. www.stiftung.ski/en/security/asu-accident-analysis
- Südtirol News (28.11.2017): Seilbahnen: Neue Kriterien für die Förderung. www.suedtirolnews.it/wirtschaft/seilbahnen-neue-kriterien-fuer-die-foerderung
- swissinfo (2007): Schneekanonen – ein löchriger Wasserkreislauf. www.swissinfo.ch/ger/archive-wissenschaft/schneekanonen-ein-loechriger-wasserkreislauf/1332284
- swissinfo (20.11.2017): Hightech auf den Pisten. www.srf.ch/news/schweiz/hightech-auf-den-pisten-keine-verschwendung-von-schnee
- TechnoAlpin (2025): Milano Cortina Winter Olympics 2026: TechnoAlpin delivers the core snowmaking projects. Pressemitteilung vom 25.7.2025. www.technoalpin.com/en-us/about-us/news/milano-cortina-winter-olympics-2026/
- Tiroler Naturschutzgesetz 2005 (Landtagsbeschluss vom 4.10.2018). www.ris.bka.gv.at
- Tiroler Tageszeitung (4.8.2026): Zu viel Wasser für Beschneiung? www.tt.com/artikel/30939481/zu-viel-wasser-fuer-beschneiung-tiwag-legt-sich-am-kaunertaler-gletscher-quer

- Traunsteiner Tagblatt (16.1.2020): Beste Bedingungen: Ruhpolding Vorreiter im Snow-Farming – Schneedepot leer. www.traunsteiner-tagblatt.de/startseite_artikel,-beste-bedingungen-ruhpolding-vorreiter-im-snowfarming-schneedepot-leer-_arid,546076.html
- Tribunal administratif de Grenoble: Beschlüsse vom 25.10.2022 (Nr. 2206293) und 23.7.2025.
- UVP-G 2000 (Österreich), Anhang 1 Z 12, i. d. F. BGBl. I 26/2023. www.ris.bka.gv.at
- UVPV (Schweiz), Anhang Nr. 60.4. www.fedlex.admin.ch
- Urlaubshamster (2026): Skipass-Preise 2026/27: Österreichs Skigebiete im Vergleich. www.urlaubshamster.at/skipass-preise-2026-27/
- Vanat, L. (2022, 2025): International Report on Snow & Mountain Tourism. Volltext nur für Unterstützer:innen. www.vanat.ch/international-report-on-snow-mountain-tourism
- Vaterland (1.9.2026): VU will Trinkwasseranteil bei der Beschneiung im Malbun senken. www.vaterland.li/liechtenstein/politik/vu-will-trinkwasseranteil-bei-der-beschneiung-im-malbun-senken-art-755709
- Vattenfall (o. J.): Stromverbrauch in Mehr-Personen-Haushalten. www.vattenfall.de/infowelt-energie/strom-ratgeber/durchschnittlicher-stromverbrauch-im-1-2-3-4-personen-haushalt (abgerufen 10/2026)
- Wex, H., Augustin-Bauditz, S., Boose, Y. et al. (2015): Intercomparing different devices for the investigation of ice nucleating particles using Snomax® as test substance. Atmospheric Chemistry and Physics 15, 1463–1485. doi.org/10.5194/acp-15-1463-2015
- Wirtschaftskammer Österreich (WKO), Fachverband der Seilbahnen: Beschneiung sowie diverse Datenblätter. www.wko.at (abgerufen 9/2026) www.wko.at/transport-verkehr/seilbahnen/beschneiung
- Wirtschaftskammer Vorarlberg (2026): Förderung von Klein- und Kleinstskigebieten – Richtlinien 2026. www.wko.at/vlbg/transport-verkehr/seilbahnen/richtlinien-2026-kleinskigebiete.pdf
- Wolfsperger, F., Rhyner, H. & Schneebeli, M. (2018): Pistenpräparation und Pistenpflege. Das Handbuch für den Praktiker. WSL-Institut für Schnee- und Lawinenforschung SLF, Davos. 232 S. ISBN 978-3-900621-59-4. www.slf.ch/en/publications/slope-preparation-and-grooming/
- Zellmann, P. (2011): Zukunft Wintersport. Vortrag beim Saisonstart-Journalistenseminar Netzwerk Winter, 20. Oktober 2011, Tauern Spa Kaprun. Institut für Freizeit- und Tourismusforschung (IFT), Wien.



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