SIEPPUR
Sustainable snow management

Co-funded by
the European Union

Roadmap to Sustainable Snow Management for Scandinavian Nordic venues

Low Altitude - High Latitude

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IBU · Peak63 OUTDOOR LAB · SLF · SMA · POLSKI ZWIĄZEK BIATHLONU POLISH BIATHLON ASSOCIATION · SLOSKI Biathlon · SWE

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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 production, storage, transportation, grooming and handling snow 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 SCANDINAVIAN VENUES

Snow management at Scandinavian venues faces the following main challenge:

1) Warming climate with limited persistent natural snow cover and reduced snow production potential.

The opportunities are the strong traditions in Nordic skiing leading to a relatively solid public support for the sport, large involvement of volunteers and income from ski passes, as well as support from municipalities providing resources to invest and adapt to a changing climate.

PRODUCTION

2025 STATE

- 2 ... 4 kWh/m³
- 70% renewable
- Water flow: 10 ... 170 m³/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/m³
- 100% renewable
- Water flow > 50 m³/h
- Sustainable water reservoirs
- Efficient optimization of existing infrastructure

STORAGE

2025 STATE

- 4 ... 6 kWh/m³
- 11 ... 45% volume loss
- 9 ... 12 EUR /m³
- 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/m³
- 10 ... 30% volume loss
- 4 ... 6 EUR /m³
- 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:

Investing in snow production systems will be the most common and effective measure to adapt to a changing climate, and this is also true in Scandinavia. Many Nordic skiing venues in Scandinavia have older, less efficient systems for snow production, or a lack of snow production systems. The development in efficiency in snow production units in the last 20 years in terms of production capacity and energy efficiency has been significant. **Updating and expanding snow production systems** is an important step to be more resilient given the changing climate, and the corresponding reduction of cold (freezing) days possible for production. For some venues, it will be necessary to build new snow production systems.

The relatively low price of electricity in Scandinavia compared to the rest of Europe is an advantage in securing snow conditions at a lower cost.

3.1.2 Climate, snow & hydrology:

In Southern Scandinavia, production potential can be a limited factor, in the rest of Scandinavia there are likely to be abundant cold days for snow production.

Water availability is generally good in Scandinavia with many lakes and rivers. Although regulation in smaller lakes and rivers on the amount of water outtake exists, which can in some places be a limiting factor, or translate to a need for building reservoirs or long pipe systems to larger water sources.

3.1.3 Governance practices

Nordic ski venue owners and operators need funding to invest in upgrading snow production systems. In Scandinavia there are national and local funds available which is crucial for the future expansion or upgrade of snow production systems. The guidance on how to apply for funding and continuing financing as well as possible expansion of the funds are important for the possibility for Nordic ski venues to invest in snow production systems.

3.2 Snow Storage

3.2.1 Operational processes, tools & technology:

Snow storage started in Scandinavia in the early 2000s and is now a relatively widespread and mature process (Kopochinski, 2024). Lot of research and development of cover materials has taken place in Scandinavia, and it is likely that **research and development** of **new, climate & site-specific, long term easy-to-use covers** for snow storage will continue in this region.

The cost for wood-based cover materials for snow storage is cheaper in Scandinavia compared to most other places in Europe, although the price has increased significantly in the last years and is predicted to increase further as the competition for the material increases, especially in the energy and fuel sectors. This can lead to more need for research into alternatives.

The transportation of snow from snow storages is the most resource intensive and costly part of snow storage. To create a more efficient transportation process of stored snow, the Nordic ski venue needs to have sufficient **structural measures, in particular access roads and soil reinforcements.** In general, there is space and no restrictions at the Scandinavian venues to update transportation roads. The number of roller ski tracks is also increasing fast, for example in Sweden. If made properly, these roller ski tracks will be made multi-purpose, both to support heavy snow transportation vehicles and provide opportunities for roller skiing.

3.3 Snow Grooming

3.3.1 Operational processes, tools & technology:

Since many Nordic ski venues in Scandinavia are owned and operated by municipalities, they tend to have high ambitions to reduce greenhouse gas emissions from municipal activities. Therefor Nordic ski venues in Scandinavia can and should be front runners in using electric groomers powered with renewable electricity and/or HVO fuel for regular groomers.

3.3.2 Climate, snow & hydrology

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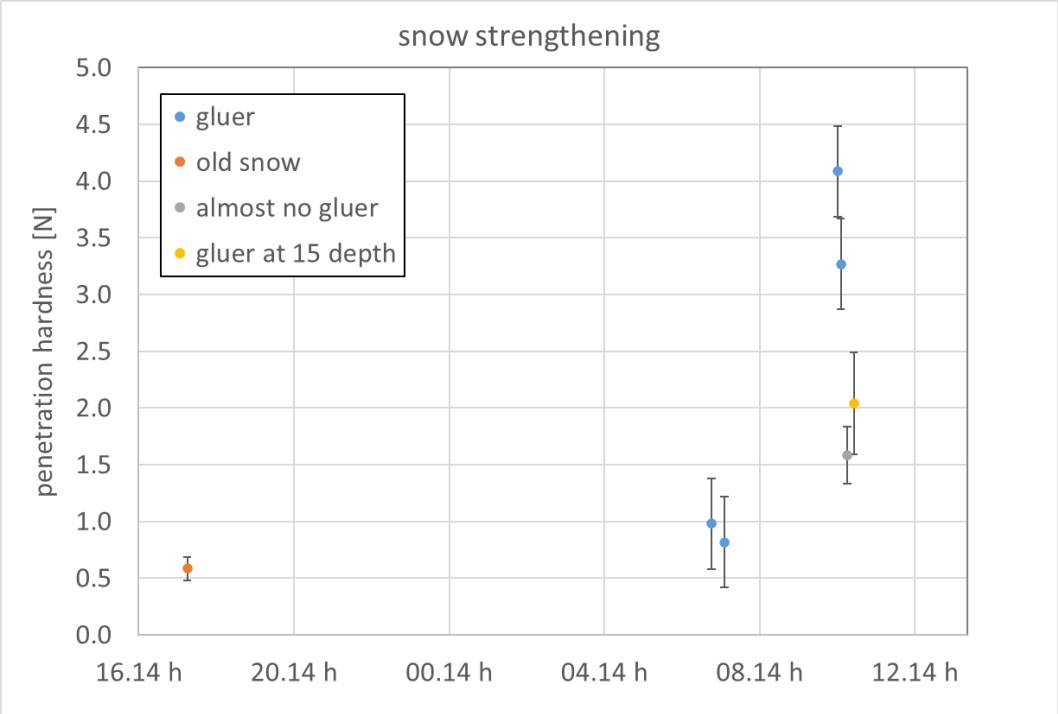
Figure 2 Field experiment to investigate the strengthening of old, coarse-grained storage snow. Right: Cone penetrometer to measure the snow hardness and boxes for snow samples to be analysed in the SLF-cold lab. Left: Further instruments to measure snow density and specific surface area (SSA) of snow.



$density_{oldSnow}$ = 491 kg/m^3
$density_{gluerMix}$ = 479 kg/m^3
$density_{gluer}$ = 310 kg/m^3

$SSA_{oldSnow}$ = 10.8 mm^{-1}
$SSA_{gluerMix}$ = 13.9 mm^{-1}
SSA_{gluer} = 43.1 mm^{-1}

Figure 3 Results of field experiment to investigate the strengthening of old, coarse-grained storage snow. The coarse-grained snow hardened significantly after mixing with fine grained machine snow called "gluer" (blue dots) compared to the grey and yellow dots, which show the less strengthening as only minor mass of fine-grained snow was mixed in. The high SSA-value (43.1 mm-1) of the used fine-grained machine-made snow the specific characteristic of the here produced snow using an indoor snow maker.

3.4 Snow Transport

3.4.1 Operational processes, tools & technology:

As explained above, given the municipal climate ambitions, Nordic ski venues in Scandinavia can and should be front runners in using **electric and/or HVO fuelled vehicles** for the outtake of snow from storage and transportation from the storage to courses.

3.5 Snow Handling

3.5.1 Climate, snow & hydrology:

Snow hardeners are frequently used in Nordic skiing competitions. They 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, as well about the physical processes of snow hardening (Wolfsperger et al., 2019) and the **feasibility of alternative, more ecological hardening substances** instead currently used ones (Sodium chloride, Ammonium Nitrate, Urea).

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

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 optimize the use of snow hardeners (timing, quantities depending on snow and weather) preventing overuse or failure. The existence of snow research groups as well as the higher societal relevance of Nordic skiing in the Alps and Scandinavia, give hope those regions will take the lead within upcoming applied research collaborations.

3.5.2 Governance practices

Due to the large number of Nordic ski venues in Scandinavia and the growing use of snow hardening substances, **research fundings would be desirable to help investigating effects on soil, flora and fauna** from using of snow hardeners. Such research could help to provide a data-based set of criteria for the use of existing snow hardening substances, as well as finding new, eco-friendly hardening substances.

3.6 General Snow Management Issues

The Scandinavian region is a quite diverse climatic region, from southern Scandinavia with a climate on-the-edge, to winters like in the mid-mountains of Europe to mid- and northern Scandinavia that still enjoys a typical cold winter climate. There is also a mountain region in Scandinavia with abundant snow and a winter climate.

The tradition of Nordic skiing is very strong in Scandinavia leading to a great interest for Nordic skiing in the population. What is also unique for the Scandinavian region is the strong involvement of citizens in sports clubs and ski clubs, with associated preparedness in volunteering in the ski venues. This involvement of volunteers ensures more resources and cheap labour for the venues, improving chances for ability to adapt to a changing climate.

3.6.1 Operational processes, tools & technology:

In Scandinavia, the ski associations fund specialised venue consultants who increase the know-how and knowledge transfer among the ski areas as well help the venues to apply for funding for investments. These positions are important especially to the smaller ski venues with smaller resources.

The introduction of ski passes with **fees for Nordic skiing** appeared in Scandinavia around the year 2010 and has since become wide-spread and accepted in society (Näslund, 2022), with some differences among the countries. The ski passes are mostly for adults, excluding kids and teenagers. The income from these ski passes is an important income for the ski venue in securing operations and financing the increased cost for more intense snow management practices in Scandinavia. The large interest in Nordic skiing among the citizens in Scandinavia ensures a large group of potential buyers of ski passes and provides a significant source of income for the ski venue. Furthermore, the large interest and tradition in Nordic skiing in most of Scandinavia ensures strong public support for the resource intensive adaptation measures, such as snow production and snow storage.

3.6.2 Governance practices

Since most of the ski venues in Scandinavia are owned, operated or supported by the municipalities it is important for the municipality to justify the cost and resources used for snow management for example by collecting data on energy use and costs for snow production, storage and transport. Data collection on the use and value of skiing that the venues generate is also important since heavy use and value generated can help ensure continued funding of the Nordic ski venue. It is therefore likely that the Scandinavian venues will be front-runners in collecting and presenting this kind of data.

4. CONCLUSION

This roadmap presents a structured approach to transforming snow management of Nordic ski venues in Scandinavia into a sustainable practice that aligns with environmental, economic, and societal goals. The path forward requires innovation in technology, governance, and public engagement to address the challenges posed by climate change and resource constraints.

In general, Nordic ski venues in Scandinavia have relatively good opportunities to adapt to changing climate. The keys to success for Scandinavian Nordic ski venues include building on the current strengths, such as high interest in Nordic skiing, public support for the sport, large involvement of volunteers and income from ski passes. The climate in most of Scandinavia is likely to remain sufficiently cold to provide skiing opportunities with a normal-sized, modern snow production systems. The investment in new or upgrades of an older systems will need some funding for investment. This will require help from the local municipalities, together with applying for national funds available for promoting public sports activities. The focus here should be on the youth (e.g. for building introductory ski activity areas) and inclusion of all citizens (including targeting groups with low representation in Nordic skiing today) to ensure greater social support and encourage financing from the municipalities and other national funding. Snow storage is another technique to ensure reliable snow conditions. However, snow storage is more expensive and in general more resource heavy compared to just snow production. The main target users for snow storages are larger Nordic venues having national or international competitions or focus on the provision of early season snow. These venues need to focus on reducing transportation from snow storage, by planning the storage and distribution routes as well as looking into new cover materials that reduce resource use. Another important pre-requisite is to have good data on resource use and costs, as well as on the use of the venues to ensure future support. Finally, the future operations at Nordic ski venues should minimise emissions using fossil-free electricity, fossil-free fuels (e.g. HVO) and transition to electric machinery, minimising climate impact of the sport.

This roadmap specifically names research topics that will 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 of the venue by their managers. 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 throughout a warmer, natural snow-deprived future.

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