universität innsbruck

Cost Structure, Resource Consumption and Greenhouse Gas Emissions of Snowmaking and Slope Preparation

Regional Mountain Conference (RMC)
Obergurgl / Austria

Günther Aigner

University of Innsbruck, Doctoral College Tourism and Leisure in Mountain Regions

Obergurgl, July 6th 2026

In review!

Abstract

Despite decades of heated debate about the environmental sustainability of ski tourism and its significant economic importance in some regions of the world, scientific research has so far paid little attention to its resource requirements and greenhouse gas emissions.

This study presents the largest sample ever collected in a scientific investigation into snowmaking and slope preparation—covering a total of 41 ski areas in 4 countries in the Alps.

Snowmaking accounts for 21 percent of the total costs of ski operations. 1 m^3 of machine-made snow costs about EUR 3.90 in a full-cost calculation and requires 3.7 kWh of electricity. 42% of a ski area's total electricity consumption is used for snowmaking. Per skier visit, 5.8 kWh of electrical energy and 900 liters of water are required, while 0.6 liters of diesel are spent on slope preparation.

In an ideal scenario (hydropower-based electricity mix and HVO as a diesel substitute), about 500 grams of CO2eq are emitted per skier visit for snowmaking, cable cars, lifts, buildings, and total fuel consumption.

This paper aims to provide an objective framework for discussions regarding the ecological sustainability of skiing and to serve as a data foundation for future research.

In review!

Ski Tourism: Status Quo and Sustainability Debate

Ski Tourism

- Global: 150 million skiers (Vanat, 2026)
- 2024/25: 399 million skier visits worldwide
  → All time high since records began
  (Vanat, 2026)
- Skiing is regarded as a major global tourism industry (Steiger et al., 2019)
- Austria: Cultural and economic significance
  52 million skier visits, 13% share of global ski tourism market
  (Vanat, 2026; Aigner et al., 2026)

Climate Change adaptation & sustainability debates

- Global ski tourism is threatened by climate change
  (Wei et al., 2025; Steiger et al., 2020)
- Snowmaking:
  Key adaptation strategy in ski tourism
  (Knowles et al., 2023; Steiger et al., 2021)
- "Heated debates" on snowmaking since the 1980s. Topics: Energy and water consumption, carbon emissions
  (Pröbstl-Haider & Weiler, 2025, p. 1; Aigner et al., 2026)
- Total emissions of skiing:
  Should people feel ashamed of skiing?
  (DATUM, 2024; Deutschlandfunk Kultur, 2019, Die ZEIT, 2022)

In review!

Thin Scientific Discourse and Significant Research Gaps

- No scientific studies on the cost structure of snowmaking

  (Damm et al., 2014; Breiling et al., 2008)

- Hard to come by: Industry data (Knowles et al., 2023; Steiger et al., 2021; Aigner et al., 2026)
- Very little data on resource consumption (water and energy) and greenhouse gas (GHG) emissions from snowmaking (Knowles et al., 2023; Steiger et al., 2021)
- Lack of data regarding total GHG emissions of skiing (Steiger et al., 2021a, p. 8)
  “Data for an accurate estimation of winter tourism’s GHG emissions is currently not available."
- Call by Steiger et al. (2021, p.1) to seek for "better knowledge of the status quo"
  of ski tourism GHG emissions.

In review!

Research Questions

1. **What is the total cost of snowmaking (full cost)?**
2. **How much electricity and water are consumed per skier visit?**
3. **How much fuel is used for preparing and grooming the slopes?**
4. **What is the carbon footprint of a skier visit, taking into account total electricity consumption and fuel use?**

In review!

Methods and Sample

- Questionnaire created using expert interviews
- Sent out through the national cable car associations of Austria and Germany to their members. The same applied to the South Tyrol region in Italy. Several ski areas in CH.
- 3 defined ski seasons: 2022/23 to 2024/25 (after Covid-19-pandemic recovery)
- Data from 41 ski areas in AT, IT, DE and CH
- Sample includes: 26.2 million skier visits
  → 15.0 percent of the total ski tourism volume in the Alps (175 million) (Vanat, 2026)

In review!

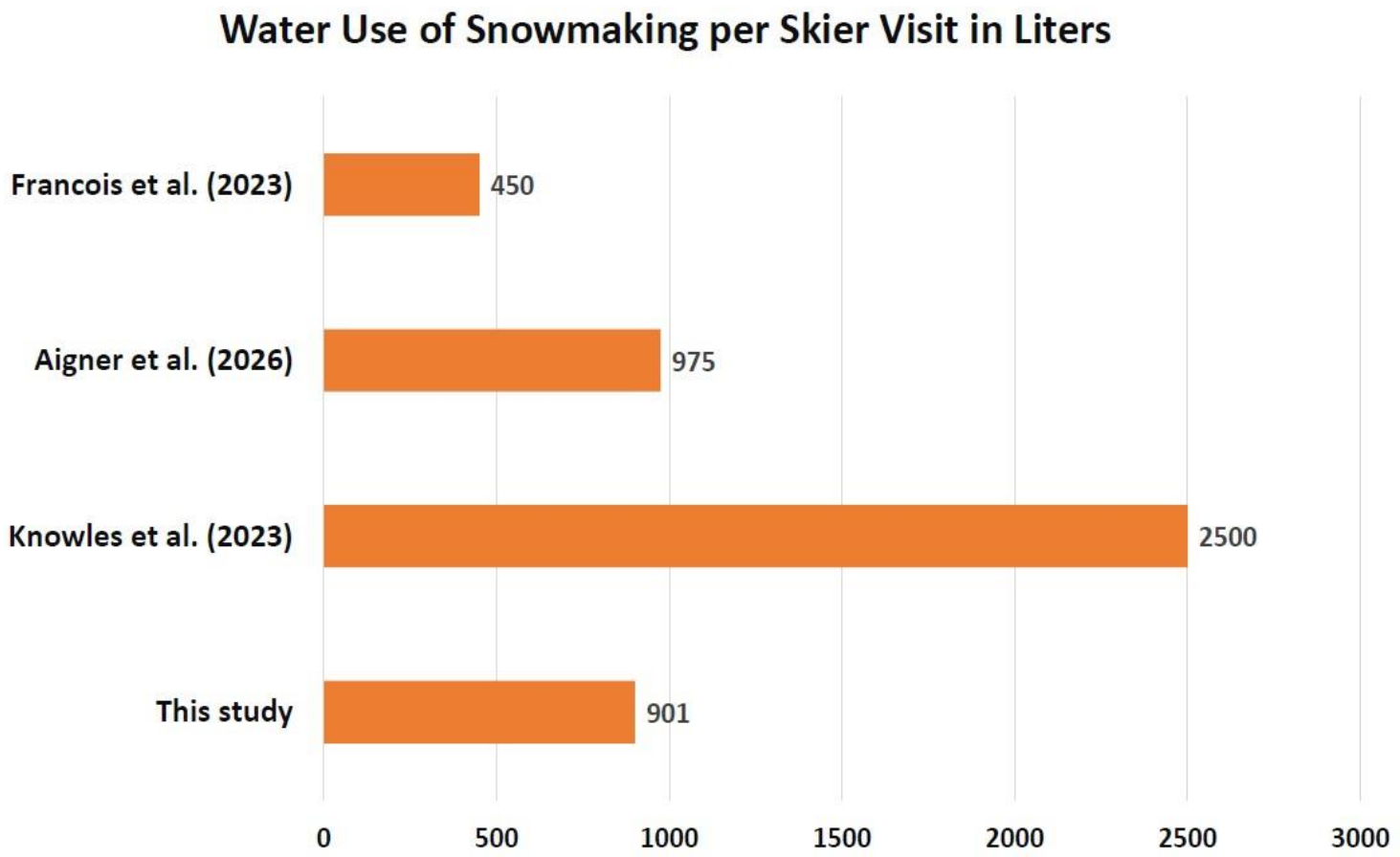
Results

Key figures of snowmaking costs and ski tourism resource consumption

Total cost (full costs) per 1 m^3 of machine-made snow, in EUR	3.9
Full costs of snowmaking, in % of the total costs of ski operations	20.7
Total operating time of the snowmakers per season, in h	188
Total water turnover for snowmaking per skier visit, in liters	901
Depth of machine-made snow (slope thickness), in cm	68.6
Total energy consumption of ski operations per skier visit, in kWh	13.8
GHG emissions of total electricity consumption per skier visit, in g CO_{2eq}	331.3
Fuel consumption per skier visit, in liter	0.56
Percentage of HVO in total fuel consumption	33.0
GHG emissions of top 7 most climate-friendly ski areas in the sample, in g CO_{2eq}	509

In review!

Discussion: Water Use

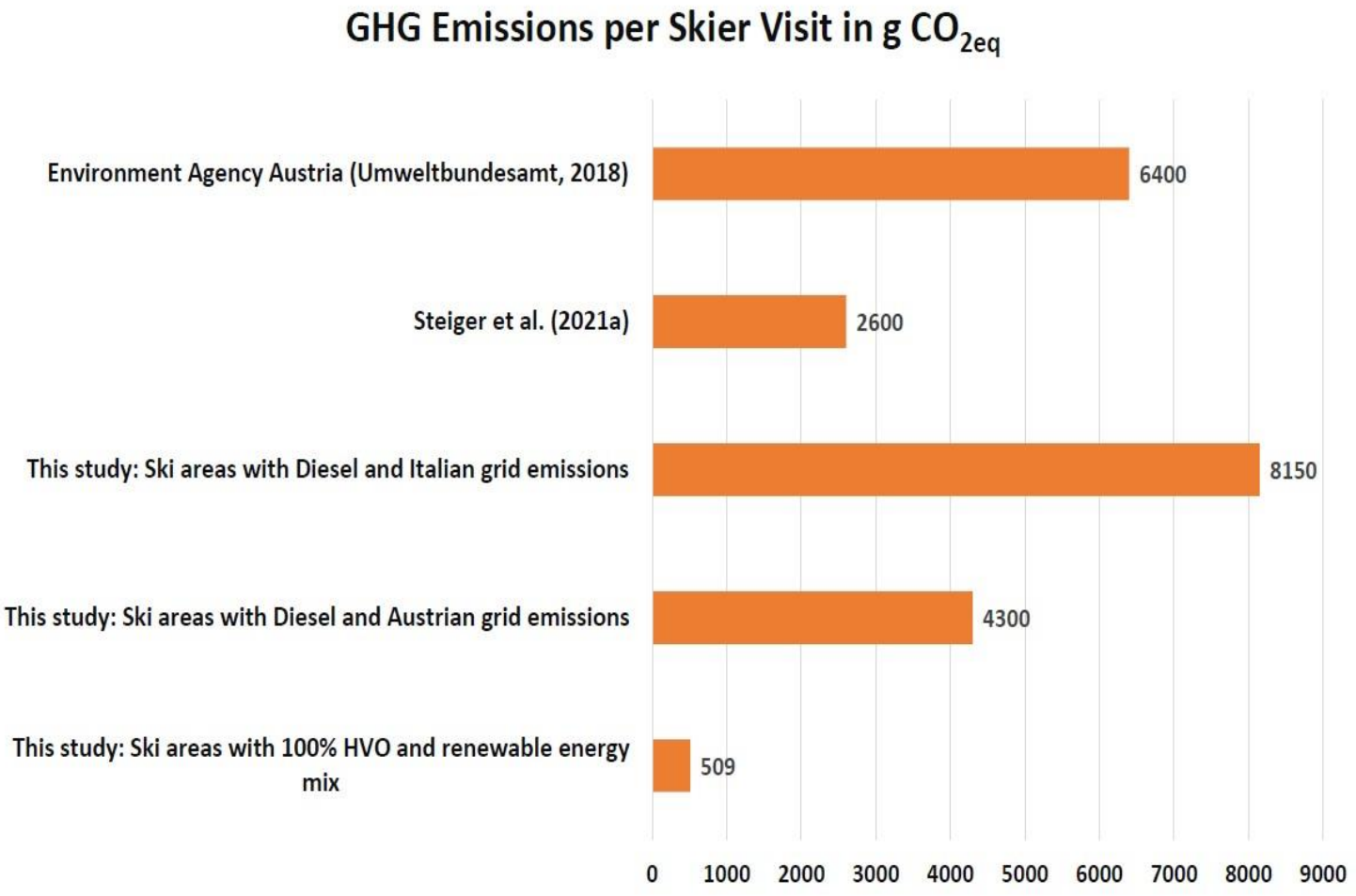


Is the water used up, or is it recirculated?

- No question: Huge amounts of water are used for ski tourism
- How is the discussion framed: Is the water being used up and/or contaminated? Or is it simply being recirculated?
  (Steiger et al., 2021; Aigner et al., 2026)

In review!

Discussion: GHG Emissions



Travel Distance Comparison

Equivalent to distances traveled in a gasoline-powered car
140,6 g CO_{2eq}/km (BMI, 2025)

- Diesel & Italian grid:
  58.0 km
- Diesel & Austrian grid:
  30.6 km
- HVO & energy from Hydropower:
  3.6 km

In review!

Management Implications

- Skiing can be more climate-friendly than is commonly assumed in public discourse.
  → Ski tourism needs a better information policy!
- Use of HVO and "green" electricity: Crucial for a low GHG footprint!
  → Ski resorts must (1) use HVO, (2) generate own electricity from renewable sources,
  (3) and convince policymakers to further decarbonize the power grid.

Limitations

- It was very difficult to obtain data (Knowles et al., 2023; Steiger et al., 2021; Aigner et al., 2026)
  1) Lack of transparency 2) Surprising lack of data availability | technical controlling

Conclusion

- Snowmaking costs: 21 % of the total costs of ski operations. EUR 3.90 / m^3 in a full-cost calculation.
- GHG emissions from ski operations can be reduced to a small residual amount of 500g CO_{2eq} per skier visit.
  → Equivalent to a drive with gasoline-powered car of < 4 km

In review!

References – I

Aigner, G., Mayer, M., & Steiger, R. (2026) Snowmaking in Austria: Resource consumption and greenhouse gas emissions. Journal of Sustainable Tourism. https://doi.org/10.1080/09669582.2026.2656746

Bundesministerium für Innovation, Mobilität und Infrastruktur (BMI) (2025). Factsheet zu den CO_2-Emissionen neu zugelassener Pkw in Österreich im Jahr 2023. Wien. Last visited: May 31, 2026. https://www.bmimi.gv.at/themen/mobilitaet/co2_monitoring/pkw.html

Breiling, B., Charamza, P., & Feilmayr, W. (2008). Klimasensibilität des Salzburger Wintertourismus nach Bezirken. Die Bedeutung eines Klimawandels und Strategien der Anpassung (Vol. E-260L). Technik.Tourismus.Landschaft, TU Wien.

Damm, A., Köberl, J., & Prettenthaler, F. (2014). Does artificial snow production pay under future climate conditions? A case study for a vulnerable ski area in Austria. Tourism Management 43 (2014) 8-21. https://doi.org/10.1016/j.tourman.2014.01.009

DATUM (2024). Ski-Scham. Last visited May 31, 2026. https://datum.at/ski-scham/

Deutschlandfunk Kultur (2019). Wo bleibt die Ski-Scham? Last visited May 31, 2026. https://www.deutschlandfunkkultur.de/wintersport-wo-bleibt-die-ski-scham-100.html

Die ZEIT (2022). Skifahren und Nachhaltigkeit. Darf man das noch? Last visited May 31, 2026. https://www.zeit.de/2022/07/skifahren-nachhaltigkeit-wintersport-skigebiete

Knowles, N., Scott, D. & Steiger, R. (2023) Sustainability of Snowmaking as Climate Change (mal)Adaptation: An Assessment of Water, Energy, and Emissions in Canada's Ski Industry. *Current Issues in Tourism*, Volume 27, 2024 – Issue 10. https://doi.org/10.1080/13683500.2023.2214358

Pröbstl-Haider, U. & Weiler, C. (2025). Technische Beschneiung und Umwelt. Hintergründe, Prozesse, Auswirkungen. Springer Spektrum. https://link.springer.com/book/10.1007/978-3-662-69778-8

In review!

References – II

Steiger, R., Scott, D., Abegg, B., Pons, M., & Aall, C. (2019). A critical review of climate change risk for ski tourism. Current Issues in Tourism, 22(11), 1343-1379. https://doi.org/10.1080/13683500.2017.1410110

Steiger, R., Posch, E., Tappeiner, G., & Walde, J. (2020): The impact of climate change on demand of ski tourism - a simulation study based on stated preferences. Ecological Economics 170, Article 106589. https://www.sciencedirect.com/science/article/abs/pii/S0921800919315344

Steiger, R., Damm, A., Prettenthaler, F., & Pröbstl-Haider, U. (2021). Climate change and winter outdoor activities in Austria. Journal of Outdoor Recreation and Tourism, 34, 100330. https://doi.org/10.1016/j.jort.2020.100330

Umweltbundesamt Österreich (2018). Vergleichende Treibhausgasbilanz typischer Arten von Urlauben. This 17-page PDF can be downloaded. Website last visited on May 13, 2026: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://greenmountain.snow-space.com/wp-content/uploads/2021/12/Vergleichende-Treibhausgasbilanz-von-Urlaubsarten_UBA_final.pdf

Vanat, L. (2026) 2026 International Report on Snow & Mountain Tourism. www.vanat.ch

Wei, Y., Li, J., Luo, D., Tang, X., Su, Z., & Wang, X. (2025) Risks and sustainability of outdoor ski resorts in China under climate changes. Npj Climate and Atmospheric Science 8, Article number 26. https://doi.org/10.1038/s41612-025-00917-0

In review!

Contact: Günther Aigner **Mail to: guenther.aigner@student.uibk.ac.at**

In review!

/uniinnsbruck

www.uibk.ac.at