MOVING MOUNTAINS FORUM

White Paper

Mountains in transition

Strategies for addressing climate, economic, and societal challenges

White Paper, version 1
A reference document created by the Moving Mountain Forum.
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Summary

This White Paper explores the responses implemented by mountain resorts to the challenges of climate change and its consequences. Rising temperatures and reduced snow reliability are shortening winter seasons and directly threatening the winter sports economy, which is closely linked to snow.

Using examples from the European Alps, North America, and other mountain ranges, it presents strategies adopted to maintain activity and reduce environmental footprints: optimizing snow management, diversifying activities, technical innovations, and committing to more sustainable practices.

Drawing on concrete cases and international experience, this document provides an initial overview of the different approaches that can be taken. It shows that there is no single solution, but rather a variety of responses tailored to the specific characteristics of each territory, in order to reconcile economic viability, environmental preservation, and the resilience of mountain communities.

This White Paper explores the challenges facing mountain resorts while the climate is changing, in particular with rising temperatures and declining snowfall. It highlights the strategies most commonly used by resorts to remain economically viable while remaining attractive to visitors. From technical snow management to diversifying tourist activities throughout the year, adaptation appears to be a necessity. In addition, the report emphasizes the importance of sustainable development as the foundation for the future of mountain tourism.

There is no one-size-fits-all solution for mountain resorts, but one challenge is universal: rising temperatures and declining snowfall. These environmental changes threaten the very heart of winter tourism and are forcing mountain resorts to adapt in order to remain econo-mically viable and continue to attract tourists. Meeting customer expectations now requires innovation and flexibility.

To cope with uncertainty about snow reliability, resorts are increasingly relying on advanced snow management techniques, including artificial snowmaking and snow conservation. At the same time, many are expanding their offerings to include year-round activities such as mountaineering, adventure parks, and hiking. This diversification not only fills the gap left by shorter ski seasons, but also reduces communities' dependence on ski tourism for their economic viability.

Sustainable development is at the heart of any long-term strategy for mountain regions. Many communities, regions and even entire countries are heavily dependent on the income generated by ski tourism. It is therefore neither viable nor sustainable to simply eliminate it. It is therefore essential to adapt to current environmental and cultural changes. A notable shift in tourist preferences, away from skiing to activities such as climbing, hiking, and urban tours, further complicates the situation.

To ensure their long-term success, ski resorts must commit to sustainable practices. This includes investing in renewable energy, improving water and snow management, and enhancing the energy efficiency and water consumption of snowmaking infrastructure. Such measures are essential to adapt to both environmental realities and changing visitor expectations.

Will we still be skiing at the end of the century? The answer remains uncertain. But one thing is for sure: the future of skiing is not as bleak as it seems. Thanks to their resilience, capacity for innovation, and sustainable actions, the slopes may still have stories to tell and snow to share for generations to come.

Declaration of intent

Since its inception in 2012, the Moving Mountains Forum has brought together those who live and breathe the mountains – residents, elected officials, economic, tourism, social, and cultural stakeholders, scientists, researchers, and passionate visitors – with the aim of sharing concrete and pragmatic ideas for building a sustainable future for mountain communities.

As a platform for best practices in sustainable transition, the Moving Mountains Forum addresses a central theme each year. It brings together diverse responses to common problems in order to raise awareness and enable mountain regions to advance their perspectives.

Over the forum's 15-year history, a recurring theme has emerged that has greatly influenced the discussions and projects presented:

how can mountain resorts, whose economies depend largely on winter tourism (skiing and snowboarding), meet the challenges posed by climate change?

True to its mission of bringing together diverse responses to a universal theme, the Moving Mountains Forum has taken the initiative to take stock of this fundamental issue in order to promote reflection and action among mountain communities. In just over half a century, skiing – and everything that goes with it – has profoundly transformed the socio-economic and cultural life of valleys, mainly in the European Alps and North America, but also in other mountainous regions of the world. The systemic change in snow conditions that these regions are now facing, and the prospect of its acceleration, raise profound questions for their populations that go far beyond technical or financial aspects.

In a divisive and passionate context, where dogmas, interests and power games clash, the Moving Mountains Forum wishes to make an initial documentary contribution: a range of observable methods and trends, illustrated by examples and facts, without passing judgment. This is not a research report on climate change, nor is it a case study or an attempt to analyze mountain regions, but rather a collection of existing practices (international benchmarking) aimed at demonstrating that there is no single answer to the problems posed by climate change. Rather, there are a number of strategies that involve specific framework conditions, existing or non-existing collective strategies, and other key factors that must be taken into account.

This first White Paper is therefore a seed that we are planting in the hope of launching a project that will be developed over the years, with the help of practitioners and academic researchers. The long-term goal is to build up a body of knowledge that is comprehensive enough to assess how mountain resorts are preparing for the future and what the environmental, economic, social, and cultural consequences will be. Ultimately, we want to bring contrasting realities and concrete facts into the discussion, as is the mission of the forum.

We would like to thank Cléo Tarashev, project manager at Dynamics Group and holder of an MSci in Biological Sciences from University College London, who was commissioned by the Moving Mountains association to collect information and examples related to this topic and to draft the first version of this document. We would also like to thank Anne Sophie Fioretto, geographer, project manager at the Institute of Tourism at HES-SO Valais-Wallis and specialist in the transformation of mountain resorts, for her expert advice and careful proofreading of the document. Finally, we would like to thank Thierry Meyer, president of the Moving Mountains association, for his valuable contribution.

Introduction

Reader's Guide

This white paper focuses on the challenges posed by climate change to mountain resorts (specifically ski resorts). It draws on examples from regions around the world where winter sports are important, popular, and/or play a major socio-economic role. More specifically, these regions are the European Alps, North America, and Scandinavia. The main focus will be on Europe, as it is the world's largest market for ski tourism (Hugues et al., 2023). It is home to around 50% of all ski resorts worldwide and more than 80% of those that welcome more than one million skiers per year (Hugues et al., 2023).

The determining factor for winter tourism is the presence of snow. Indeed, it has been shown that the depth of natural snow has a statistically significant impact on the number of overnight stays in ski resorts (Steiger et al., 2024). It should be noted that this is almost exclusively the case in medium- and low-altitude resorts, as high-altitude resorts do not face the same difficulties in terms of natural snow availability (Steiger et al., 2024).

Each season, Sweden welcomes around 10 million alpine skiers, more than 80% of whom visit the 32 largest ski resorts (Steiger et al., 2024).

There is a controversial truth that high-altitude resorts ironically have more resources to manage sustainable development than lower-altitude resorts and are therefore also better equipped to meet the challenges posed by climate change. The graph below, taken from an article on climate change published in 2023, will serve as a guide for this report (see Figure 1).

Mountain tourism is one of the most weather-sensitive forms of tourism. This means that the feasibility of tourist activities depends on variables such as temperature and precipitation. Climate change will undoubtedly alter the likelihood of these ideal weather conditions and will therefore have a considerable impact on tourist behavior and tourism in general.

As mentioned above, ski tourism is highly dependent on snowfall (see Figure 1). The risk associated with snow cover for ski tourism is defined as the frequency of insufficient snow conditions on ski slopes. Three main factors influence this risk: first, low frequency of snowfall and high temperatures during the winter months. Second, exposure, i.e., the altitude, geographical orientation, and elevation of the resort. Third, the socioeconomic factor: to what extent do these communities depend on income generated by ski tourism and, consequently, on snowfall?

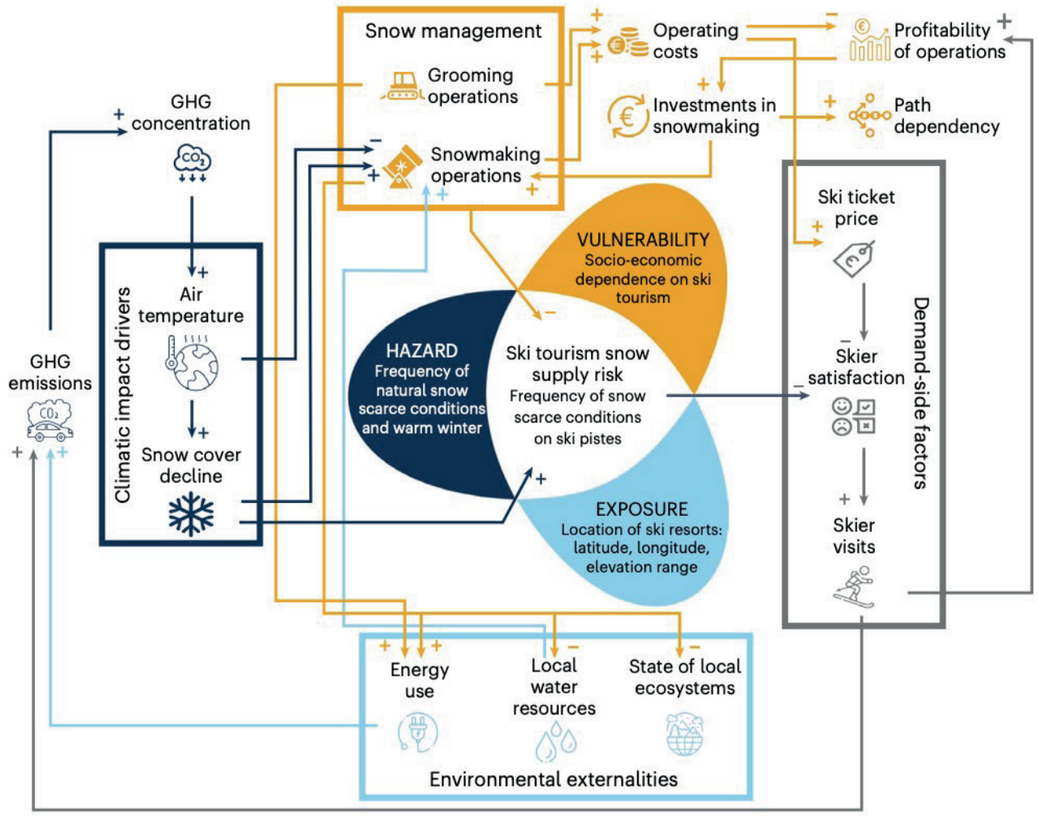


Figure 1: This chart illustrates and summarizes the problem facing ski resorts. This problem stems from the decline in natural snowfall due to global warming. The graph then shows the links between the four main issues: climate, environment, snow management, and customer demand. This graph is taken from an article published in 2022 on climate change entitled "Climate change exacerbates snow, water, and energy challenges for ski tourism in Europe."

Other factors then come into play and have an impact on the variables mentioned above. First and foremost is snow management, which has become a determining factor over the last decade. Low-altitude resorts in particular are increasingly dependent on artificial snowmaking techniques, which themselves depend on the availability of environmental resources. This technological solution consumes energy and water and increases the resort's carbon footprint. On the other hand, artificial snowmaking and snow grooming techniques increase skier satisfaction and demand (increase in the number of visits and ski passes sold). The profits can be reinvested in infrastructure and equipment to improve artificial snowmaking infrastructure and snowpack management. The downside is that an increase in tourism also leads to an increase in transport and accommodation needs, which also contribute, and to a considerable extent in the case of transport, to greenhouse gas emissions.

An example of an automatic snow pole connected to a fixed water distribution network.

These contradictory factors perfectly illustrate the biggest challenge facing mountain resorts today. They must find a way to remain profitable in order to continue operating while facing and adapting to the challenges posed by climate change. Their response to these challenges depends mainly on their altitude and the financial resources available to them. Resorts located at low and medium altitudes are the most affected, while those at high altitudes are not yet as affected. Ultimately, the goal of all mountain resorts is the same: to find a way to develop sustainably—economically, socially, and environmentally.

Origin and evolution of the cultural and socioeconomic importance of ski resorts

Since their creation in the aftermath of World War II, and especially in the 1960s and 1970s, when skiing as a mass tourist activity became popular in developed countries with mountainous regions, ski resorts have played an important role in the local economy, significantly altering the economic balance, purchasing power, and lifestyle of these regions. In some countries, such as Austria and Switzerland, ski resorts are even the main contributors to the national tourism economy. In valleys where winter tourism dominates, it accounts for 75% to 95% of annual income. Only a few renowned destinations have a more stable balance between winter and summer activities, not to mention the income generated by all four seasons—the share of fall and spring, outside the ski season, is minimal.

Traditionally, ski resorts have been important economic drivers, creating jobs and stimulating the tourism industry, but with the decline in the predictability of snowfall and the increase in the cost of maintaining ski infrastructure, some of the communities that depend primarily on winter tourism are seeing their economic balance threatened. It remains to be seen how the recent trend toward higher prices and upmarket positioning of the largest and most famous destinations will affect the economic balance of the regions concerned. The closure of ski lifts such as Château d'Oex/Les Moulins-Monts Chevreuils (Switzerland) in 2001 and Grand Puy (France) in 2024, among dozens of other examples, demonstrates the social and economic consequences of the instability and increasing unpredictability of this sector. When ski lift companies close, the entire tourist ecosystem of the resort is affected. In the worst cases, businesses such as rental shops and hotels close their doors and local economies face immediate decline. Some resorts or regions have been able to anticipate change and reorient their economic model, but this often comes at a high economic cost and creates tensions within communities.

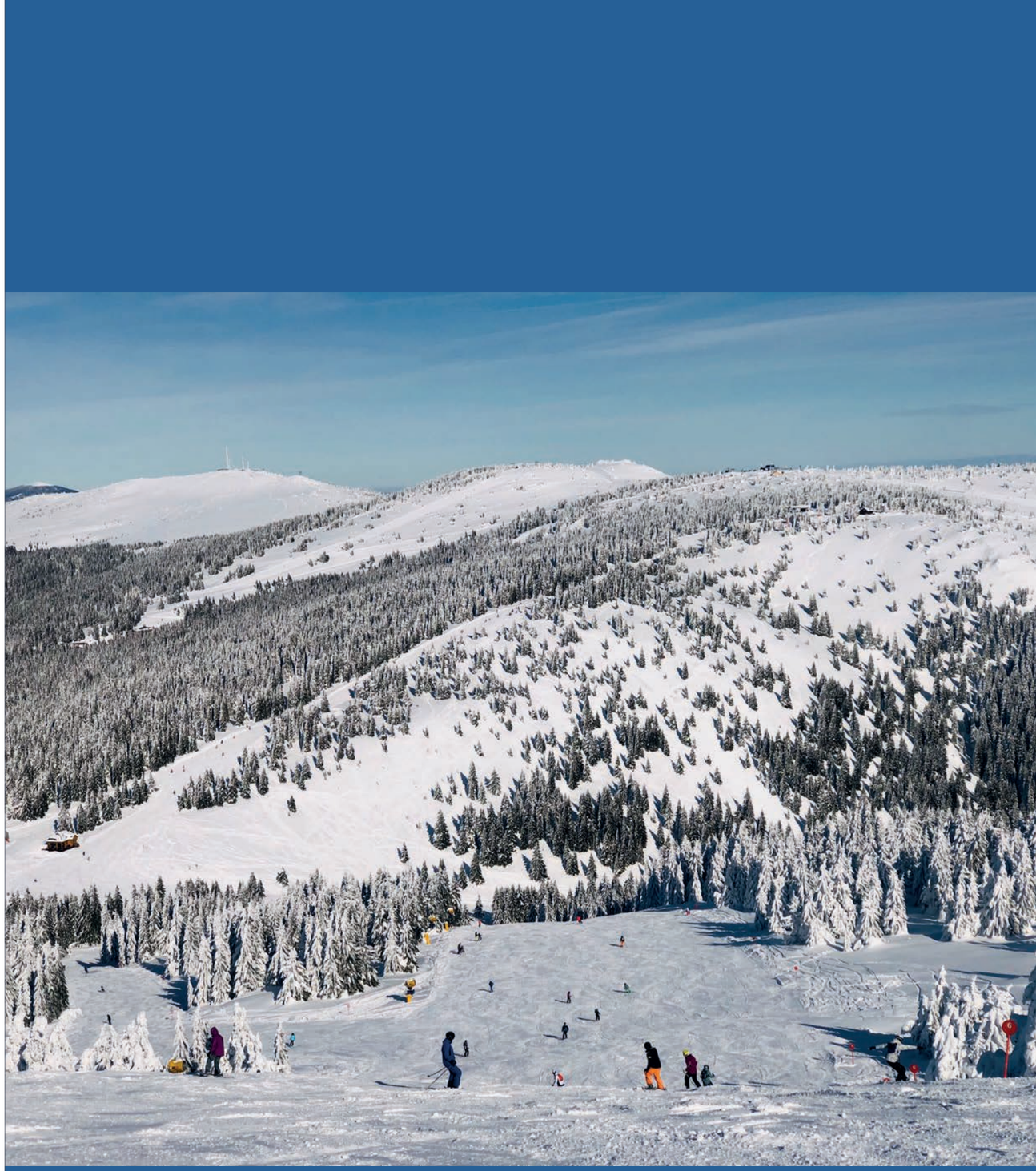
The Savoyard resort of Val-d'Isère, one of the first to develop after the war in the French Alps.

Inauguration of the first facilities at Monts-Chevreuils, in the Vaud Alps, on February 10, 1945. Modernization took place in the 1970s. Musée du Pays-d'Enhaut

To address these challenges, ski resort operators have increasingly focused on diversifying their offerings, improving infrastructure, and adopting new business models to ensure the sustainability of their operations and remain competitive. Larger resorts, particularly those at high altitudes, have generally been more successful in adapting to these changes. As noted above, this is the paradox of the current situation, which could be summed up by the expression “you only lend to the rich”: the highest altitude resorts with the largest ski areas, which are less immediately affected by the effects of climate change, have more resources to respond, upgrade their facilities, and diversify their tourism strategy. This apparent advantage is only temporary and does not call into question the fundamental need for strategic thinking: for example, Zermatt has to review the mapping of its glacier ski area and has had to equip certain sectors with mechanical snowmaking facilities at very high altitudes. On the other hand, the future of small resorts remains uncertain, regardless of their altitude, due to the investments required to ensure economic sustainability.

Another factor worth mentioning, which plays an additional role in the obstacles facing the winter tourism industry, is the cultural importance of winter sports, which is also evolving. In several Western countries, such as Switzerland and Austria, skiing is deeply rooted in the culture and is part of the national identity. Austria is the best example of this, where skiing is the national sport, even more so than in Switzerland. For these countries, ski tourism is therefore a pillar of the national economy, contributing significantly to local economies by creating jobs in mountain communities, but also, to a certain extent, by strengthening the sense of identity and unity within the country. Traditional ski camps, which have welcomed hundreds of thousands of young people to Switzerland and Austria over the past 50 years, are the best example of this.

However, the sector is now facing a decline in demand due to changing weather conditions, stricter logistical, regulatory and financial conditions, changing consumer preferences, and cultural change. Mergers and acquisitions between ski resorts, combined seasonal pass offers, and the restructuring of ski lifts are a direct response to these challenges. Skiing is no longer the only attraction of mountain tourism, as alternatives in mountain areas develop, and beach vacations and city trips have become more popular. In addition, the aging population in key markets such as Germany, the trend toward shorter vacations, and cultural changes brought about by the arrival of a large immigrant population from non-skiing countries have reduced the pool of potential skiers.



How climate change affects mountain areas

The consequences of climate change are visible all over the world. Increased seasonal unpredictability and extreme weather events are being felt and observed everywhere. Mountain regions are particularly affected because temperatures are rising faster there than in lowland areas (Steiger et al., 2024). In the Alps, for example, which stretch 1,200 km from west to east across western and central Europe and have some 40 peaks over 4,000 m above sea level, the average temperature has risen by nearly 2°C since the 19th century, twice the global average (Kotlarski et al., 2022).

This warming trend has led to a reduction in snow cover and permafrost and accelerated glacier retreat. This has in turn caused a change in environmental conditions that is having serious repercussions on mountain ecosystems (Kotlarski et al., 2022). Due to higher temperatures and the rise in the snow line, ecosystems are forced to adapt or face decline (Kotlarski et al., 2022; Tito, Vasconcelos, and Feeley, 2022). Plant species are the most disadvantaged, as their migration to higher altitudes is very complicated and threatened by invasive species, which threatens the biodiversity and overall stability of mountain ecosystems (Petitpierre et al., 2016). Even species capable of migrating will see their territory shrink, further straining their ability to survive (Elsen and Tingley, 2015).

Ski resorts, which depend on regular periods of snowfall to maintain their economic activities, are undergoing a similar stress test (Reynard, 2020). The stakes go far beyond the mere continuity of current tourism and commercial activities: over the past 50 to 70 years, winter sports and modern mass tourism have shaped entire territories, lifestyles, and identities (Reynard, 2020). This white paper does not examine in detail the many social, cultural, and economic implications of the major changes that the duration, predictability, and regularity of snowfall will bring to mountain regions. However, it is important to bear in mind that any development perspective or project raises fundamental questions that affect all sectors of human activity.

Resorts located at low altitudes (between 1,000 and 2,000 meters above sea level) are particularly vulnerable. Some of them do not have the means to compensate for the lack of snow and are therefore forced to close or switch to other activities that do not depend on regular snowfall during the winter season. Artificial snow machines are a very popular way of compensating for the lack of snow, but at low altitudes, this is simply not worthwhile, as the average temperature conditions, including at night, make it impossible to cover the entire ski area with artificial snow. In addition, increasingly frequent, drastic and rapid climate change, with temperature variations of more than 10°C in a few days, make any investment unviable due to a total lack of predictability and the impossibility of logistical and economic planning.

That said, even larger resorts at medium and high altitudes, which have greater resources, are feeling the effects of climate change and already have to rely heavily on artificial snow to remain competitive.

Artificial snow, a multifaceted tool

On this subject, it is probably worth mentioning that artificial snowmaking is not strictly linked to the need to compensate for a shortage of natural snow. In the late 1990s, the ski industry had to respond to a significant loss of popularity in the face of competition from new leisure sports that were considered more attractive and less restrictive, such as snowboarding in particular.

A new ski manufacturing technology, incorporating a cut into the ski design to make turning easier (“carving”), was met with the need for perfectly groomed slopes with a stable and even base layer, so that this transformation would appeal to the widest possible customer base, without any particular sporting ability. Thanks to its compactness, uniform distribution, and ability to withstand intensive grooming, artificial snow became an integral part of this evolution. Added to this was the need to guarantee skiers safe access, particularly to resorts and at the bottom of ski areas, with no visible rocks and a compact, safe snow cover.

Snow management

Snow management refers to the strategic and proactive management of snow in the context of winter sports. It encompasses a range of practices aimed at optimizing snow conditions while taking into account environmental, economic, and technical factors. These practices vary considerably depending on the specific requirements of ski resorts, event venues or sports disciplines, each shaped by a unique climatic and geographical context. At the heart of snow management is the efficient use of resources for snow production and slope maintenance, an approach that aims to improve the quality of facilities, minimize operating costs and support long-term sustainability. As such, snow management plays a crucial role in ensuring that winter sports infrastructure operates in a responsible and forward-looking manner. This chapter explores two key elements of these practices in more detail: snowmaking (artificial snow production) and snow conservation (or storage).

As situations vary from resort to resort in terms of altitude, exposure, topographical and meteorological conditions, history and identity, economic and financial resources, market positioning, etc., current practices also differ from one another. Among the common responses adopted by the majority of resort operators or authorities, artificial snow machines and snow conservation techniques, such as snow storage, have enabled resorts to continue operating even in the event of reduced and unpredictable snowfall.

Although these technologies are only temporary solutions, they enable resorts to plan and even extend their seasons and mitigate some of the revenue losses caused by climate change.

Advances in the efficiency and reliability of these various techniques and programs have also enabled resorts to define investment and operating capacity plans for the foreseeable future. However, they do not address the root cause of the problem: global warming. Without broader efforts and policy changes to combat climate change, the long-term viability of ski resorts (i.e., over the next few decades) remains uncertain at best.

Artificial snow

All major ski resorts around the world are increasingly using artificial snow (“snow making”) to support their winter sports activities. Some of them now have an artificial snowmaking network covering more than 75% of their marked trails (Ebner et al., 2021; Hugues François et al., 2023). This technology allows them to remain open, attractive and therefore competitive throughout the winter season, from the run-up to the end-of-year holidays until March, or even Easter for the largest and highest resorts.

Artificial snow has been popular for decades and today snow cannons are a staple in ski resorts around the world. These machines, which release droplets of water that freeze to form snow particles, require water and compressed air from the valley. Although this technology is not new, modern snowmaking systems have evolved to use more energy-efficient refrigeration methods, similar to those used in supermarket cooling systems. Over the past decade, advances have led to the development of more efficient and environmentally friendly snowmaking processes, significantly reducing operating costs and lowering water and energy requirements. Artificial snowmaking is therefore more attractive to ski resorts, particularly in developed countries where the technology has been perfected.

There are two types of artificial snowmaking technology: traditional snow guns and all-weather snowmakers. These two categories are subdivided into several alternatives, such as mobile snow machines that propel snow using a large fan, or pole-shaped systems that are installed along groomed slopes throughout the season. Snow guns are only effective when temperatures are at or below zero degrees Celsius. They are used to create a thicker, more compact base of snow to ensure sufficient coverage and make it more resistant to melting when temperatures rise, as well as to redistribute snow on the slopes. All-weather snow cannons, on the other hand, can operate in warmer conditions – technically up to 30°C – allowing ski resorts to extend their season and guarantee reliable snow cover, even in unpredictable weather conditions (Laskin, 2020). In order to transform the snow into skiable slopes, snow groomers are then used to distribute and compact the snow evenly.

The case of Boler Mountain in Canada illustrates how all-weather snowmaking technology can be a game-changer for small ski resorts (Goh, 2022). Faced with global warming, Boler Mountain has been able to secure a reliable snow supply by investing in snow cannons. This has not only enabled the resort to guarantee the opening of the ski sea-son regardless of weather conditions, but has also given it a competitive advantage thanks to an extended ski season. In fact, Boler Mountain has become one of the few ski resorts to keep its slopes open throughout the 2022-2023 season in its region. Similarly, Ski Ward in Massachusetts, USA, has found that artificial snow allows it to attract visitors by offering predictability in an increasingly uncertain climate.

Snow cannon at Boler Mountain. Source: https://www.cbc.ca/news/canada/london/boler-makes-snow-in-war-mer-temperatures-1.6661874

While artificial snow helps mitigate the economic impacts of climate change, it is not without drawbacks for the environment. The increased use of artificial snow and slope preparation has raised concerns about its effects on alpine ecosystems. This practice can cause soil freezing, delay plant growth, and alter plant species composition, ultimately reducing biodiversity. In addition, the use of snow additives, such as salts and ice-nucleating bacteria, can further alter the soil's water and nutrient balance, which can harm plant life. Some studies suggest that these additives, particularly salts, may have fertilizing effects that promote the growth of some plants while damaging others, further disrupting the ecological balance.

Beyond artificial snowmaking, the physical modification of ski slopes to prepare them for artificial snowmaking can have lasting effects on the terrain. Soil warming caused by slope leveling can lead to the loss of permafrost, an essential component of alpine ecosystems. Even when ski slopes are no longer used, land regeneration remains slow, with vegetation growing back more sparsely than before and biodiversity never fully returning to its original state. These ecological challenges highlight the need for ski resorts to go beyond simply using artificial snow and adopt strategies to diversify tourism and reduce dependence on winter sports.

Water is a major issue and subject of environmental controversy, as it is essential for making artificial snow. In order to guarantee access to water and centralize it at strategically distributed points, most ski areas have created artificial reservoirs to store water and pump it as needed to supply the network of snowlifts or snow cannons. These ponds have an impact on the landscape and the natural environment. Water itself is an issue: its many uses (irrigation, energy, domestic and industrial consumption, etc.) put pressure on its availability, at a time when one of its renewable sources – glaciers – is being hit hard by climate change. The latest technological developments in artificial snowmaking have significantly reduced water requirements, but the issue of water management as a raw material remains an important one.

Snow farming

Snow farming is another innovative and popular response to the challenges posed by climate change in the ski resort industry (Grünewald et al., 2018). With natural snowfall becoming increasingly unpredictable and climate variability increasing, ski resorts are turning to snow storage as a solution to maintain a constant supply of snow during the winter season. This practice involves storing artificial snow at the end of a season, keeping it during the warmer months, and using it to start the next season (Grünewald et al., 2018). By insulating snow piles with materials such as sawdust or specialized insulators such as geotextiles, ski resorts can reduce their reliance on energy-intensive artificial snowmaking and thus lower their electricity and water consumption (Grünewald et al., 2018).

In recent years, snow conservation has gained popularity, particularly in Central European countries such as Switzerland, where this practice helps combat the unpredictability of snowfall. The effectiveness of snow storage relies on advanced technology that allows ski resorts to identify the optimal methods and locations for storing snow to withstand rising temperatures, precipitation, and wind. While this practice offers considerable advantages, including reduced operating costs and a better skiing experience thanks to improved snow quality, it is not without its challenges in terms of the environment and carbon footprint (Grünewald et al., 2018).

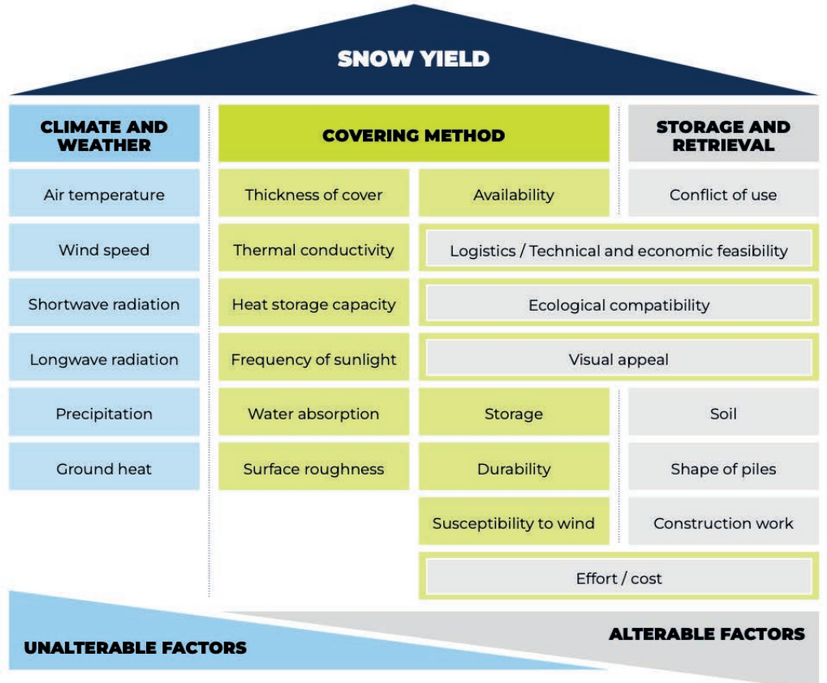
For ski resorts, engaging in snow storage is a major undertaking that comes with a series of logistical challenges, starting with the selection of a suitable storage site. Snow piles consist of tens of thousands of cubic meters and have an average height of around 20 meters, making it difficult to find a suitable site. Most mountainous sites at the required altitude do not have a flat, shaded area where the snow piles would not be overly exposed to the sun and at risk of sliding due to the uneven terrain. In addition, the part of the snow pile that will inevitably melt must be disposed of biologically, which must be done via mountain streams or rivers so as not to disturb existing ecosystems more than necessary.

Once the site has been found, here is how storage works: during the ski season, artificial snowmaking technology is used to create abundant snow, which is then stored. Some resorts also sometimes use natural snow or a mixture of the two. However, natural snow is not generally used because its properties are less favorable. Once the mound has been formed, it is covered with a 40 cm thick layer of sawdust.

Glaciers are protected during the summer with geotextiles, which act as a protective layer insulating the ice from the sun thanks to an albedo effect, which reflects solar radiation. However, this method does not work for snow cultivation due to insufficient altitude. Mounds covered with geotextiles would melt completely before summer.

Sawdust is ideal for several reasons. It provides uniform, even coverage and acts as an effective insulating layer. A series of scientific experiments has shown that 40 cm is the optimal thickness for heat retention (additional thickness does not significantly improve snow retention and does not justify the additional cost), preventing the sun's rays from penetrating the snow. Sawdust also stores heat, which it releases during the night, and absorbs precipitation, which cools the snow as it evaporates. If implemented correctly, snow farming results in a 20-30% loss of volume due to melting and natural compression under its own weight. Nevertheless, the remaining volume of snow has a valuable impact. For example, if the snow mound at the end of summer is around 20,000 cubic meters, it can create a 4 km long cross-country ski trail, which will only need to be a few meters wide to function satisfactorily.

Snow storage in Davos under a protective layer of sawdust.



As mentioned above, artificial snow is better suited to snow cultivation than natural snow for many reasons. The difference between natural and artificial snow is evident at the microscopic level. Artificial snow consists of frozen, compact water droplets, while natural snow is composed of loose crystals (see Figure 2). The denser, rounder structure of artificial snow is not only better suited to winter sports, but is also more resistant to high temperatures and precipitation than natural snow, making it ideal not only for cultivation, but also for artificial slopes or competition venues.

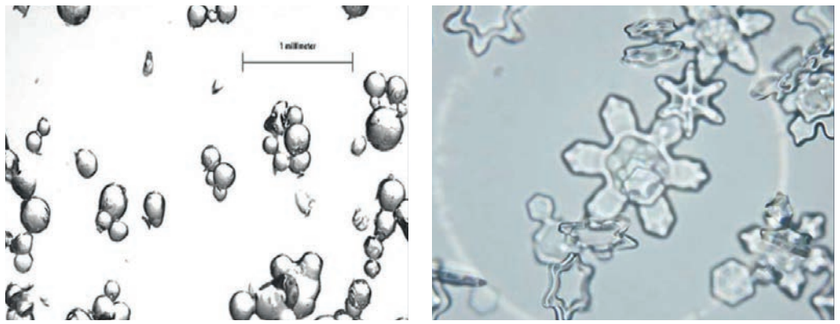


Figure 2: This illustration shows the microscopic differences that make artificial snow more suitable for snow cultivation than natural snow. Left: microscopic view of artificial snow particles. Right: microscopic view of natural snowflakes.

Snow conservation is a colossal undertaking that represents a significant financial commitment for ski resorts. For example, Davos, Switzerland, where snow conservation has been common practice since 2008, spends CHF 150,000 per year (excluding investment costs) on snow storage and the creation of a cross-country ski trail. It takes about a week to clear and distribute the snow over some 4 km of trails. It is interesting to note that while snow storage represents an additional investment, the most expensive part is sprea-ding the snow, not the actual production or storage. Nevertheless, once a resort has decided to store snow, it can guarantee an early start to the season and offer athletes training opportunities that give them a competitive advantage.

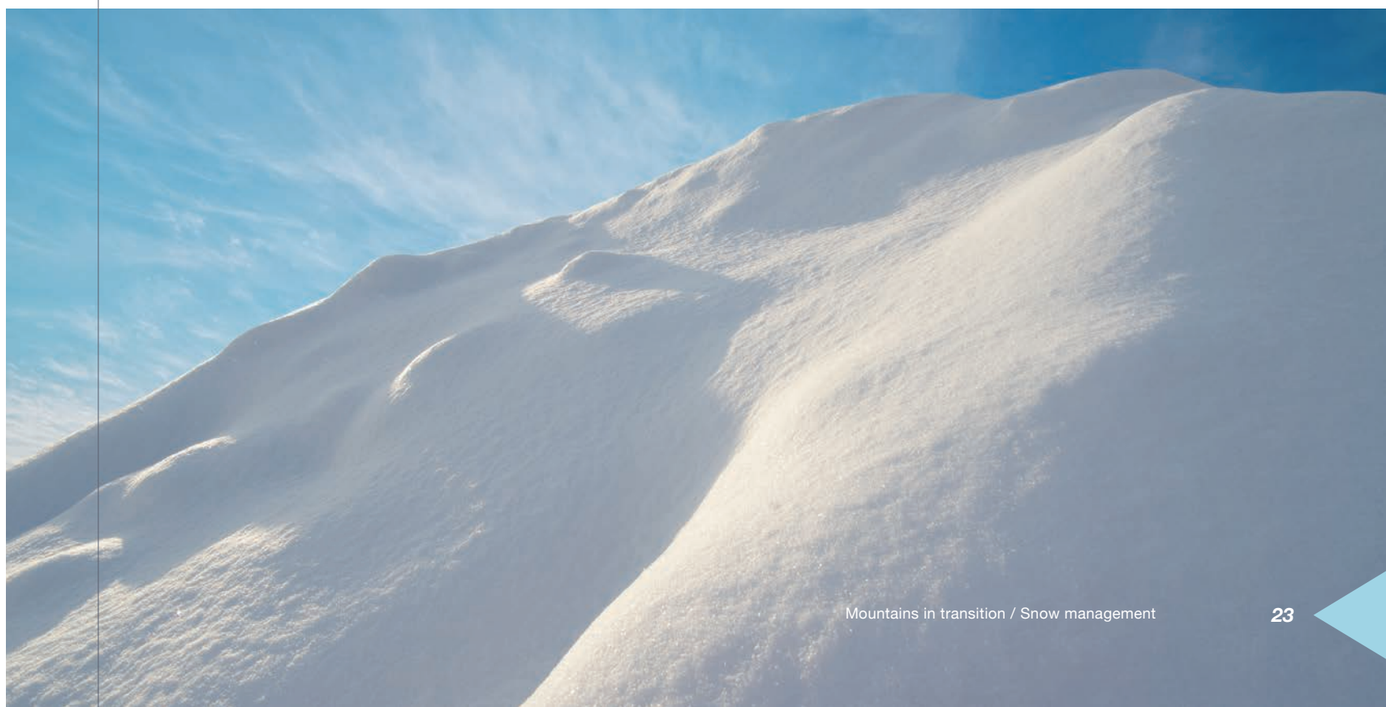
Heavy goods vehicles transporting stored snow to the slopes.

When it comes to snow conservation, ski resorts must consider not only their economic footprint, but also their ecological footprint. On the one hand, conserved snow allows athletes to train in their own countries, reducing their carbon footprint by avoiding air travel to northern regions. However, snow conservation is not without its ecological impact. In Davos alone, around 1,000 truck trips and hours of work with snow groomers are required to prepare the cross-country ski trails, which significantly increases the resort's carbon footprint. The transition to a zero-emission machine fleet is an important goal for resorts, even as snow conservation operations are set to expand.

Advances in scientific research in the field of snow storage are one of the main ways of ensuring more energy-efficient and resource-friendly operations in the future. By measuring variables such as temperature, wind speed, and precipitation at different levels above the snow, data is collected to maintain snow quality and sustainability over time. For example, it is known that the air just above the snow is slightly cooler than the air higher up. One hypothesis is that fences placed on either side of the slope could be used to trap this cooler air, thus preserving the snow for longer.

Davos is not the only Swiss resort to use snow cultivation. Popular destinations such as Adelboden and Engelberg also use it regularly. Snow cultivation is particularly important for international competitions such as ski jumping, biathlon, and slalom, where events must be planned in advance and cannot depend on increasingly unpredictable weather.

While snow storage does not solve the underlying climate crisis, it helps ski resorts remain competitive and continue their operations. By ensuring an early start to the season, snow storage offers a significant advantage to communities whose economic stability depends on winter tourism.



Which strategies for which situations?

The last part of this white paper is devoted to best practices, illustrated with concrete examples. With rising global temperatures, ski resorts, particularly those located in mid-altitude mountain regions, are facing a growing challenge: decreasing and unpredictable snowfall.

Climate change not only disrupts local ecosystems, but also affects the predictability and sustainability of ski seasons, sometimes to unsustainable levels, when temperature and humidity variations during the high season prevent activities from continuing, thus turning the challenge into a logistical and human nightmare even before the snow factor is taken into account.

As mentioned above, in response to climate change, most resorts are resorting to artificial snowmaking and, increasingly, to various snow storage methods. The increased reliability offered by artificial snow and snow storage allows ski resorts to maintain regular activity, thus ensuring job security and the economic viability of the resorts. In cases where even artificial snowmaking and snow storage are not enough to combat climate change, resorts are forced to diversify and modify their offerings in order to maintain the economic viability of their communities.

It is important to note that this diversification varies considerably depending on the altitude of the resort. Three categories can be broadly distinguished: low altitude, medium altitude, and high altitude.

Of course, there are no universal figures for defining average altitude, as latitudes and weather systems mean that altitudes vary considerably from one region of the world to another. In the Alps, the average altitude can be considered to be resorts with a vertical drop between a minimum altitude of 1,000 m above sea level and a summit below 2,500 m. These figures are significantly lower in Scandinavia and the northeastern United States, for example, while resorts in the Rockies are located at higher average altitudes but with smaller differences in altitude than in the Alps. Nevertheless, certain trends can be observed in these three categories.

Low-altitude ski resorts are most often forced to stop their ski-related activities (or cease to make them a priority) and diversify by offering year-round tourism. Mid-altitude resorts are the most affected, as they have to juggle many challenges. Not only do they have to find ways to compensate for the lack of natural snow and shorter seasons due to global warming, but they also have to find a way to maintain their economic viability. This most often means offering a wider range of activities that can be enjoyed regardless of snow conditions and also during other seasons. High-altitude resorts have an advantage over the other two, as they are not as affected by the problem of natural snow. They have sufficient economic stability to invest in their own sustainable development. These ski resorts are more or less able to operate normally, perhaps with a little help from snow cannons, and can look forward to a future where snow may become scarce. For now, they have the luxury of being able to anticipate and prepare for the future in order to ensure their long-term survival as much as possible.

Technology and diversification

Ski resorts face a dilemma: ensure their survival or make changes and sacrifices in their operations to combat climate change, which would guarantee their long-term viability. However, they must remain in business, as the reality is that countless people and communities depend on the winter sports industry for their income and economic viability.

In Levi (Finland), due to the resort's very northern location, the ski area is lit with LEDs.

The «Cliff Walk» in Grindelwald, in the Bernese Alps (Switzerland).

For example, the Levi ski resort in Finnish Lapland is a perfect example of how energy efficiency and resource conservation are priorities in resort operations. The resort uses LED lighting, automated snowmaking systems (which produce only the amount of snow needed to save energy), and snow conservation techniques to reduce energy consumption and promote water conservation. In addition, slope development focuses on improving existing areas rather than expanding into new terrain, and landscaping efforts are undertaken to preserve local biodiversity and cultural heritage.

To ensure their long-term viability, ski resorts are increasingly turning to diversification. It is essential to offer activities other than skiing during the winter and summer seasons in order to adapt to the effects of climate change. Expanding the range of activities on offer, for example with sleigh rides, guided mountain tours, hiking, mountain biking, and festivals, can attract visitors throughout the year. For example, in the Swiss Alps, which cover more than 60% of the country, activities such as ski touring, off-piste skiing, hiking, and even paragliding have gained popularity as skiing alone has become less reliable. These so-called “four-season” offerings for tourists are increasingly featured on ski resort websites.

Grindelwald is one such example. Although it remains a popular ski destination, the resort has introduced a wide range of activities for the warmer months. These include trail running, via ferrata and thrill-seeking sports such as paragliding and skydiving. By diversifying their offering, resorts can reduce their dependence on the winter season and maintain stable revenues throughout the year.

A crucial aspect of sustainable mountain tourism is changing consumer behavior, particularly with regard to waste and food consumption. Ski resorts often generate large amounts of waste, particularly from catering. Reducing single-use plastics, encouraging recycling, and streamlining waste management are essential to minimizing the environmental footprint of ski resorts. In addition, sustainable means of transport for food and supplies to mountain areas can further reduce the carbon footprint of skiing-related activities.

These examples illustrate the transitions that ski resorts around the world are being forced to undergo. Obviously, some have an easier time than others, as they have the resources and time to make this transition in the most harmonious and environmentally friendly way possible. For others, it is not so simple, as in order to begin a sustainable transition, they must remain economically viable in the present. These resorts must first invest in “survival insurance” to ensure they have a reasonable winter season. This is where investments in snow cannons and snow culture come in.

Other resorts have taken an even more radical approach by guaranteeing skiing regardless of external factors. For example, in a small Swedish town near the Norwegian border called Torbsy, a “ski tunnel” has been built. It is exactly what its name suggests: a concrete tunnel covered with a layer of artificial snow at a constant temperature of -4°C. Even if natural conditions are still favorable for skiing, this community is ensuring the future of the activity with this approach.

However, this latter approach is not yet widespread, especially since, unlike other sports such as skating and hockey, skiing is considered an outdoor sport. Thus, ski resorts that have ensured their survival in the present can use their resources to invest in sustainable solutions and new technologies.

The cross-country skiing tunnel in Torsby, Norway.

Five international examples, from the American Rockies to the French Jura, from the Graubünden and Vaud Alps to the Austrian Prealps

The following section, which presents concrete examples from several countries, shows how ski resorts not only have the potential to achieve remarkable transitions, but can also serve as benchmarks for other industries in terms of sustainable development. We have chosen five emblematic examples: **Aspen**, a historic and upscale resort in the American Rockies, in the state of Colorado, a pioneer in the sustainable approach; **Laax-Flims**, a Swiss resort in the canton of Graubünden, which has set itself the goal of becoming carbon neutral by 2030; **Métabief**, in the French Jura, which has decided to stop operating its alpine ski area, a first in Europe; **Austria in general**, which is trying to reconcile its intrinsic culture of alpine skiing with sustainability measures, all at critical altitudes (between less than 1,000 m and 2,300 m on average); and **the Vaud Alps**, with three very close sub-regions, but with different characteristics and responses.

Aspen, Colorado.

The Aspen Skiing Company – USA

Since its inception, the Environmental Affairs Department has reduced resource consumption, improved efficiency, implemented green building practices for renovations and new construction, and invested in renewable energy and alternative fuels across the Aspen Ski Group. ASC has not only demonstrated ongoing effort and commitment, but has also successfully demonstrated its public responsibility, earning several environmental certifications such as ISO certification (an internationally recognized standard for environmental management systems), which is legally binding and therefore requires it to adhere to stricter standards.

What makes ASC unique is that it is one of the first resorts to extend its environmental commitment beyond the ski sector. In short, its leaders understood that to have a significant impact and effectively combat climate change, they had to aim higher than efficiency and conservation and commit to clean energy and national climate legislation.

Since the first publication of their sustainability report in 1999/2000, which already showed that they had acted relatively early compared to other resorts, which waited until the urgency was publicly recognized before taking action, they have taken measures that are quite “extreme” by today's standards in order to develop with the least possible impact on the environment. For example, in its 1999/2000 report, it describes how it built a wind-powered chairlift, making it entirely environmentally friendly. Construction was scheduled between animal nesting and breeding seasons, and no mechanical equipment ever touched the tundra; everything was carried by the workers themselves. ASC is also the first company to purchase renewable wind energy credits to offset its entire energy consumption.

While the company has succeeded in reducing the environmental impact of its mountain activities, its most notable contribution to sustainability lies in its advocacy for broader climate and energy policies. This sets ASC apart in the ski industry, as it recognizes that real environmental progress goes beyond immediate operational efficiencies. Driven by this perspective, Aspen has collaborated with local communities on a variety of initiatives, including education, wilderness restoration, and healthcare.

It is worth mentioning that ASC is not an exceptional example of sustainability in the ski industry simply because of its willingness. The company's management structure contributes greatly to this, as having a CEO committed to the environment shifts the corporate culture in a unique way toward that same cause. This leads to potential projects and business plans being treated differently, with profits being sacrificed for the sake of the environment. As mentioned above, ASC is also involved in the fight against climate change outside the ski industry and can use its position in the sector and its contribution to the economy as leverage to influence legislation at regional and national level. The final, and perhaps most important, factor is that ASC has the necessary means and resources at its disposal.

These arguments challenge the notion that “going green” is simple and profitable, suggesting instead that sustainability requires significant investment and resources. At the same time, they highlight Aspen's management's willingness to openly and transparently acknowledge the challenges faced by ski resorts and other industries. A realistic approach to climate issues is an essential characteristic for a company at the forefront of sustainability in its field.

The “Clean-Up Day” in the Laax-Flims-Falera area on June 14, 2025, where volunteers helped collect trash left behind in nature after the ski season. (Philipp Ruggli)

Laax-Flims/Weisse Arena – Graubünden, Switzerland

The first Swiss resort to clearly state this objective, the Laax-Flims ski area in Graubünden states on its website that “winter seasons are getting shorter and the snow line is rising. We therefore have a clear goal of no longer using fossil fuels and powering all our activities with 100% renewable energy, from consumer to producer.”

The resort's strategic policy is based on five main areas: energy management, water management, a zero-waste approach, food waste management, and biodiversity. In the energy sector, the electrification of mobility and the replacement of all hydrocarbon-based infrastructure with renewable energy sources is underway. Weisse Arena has set itself the goal of replacing all oil-fired heating systems with efficient and renewable systems by 2025. By replacing the existing heating system in the Nagens cable car departure building with an air/water heat pump, the company has taken an important step towards achieving this goal.

Active promotion of a circular water economy, short consumption cycles, and resources available to tourists aims to minimize waste and transportation. Biomass exploitation is part of the resort's strategy, as is the implementation of digital systems and a fleet of electric vehicles of various sizes that can be ordered on demand to optimize customer transportation and limit the impact of traffic.

Weisse Arena, like other resorts, has adopted technologies such as LIDAR to monitor snow cover and snow groomer operations in the resort, in order to limit the impact on the terrain to what is strictly necessary.

The “luge des cimes” (tree-top toboggan run) in Métabief, opened since the summer of 2022.

Métabief – Doubs, France

The first major European ski resort to take the plunge, Métabief, in the French Jura (Doubs), on the border with Switzerland, decided in 2018 to make a complete transition to alternatives to alpine skiing. The impetus came in 2016, as transition director Olivier Evard (https://www.inexpeditions.com/immersion/metabief) explains: “We were struggling to recoup our previous investments in artificial snow, and it was impossible to take any more risks by financing new ski lifts. We had to make a choice.” The resort carried out a study based on data from DRIAS (Donner accès aux scénarios climatiques Régionalisés français pour l’Impact et l’Adaptation de nos Sociétés et environnement, or Providing access to regionalized climate scenarios for the impact and adaptation of our societies and environment), which came to the same conclusion as the initial models: within 10 to 15 years, it would no longer be possible to rely on skiing.

In order to make a decision that commits to the future and is not seen as capitulation, the local authorities are launching a master plan that includes the population and all economic activities. Seven years after the decision was made, some interesting developments are emerging: first of all, skiing is still happening in Métabief, and the transition does not mean a clean break. Secondly, while no one can say what will replace skiing, everyone agrees that it will not be a single activity, but a multitude of solutions. For now, one piece of infrastructure symbolizes the change: a 710-meter-long rail sled, which operates year-round.

Third observation: this decision, which will result in the closure of 30% of the ski area in 2024-2025, is not without controversy. A petition with 4,000 signatures urged the authorities not to close a section of the resort that provided access from the Swiss border to a resort that was the first in the French Jura to join the Magic Pass, an alliance of 80 resorts offering an annual pass.

Métabief is an open-air laboratory for the transformation of a ski resort, and it will be fascinating to follow its progress in the coming years.

Austria – multiple examples

As in other Alpine countries, skiing is deeply rooted in Austrian culture and linked to national identity. The ski industry in Austria boosts not only the economy of the communities where the resorts are located, but also the national economy. The 2022/2023 season generated total gross revenue of €12.6 billion, with more than 50 million skier days recorded during the same season. Austria has established itself as a top destination for winter sports with around 70 million overnight stays recorded in the 2022/2023 season. Nevertheless, as in other Alpine regions, Austrian ski resorts face the same problems associated with rising global temperatures that are affecting mountainous regions.

One of the main ways to reduce emissions and become more environmentally friendly is to switch to renewable energy sources and integrate them into everyday activities. In Austria, many ski resorts have already made this transition and use only renewable energy to power their operations. Austria has established itself as one of the leading countries in the sustainable transition of its ski regions by using renewable energy to power its buildings and ski lifts and by using cutting-edge technology for snowmaking and snow conservation to save energy and water.

A photovoltaic installation on the Pitzol glacier resort in the Austrian Tyrol. (Julia Brunner)

The three main areas of progress are renewable energy, greener transportation, and more efficient snowmaking and maintenance. Here are some exemplary ski resorts that are doing everything they can to reduce their carbon footprint and be more sustainable.

Ski Arlberg: Ski Arlberg is one of the largest ski resorts in the world, with its renowned areas of St. Anton and Lech Zürs, and is powered by an autonomous hydroelectric power plant. In addition, St. Anton operates a biomass heating plant, while Lech Zürs uses four biomass power plants fueled by local wood chips to heat its ski lifts, cable cars, and most of the nearby buildings. The entire resort infrastructure, including ski lifts, restaurants, and cable cars, is powered entirely by pumped hydraulic energy.

Other resorts such as Kitzbühel, Snow Space Salzburg, and Zell am See Kaprun also use as much green energy as possible. Whether it's running ski lifts on hydraulic and solar power, using renewable energy for snow cannons and cable cars, or recovering excess heat from cable car engines to heat buildings, these resorts are making significant efforts to achieve their respective carbon neutrality goals in the near future.

As mentioned earlier in this report, a large part of a ski resort's carbon footprint comes from the means of transport used by visitors to get to the resort and on the slopes. Ski resorts have little influence on the mode of transport chosen by visitors to get to the resort. People coming from abroad automatically have a significant carbon footprint for their week's skiing. However, the resort has a say in the route between the accommodation and the slopes, as well as connections to neighboring resorts, if applicable. In summary, this problem can be solved by making public transport more accessible and comfortable, which would reduce the carbon footprint of visitors to the resort. Austrian ski resorts have also made considerable efforts in this area.

Kitzbühel has the largest free transport network in the Alps, with numerous buses, many of which are electric, connecting all resorts in the valley. In addition, its car parks are equipped with charging stations for electric vehicles. Zell am See-Kaprun also encourages car-free travel by offering free bus and train travel throughout the region from spring to fall with its mobility card. In the Seefeld region, visitors can access local buses and trains with a single guest card. Lech Zürs' Blue Fleet offers free buses for skiers, as well as electric bike rentals and an electric garage for charging electric vehicles. St. Anton is another convenient car-free destination, benefiting from its integration into the international rail network and frequent bus services.

As we have seen, ski resorts are increasingly dependent on artificial snow, which has its own carbon footprint and impact on the environment. In Kitzbühel, as in most major European and American resorts, artificial snowmaking technology has been perfected by collecting data on the altitude and exposure of the slopes and using GPS data to measure snow depth in order to calculate exactly how much snow is needed to avoid overproduction and save water and energy. Another factor to consider when preparing the slopes is grooming, which also requires a lot of energy. Since the 2023/2024 season, Zell am See-Kaprun has been using a renewable fuel, HVO100, for its snow groomers and snowcats. This is a fossil-free substitute (which, according to the manufacturer, emits around 90% less CO2 than traditional fossil fuels) made from natural waste products such as cooking oil.

Another fundamental aspect of these resorts' sustainability is the origin of all the ski equipment and products used by restaurants and hotels. Being able to support local businesses and local products, which reduces emissions linked to imports (reducing the carbon impact of long-distance goods transport) and stimulates innovation and local economic activity as a whole, is a very effective way of achieving this. Austria is a world leader in organic farming and has more than 24,000 certified organic farms, accounting for more than a fifth of the country's total. In addition, there is a strong sense of community and heritage that stems from the organic evolution of the ski resorts. The majority of restaurants and hotels are family-run businesses that are proud of their heritage and reinforce this sense of community.

The Vaud Alps – Switzerland: a three-part laboratory

1) The adaptation strategy for Villars-Gryon-Les Diablerets, resulting from the Climsnow project presented in 2024.

The TVGD (Télé Villars-Gryon-Les Diablerets) mountain lift strategy: investing in quality and sustainability.
The ski lift company in the Villars-Gryon-Les Diablerets area, located between 1,200 and 2,000 meters above sea level, with varying orientations (south to north), has embarked on an ambitious modernization strategy that combines improving the customer experience with reducing its environmental footprint. Investments are focused on renewing facilities to increase their energy efficiency, optimize throughput, and limit the impact on natural areas. The use of artificial snowmaking is carefully considered, with precise management of water resources thanks to real-time measurement and control systems. Minimal developments, such as barriers to retain wind-blown snow, aim to help preserve natural snow cover. At the same time, the resort is enhancing its appeal with a four-season offering, focusing on mountain biking, hiking, and cultural events to diversify visitor flows and stabilize revenues beyond the winter season.

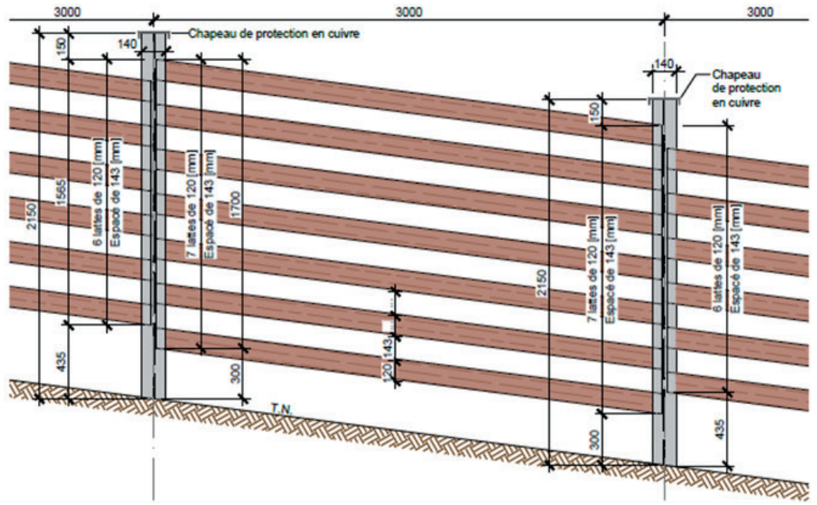


Diagram showing the snow barrier project at Chamossaire, in the Villars-Bretaye ski area (VD). Wooden barriers designed to allow snow to be deposited on the slopes: two rows measuring 223m and 247m. Estimated gain: ~37,600m3 of snow.

2) Pays-d’Enhaut’s transition strategy

In the Pays-d’Enhaut region, a determined transition to “gentle” tourism

Following the closure of most of its ski lifts (except for the Rougement area, which is connected to Gstaad and neighboring resorts) and the pessimistic conclusions for this valley in a comprehensive study on the economic future of winter tourism in the Vaud Alps, the Pays-d'Enhaut has chosen to make sustainable development the guiding principle of its tourism strategy. This positioning, which has sparked heated debate among the population, is reflected in a **focus on local resources** – local products, crafts, built heritage – and a strong commitment to soft mobility and short supply chains. The region is capitalizing on the complementary nature of the seasons by developing offerings that combine nature activities, cultural events, and authentic experiences. This participatory approach, developed in collaboration with local stakeholders, aims to strengthen the region's economic resilience while preserving its landscapes, biodiversity, and cultural identity..

The Château d'Oex International Hot Air Balloon Festival, which takes place at the end of January, is a highlight of the Pays-d'Enhaut region.

Illustrative image of the public natural swimming project in Les Mosses, in the municipality of Ormont-Dessous.

3) The transformation strategy of Ormont-Dessous

In Ormont-Dessous, a transformation strategy to tackle climate change

Aware of its vulnerability to global warming, the municipality of Ormont-Dessous has launched a strategic review of the future of its tourism industry. Rather than seeking to maintain a ski-centric model at all costs, it is exploring scenarios for diversification that include year-round experiences, showcasing the natural and landscape heritage, and hosting sporting and cultural events. This approach is based on a shared diagnosis and the mobilization of local stakeholders in order to build a tourism model that is aligned with the region's actual resources, integrates new stakeholders, and is adapted to future climate and societal changes. Awareness of this issue is recent, having been initiated in 2024 and 2025, but the process of “changing mindsets” is underway and should make it possible to move away from thinking solely in terms of “skiing on a resort scale” to thinking in terms of “year-round tourist appeal on a regional scale.”

Conclusion

Climate change is profoundly transforming mountain tourism. Rising temperatures, less reliable snowfall and changing visitor expectations are forcing resorts to adapt in order to remain economically viable while reducing their environmental impact.

This White Paper shows that there is no single solution. Responses vary according to altitude, available resources, and local culture: from optimized snow management to four-season diversification, from technological innovation to the complete reinvention of the tourism model.

The examples analyzed demonstrate that a successful strategy relies on three essential levers: the ability to anticipate, investment in sustainable solutions, and the collective mobilization of local stakeholders.

More than ever, the future of resorts will depend on their ability to combine economic performance with ecological responsibility. This means integrating sustainability into every decision, strengthening cooperation between destinations, and drawing on the strength of local communities. While climate uncertainty remains, resilience, innovation, and commitment can pave the way for mountain tourism that can thrive in a changing environment—and continue to pass on the passion and magic of mountain sports to future generations.

Openness – Changing perceptions to bring about lasting change in mountain areas

By Anne-Sophie Fioretto

Transforming a mountain region is not just about changing its infrastructure, what it has to offer or its economic models: above all, it is about changing the way we imagine it, the way we talk about it and the way we collectively envision its future. As long as the imagination remains rooted in a fixed vision—that of an eternally snow-covered winter centered on skiing—every decision will be made with one eye on the rearview mirror. However, in a context of climate and societal change, it is vital to open up new mental horizons in order to open up new avenues for action. ***Changing the imagination means moving from:***

From denial to lucidity *– accepting climate and economic facts without paralyzing nostalgia.*

From resistance to adaptation *– seeing change as an opportunity for reinvention rather than a threat.*

From "skiing above all else" to a global experience *– promoting all aspects of a mountain vacation, in all seasons.*

From compartmentalization to cooperation *– mobilizing residents, economic actors, elected officials, and visitors around a shared vision.*

The key success factors for initiating this change in mindset are clear:

Unifying narratives *– telling the story of the mountains differently, with authenticity and inspiration.*

Concrete experiences *– translating the vision into visible, tangible, and engaging projects.*

Open governance *– making room for diverse points of view and collective intelligence.*

Broader alliances *– bringing different worlds together (tourism, culture, agriculture, innovation) to invent together.*

Continuous education *– supporting change through dialogue, training, and experimentation.*

Changing perceptions is not a luxury: it is essential if the investments, strategies, and efforts made today are to build a desirable and sustainable future. Because before we can change landscapes, we must change the mental map that shapes them.

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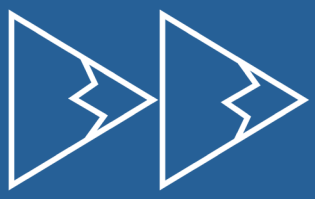

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