SIEPPUR
Sustainable snow management

Toolkit Snow Storage

How to maximise the efficiency of snow storage

Deliverable 4.4

31st May 2025

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Content – Snow Storage

(1) Storing snow – a part of sustainable **snow management**
(2) Which **factors** affect a snow storage?
(3) Examples of **good practices**
(4) **Cover materials** – the ongoing search for the ultimate cover
(5) **Environmental impact** & costs

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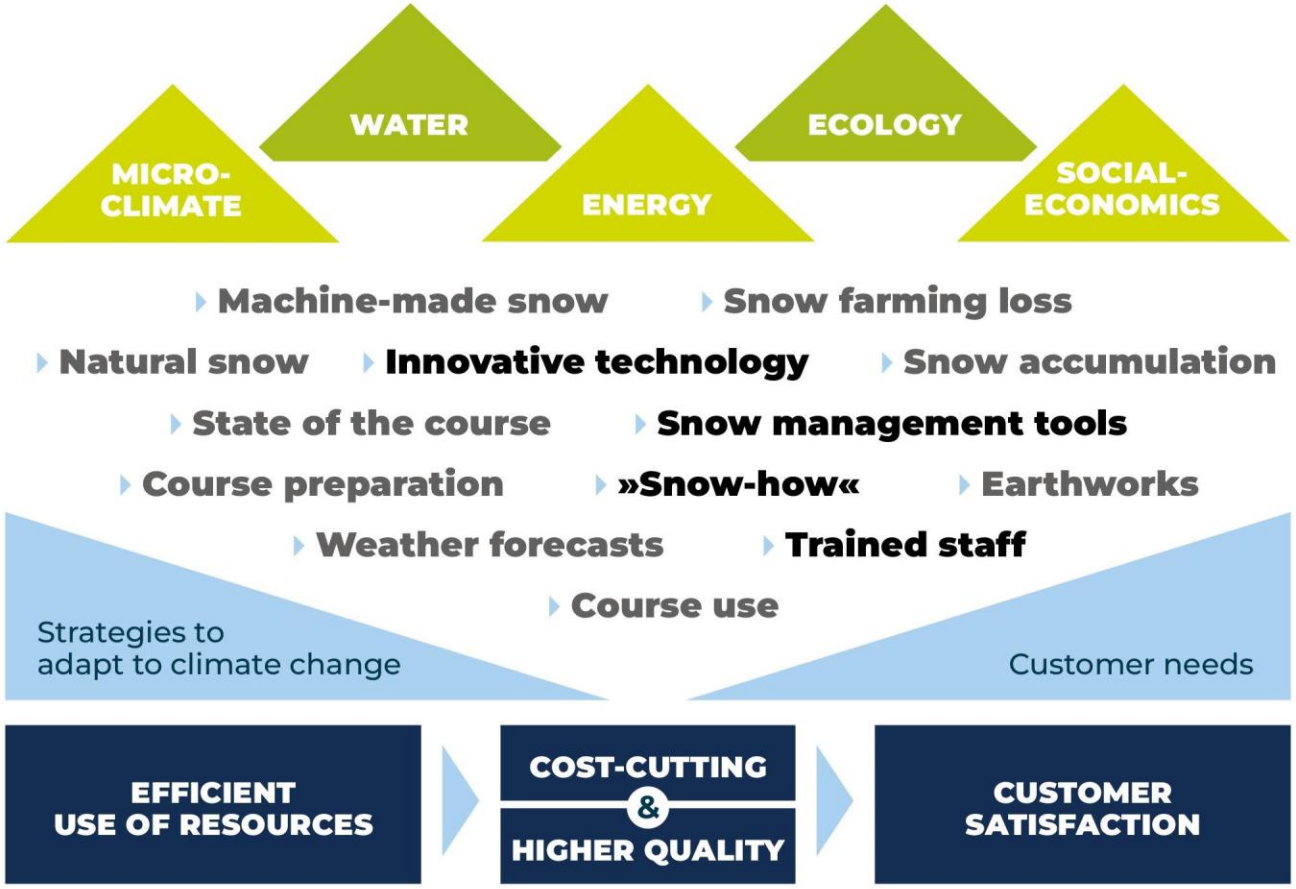
(1) Sustainable snow management



...to **reliably provide snow**...

...within a given set of climatological, hydrological, ecological, and social-economical constraints...

...to run snow sport infrastructures in an **ecologically and economically sustainable** manner.

...to reduce **costs** while improving the **quality of snow** sports facilities.

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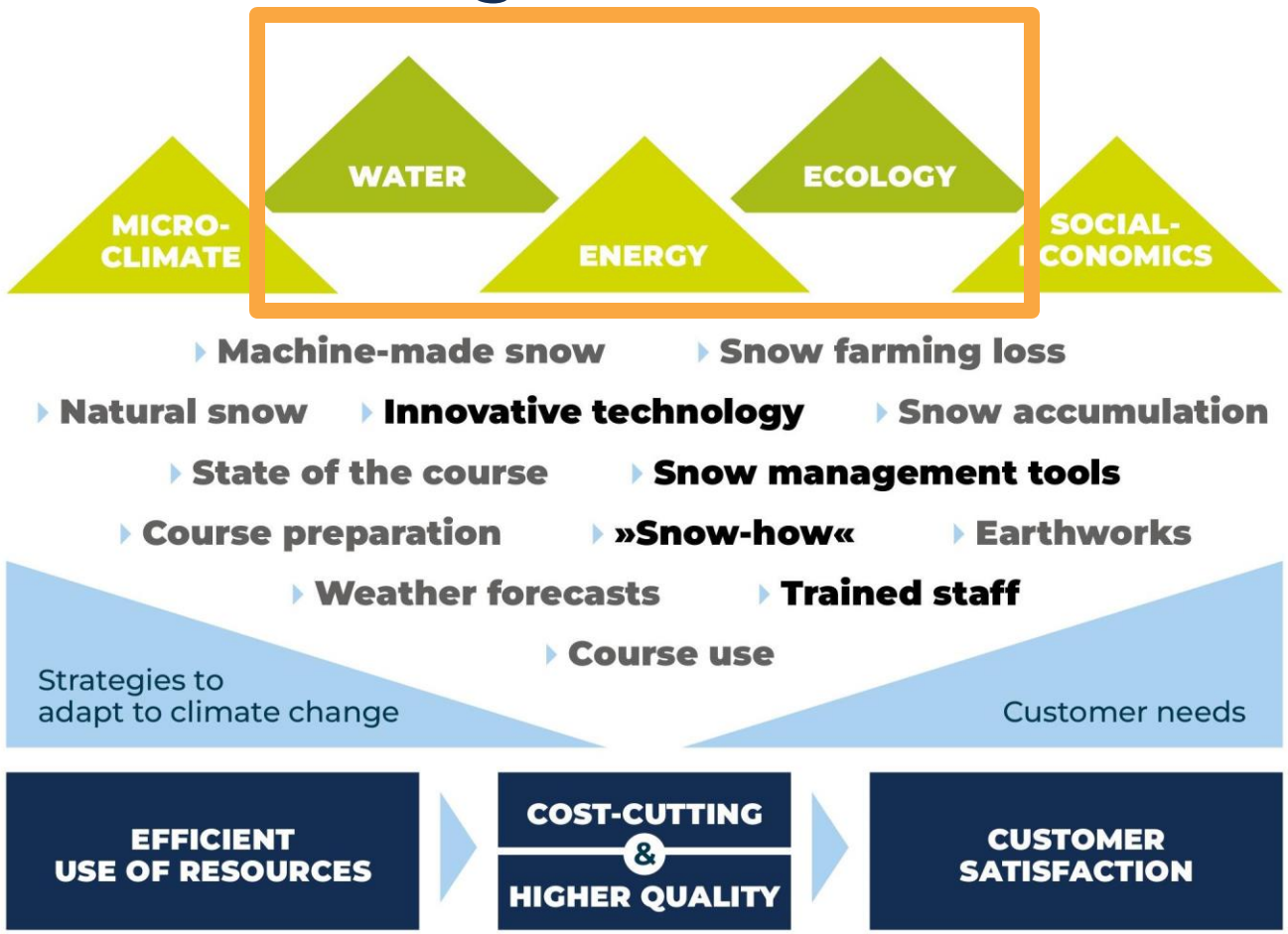
(1) Sustainable snow management - Snow Storage



SNOW...

Snow Storage
the on-schedule snow reliability

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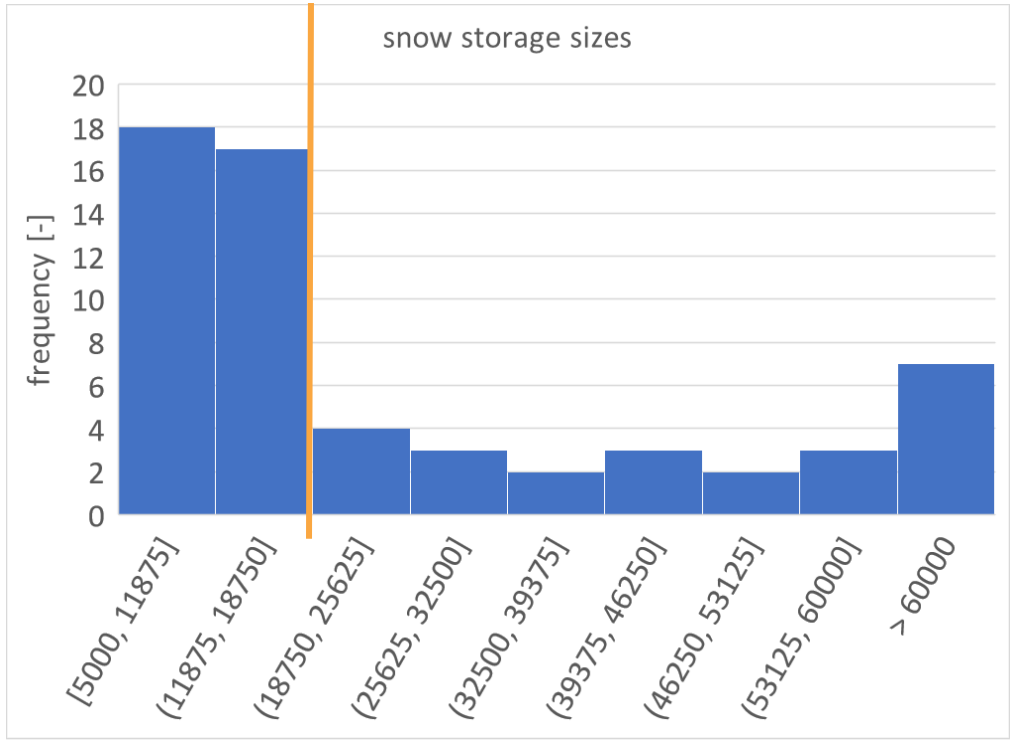
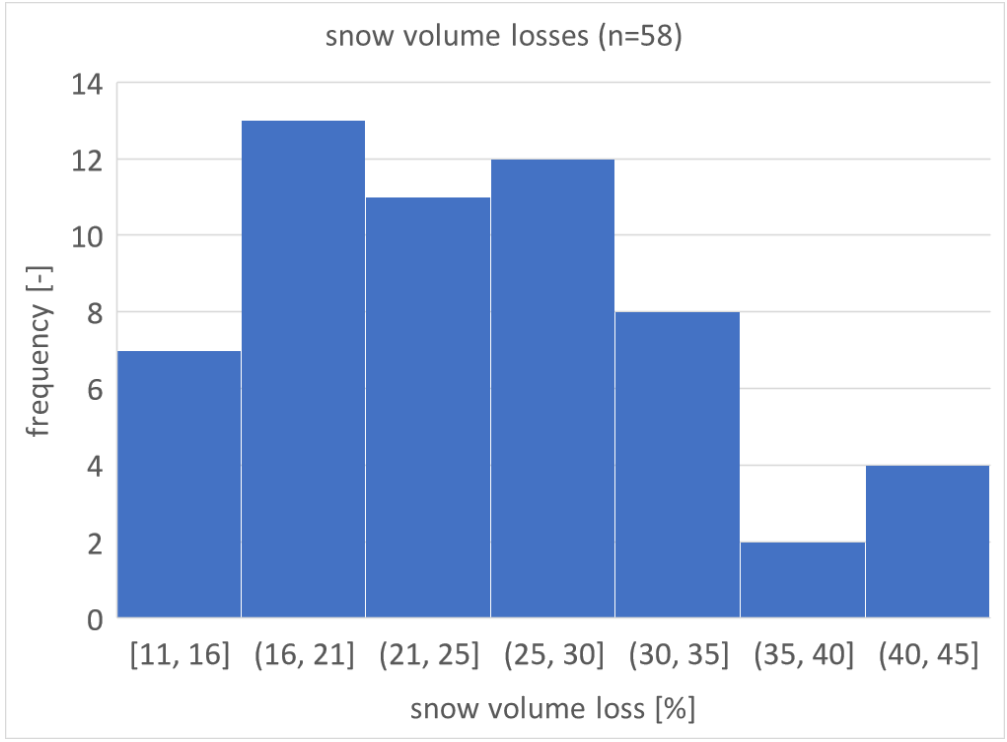
(1) Storing snow – overview at IBU venues

most storages (ca. 60%) < 20k m3



- **wide range of losses from 11% to 45%**
- **75 % (43 of 57) of storages lost less than 30%**



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(2) Factors affecting a snow storage

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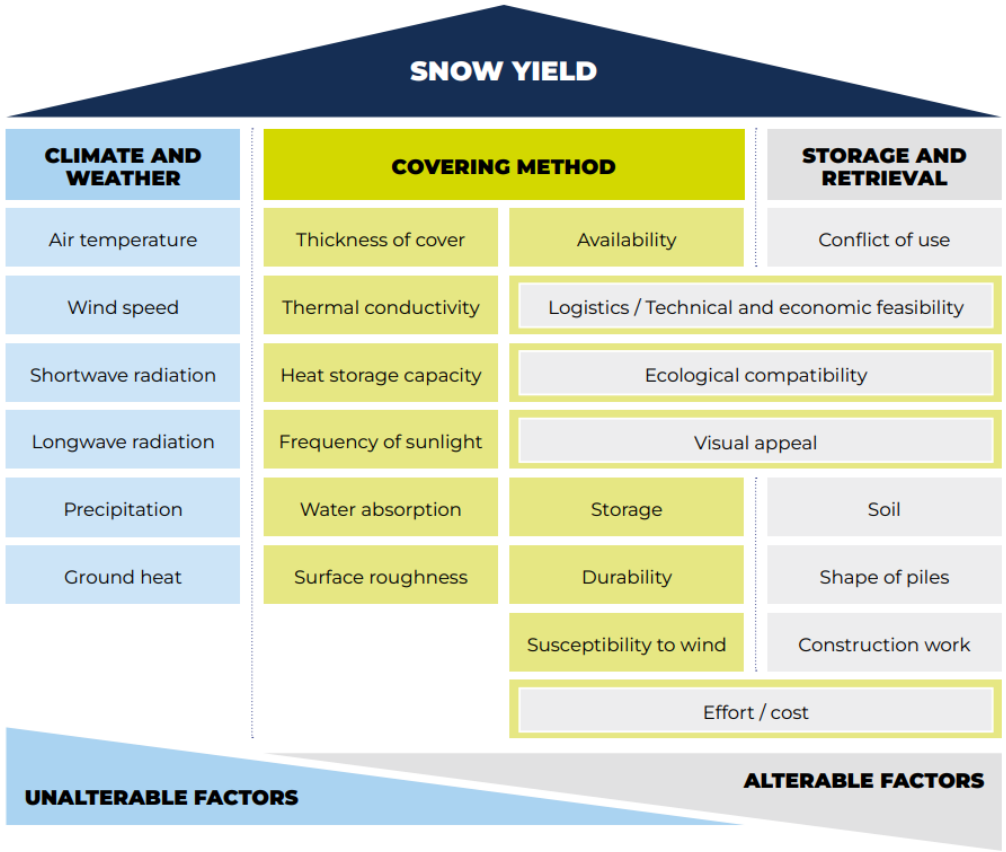
(2) Which factors affect a snow storage?

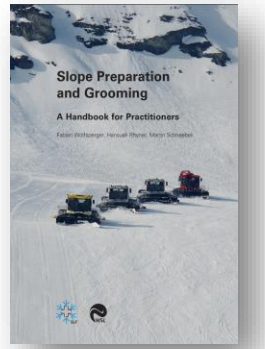


Practical guidelines

1 - Planning
2 - Structural measures
3 - Snowmaking /pile size & shape
4 - Applying the cover
5 - Storage
6 - Removing the cover
7 - Spreading and preparing
8 - Storing coverings

Find more information in the freely available e-book:

https://www.dora.lib4ri.ch/wsl/islandora/object/wsl%3A21755/datastream/PDF/Wolfsperger-2019-Slope_preparation_and_grooming._A-%28published_version%29.pdf



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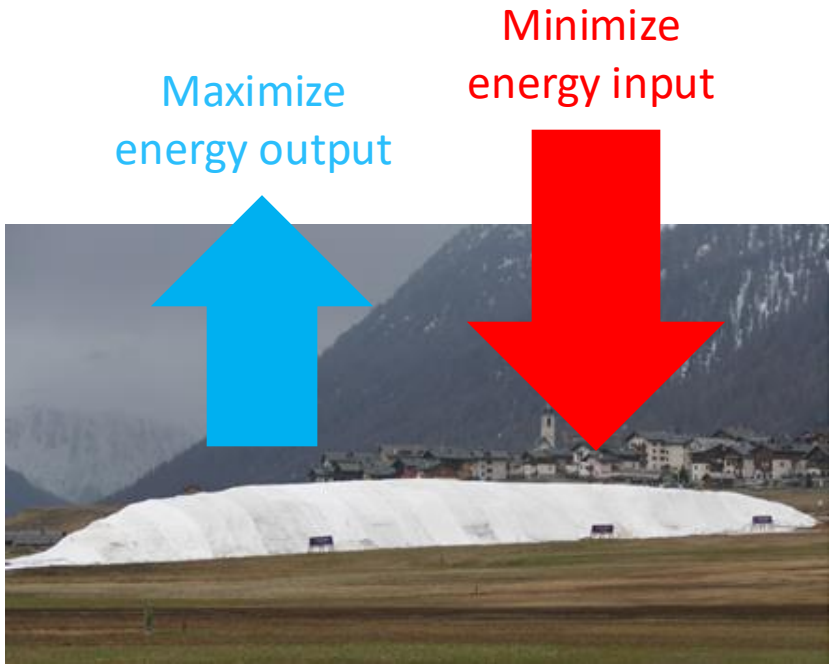
(2) Which factors affect a snow storage?

- **Surface energy balance**
- **Size & shape: Surface-to-mass ratio**
  - **The bigger** the storage, **the lower the energy input** per m^3 snow
- **Size & shape: Settling by dead load**
  - **BUT**: ... the higher the load on lower layers (→ icing)
- **Growing gaps**
  - a **closed cover** prevents direct (convective) heat transfer from air to snow
- **Cover thickness**
  - the **thicker the cover** the less heat is transferred
  - Sufficient cover thickness > 30 cm is needed
- **Cover materials heat conductivity**
  - the **lower the heat conductivity** the less heat is transferred



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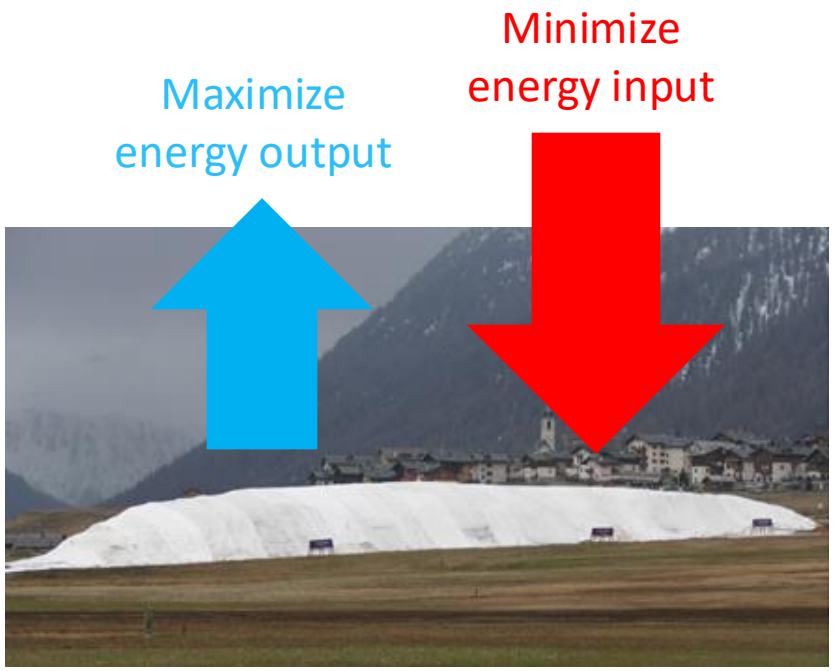
(2) Which factors affect a snow storage?

- **Cover materials water absorption**
  - materials with a **high heat storage capacity** absorb heat during the day and **release it back** at night
  - materials that **absorb water** release heat when the water evaporates
- **Cover materials colour**
  - **highly reflective surfaces** prevent energy input by **shortwave radiation** (cover as light as possible and resistant to contamination)
- **Cover materials heat emissivity**
  - the **cover emits heat overnight**, and thereby cool down – this needs a good **longwave radiation** emissivity (no reflective metal film's)



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(3) Examples of good practices

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(3) Examples - Östersund, SWE

Size: 2 piles at about 30 000 m3 each (15-20% loss)
Cover material: Saw dust 40 cm
Good practices: Crushing snow with a forked excavator shovel reduces large boulders, making preparation easier

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(3) Examples - Otepää, EST

Size: 1 piles at about 11 000 m3 (27% loss)
Cover material: Saw dust
Good practices: Partly dug into a hill with a wall behind.

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(3) Examples – Kontiolahti, FIN

Size: 2 piles at about 25 000 m3 each (20% loss)
Cover material: Saw dust 40 cm
Good practices: 2 piles for shorter transportation distance

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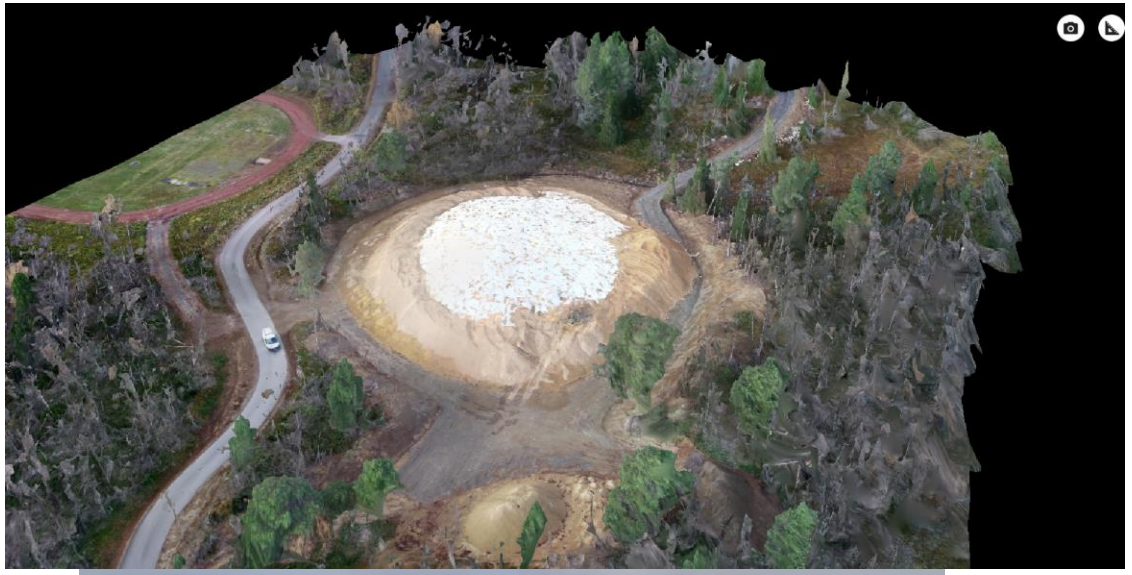
(3) Examples - Vålådalen, SWE

Size: 2 piles at about 7000 m3 each (10-20% loss)
Cover material: Saw dust 50 cm
Good practices: Shaving snow with an excavator shovel, two piles for shorter transportation distance



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(3) Examples – Livigno, IT

Since 2017:
Fleece & 20 cm wood chips
ca. 30% loss
Costs/season: ca. 70k EUR

Since 2022:
Fleece & 6 cm Wood Wool
ca. 40% loss
Costs/season: ca. 30k EUR

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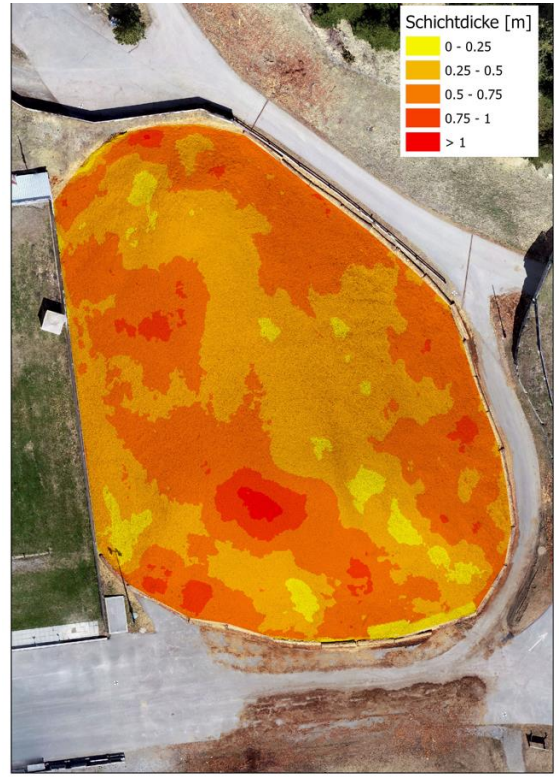
(3) Examples – Lenzerheide, SUI

2022
ca. 11’000 m3
40cm wood chips
Loss: -29%

2023
10’265 m3
Avg. 50 cm woodchips
6 cm - 115 cm
Loss: -27%



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(3) Examples – Martel, IT

Standards: wood chips, saw dust & geotextile

Smart way to reduce cost of transportation

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(3) Examples – Pokljuka, SLO

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(3) Examples – Ruhpolding, GER

Year	Volume (m3)	Loss (%)
2015	6890	43
2016	10595	30
2017	14437	20
2018	17501	25
2019	13976	31
2020	12808	30

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(3) Examples – Oberhof, GER

Storage 3:
7500 m3
Production Hall 200 m3/day

Storage 2:
15000 m3
Sawdust -> Mats

Storage 1:
12500 m3
Plates & Fleece

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(3) Examples – Nove Mesto Na Morave, CZE

Size: 30-35 000 m3 (20-25% loss)
Cover material: Saw dust
Good practices: Storage dug into a hill, Interlocking paving bricks at the bottom, snow distribution plan

Interlocking paving bricks

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(4) Cover materials

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(4) Cover materials - overview

Category	Cover	Advantages	Disadvantages
films and fleeces	geotextiles	– less effort	– high snow loss – reduced albedo[12] – prone to tearing
	silage film		
	truck tarpaulin		
natural materials	sawdust	– less snow loss – water absorption	– more effort – winter storage – snow contamination
	woodchips		
	bark mulch		
	straw		
insulating materials	insulation slabs	– less snow loss – no snow contamination	– more effort – winter storage – decreasing insulating effect due to gradual formation of gaps (Fig. 7.12)
	insulating mats[13]		
combinations	sawdust + fleece	– higher albedo – protection from water – protection from wind	– additional effort and costs
	woodchips + truck tarpaulin		
	insulation slabs + fleece + silage film		
	etc.		

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(4) Cover materials – most common

Standards: wood chips, saw dust & geotextile

Saw dust λ = 0.35 W/(mK)
ca. 47 EUR / m^3
(today Switzerland incl. transport)
10-15 EUR/ m^3 In Scandinavia

Wood chips λ = 0.4 W/(mK)
ca. 47 EUR / m^3
(today Switzerland incl. transport)
10-15 EUR/ m^3 In Scandinavia

→ strongly depends on the region and logistics

→ costs doubled over the last 5 years

Geotextile Polypropylene (PP) - typically 500 g/m^2 - 4 mm; λ = 0.06 W/(mK)
e.g. Coverice 500, TenCate Toptex GLS 550 (2.9 EUR / m^2)
TenCate Toptex GLS 340 (1.9 EUR / m^2)

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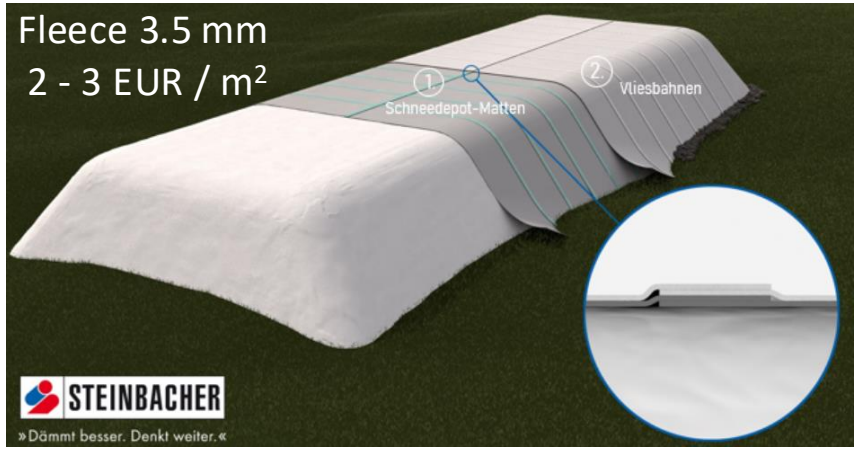
(4) Cover materials – plate, mat & fleece combi

Steinbacher 2 or 3-layer system



PE mat:
30 m x 6 m x 18 mm
13 EUR / m²
0.08 W/(mK)

XPS plates:
1250 mm x 600 mm x 10 mm
23 EUR / m²
0.036 W/(mK)

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(4) Cover materials – plate system

Snow Secure 2-layer system

XPS plates encased in PVC fabric

18 m x 4 m x 70 mm
(folded 4 m x 1.2 m x 1.05 m)
28 EUR / m²

Surface cover

PE film: 40…100 m x 16…22 m x 0.3 mm
or

PP geotextile: 1000 g/m²
8 EUR / m²

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(4) Cover materials

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(4) Cover materials – investment costs

Investment costs estimation 10’000 m^3 pile / 2’500 m^2 surface / 0.4 m cover thickness

Snow secure:	90’000 EUR
Steinbacher 3-layer:	94’750 EUR
Steinbacher 2-layer:	37’250 EUR
Saw dust / wood chips:	47’000 EUR
Geotextile 2-layer:	14’500 EUR
Geotextile:	4’750 - 7’250 EUR

Costs per m^3 snow then result from…

- duration of life
- workload for covering and uncovering
- snow storage performance
- costs for winter storage / winter use benefits

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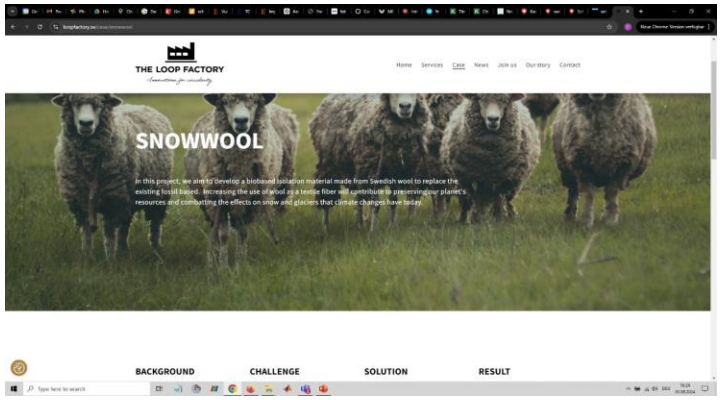
(4) Cover materials – wool based

Snow wool – Non to low micro plastic contamination

- Helags glacier
- Tryvann Skisenter
- Ål skisenter
- Björling glacier (Kebnekaise)
- Linbäcksstadion Piteå



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(4) Cover materials – Oberhof experiment

Photos: Heiko Krause

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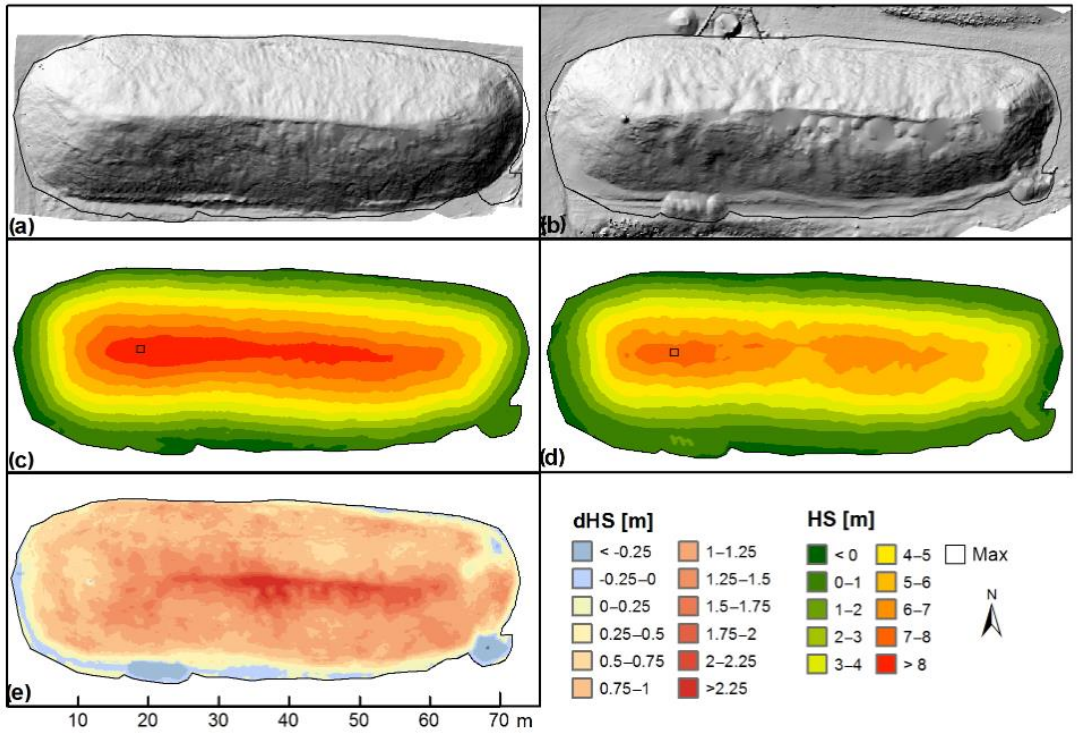
(4) Cover materials – Davos experiment

EXPERIMENTS OF SNOW STORAGE COVER - large scale field



Davos, CH, 1620 m.a.s.l.

Saw dust ca. 40 cm

6'862 m3 (29th April, 2015)
5'307 m3 (8th Oct., 2015)

-22.6 % volume loss
ca. -17 % mass loss

T_{avg} = 11.3 °C

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(4) Cover materials – high alpine storage

EXPERIMENTS OF SNOW STORAGE COVER - large scale field

Jakobshorn, Davos, CH, 2440 m.a.s.l.

Double layer geotextile 4 mm

20’521 m3 (9th May, 2011)
8’868 m3 (28th Sept., 2011)

-57 % volume loss

T_{avg} ≈ 5 °C

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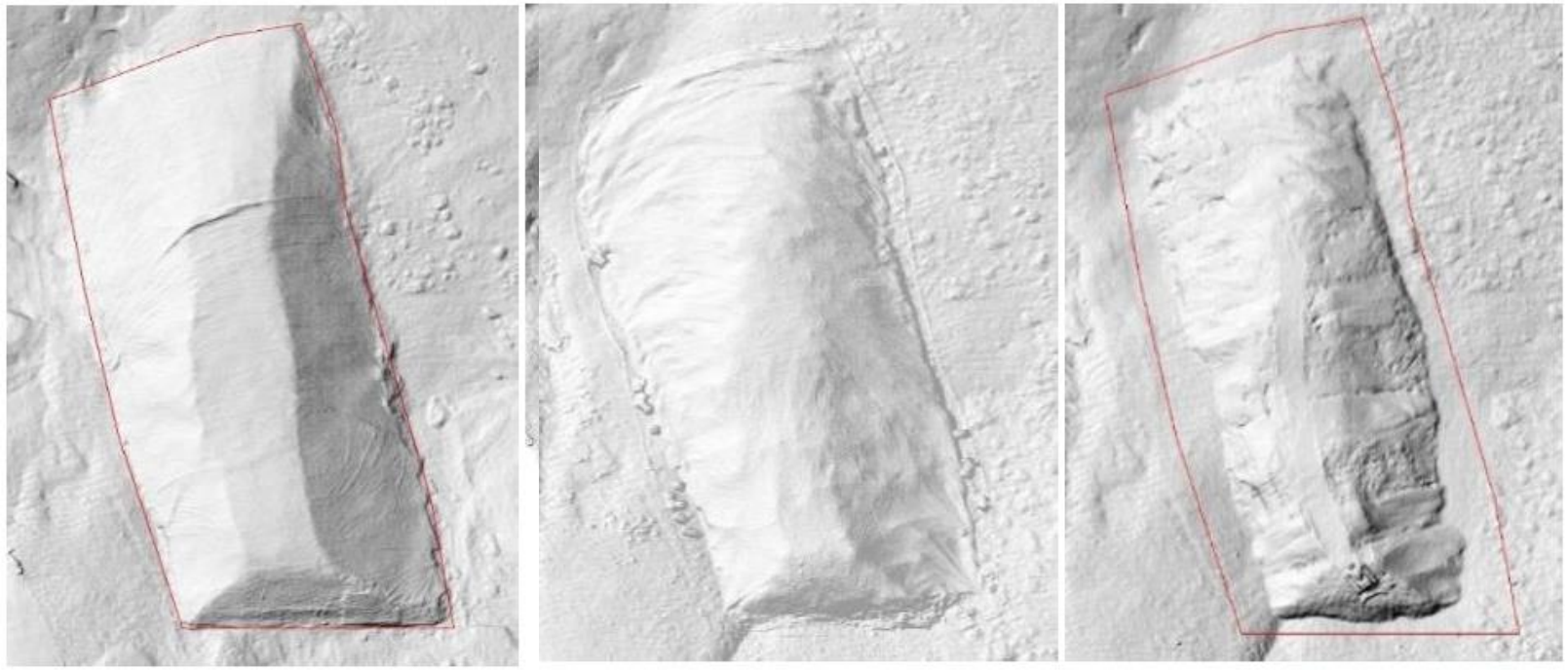
(4) Cover materials – alpine storage

EXPERIMENTS OF SNOW STORAGE COVER - large scale field



12.05.2018 27.07.2018 07.10.2018

Tschnetenalp, Adelboden, CH, 1800 m.a.s.l.

XPS plates 100 mm
Geotextile 4 mm

31’300 m3 (12th May, 2018)
13’200 m3 (7th Oct., 2018)

-57.8 % volume loss

T_{avg} = 11.6 °C

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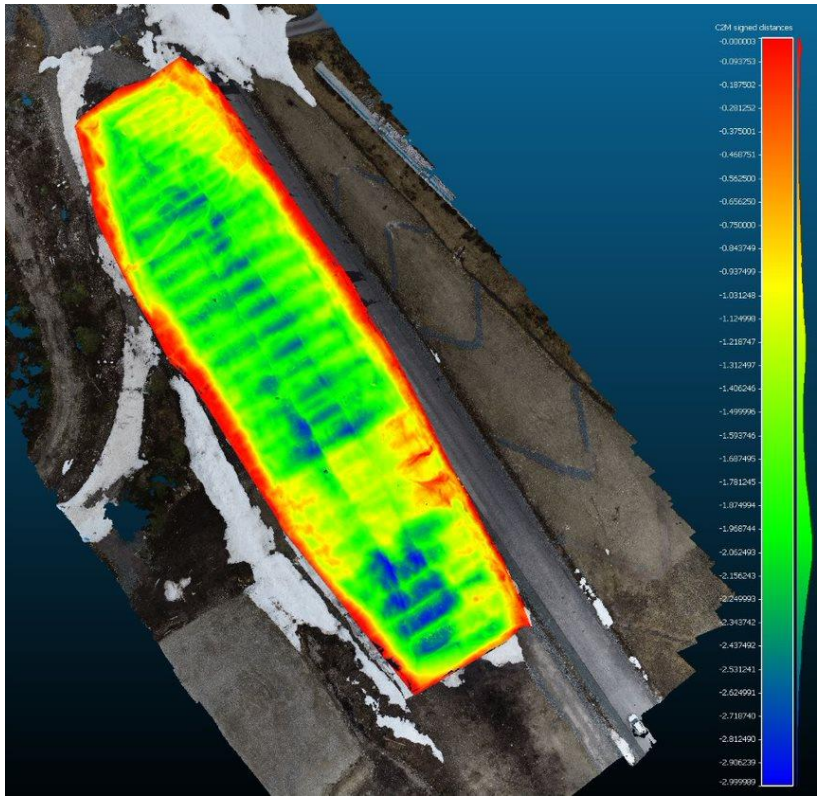
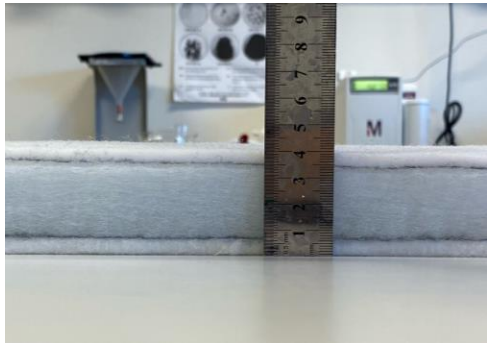
(4) Cover materials – multilayer

EXPERIMENTS OF SNOW STORAGE COVER - large scale field





Snow loss different cover materials

2 layers geotextiles 40 %
Geotextiles + wadding + Geotextiles 30 %

Temp = 10.8 C

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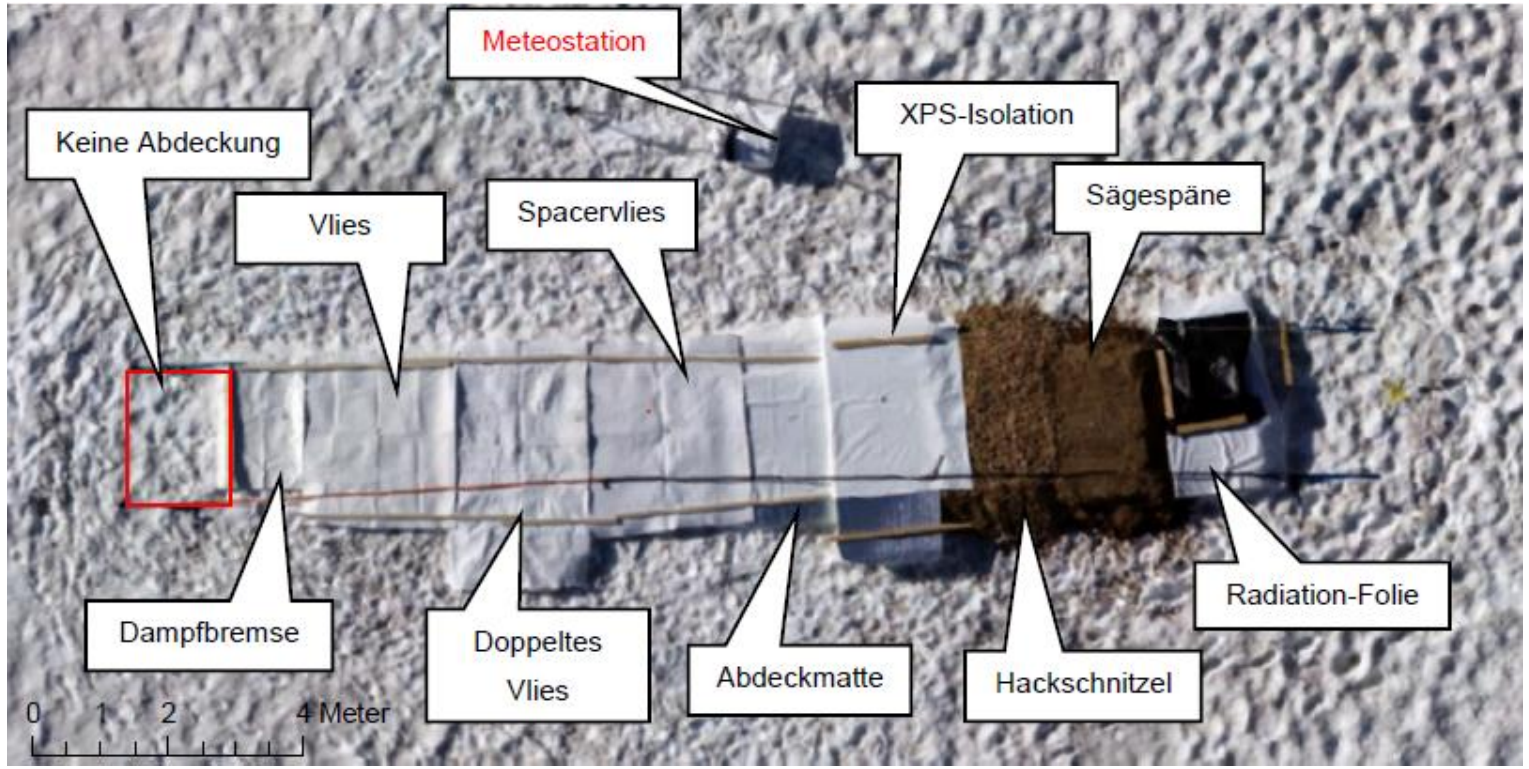
(4) Cover materials – Davos experiments

EXPERIMENTS OF SNOW STORAGE COVER - small scale outdoor



	Temperatur	Relative Luftf.	Kurzwellige Strahlung	Wind-geschw.
Total	°C	%	W/m^2	m/s
Ø	12.4	65	183.9	2.5
Max	23.7	100	1040.0	16.2
Min	3.4	20	-5.0	0.1

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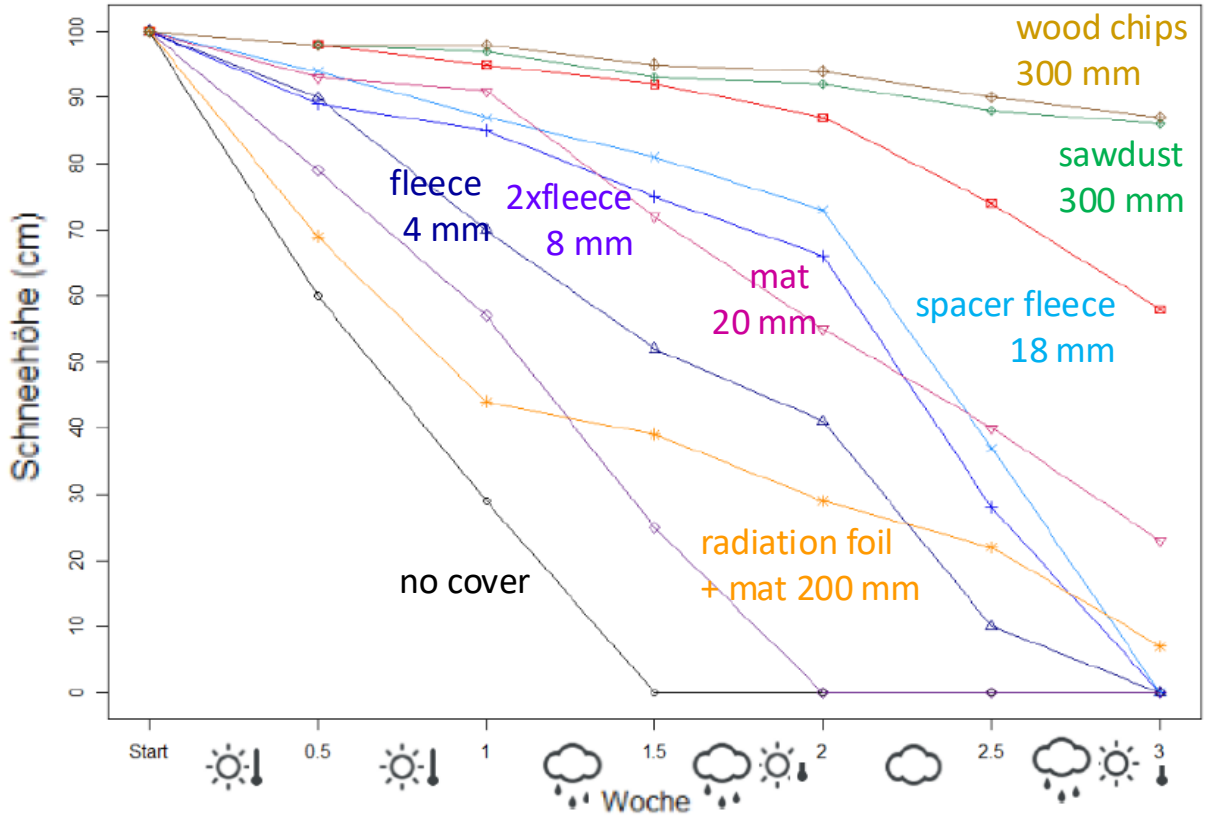
(4) Cover materials - Davos experiments

EXPERIMENTS OF SNOW STORAGE COVER - small scale outdoor



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(4) Cover materials – average losses

EXPERIMENTS OF SNOW STORAGE COVER - large scale field

Place	Cover material, Thickness	Volume (m3)	Surface area/ Volume (m-1)	Tmp during snow storage	Snow loss (%)	Snow loss per day (%/day)
Granåsen 2020	Sagflis, 44 cm	29267	0,216	9,87	17,4	0,092
2019	Sagflis, 44 cm	23481	0,234	9,26	20,3	0,099
2018	Sagflis, 46 cm	30055	0,208	11,4	18,5	0,099
2017	Sagflis, 45 cm	18122	0,277	12,84	20,5	0,138
2016	Sagflis, 46 cm	18300	0,274	12,18	24,7	0,131
Beitostølen 2016	Sagflis, -	29677	0,254	-	10,3	0,131
Østersund 2020 P1	Spån, 45 cm	39897	0,239	11,61	14,6	0,091
P2 2020	Spån, 50 cm	30526	0,255		15,7	0,098
P1 2019	Spån, 54 cm	38435	0,245	11,64	16,7	0,091
P2 2019	Spån, 47 cm	38271	0,240		14,0	0,076
P1 2018	Spån, 36 cm	42860	0,245	12,67	17,4	0,108
P2 2018	Spån, 42 cm	36715	0,232		15,5	0,096
Vålådalen P1 2020	Spån, 48 cm	6021	0,388	10,3	14,4	0,123
P2 2020	Spån, 52 cm	4413	0,451		14,2	0,121
P1 2019	Spån, 51 cm	5505	0,393	11,6	11,6	0,144
P2 2019	Spån, 53 cm	5031	0,371		11,6	0,144
P1 2018	Spån, 48 cm	5801	0,402	10,6	14,6	0,0971
P2 2018	Spån, 51 cm	4806	0,397		16,5	0,109
Idre 2020- Stadion	Duk, 2 lager*	22797	0,253	10,81	38,5	0,329
P2-bark	Bark, 58 cm	26432	0,265		17,1	0,124
P3 -vest	Duk, 1,5 lag	45710	0,232		47,6	0,402
P4-Nord toppen	Duk, 2 lag	50658	0,195		37,0	0,313
P5-Nord botten	Duk, 1 lag	30277	0,270		63,2	0,535
Buksvalarna 2020	Spån, 40 cm	19565	0,289	10,55	15,9	0,158
2016	Spån, 35 cm	21624	0,242	10,2	15,1	0,132
Åre 2018	Duk, 2 lag	9739	0,344	-	63,8	0,456
Oppdal 2016	Sagflis	6914	0,324	-	13	0,156
Dombås 2016	Flis	11970	0,250	-	8,37	0,103
Geilo 2016	Duk, 2 lag	20540	0,251	-	30,2	0,378

Snow loss different cover materials

Sawdust/woodchip 8-25 %
2 layer of geotextile 30-65 %
1 layer geotexile 60-70 %

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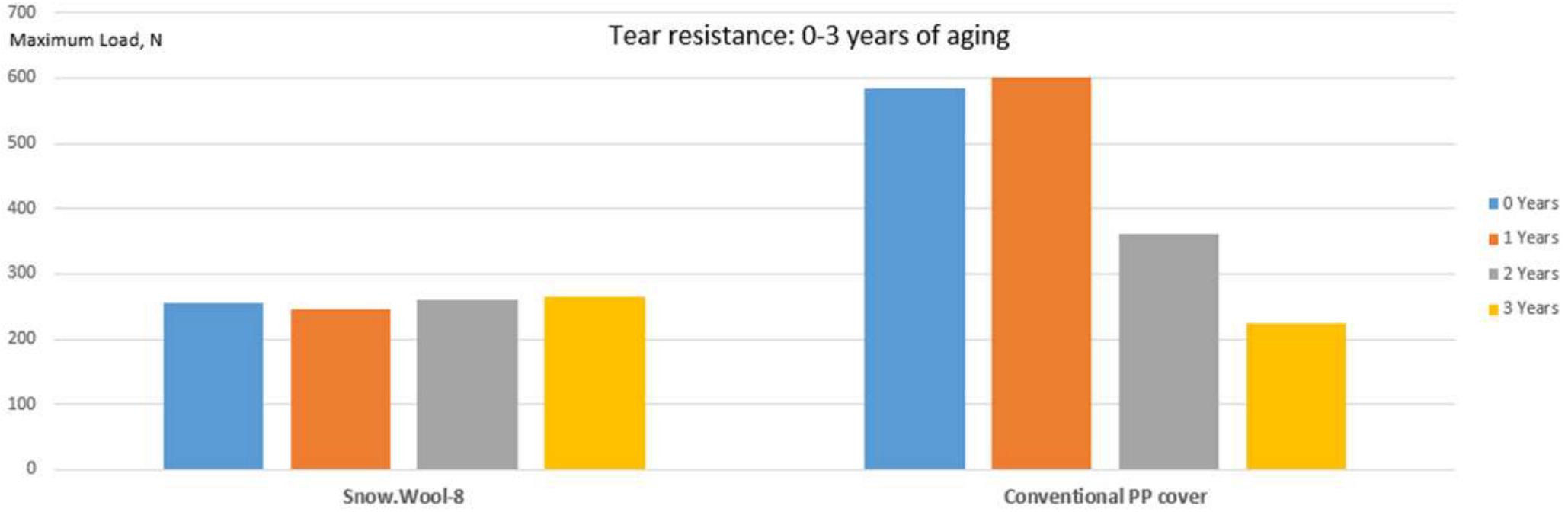
(4) Cover materials – tear strength

EXPERIMENTS OF SNOW STORAGE COVER - Östersund 2020

Tear resistance of aging cover materials



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(5) Environmental impact & costs

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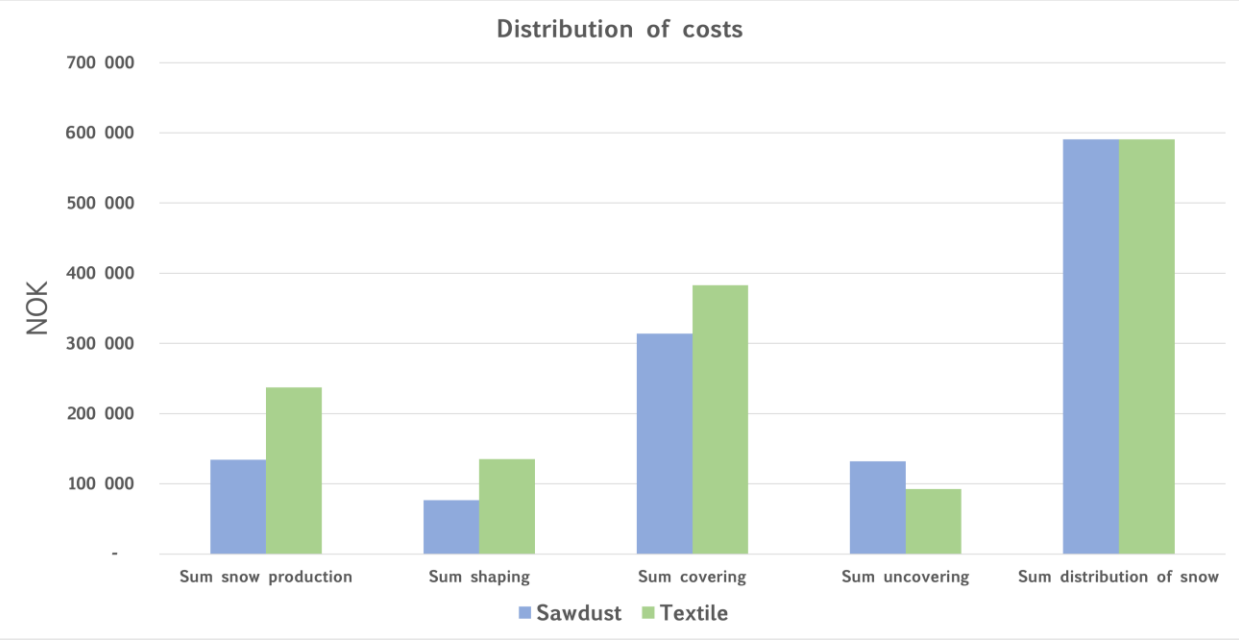
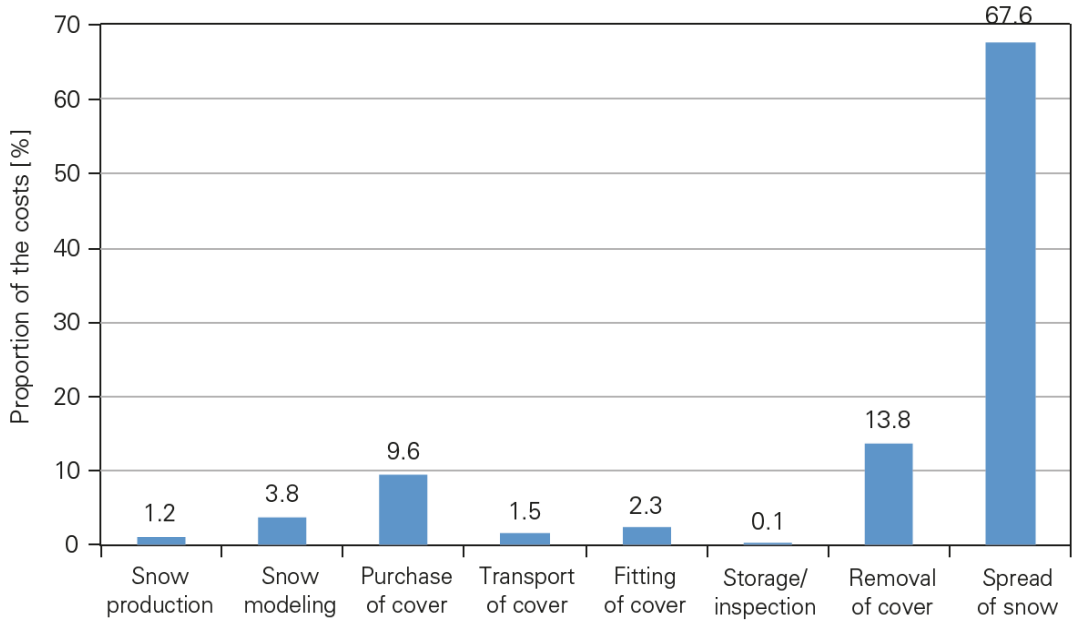
(5) Environmental impact & costs

Cost from different parts of snow storage





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(5) Environmental impact & costs

Cost from different parts of snow storage

	Storage					
	Energy snow ratio ESR [kWh/m3]					
Venue	Pile shaping	Covering	De-covering	Distribution	Others	Total
Lenzerheide	0,39	1,51	no data so far			
Pokljuka	0,15	0,24	0,21	1,29	0,04	1,93
Martell	0,31	0,82	no data so far			
Notschrei	no data so far					
Jakucyce	no storage					
NMNM	0,32	0,23	0,57	1,62		2,74
Östersund			1,01	2,4	0,43	
Vålådalen			0,62	2,85	0,12	
Kontiolahti						3,69
Otepää	0,40					

SIEPPUR venues 23:
ESR(storage) = 1.9…3.7 kWh/m³

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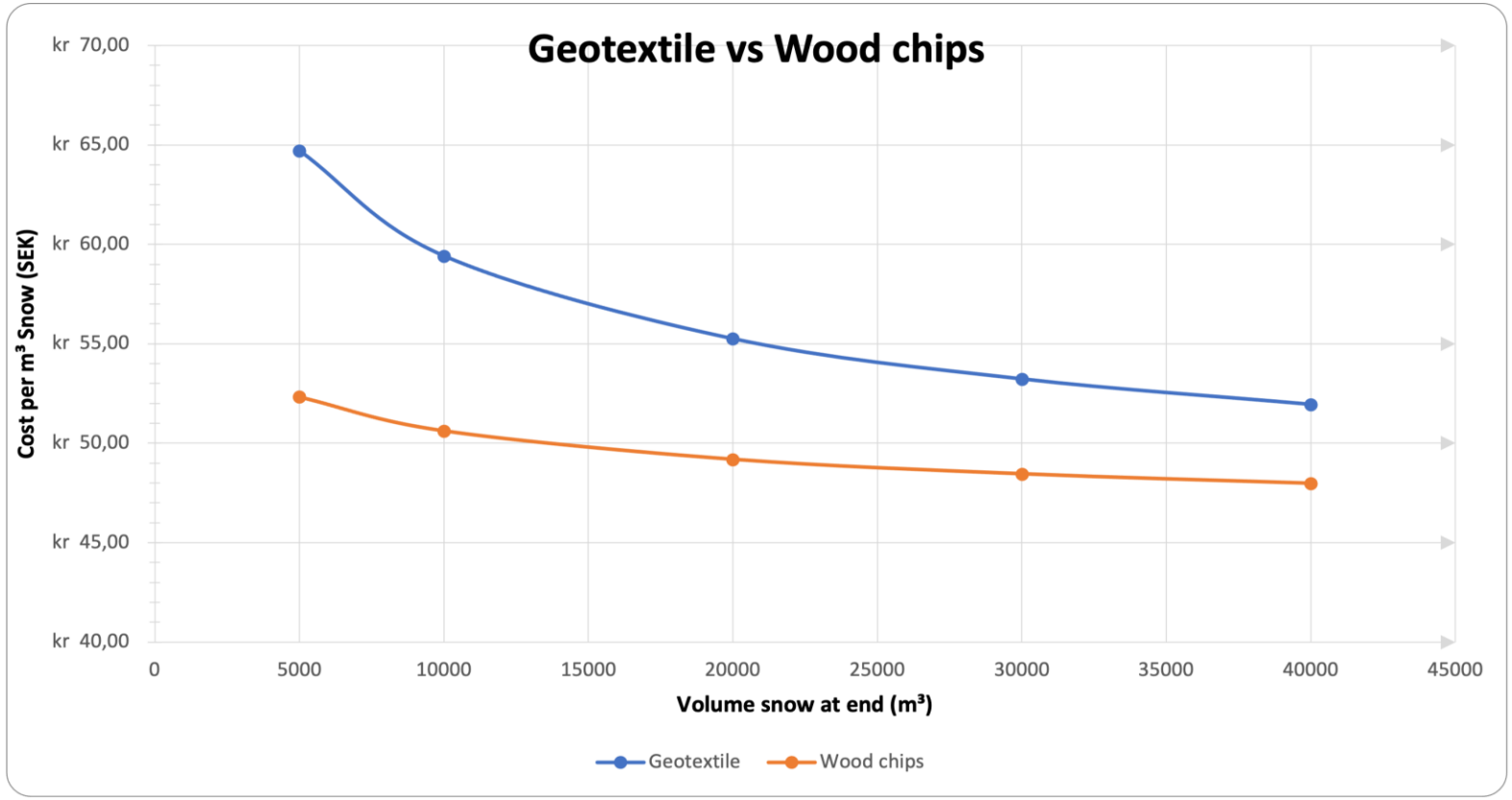
(5) Environmental impact & costs

Size related costs



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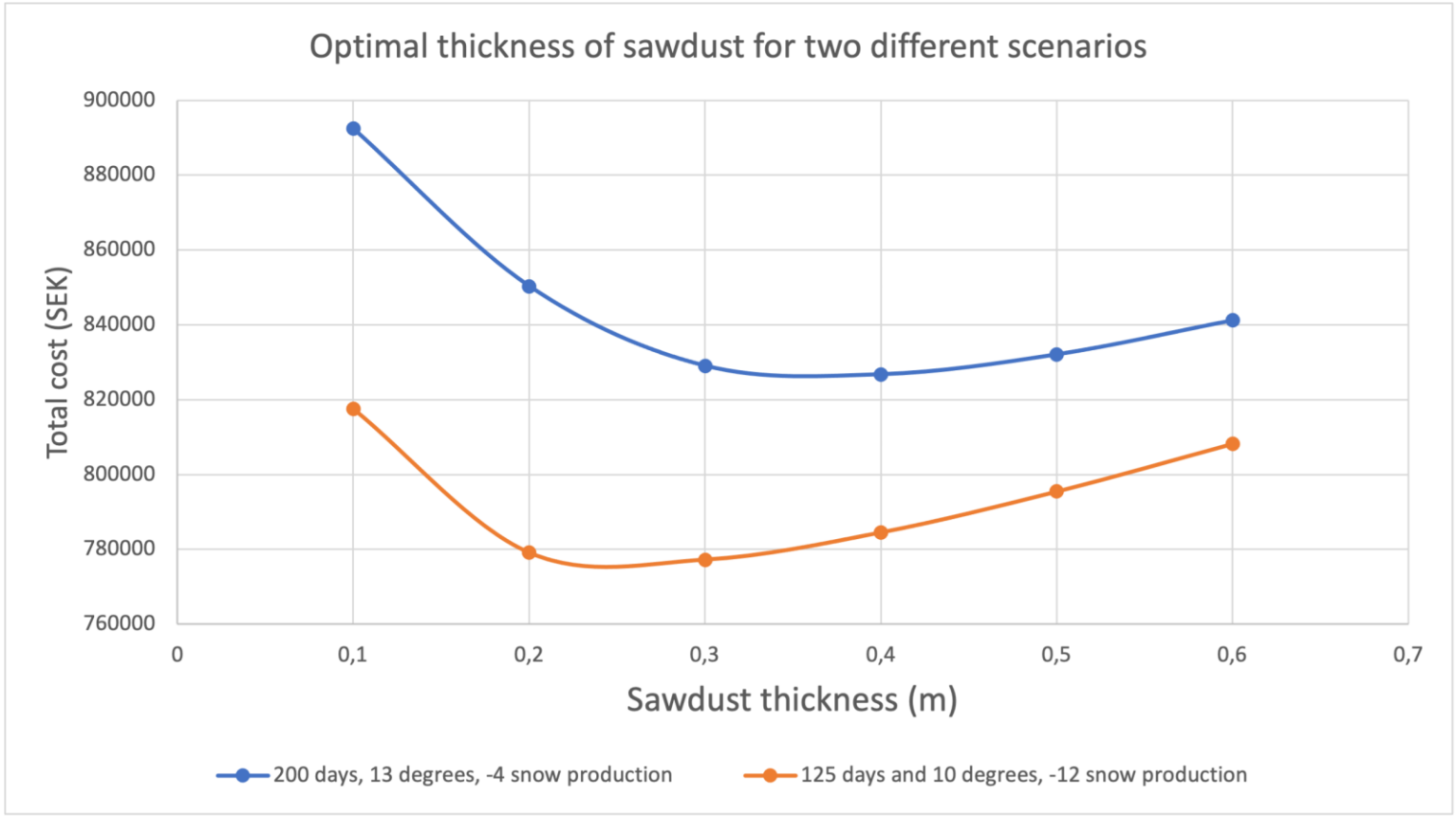
(5) Environmental impact & costs

Cost related optimal thickness



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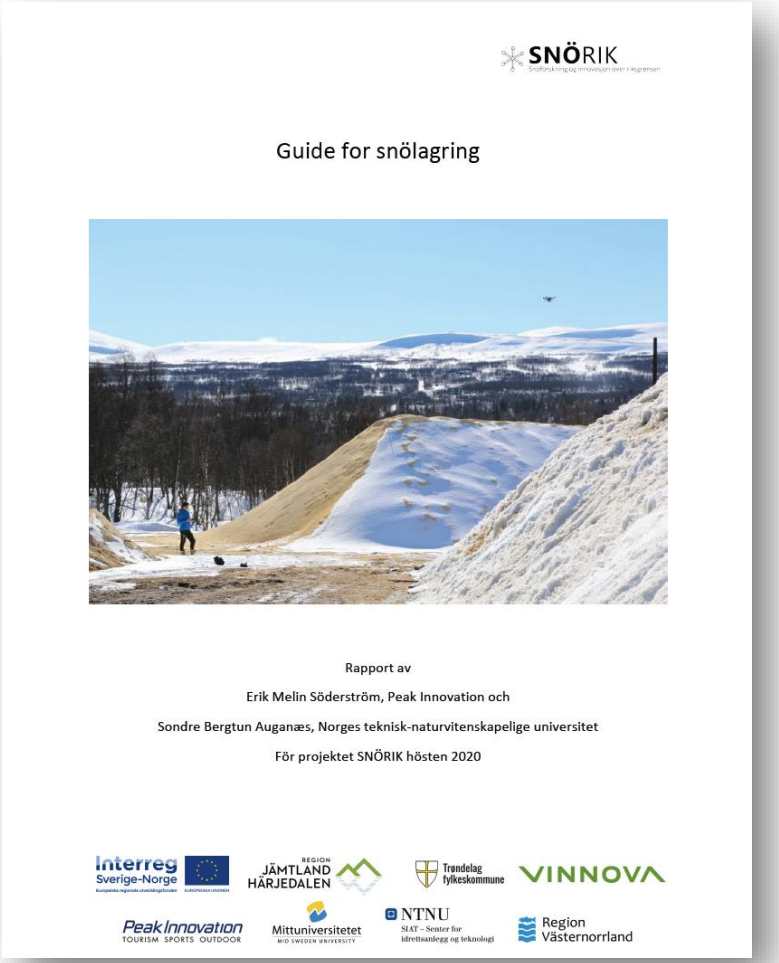
(5) Environmental impact & costs

Guidelines

Improve snow storage and reduce environmental impact

- Increase efficiency, reduce cost and environmental impact
- If possible, produce the snow at optimal temperatures
- Store the right amount
- Use the right cover and amount/thickness,
- Reduce distance between storage and tracks,
- Make a distribution plan.
- Don't put out the snow too early so that it melts
- Use renewable energy
- Avoid micro plastic pollutions



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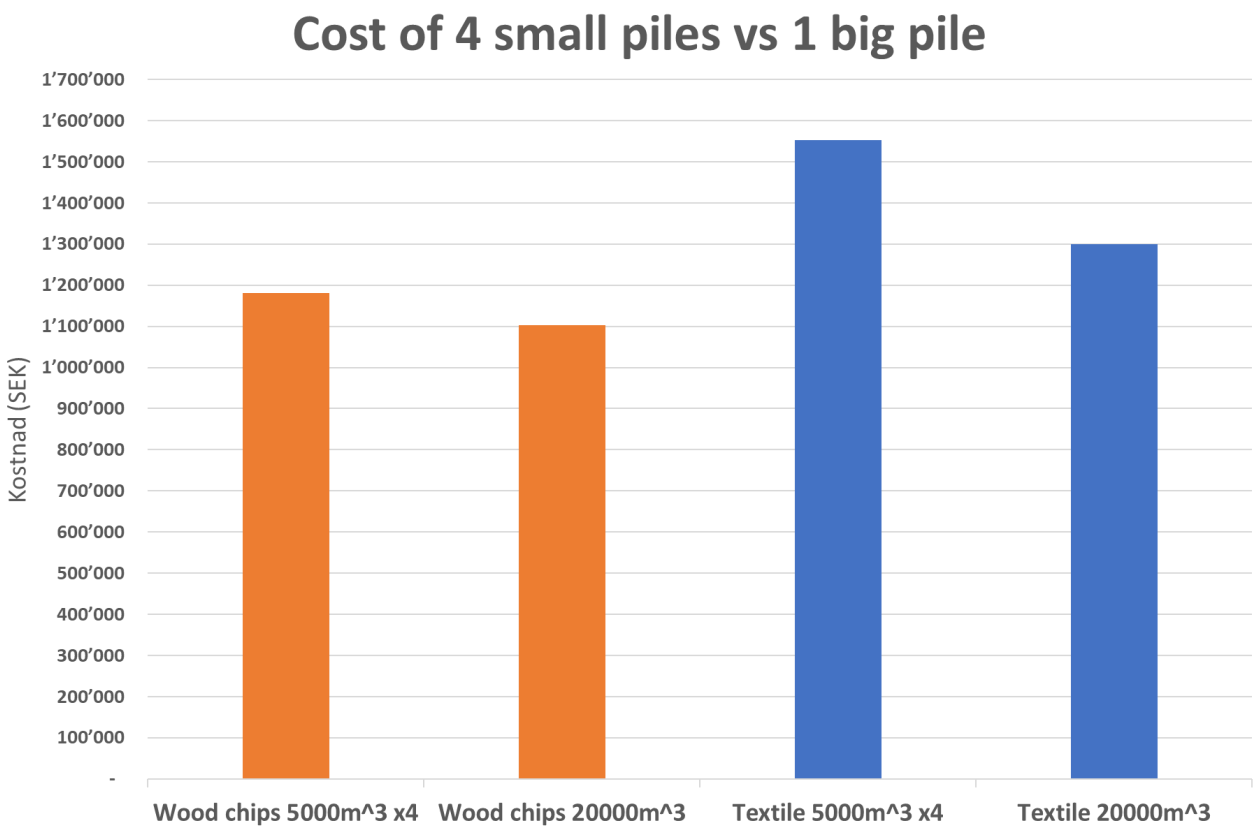
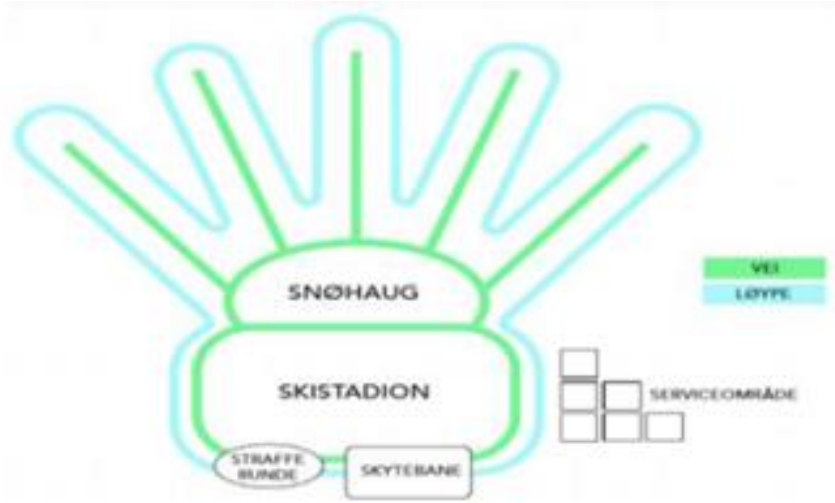
(5) Environmental impact & costs

Snow distribution and course access



- Smart design of the Venues
- Usually more than one pile at different location is beneficial to reduce the traveling distance, even though there are some extra work and cost with two or more piles (except distribution).



From Auganæs & Melin Söderström., 2020

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(6) SUMMARY

IBU SLF Peak63 OUTDOOR LAB SMA SUSTAINABLE MOUNTAIN ALLIANCE POLSKI ZWIĄZEK BIATHLONU POLISH BIATHLON ASSOCIATION SLOSKI Biathlon SWE

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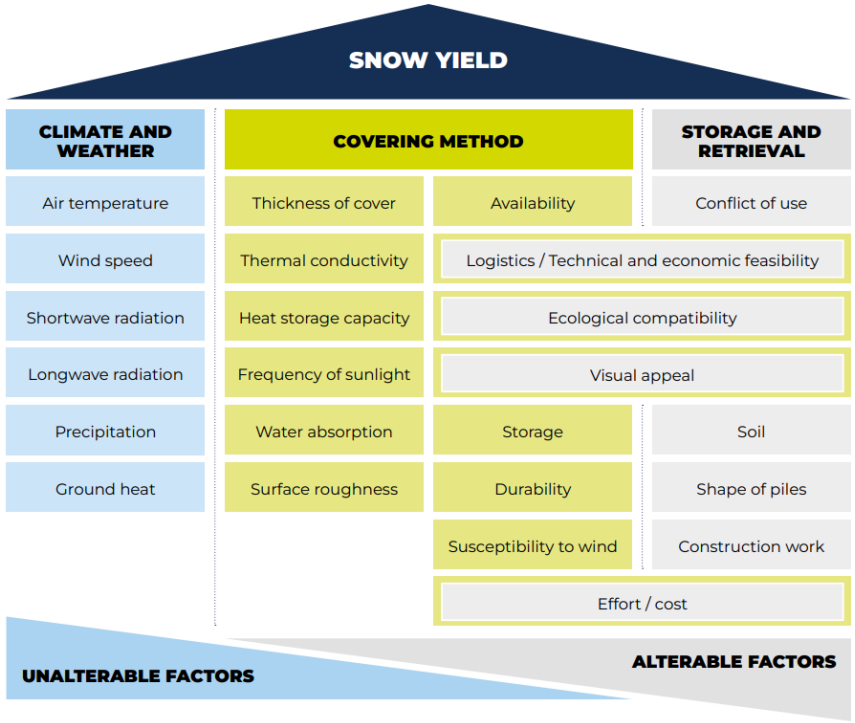
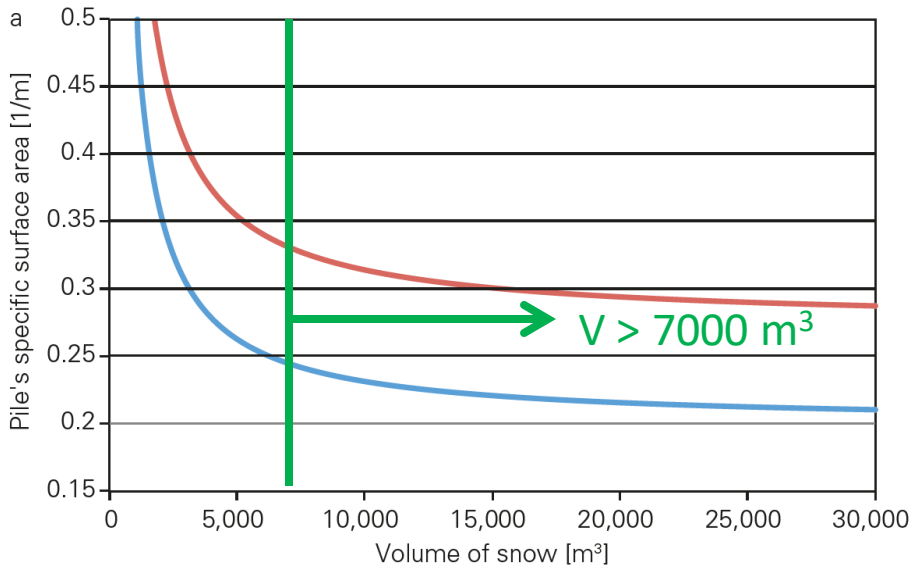
(6) Summary

Snow storage – on schedule snow reliability

Overview of the factors affecting snow farming.





Practical guidelines

1 - Planning
2 - Structural measures
3 - Snowmaking /pile size & shape
4 - Applying the cover
5 - Storage
6 - Removing the cover
7 - Spreading and preparing
8 - Storing coverings

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(6) Summary

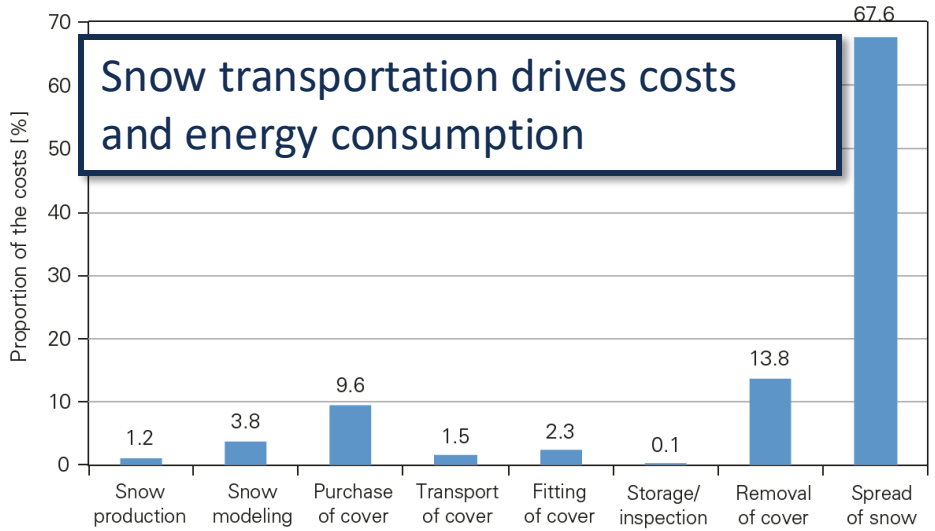
Snow storage – on schedule snow reliability

Research on storage melt using woodchips / sawdust

Sufficient cover thickness > 30 cm is needed

SIEPPUR venues 23:
ESR(storage) = 1.9…3.7 kWh/m³

Case studies analysing cost distribution



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(6) Summary

Snow storage – on schedule snow reliability

The holy grail – the ongoing search for the ultimate cover

- easy to install & minimal work
- small snow losses
- long-living
- low price
- no microplastic source

...

Laborexperiment – Radiation-Folie.

Beispielstücke Spacervlies. Quelle: snowfarming.ch

	Cover	Advantages	Disadvantages
insulating materials	geotextiles silage film truck tarpaulin	– less effort	– high snow loss – reduced albedo[12] – prone to tearing
	sawdust woodchips bark mulch straw	– less snow loss – water absorption	– more effort – winter storage – snow contamination
	insulation slabs insulating mats[13]	– less snow loss – no snow contamination	– more effort – winter storage – decreasing insulating effect due to gradual formation of gaps (Fig. 7.12)
combinations	sawdust + fleece woodchips + truck tarpaulin insulation slabs + fleece + silage film etc.	– higher albedo – protection from water – protection from wind	– additional effort and costs

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