SIEPPUR
Sustainable snow management

Co-funded by the European Union

Roadmap to Sustainable Snow Management for Nordic venues in the Alps

High Altitude – Low Latitude

Deliverable 3.2 | 28TH February 2025

TABLE OF CONTENTS

1. OVERALL ROADMAP TO SUSTAINABLE SNOW MANAGEMENT

The overall roadmap, as developed in D3.1, laid out a comprehensive, generalised strategy for transitioning current snow management practices into a more sustainable, more efficient, and increasingly climate-resilient framework. Developed to address the ecological, societal, and operational challenges facing snow management, the overall roadmap identified the necessary transformations across snow production, storage, transportation, grooming and handling on a broad basis. It also examined overarching governance practices and the socio-economic context within which these activities occur.

2. ELABORATED GEOGRAPHY-SPECIFIC ROADMAPS TO SUSTAINABLE SNOW MANAGEMENT

The overall roadmap to sustainable snow management serves as a common strategy, upon which more specific snow management activities and strategies, as well as different governance practices were investigated considering the geographical regions with their different constraints as follows:

- Alps venues (high altitude, low latitude)
- Scandinavian venues (low altitude - high latitude)
- Central & Eastern European mid-mountain venues (mid altitude - mid latitude)

Like the overall roadmap, the geography-specific roadmaps aim to ensure a transition towards resource-efficient operations, reduced environmental impacts, and increased societal acceptance of modern snow management practices, ensuring the long-term sustainability of snow sports venues and events under the purview of the International Biathlon Union (IBU). Key components of this transition are operational activities, as well as the incorporation of governance practices which enable effective decision-making, infrastructure development, and technology adoption and development.

Key factors that must be addressed include:

- Understanding the **microclimate** of each venue to evaluate the site-specific snow production potential and snow reliability.
- Assessing **water availability** for snow production and addressing hydrological constraints, as well as influencing venue-specific technical factors.
- Resolving potential **ecological conflicts** arising from snow management infrastructure and practices.
- Overcoming **socio-economic** barriers, including financing and societal acceptance of resource-intensive venues.

Beyond the generalised concepts formulated in the overall roadmap, the geography-specific roadmaps integrate more specific research carried out in the SIEPPUR project to gain new knowledge (T3.2 to T3.5) on snow production, storage, transport, grooming and handling. Moreover, good governance practices typical for the three geographical regions are presented in D3.5 and integrated with the roadmap description.

3. ROADMAP TO SUSTAINABLE SNOW MANAGEMENT FOR NORDIC VENUES IN THE ALPS

Snow management at Nordic venues in the Alps faces two major challenges:

1) Limited space in already heavily used environments mainly due to winter mass tourism
2) Environmental conflicts, use conflicts and natural hazards further reducing the available space, preventing snow management infrastructure expansion.

Opportunities at Nordic venues in the Alps comprise the cold(er) climate (due to altitude) as well as the tradition and economic relevance of winter sports in general.

PRODUCTION

2025 STATE

- 2 … 4 kWh/m^3
- 70% renewable
- Water flow: 10 … 170 m^3/h
- Water limitations
- High level of know-how

OPERATIONAL PROCESSES, TOOLS & TECHNOLOGY	· Infrastructure optimisation adapted to venues, climate, hydrology, flora & fauna · Resource use monitoring with management software · Delivery risk & production planning tool (management software)
CLIMATE, SNOW & HYDROLOGY	· Microclimatological descriptions of venue · Production potential model · Hydrological constraints of a venue · Water availability model (prospections) · Snow reliability model (prospections)
GOVERNANCE PRACTICES	· Fast approval procedures · Funded compensation for landowner · Federal funding to expand/renew infrastructure · Clear rules for water use concessions

2030 GOALS

- 1 … 2 kWh/m^3
- 100% renewable
- Water flow > 50 m^3/h
- Sustainable water reservoirs
- Efficient optimization of existing infrastructure

STORAGE

2025 STATE

- 4 … 6 kWh/m^3
- 11 … 45% volume loss
- 9 … 12 EUR /m^3
- Self-made cover solutions
- Considerable level of know-how

OPERATIONAL PROCESSES, TOOLS & TECHNOLOGY	· Planning tool for cost & feasibility estimation · Structural measures: access roads, soil reinforcement, storage throughs etc. · HVO fuels · Production infrastructure · New, climate & site-specific, long living, easy-to use covers
CLIMATE, SNOW & HYDROLOGY	· Microclimatological descriptions of venue · Production potential prospections · Storage loss model · Melt model for distributed storage snow (prospections) · R&D towards new cover methods
GOVERNANCE PRACTICES	· Federal regulations defining land use for snow storage · Fast approval procedures · Funded compensation for landowner

2030 GOALS

- 2 … 3 kWh/m^3
- 10 … 30% volume loss
- 4 … 6 EUR /m^3
- Professional cover solutions
- High level of know-how

GROOMING

2025 STATE

- 1 … 3 kWh/m²
- 10 … 20% renewable
- Biofuels costly or unavailable
- E-groomers limited range
- High level of know-how

OPERATIONAL PROCESSES, TOOLS & TECHNOLOGY	• HVO fuels • Automated snow height measurement • Fleet management tools for resource monitoring • Groundwork to minimize snow and off-season use • Automated grooming param. to max. track quality • E-groomer
CLIMATE, SNOW & HYDROLOGY	• Weather data / forecasting for automated grooming management • Improve understanding of snow strengthening due to grooming and weather interaction
GOVERNANCE PRACTICES	• Fiscal stimulus using HVO (equal prices as fossil fuels) • R&D funding of industry- science collaborations

2030 GOALS

- 0.5 … 1.5 kWh/m²
- 80% renewable
- Biofuels widely used
- E-groomers well used for shorter tracks
- Advanced grooming management tools

HANDLING

2025 STATE

- Improvised practices & procedures
- Lacking tools
- Rain & melting events
- Considerable level of know-how

OPERATIONAL PROCESSES, TOOLS & TECHNOLOGY	• HVO fuels to replace fossil fuels • Small, (e)-vehicles for snow specific preparation tasks Groomer • Nature-friendly snow hardener • Snow hardening calculation tool • Snow conserving actions
CLIMATE, SNOW & HYDROLOGY	• Snow hardening model • Snow hardeners effects on soil and plants • Investigating new methods for conserving snow tracks
GOVERNANCE PRACTICES	• Application rules & guidelines for chemical hardening by national/international ski federations • Fundings to investigate effects on soil, flora and fauna using snow hardener

2030 GOALS

- Well protocolled practices & procedures
- Proper similarly tools at various venues
- Rain & melting events manageable
- High level of know-how

TRANSPORT

2025 STATE

- New, increasing task in snow management
- Fossil fuel based
- No snow conveying systems exist
- Moderate level of know-how

OPERATIONAL PROCESSES, TOOLS & TECHNOLOGY	· HVO fuels to replace fossil fuels · Groundwork/roads reducing soil damage & better access · Collect data on resources used Transport · Pneumatic conveying systems · E-vehicles powered by renewable sources
CLIMATE, SNOW & HYDROLOGY	· Soil wetness, temperature & strength monitoring/ forecasting for planning snow distribution
GOVERNANCE PRACTICES	· Fiscal stimulus using HVO (equal prices as fossil fuels)

2030 GOALS

- Well managed, minimized transport distances
- Renewable fuel based
- Pneumatic snow conveying systems
- High level of know-how

GENERAL SNOW MANAGEMENT ISSUES

2025 STATE

- Rising costs
- 24% of venues produce renewable electricity
- Poor financing of new infrastructure
- Political & societal dissents

OPERATIONAL PROCESSES, TOOLS & TECHNOLOGY	· Staff snow-how training / transfer · Information campaigns & political debate · Fees for Nordic skiing · Events & Sponsoring · Creating synergies of Nordic skiing & other touristic offers
CLIMATE, SNOW & HYDROLOGY	· Local analysis of future snow reliability and water availability · Societal role, tradition, and economic weight of Nordic skiing in the region
GOVERNANCE PRACTICES	· Funding / operation by the National Sport Association · Federal funding of venues with over-regional relevance · Finding political positions on the future of Nordic venues · National Nordic skiing consolidation plan

2030 GOALS

- Stabilizing costs
- 50% of venues produce renewable electricity
- Quantified benefits gained resource use
- Political & societal consensus

3.1 Snow Production

3.1.1 Operational processes, tools & technology:

Nordic venues in the Alps were found to have to comply with very strict environmental regulations. On one hand, climate warming in alpine regions is more substantial, putting pressure on threatened flora and fauna which are unable to adapt at the same pace. On the other hand, alpine regions suffer from mass tourism and limited space for various infrastructure. Moreover, alpine vegetation cannot recover fast, e.g. after water pipe installations, as vegetation periods are generally shorter at higher elevations. Therefore, for Nordic venues in the Alps it is important to **optimise existing Infrastructure rather than seeking expansion.** Moreover, it is important to integrate multiple use cases for snow production infrastructure, e.g. drinking water supply, or hydropower.

3.1.2 Governance practices:

In several regions of the Alps, land is owned by private entities or individuals. To successfully use snow production as a mitigation measure for ongoing climate warming, new water reservoirs will be needed. Besides well-designed funding processes for infrastructure investment including a set of environmental criteria to fulfil, a **fair funding system to compensate landowners** is required.

3.2 Snow Storage

3.2.1 Operational processes, tools & technology:

Although snow storages were found to be of only medium importance for the snow strategy of Nordic venues in the Alps it was evident that most existing storages are accessed by rather narrow and poorly maintained roads that do not allow the use of larger, more efficient trucks for snow transport/distribution. Moreover, higher average precipitation and more extreme precipitation events, as noted in regional climate scenario projections (Kotlarski et al., 2024) point out that Nordic venues in the Alps are particularly challenged in creating **resilient storage infrastructures and access roads** while respecting the regulations for nature protection. Integrated planning combining multiple use cases and functions by a single set of infrastructure is considered a key to successfully balancing resilience, sustainability and nature protection.

New, climate & site-specific, long-term easy-to-use covers are required especially at Nordic venues in the Alps as storage is frequently embedded in protected areas, or in elevated areas with high wind speeds and intensive solar radiation.

3.2.2 Governance practices:

National/federal regulations defining land use for snow storage based on a set of defined criteria would help venues to find suitable new locations for snow storage and would reduce both administrative hurdles and the time to implementation.

3.3 Snow Grooming

3.3.1 Operational processes, tools & technology:

Although HVO fuels cannot replace fossil fuels in large-scale use cases such as private mobility, they can serve as an interim sustainable fuel solution for grooming, which is a niche application with specific e-unfriendly constraints. Altitude differences, colder temperatures and the trend towards longer courses make **HVO driven machines** more suitable compared to e-groomers with their limited battery capacity, also because consistent natural snow cover is still frequently given at the Nordic ski venues in the Alps.

Fiscal stimulus reducing the costs for HVO fuels down to the level of traditional fossil fuels could help to widely replace fossil fuels with HVO for grooming.

3.4 Snow Handling

3.4.1 Climate, snow & hydrology

Snow hardeners are frequently used in Nordic skiing competitions. They have become necessary to provide constant snow conditions to enable fair competitions when diurnal warming softens the snow. However, although snow hardening substances have been used for decades in alpine skiing there has been only limited research carried out about possible negative **effects on flora and fauna** (Leidermark, 2014; Schwörer et al., 2007), e.g. loss in biodiversity, and about the physical processes of snow hardening (Wolfsperger et al., 2019). **The feasibility of alternative, more ecological hardening substances** instead current ones (sodium chloride, ammonium nitrate, Urea) is also not sufficiently researched.

Within this project, existing knowledge was reviewed, and guidelines were summarised for the **responsible use of hardening substances** (Fig. 2). Moreover, data were collected (Fig. 3) to analyse the relationship of use and resulting track quality (rate of success), which will be described in more detail in the Final Report of the SIEPPUR project (May 2025).

Further research regarding the physical processes of snow hardening to understand the interplay of snow properties, atmospheric conditions and hardening result (a **snow hardener model**) is needed to develop planning tools for practitioners to optimise the use of snow hardeners (timing, quantities depending on snow and weather) and to prevent overuse or failure. The existence of snow research groups as well as a higher societal relevance of skiing in the Alps and in Scandinavia, give hope those regions will take the lead within upcoming applied research collaborations.

3.4.2 Governance practices:

As alpine areas are particularly sensitive to nutrition inputs, **research funding would be desirable to help investigate effects on soil, flora and fauna** from the use of snow hardeners. Such research could help provide a data-based set of criteria for the use of existing snow hardening substances, as well as discover new, eco-friendly snow hardening substances.

PRAXIS OF SALTING

GENERAL GUIDELINES

IBU

- **Snow:** Liquid water in the snow is required (T_{snow} = 0°C)
- **Snow:** Very coarse grained snow can not hold much water → hardens worse
- **Quantities**: If too much is used, snow hardens less (5 to 50 g/m2)
- **Grain size**: Larger grains have a longer, deeper but weaker effect
- **Weather**: Snow hardeners are very ineffective in snowfall and fog
  (incoming longwave radiation; low heat conduction, no water accumulation at graind bonds)
- **Weather:** Rainwater can be conducive, but additional hardener is required
- **Grooming:** If tilling then right after the hardener was spread
- **Grooming:** Once the harding process has begun, the snow should no longer be worked on

Figure 2 Guidelines for using snow hardener

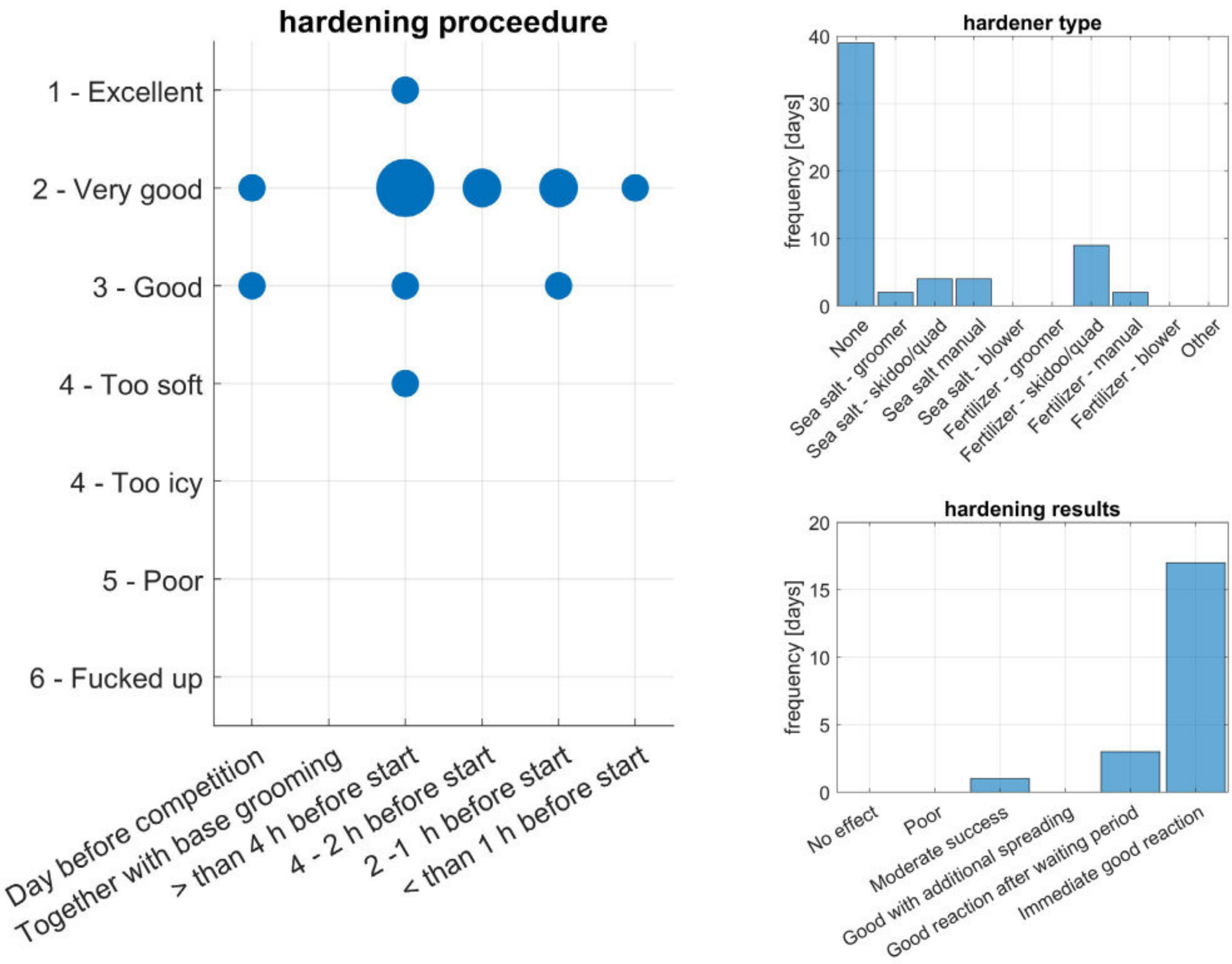

Figure 3 Analysis of snow hardener use. Left: Track quality following the snow hardening procedure. Top right: Frequency and type of used substance. Bottom right: Frequency of hardening result ranging from moderate to good snow hardening.

3.5 Snow Transport

3.5.1 Operational processes, tools & technology:

The transportation of snow is increasingly needed to distribute stored snow along the courses. As described above concerning snow storage infrastructure (see 3.2), Nordic venues in the Alps are particularly challenged (due to a lack of space, and damage from extreme precipitation/melting) to ensure access to their snow storages and courses **without damaging the soil**, and hence are required to **perform groundwork, adapt roads, and use suitable vehicles**. This does not necessarily mean a need to build wide, paved roads, but rather a need to have intelligent transportation concepts integrating specific types of vehicles and wisely choose the access paths, with correctly dimensioned roads and ground enforcements. The latter can also be mobile to serve as temporary measures and to provide access without damaging the soil.

Like grooming machines on alpine terrain, **HVO fuels** are considered optimal to help reduce CO_2 emissions of snow transportation if vehicles like trucks or tractors are used. Beyond conventional snow transportation using vehicles, **pneumatic conveying systems** using a series of pipelines that move snow by pumping are a promising alternative (notably if the terrain limits driving).

3.6 General Snow Management Issues

3.6.1 Operational processes, tools & technology:

Traditionally, Nordic skiing in the Alps is less commercialised compared to alpine skiing tourism. However, while participation in alpine skiing plateaus (Vanat, 2024), Nordic skiing is well aligned with thea changing Zeitgeist towards more health-oriented, ecologically sustainable and individualised sports. For venues in the Alps these developments have led to a growing supply-and-demand, and so, commercialisation of Nordic skiing activities. Therefore, paying fees for Nordic skiing, which are still low compared to Alpine skiing, has become increasingly accepted by users and increasingly important in financing snow management activities and infrastructure.

For Nordic skiing venues it is also recommended to find synergies with integrating typical Nordic skiing activities into further touristic offers, sports activities and events. For example, this could be Nordic skiing - active wellness stays, Nordic skiing – nature paths / winter hiking, public family-fun-relay events, on-snow shooting simulations etc.

4. CONCLUSION

This roadmap presents a structured approach to transforming snow management of Nordic venues in the Alps into a viable and sustainable practice that aligns with environmental, economic, and societal goals to address the challenges posed by climate change and resource constraints. Within an alpine environment, the path forward needs to focus innovation on snow management technology and tools to expand and ensure reliable snow activities as core offers. Moreover, the on-going touristic transformation from a vulnerable and resource intensive mass market sport towards a more resilient, resource neutral and less snow dependent sports offer with diverse ski and nature-related activities should be the goal. Expanding Nordic skiing in the Alps integrated with diverse touristic offers and events provides opportunities to transform winter tourism towards a less snow dependent, resource conserving and healthier variation of winter sport.

The roadmap specifically names research topics that are partly be addressed in the frame of the SIEPPUR project or should be investigated in the future. However, a major part of the transformation must be carried out by decision-making focused on innovation and step-by-step improvements driven by the managers at the Nordic venues in the Alps. Providing them with this mid-term strategic roadmap based on a wide base of knowledge and good practices aims to help strengthen the resilience of Nordic skiing in a warmer, natural snow-deprived future.

5. REFERENCES

- Kotlarski, S., Gobiet, A., Morin, S. et al. (2023). 21st Century alpine climate change. Clim Dyn 60, 65– 86. https://doi.org/10.1007/s00382-022-06303-3.
- Leidermark, I. (2014). Salt use in ski slopes. Distribution and impact of sodium chloride in the local environment. MId Sweden University. Östersund.
- Schwörer, C., Rhyner, H., Rixen, C. C., Schneebeli, M., & Iten, B. (2007). Chemische Pistenpräparation – Grundlagenbericht. Davos: Eidgenössisches Institut für Schnee- und Lawinenforschung SLF. https://www.dora.lib4ri.ch/wsl/islandora/object/wsl%3A10354
- Vanat, L. (2024). International Report on Snow & Mountain Tourism. https://www.vanat.ch/international-report-on-snow-mountain-tourism
- Wolfsperger, F., Rhyner, H., & Schneebeli, M. (2019). Slope preparation and grooming. A handbook for practitioners. Davos: WSL Institute for Snow and Avalanche Research SLF. https://www.dora.lib4ri.ch/wsl/islandora/object/wsl%3A21755

SIEPPUR
Sustainable snow management

Co-funded by the European Union

CONTACT US

Email: sustainability@ibu.at
Website: https://sustainablesnow.sport/

IBU Peak63N OUTDOOR LAB SLF SMA POLSKI ZWIĄZEK BIATHLONU POLISH BIATHLON ASSOCIATION SLOSKI Biathlon SWE