



Environmental Engineering and the Swiss Energy Turn-Around



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Menue

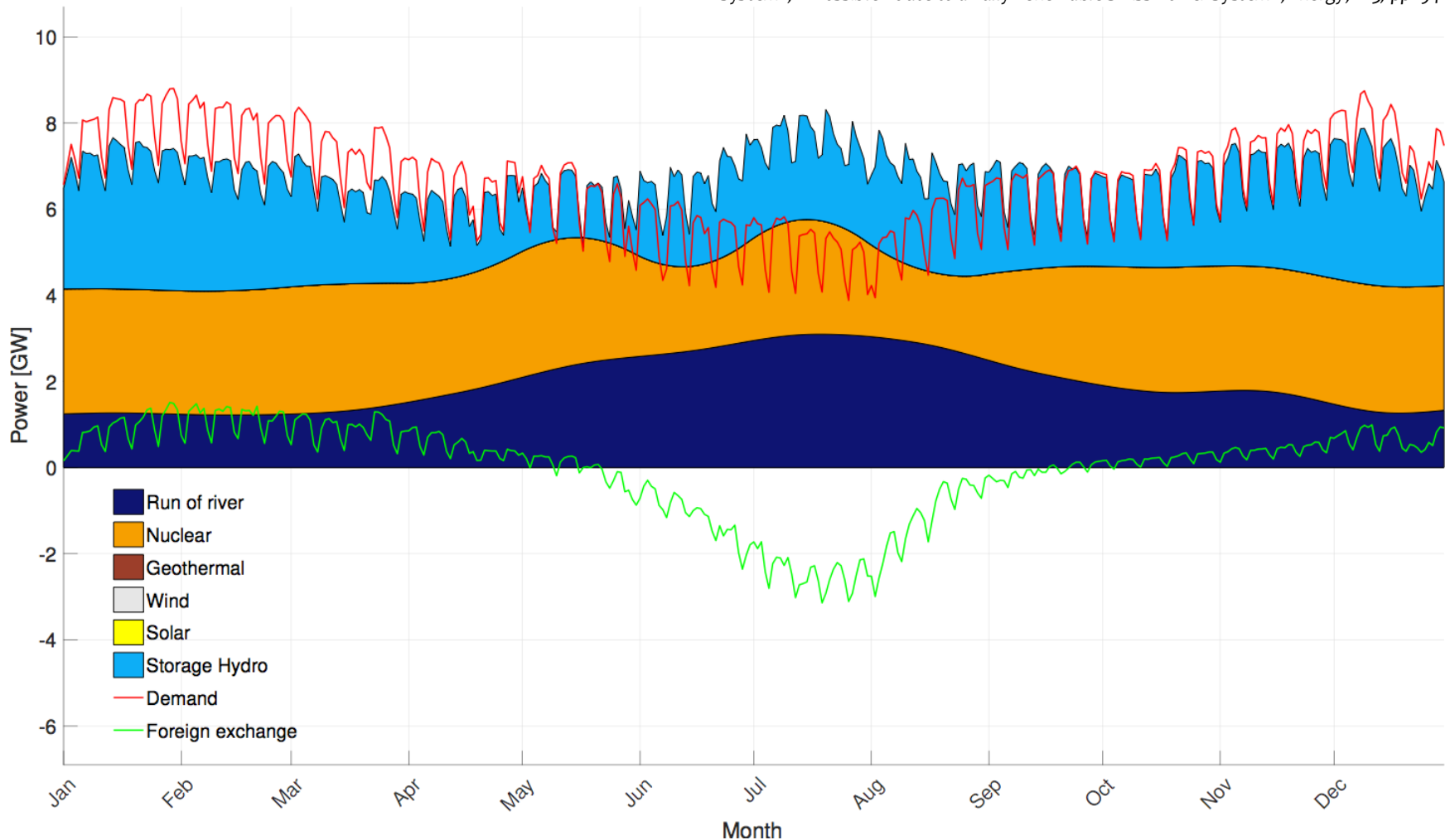
- * The Swiss energy problem
- * The renewable scenario with PV in the Swiss electricity world
- * The correct radiation energy balance in complex snowy terrain
- * What about wind?
- * The current situation in Switzerland and scenarios
- * Possible solutions, actions and conclusions

→ Let's see what the snow on mountains can contribute for a
Future Renewable Switzerland

Current Average Production and Demand (CH)

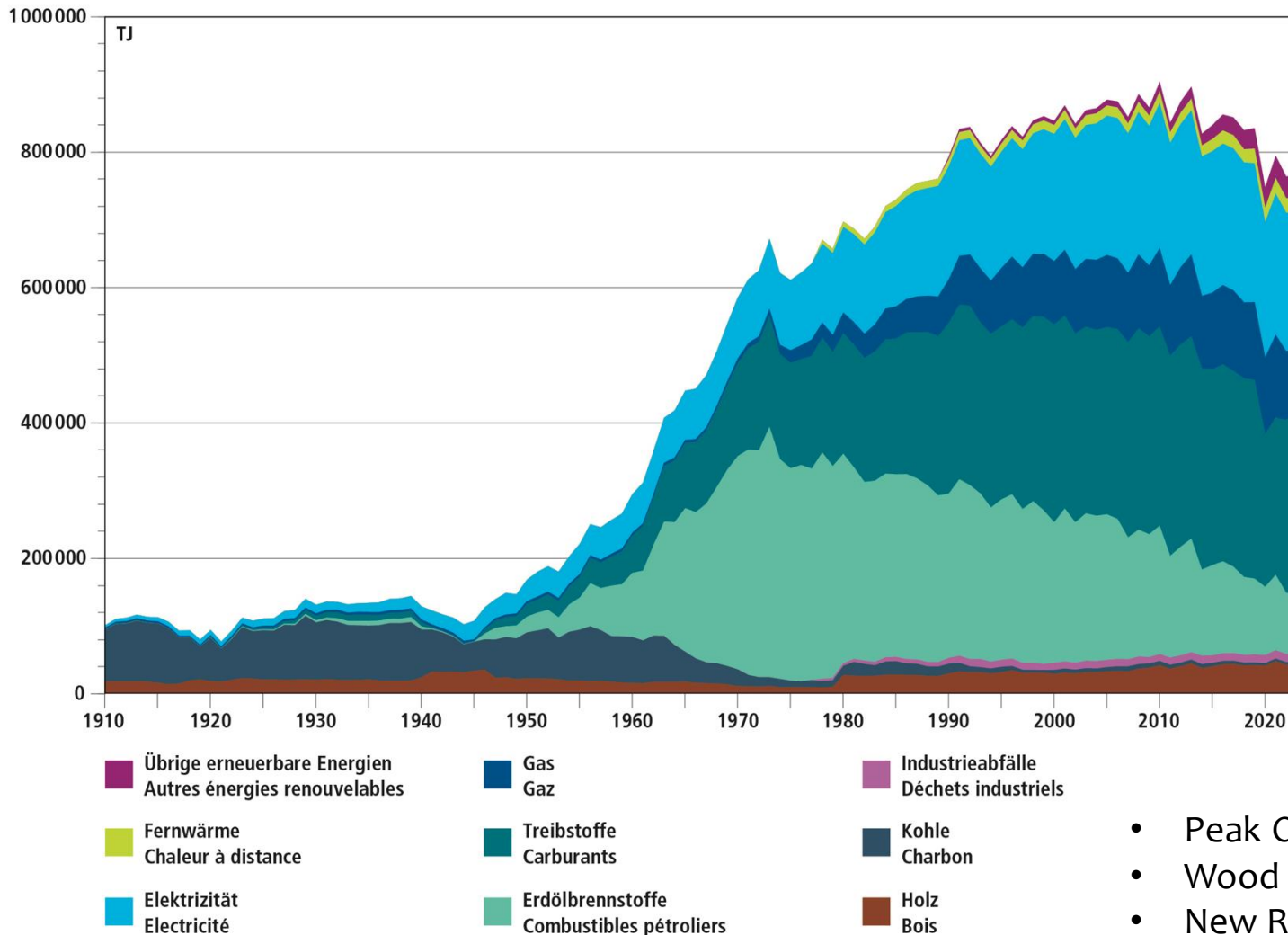
- Overall good balance
- Winter Import
- Sommer Export

Bartlett, S. et al., 2018. Charting the Course : A Possible Route to a Fully Renewable Swiss Power System. , *Energy*, 163, pp. 942–955.



Total Energy Demand (CH)

Fig. 1 Endenergieverbrauch 1910–2023 nach Energieträgern
Consommation finale 1910–2023 selon les agents énergétiques



- Peak Oil has been reached
- Wood is still important
- New Renewables are tiny

Total Energy Demand (CH)

Fig. 2 Aufteilung des Endverbrauchs nach Energieträgern (2023)
Répartition de la consommation finale selon les agents énergétiques (2023)

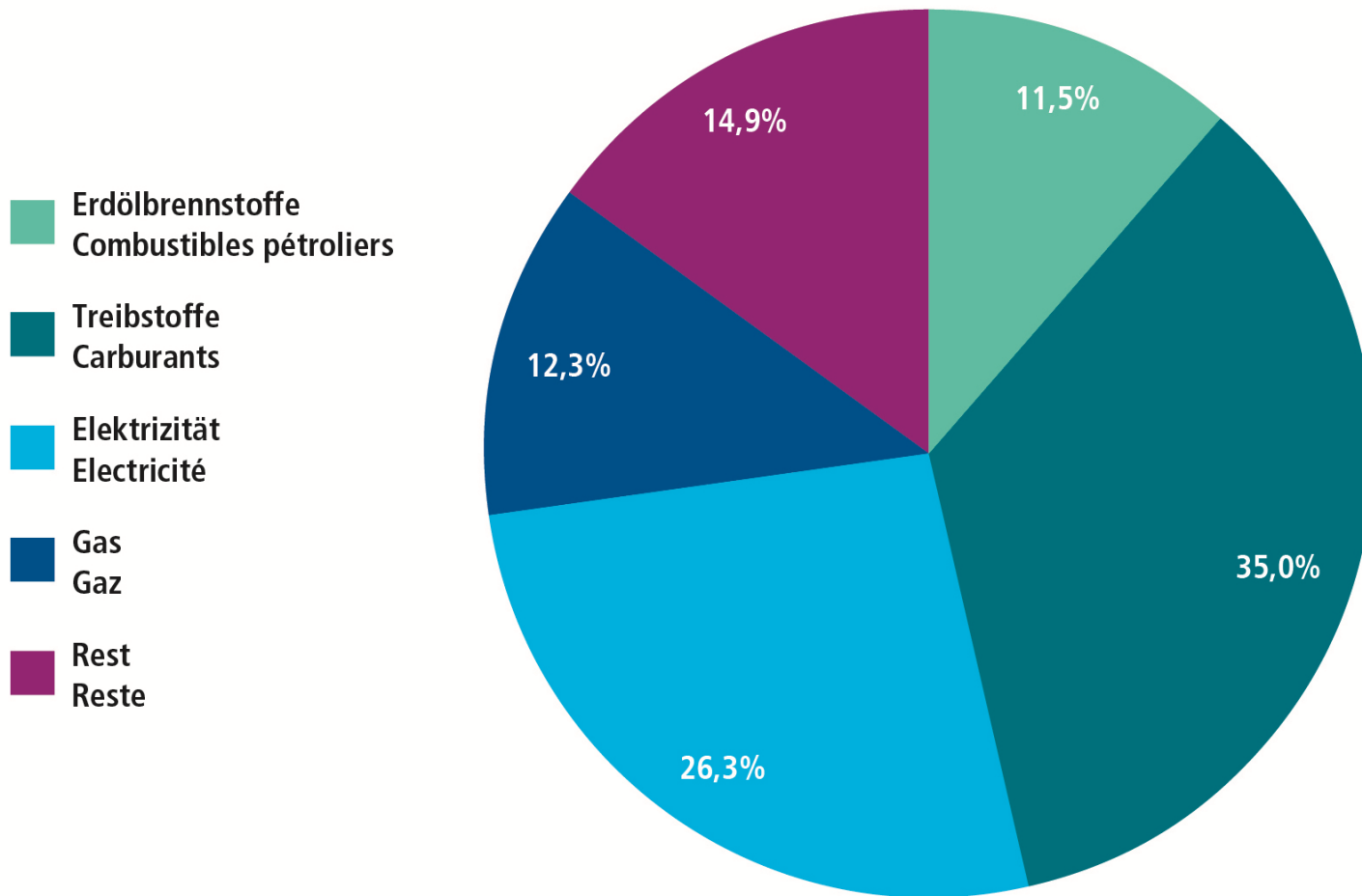
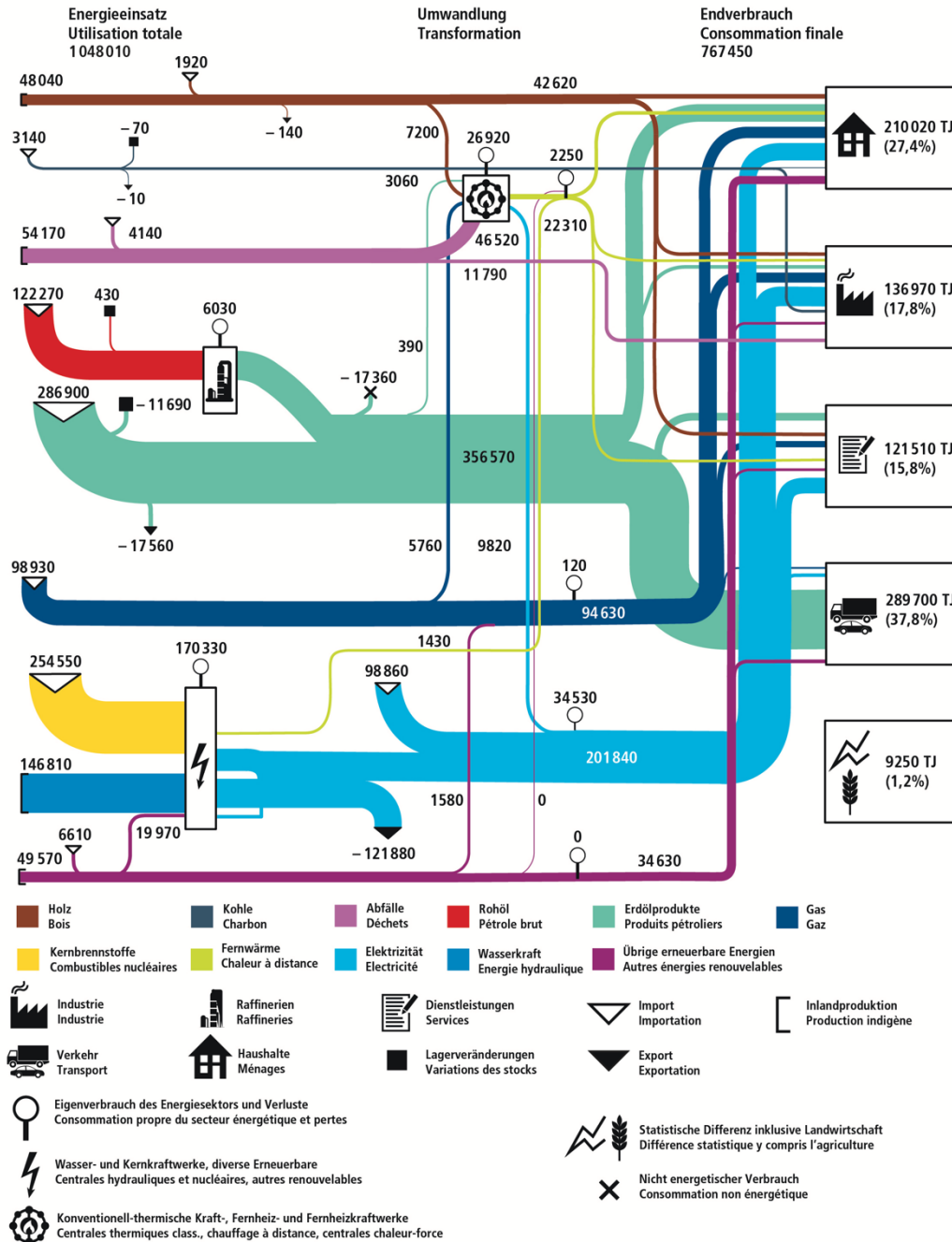


Fig. 5 Detailliertes Energieflussdiagramm der Schweiz 2023 (in TJ)
Flux énergétique détaillé de la Suisse en 2023 (en TJ)

BFE, Schweizerische Gesamtenergiestatistik 2023 (Fig. 5)
OFEN, Statistique globale suisse de l'énergie 2023 (fig. 5)



Detailed Energy Fluxes

- Traffic and Households are main consumers
- Industry and Services are smaller
- Fossil Sources still dominate

Problem Setting 2019

Neue Zürcher Zeitung

KOMMENTAR

Drohender Strommangel: Die Schweiz braucht einen Elektroschock

Ohne Strom geht nichts. Die Schweiz setzt ihre Versorgungssicherheit fahrlässig aufs Spiel. Ein Weckruf für ein Land, das sich in falscher Sicherheit wiegt.

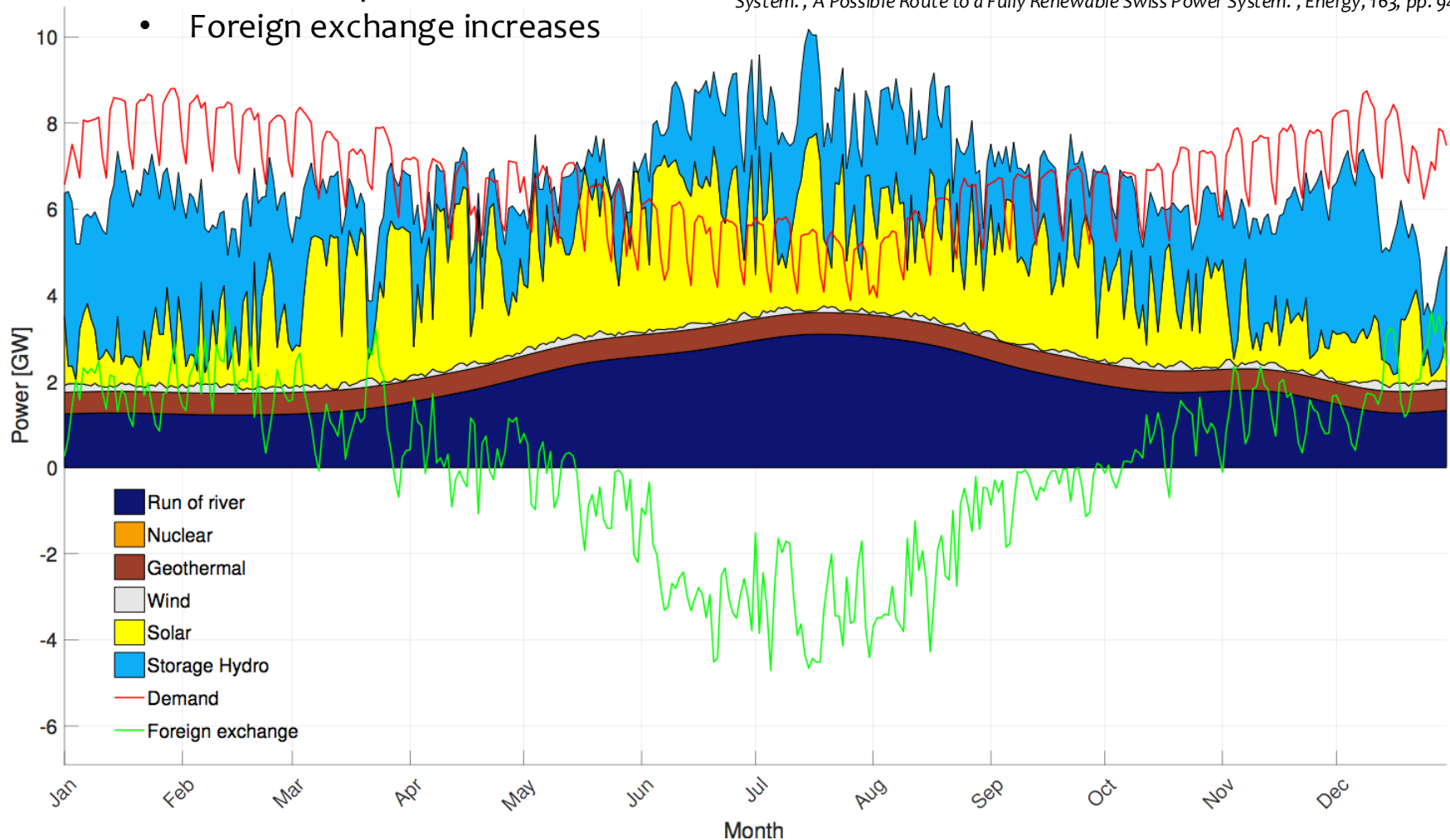
Helmut Stalder 22.5.2019, 05:30 Uhr

- * Security of Supply
- * Dependence on Import
- * Winter Electricity Gap
- * Fossil Fuel Dependence

Renewable Scenario with PV (CH)

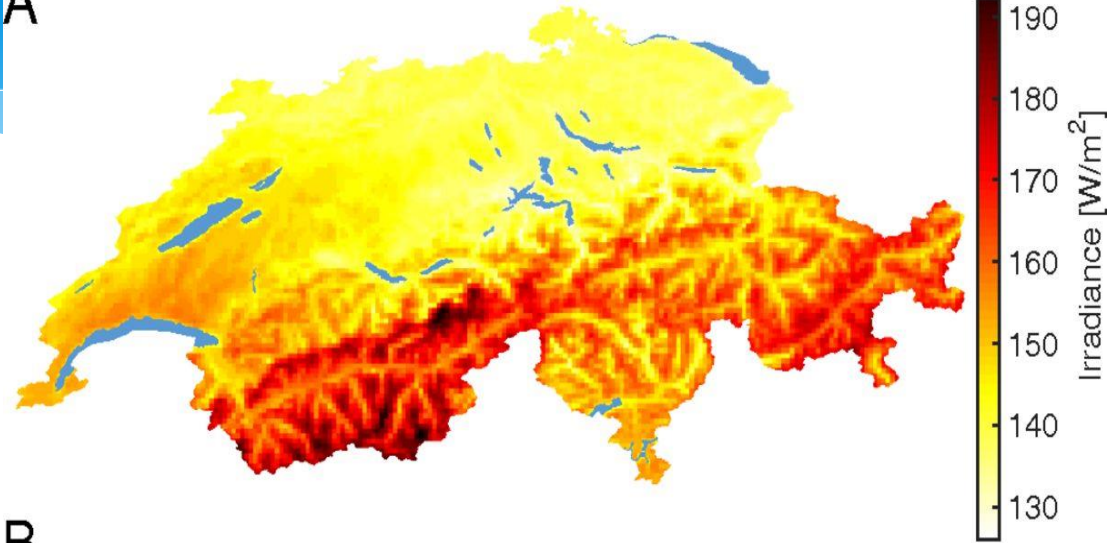
- Overall good balance
- Winter Import
- Sommer Export
- Foreign exchange increases

Bartlett, S. et al., 2018. Charting the Course : A Possible Route to a Fully Renewable Swiss Power System. , *Energy*, 163, pp. 942–955.



Situation for PV

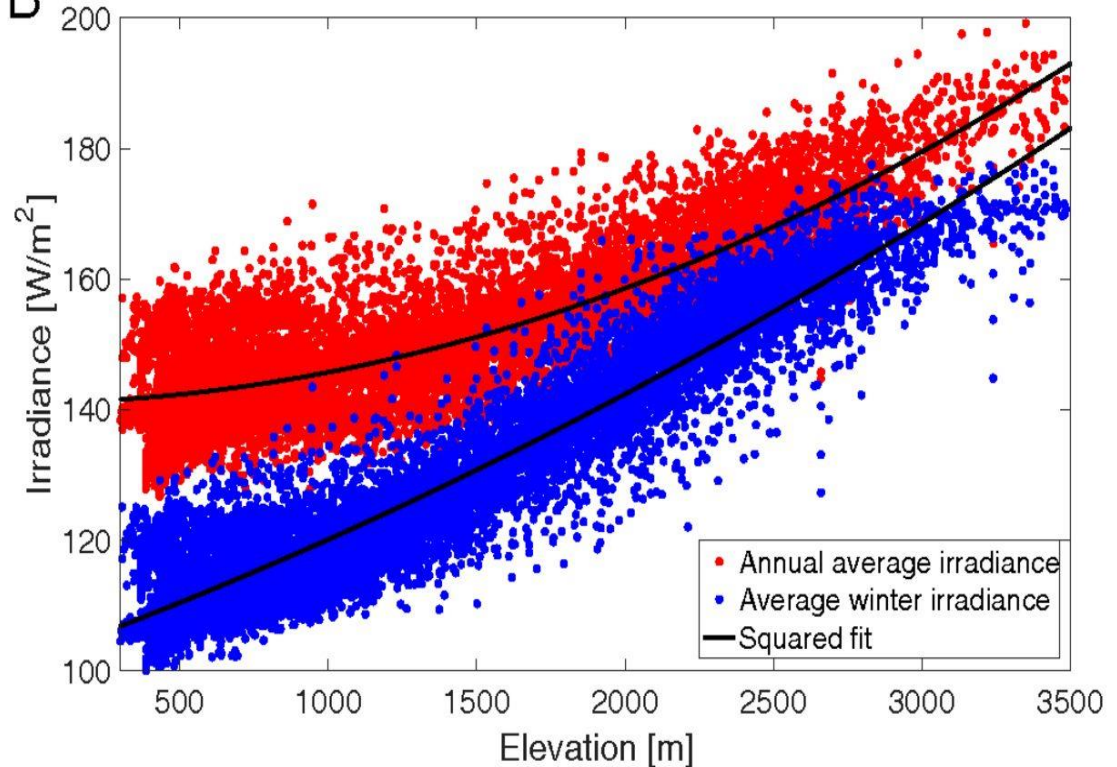
A



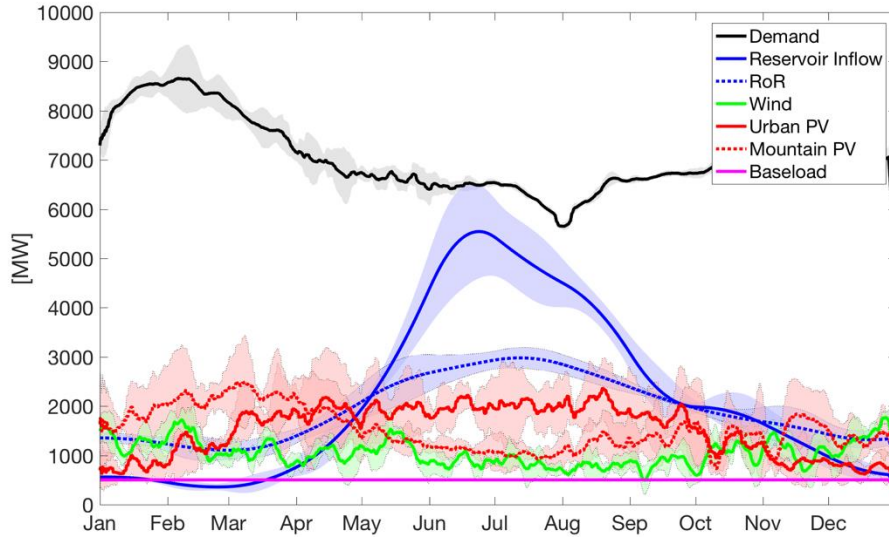
Distribution of incoming global irradiance (Heliomont product by MeteoSwiss) in Switzerland (2011 – 2016).

Winter shows an even stronger increase with elevation

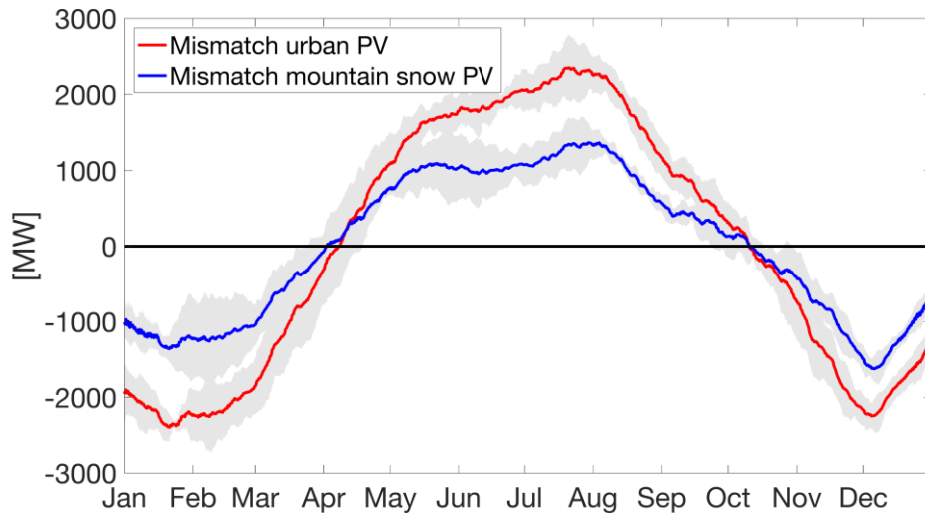
B



Significant seasonal mismatch reduction



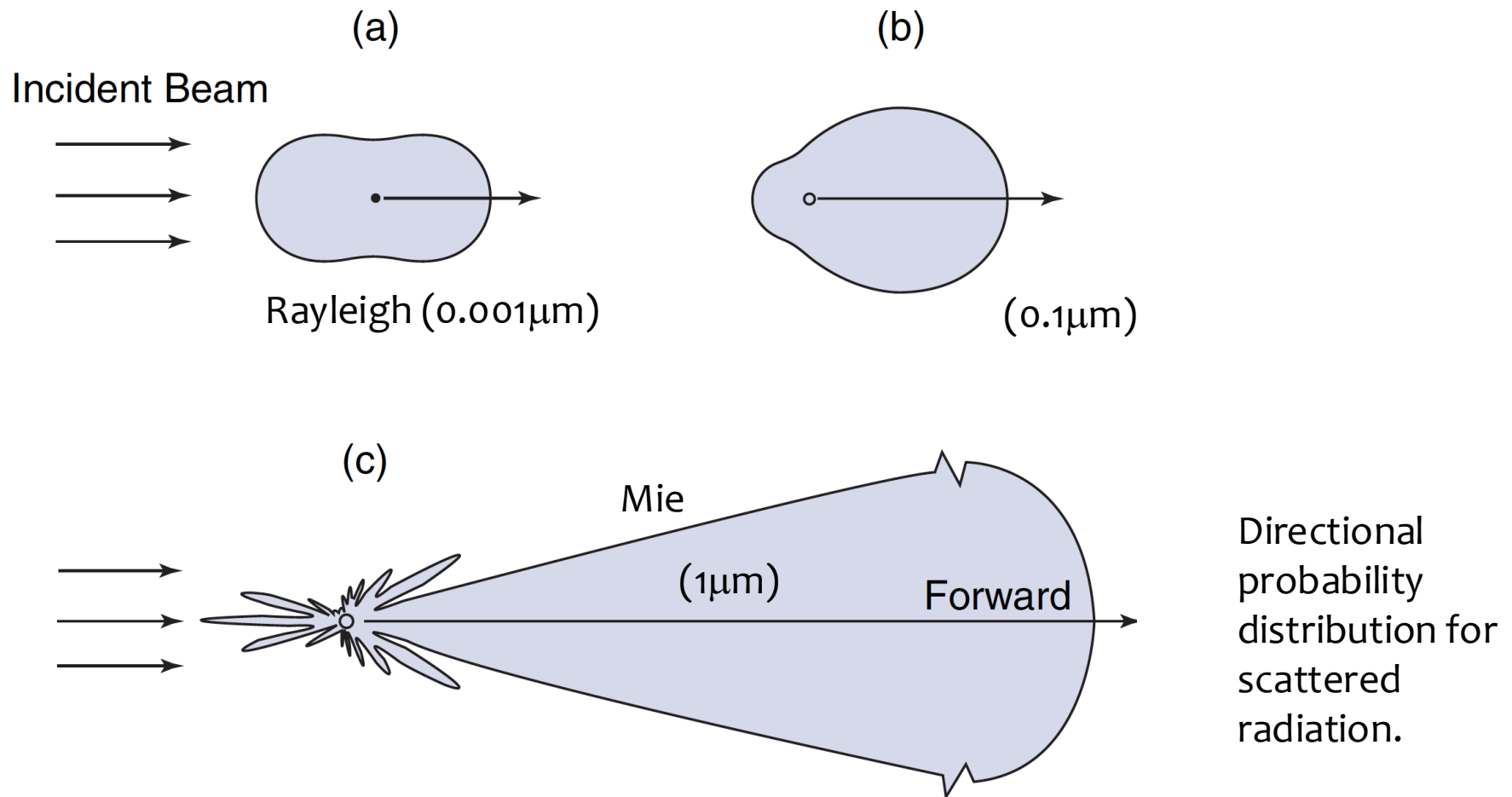
This mismatch reduction also reduces the required import of energy



	Panel tilt	PV area
urban	40°	53km ²
mountain	90°	42km ²

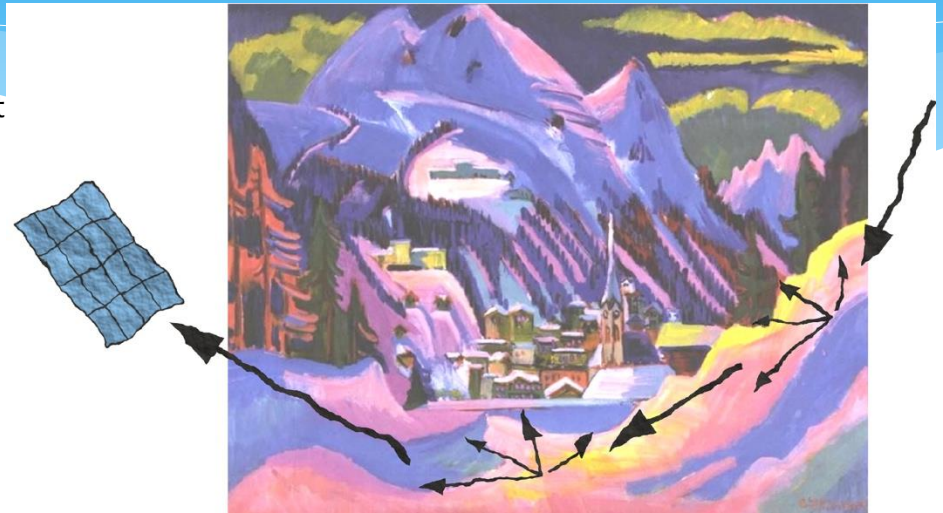
Back to radiation: The effect of snow

Snow is "forward scattering", multiple reflections from terrain and between clouds and snow covered surface

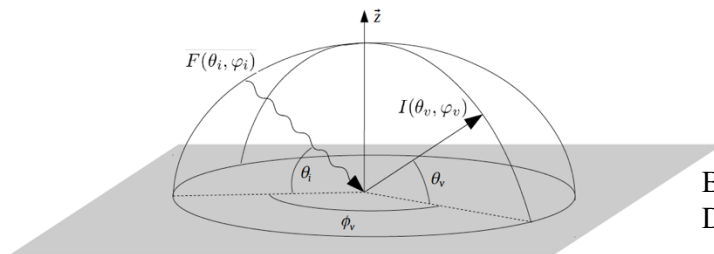


Radiative Transport Processes to Consider over Terrain

- **Assumptions:**
- We know incoming shortwave radiation (direct and diffuse) at the surface
- Diffuse radiation from the sky is isotropic
- Broadband treatment is sufficient
- Geometric optics can be used



Anisotropy



Broadband Bidirectional Reflectance Distribution Function (BRDF)

F SW Flux density (W/m^2)

I Radiance ($W/m^2/sr$)

R Anisotropy Factor

$$R(\theta_v, \varphi_v, \theta_i, \varphi_i) = \frac{\pi I(\theta_v, \varphi_v)}{\alpha F(\theta_i, \varphi_i)}$$

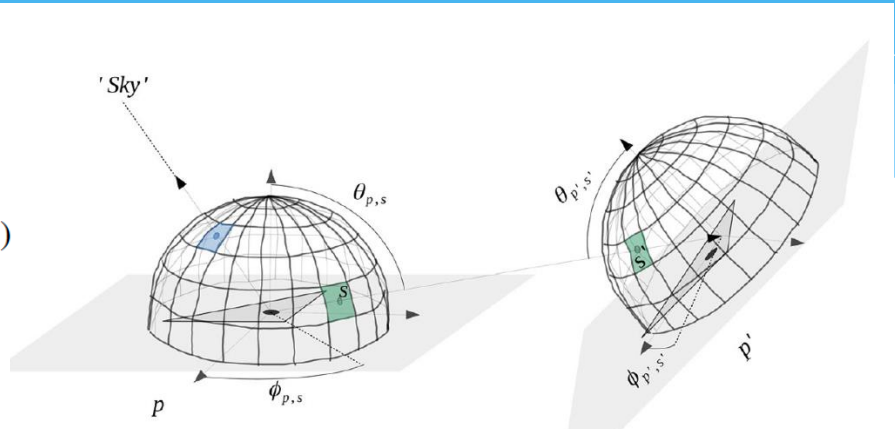
$$\text{Albedo: } \alpha(\theta_i, \varphi_i) = \int_0^{\pi} \int_0^{2\pi} d\phi_v d\theta_v \rho(\theta_i, \phi_i, \theta_v, \phi_v) \sin \theta_v \cos \theta_v.$$

Implementation of Groundeye into Alpine3D

Solve iteratively:

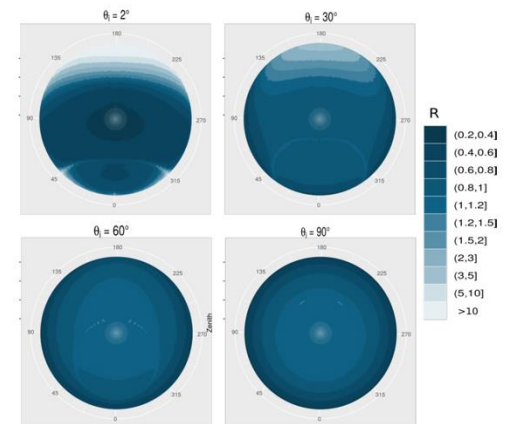
$$I_p(\theta, \phi) = I_p^{single}(\theta, \phi) + \frac{\pi}{S} \cdot \sum_{(p,s) \rightarrow Sky} I_{p'}(\theta_{p',s'}, \phi_{p',s'}) \rho_p(\theta_{p,s}, \phi_{p,s}, \theta, \phi)$$

$$I_p^{single}(\theta, \phi) = \rho_p(\theta_{p,sun}, \phi_{p,sun}, \theta, \phi) F_p^{direct} + \frac{\alpha_p}{\pi} F_p^{diffuse}$$



S: Number of Segments

- **Define:**
- Effect of forward scattering
- Effect multiple scattering
- Forward scattering enhancement of multiple scattering

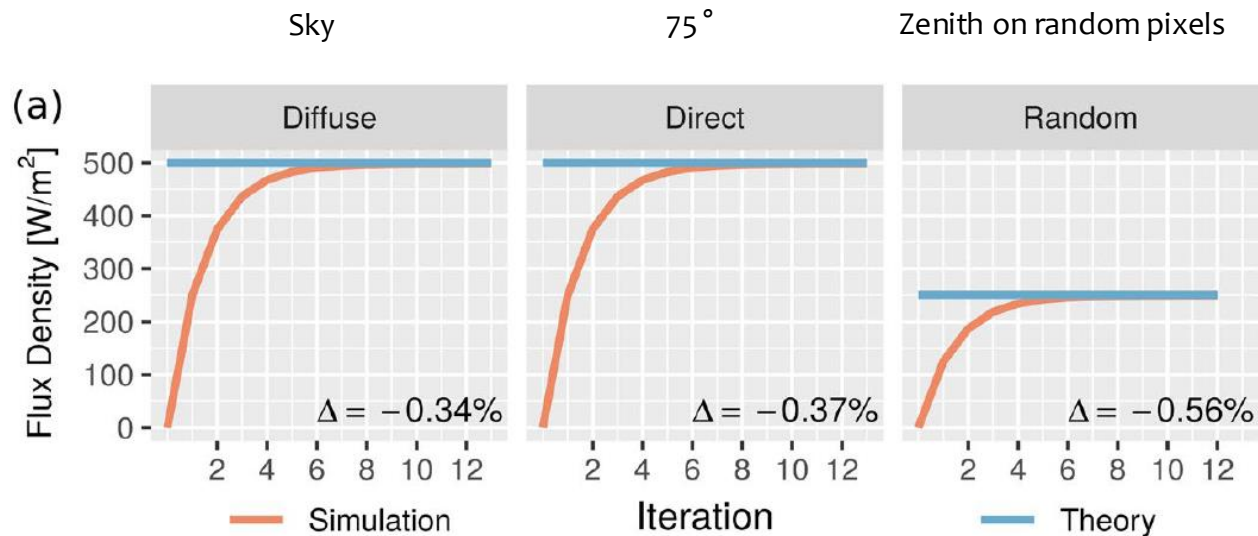
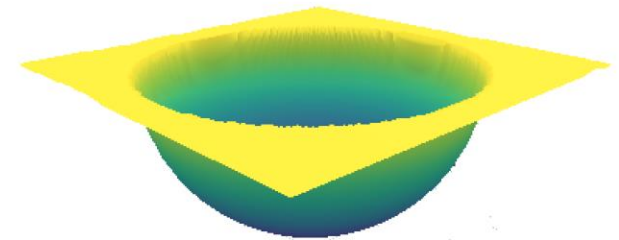


Anisotropy based on Mishchenko Model

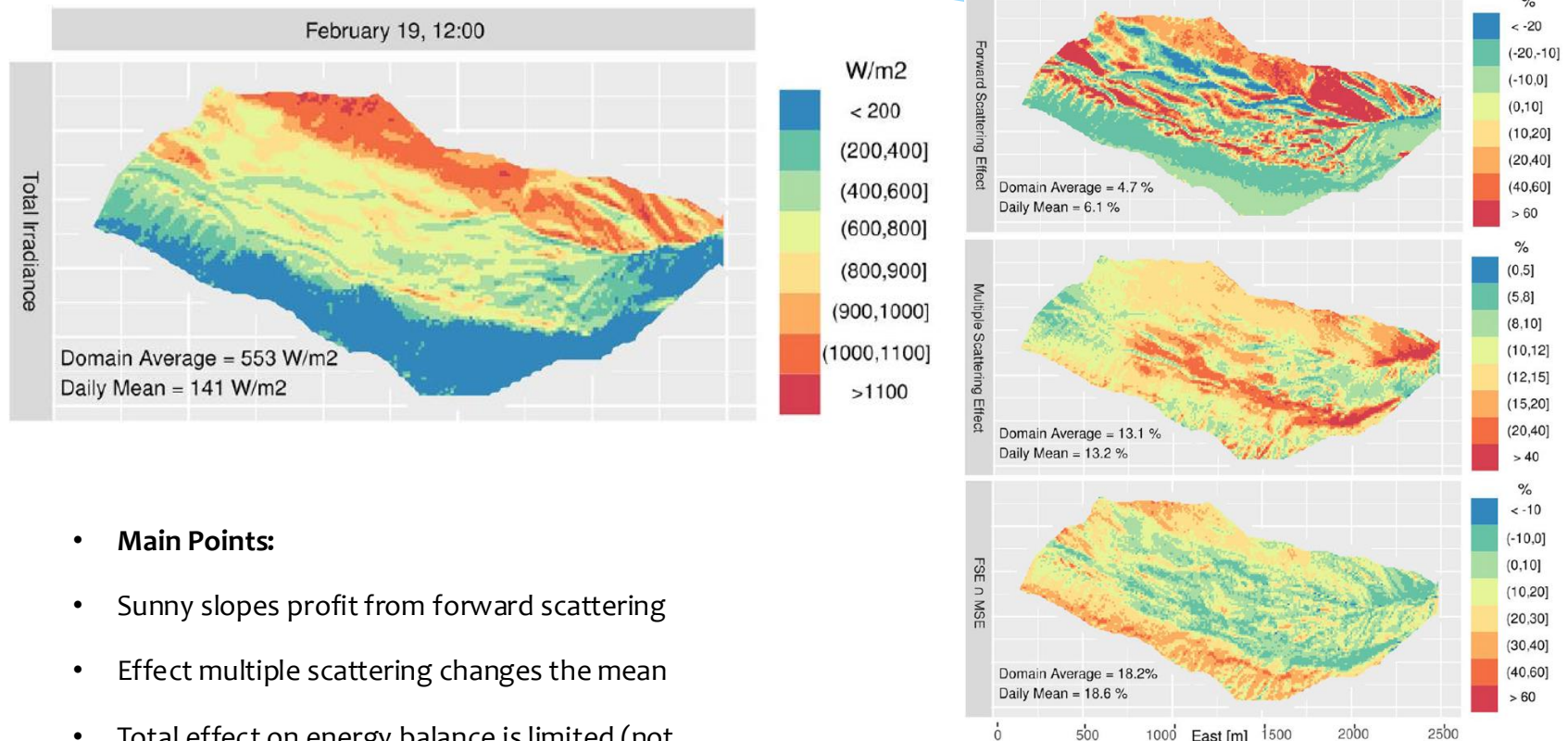
Verification of Groundeye – Hemispherical Cavity

- **Characteristics:**
- Sky view factor = $\frac{1}{2}$ for all points
- Lambertian, non-absorbing surface
- Geometric series gives you solution of radiation distribution
- Shown are three cases of radiation input

Hemispherical cavity



Results: Spatial distribution of radiation and effect on Energy Balance

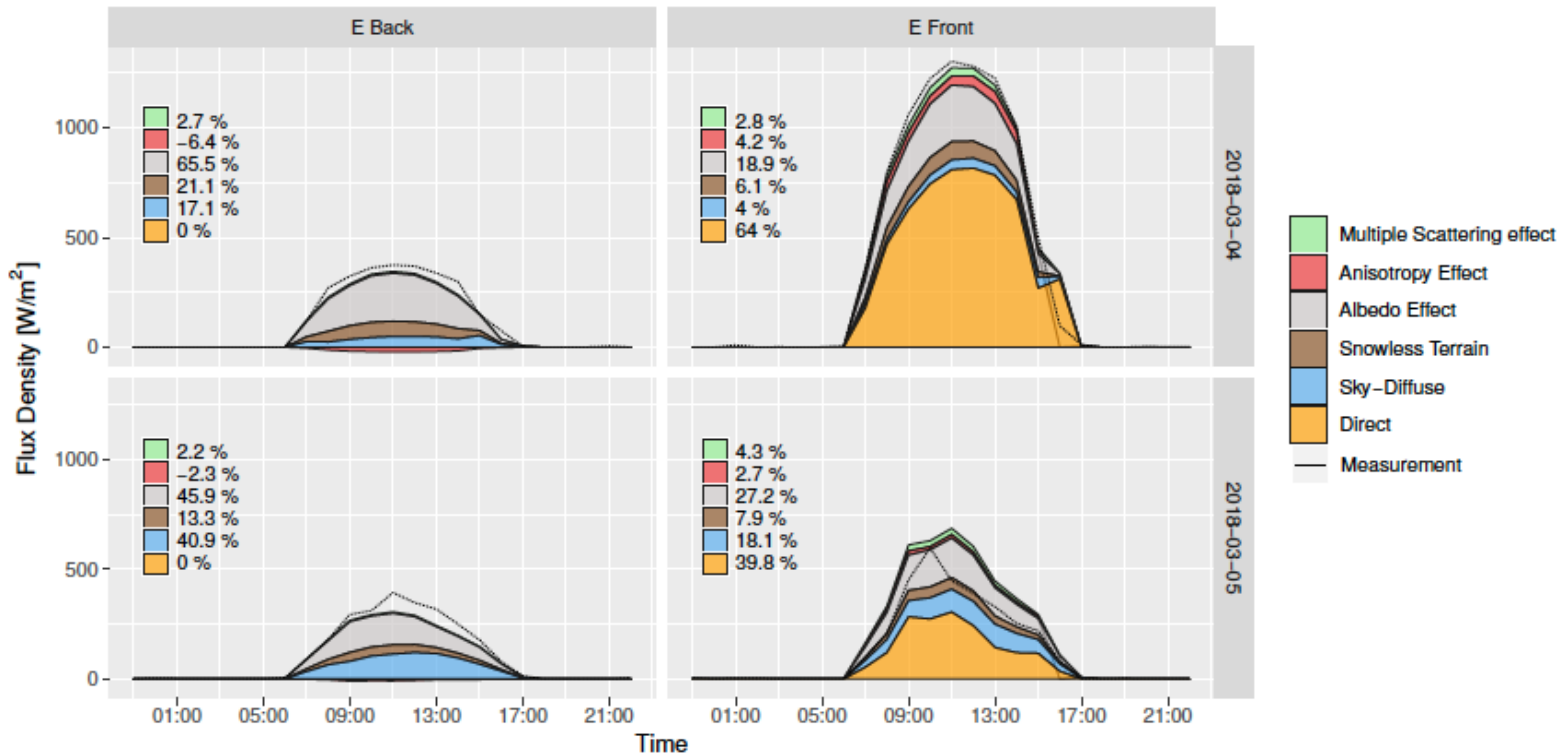


- **Main Points:**
- Sunny slopes profit from forward scattering
- Effect multiple scattering changes the mean
- Total effect on energy balance is limited (not shown)

The effect of snow on solar panels

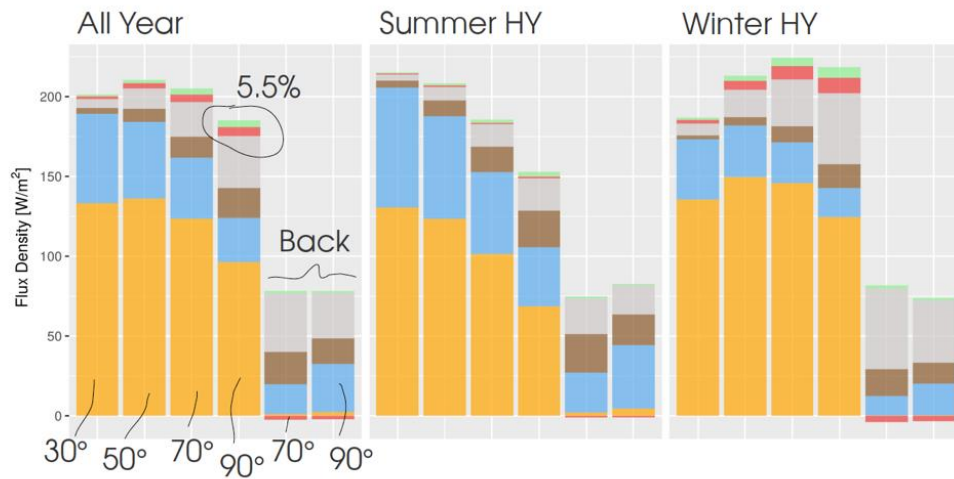


Total Installation (EKZ+ ZHAW)



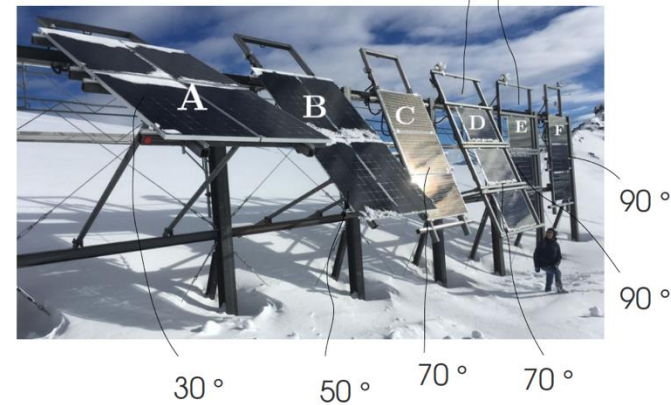
Effect on Solar PhotoVoltaics (PV) Yield

Radiation Contributions



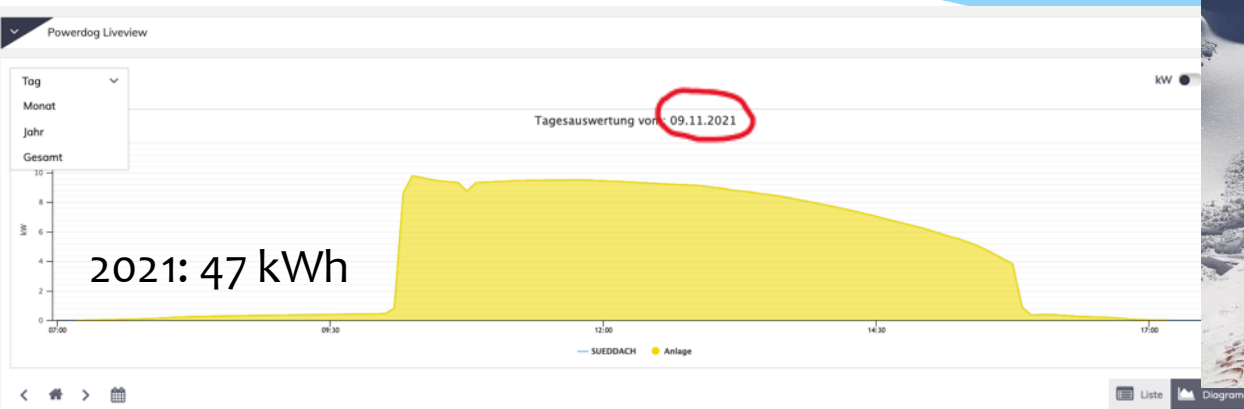
Test Facility Totalp

Bifacial



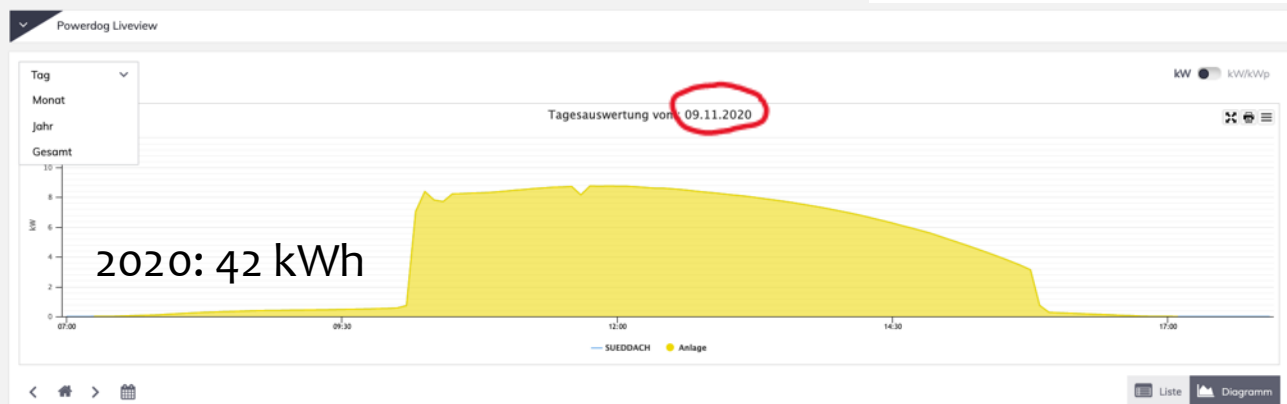
- **Main Points:**
- During the winter months, effect of forward scattering can be considerable (>10%)
- Back side of bi-facial panels get reduced radiation
- Total effect on energy balance is limited (not shown)

Does it matter in practice ?



Produktionsdaten 09.11.2021

Produktion	Ertrag	spezifis
47,52 kWh	14,26 CHF	3,88 kWh

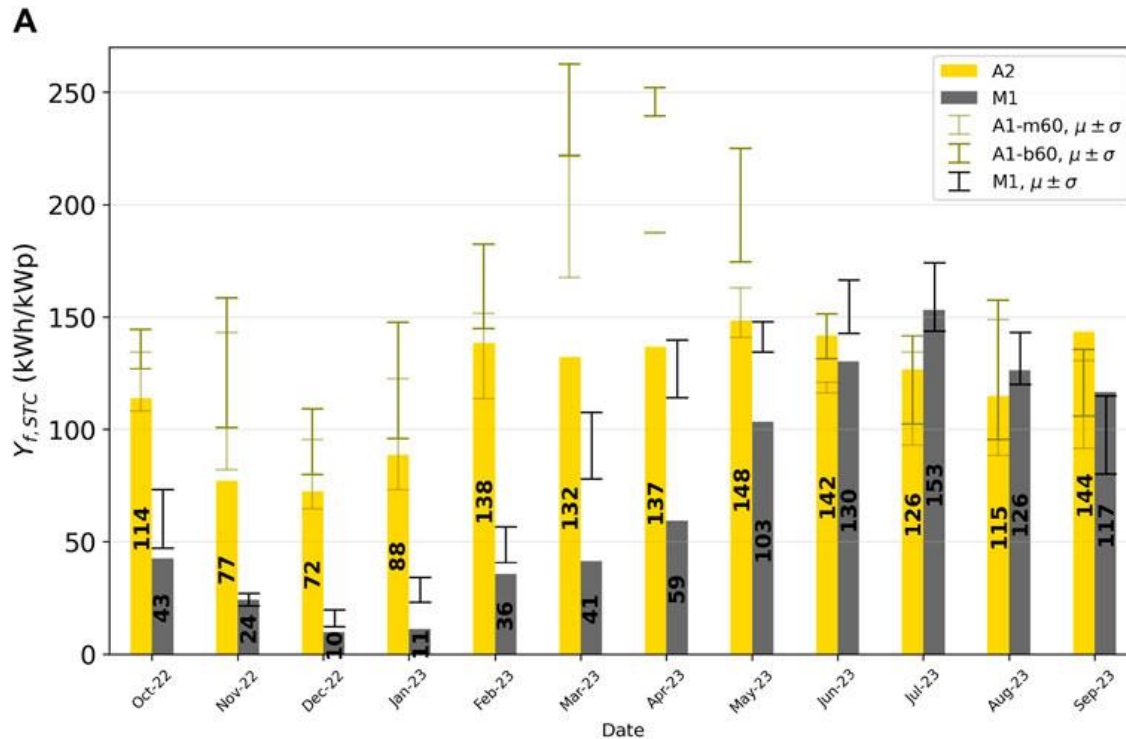


Produktionsdaten 09.11.2020

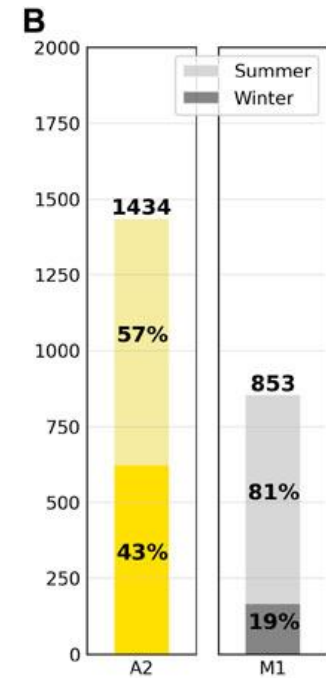
Produktion	Ertrag	spezifischer Ertrag	CO ₂ - Ersparnis in diesem Zeitraum
42,58 kWh	12,77 CHF	3,48 kWh/kWp	CO ₂ - Ersparnis in diesem Zeitraum: 29,81 kg

Praxis: Production @ Muttsee

Comparison of the production between a high-Alpine installation and a plant in the Swiss plateau



A2 / M1 267% 319% 750% 797% 389% 320% 230% 144% 109% 83% 91% 123%

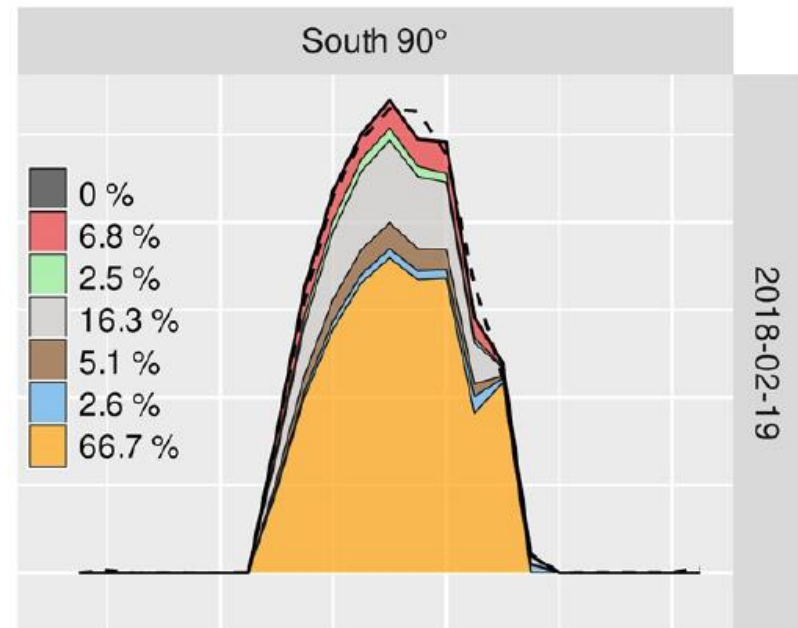


Frischholz et al., Frontiers, 2024

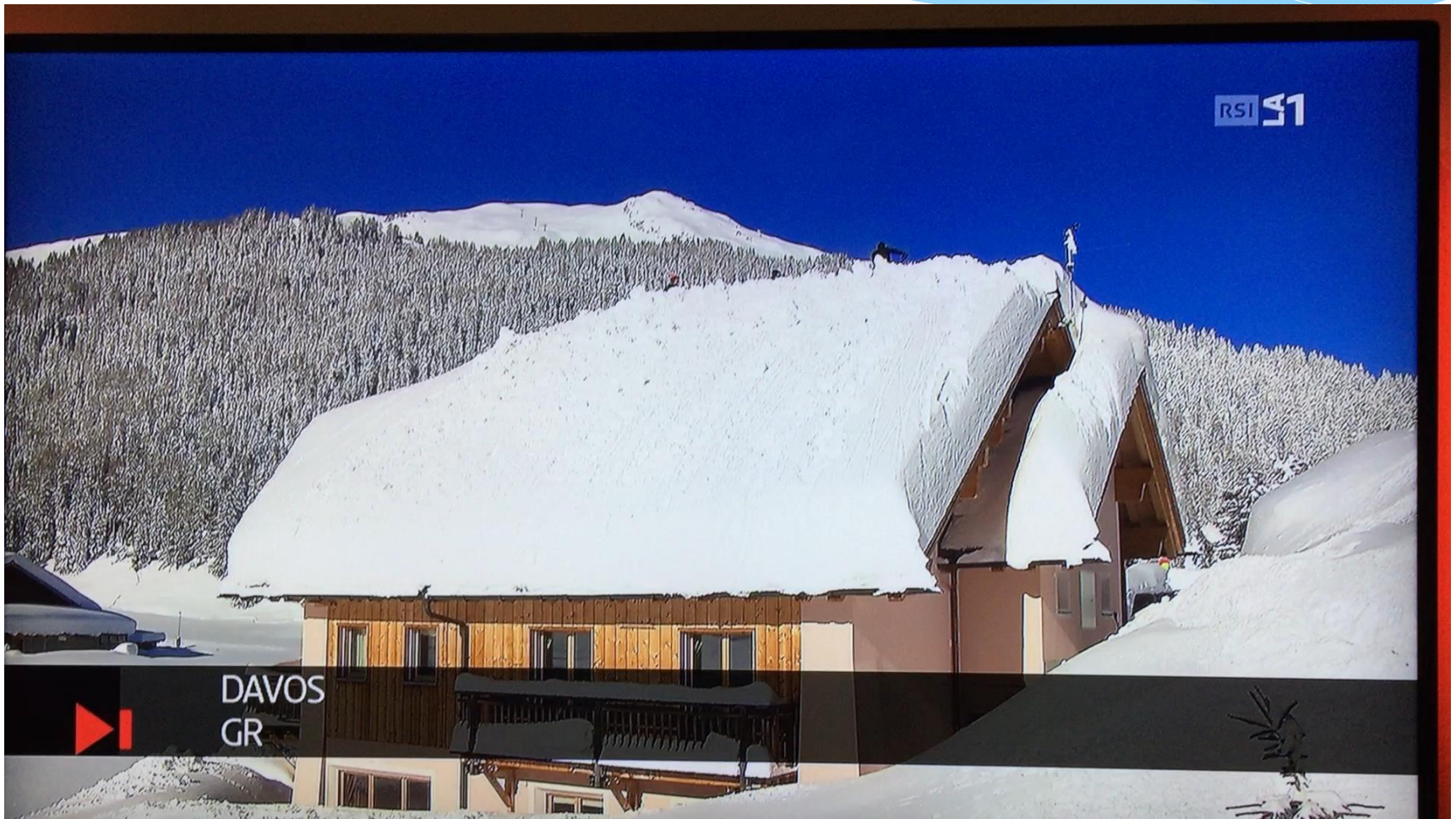
168%

Conclusions I

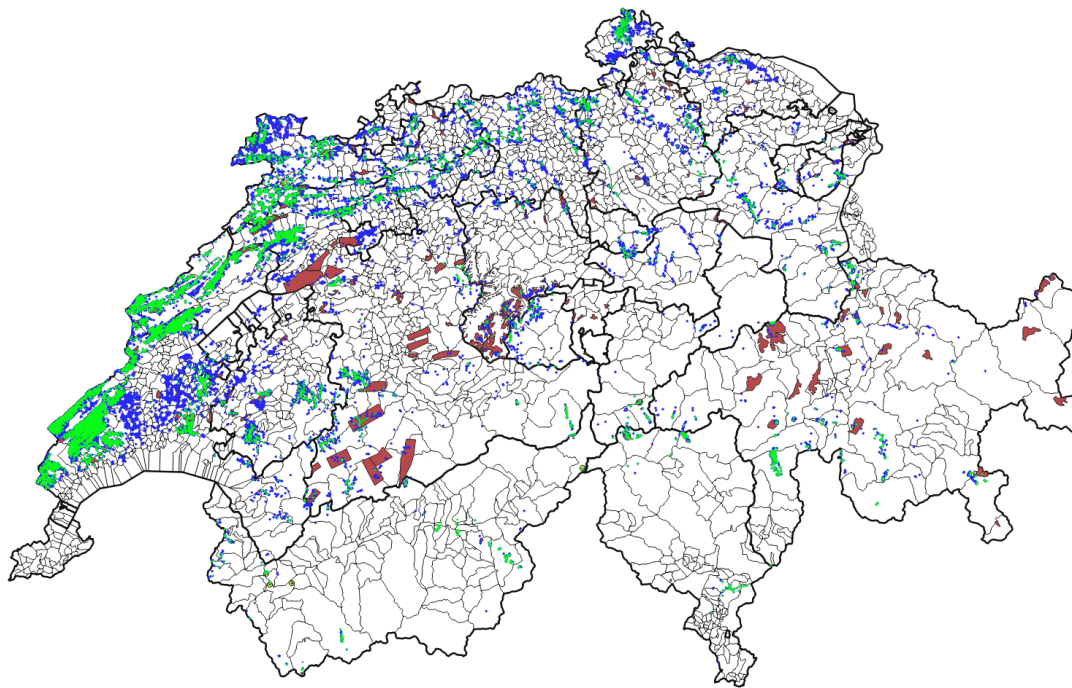
- * **Forward Scattering of Snow Matters**
- * For closing the winter energy gap in mid latitudes
- * For correctly representing **local** energy balance in terrain
- * Can be calculated with GROUNDEYE model (Alpine3D)
- * **The winner takes it all: Sunny slopes (and South-oriented vertical PV) profit most**



A real world example from my house (Davos Laret)



Breaking the wind lull in Switzerland



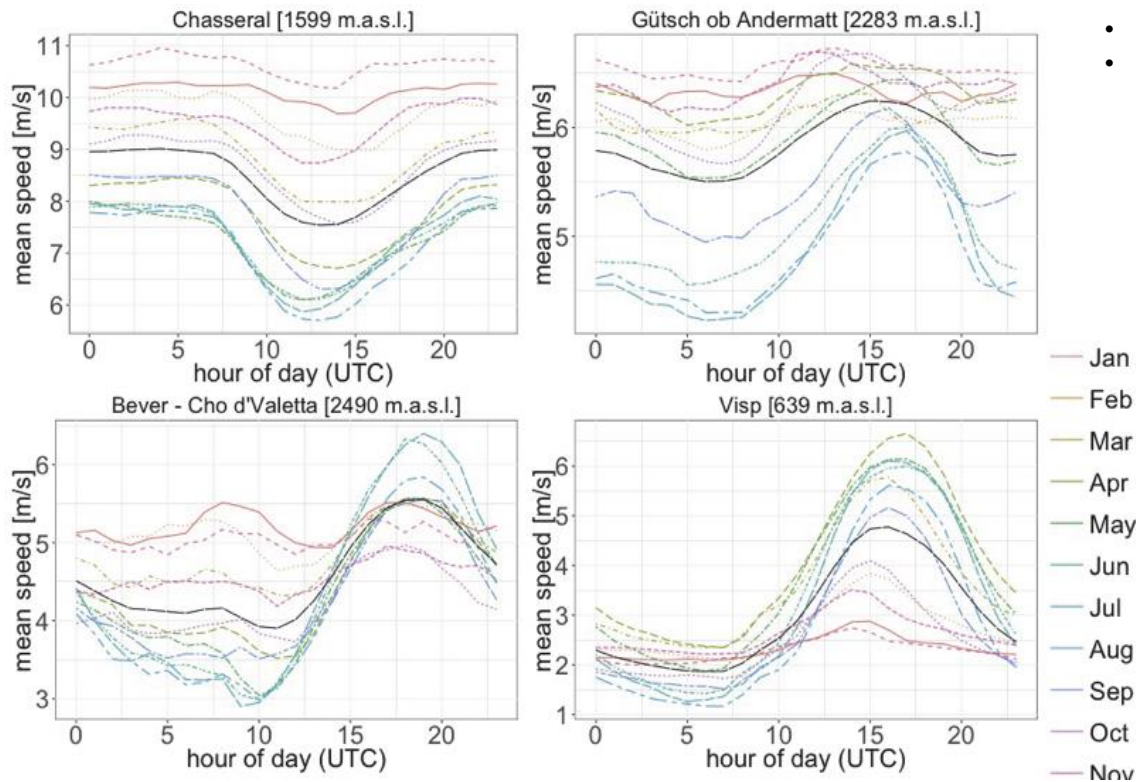
- Winter, all year season optimal turbine sites (Enercon E92, min capacity factor of 20%)
- Positive planning areas in cantonal structure plans (KRIP)

Wind is a competitive and economic part of a future renewable energy mix **IN** Switzerland

Analyses of policy actions:

- Restrictions overall make sense (landscape, birds, infrastructure)
- Positive planning areas in general not too well aligned with potential
- Offer information in a time-resolved (seasons, daily cycle) manner
- Problem: Increase installations by factor 10 until 2030 (goal confederation)

What we (don't) know about wind in Switzerland



- Different locations have very different wind profiles
- We can use this information for an optimal planning of wind production sites!



Laseier Wind Schwendetal (AI)

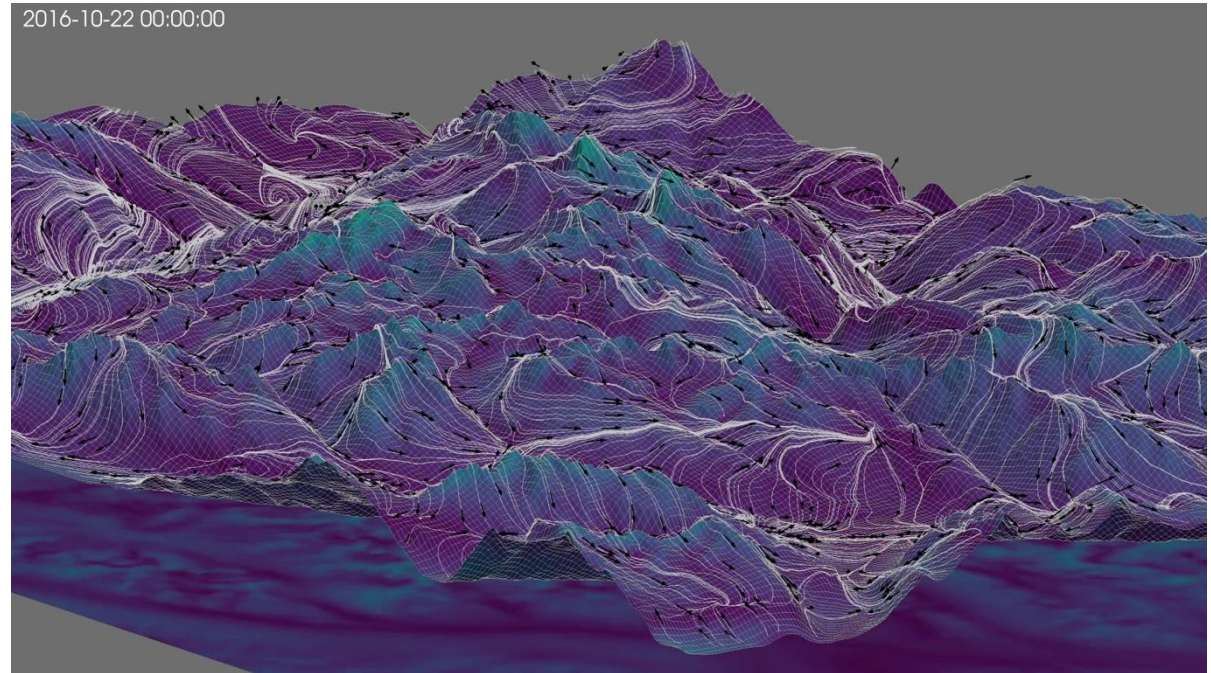


Satisfying the demand for better potential estimates: Wind estimates with ML

Work on more suitable and more fine-scaled wind assessments

Machine learning model:

- Provides more accurate estimates than current products
- Offers high time resolution (hourly) and amazing spatial resolution (25 m)
- Is used for wind potential and wind load or snow transport

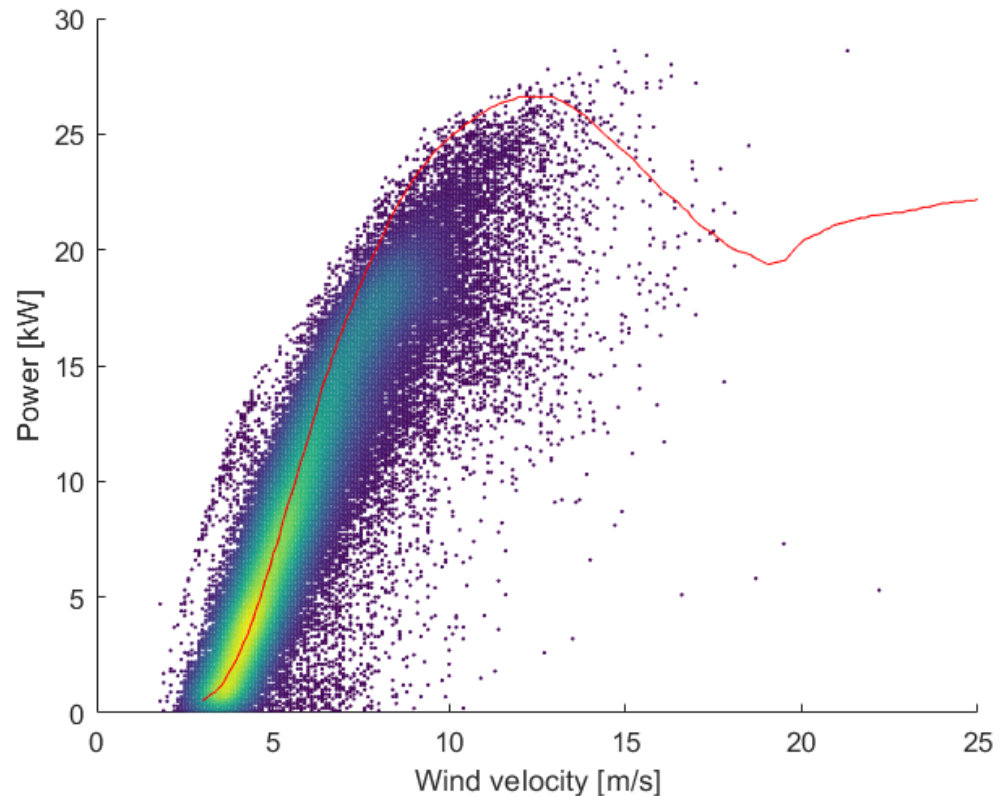


Assessment of Performance of High Alpine PV and Wind Installations

Analysis of operation of small-scale (25 kW) and full-scale (2 MW) from demonstration cases

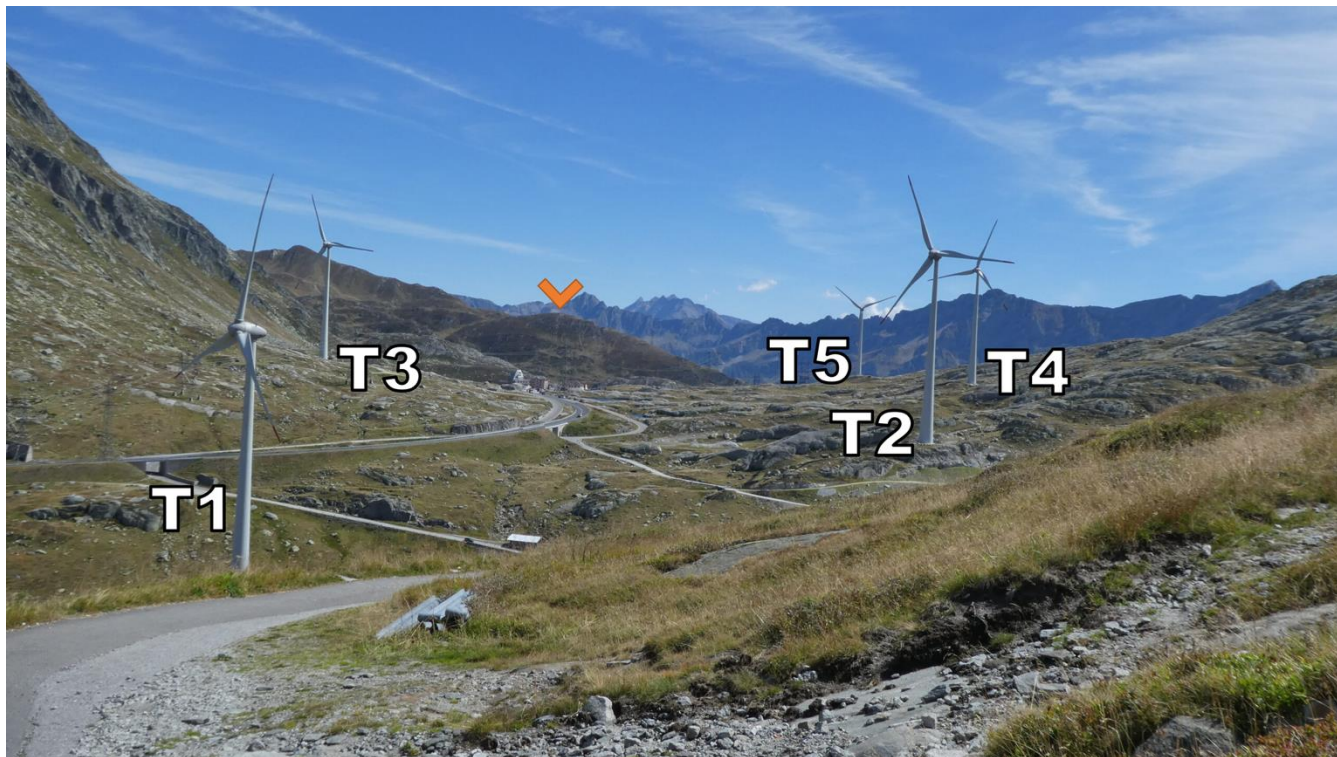
Explaining deviations from expected yield:

- Negative effects of density
- Positive effects of snow cover and temperature
- Important effects of topography (negative and positive)
- Positive effects of turbulence on small turbines

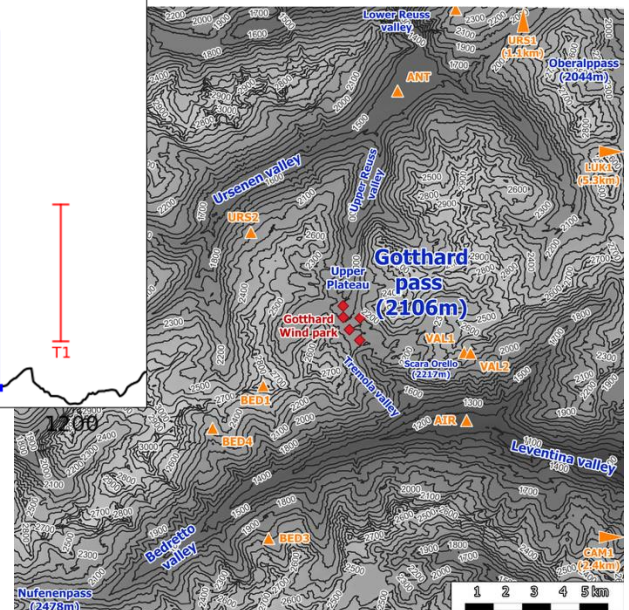
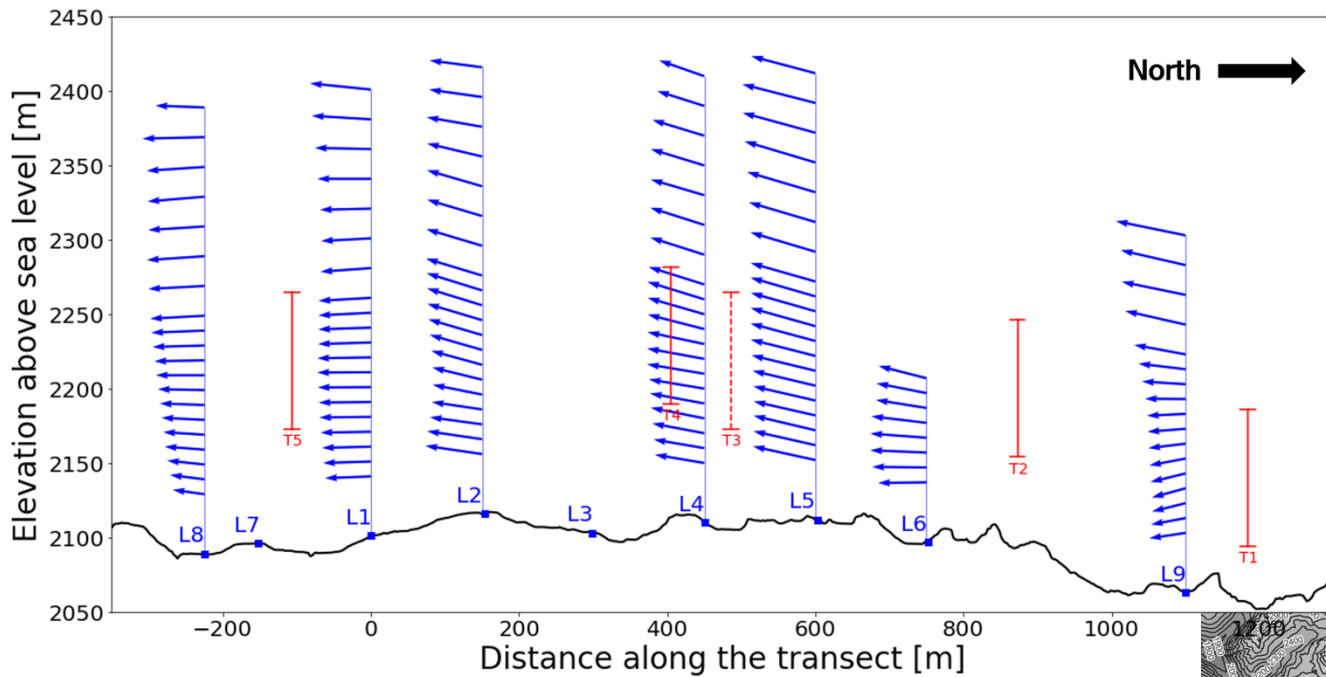


La Stadera wind turbine performance

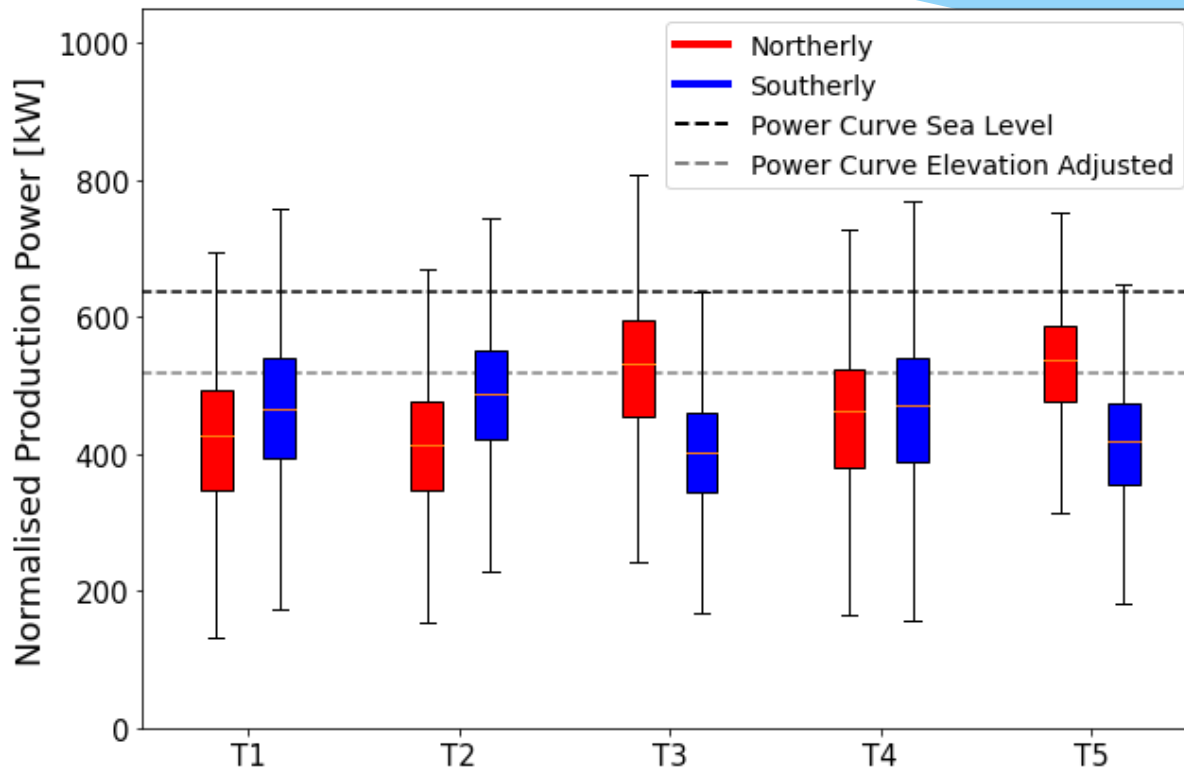
Praxis: Produktion @ Gotthard



Praxis: Wind Profiles @ Gotthard



Praxis: Produktion @ Gotthard



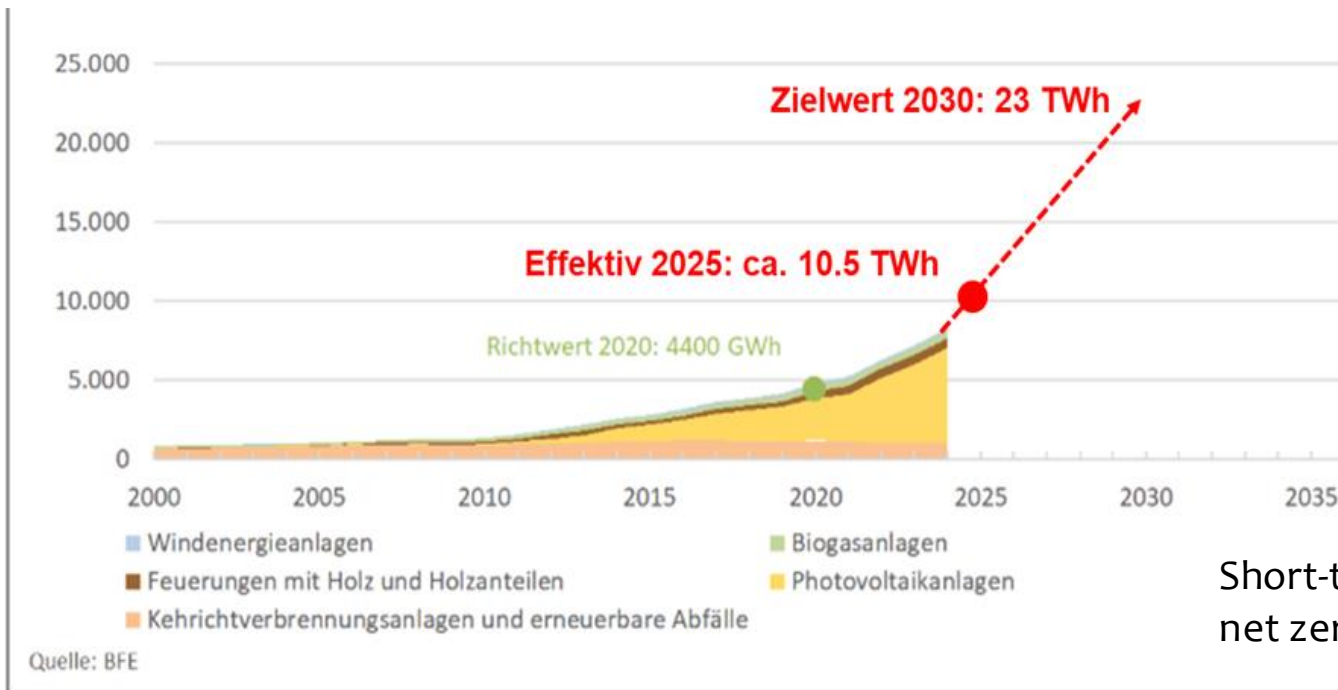
- Significantly different yield for the 5 very similarly positioned turbines
- Some of them perform better than expectations
- Need to explain differences to allow for better planning of additional parks (which we really need)

Conclusions II

- * **Wind matters in Switzerland**
- * For closing the winter energy gap in mid latitudes
- * For balancing with other renewables such as hydropower and PV
- * **Detailed assessment is necessary to have best possible results**



Goals for Switzerland



Wind from 0.2 to 2.3 TWh
Solar from 8.5 to 19 TWh

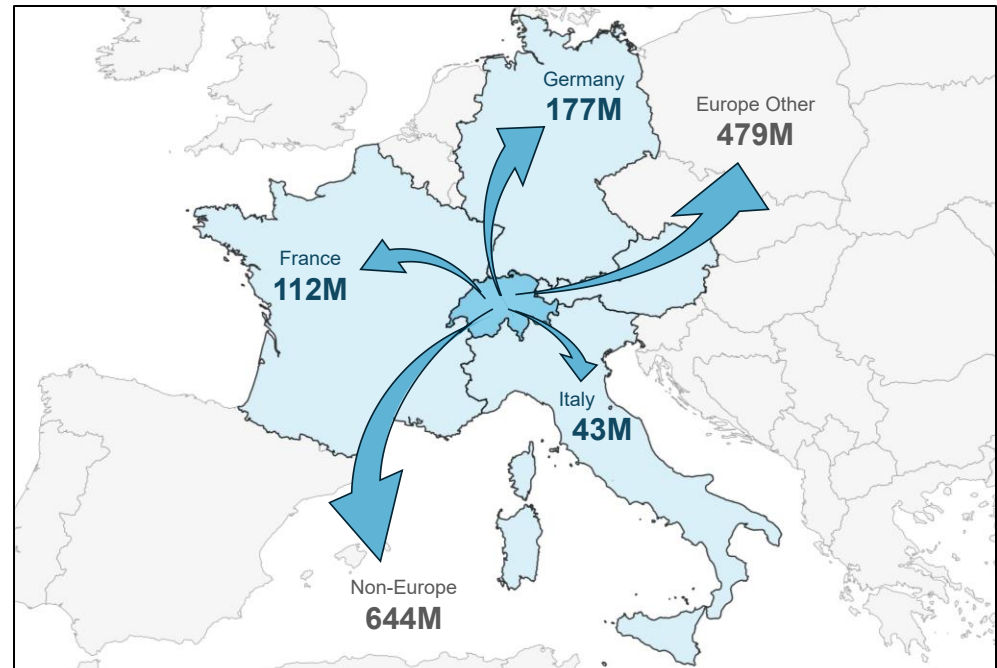
Short-term goals on the way to net zero in 2050

45 TWh new renewables in 2050

Cap import to 5 TWh

Switzerland's cross-border renewable energy investments

- Switzerland is not only **closely connected to Europe** via electricity trade but also **renewable energy financing**
- **More than half** of Swiss investments go to neighboring (23%) and other **European countries** (33%)
- Only **1%** of the investments **stay in Switzerland**, the **remainder** flows to other countries, **mostly the US**
- Nearly **60%** of Swiss renewable energy **investments abroad** go into **wind technologies**
- While **financial investors** drive Swiss investments abroad, **utilities and project developers** also play an important role



Via investments, Switzerland is highly interconnected with broader renewable energy landscape – especially in Europe and other developed economies

Annual renewable energy investment flows out of Switzerland into direct neighbor countries, the rest of Europe, and outside Europe in 2020 US\$

Limited preference for stronger EU collaboration

- Collaboration with EU to secure energy supply:**

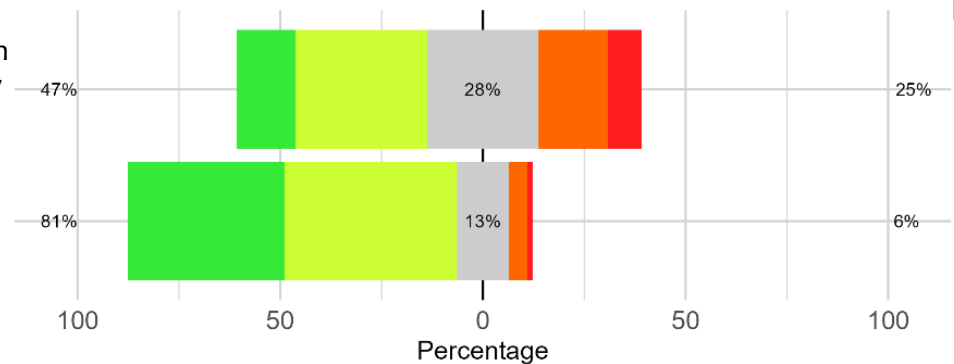
- A relative majority is in favor – but 25% do (strongly) not like it
 - No debate over the last two years, no change in opinions

- Energy independence is a strong preference, but less so in 2024 than 2022**

- Hot topic in 2022

Preferences for independence and EU cooperation (2022)

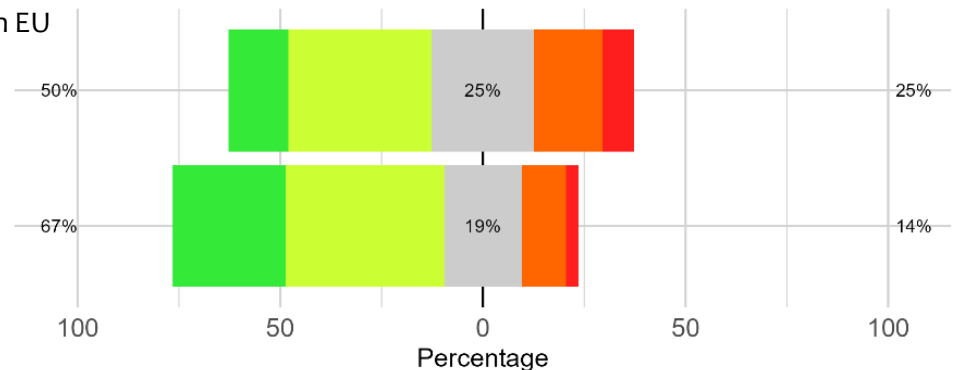
Stronger collaboration with EU to secure energy supply



CH should be energy independent

Preferences for independence and EU cooperation (2024)

Stronger collaboration with EU to secure energy supply

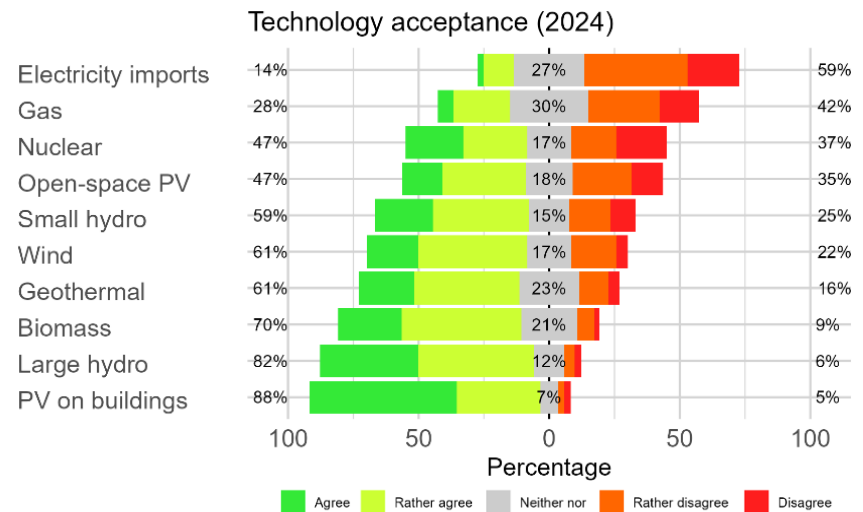
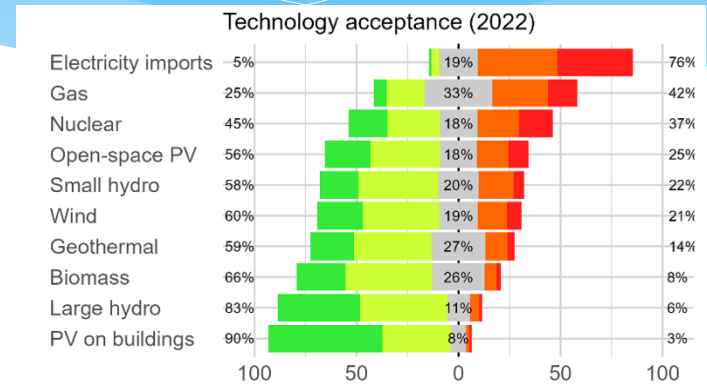


CH should be energy independent

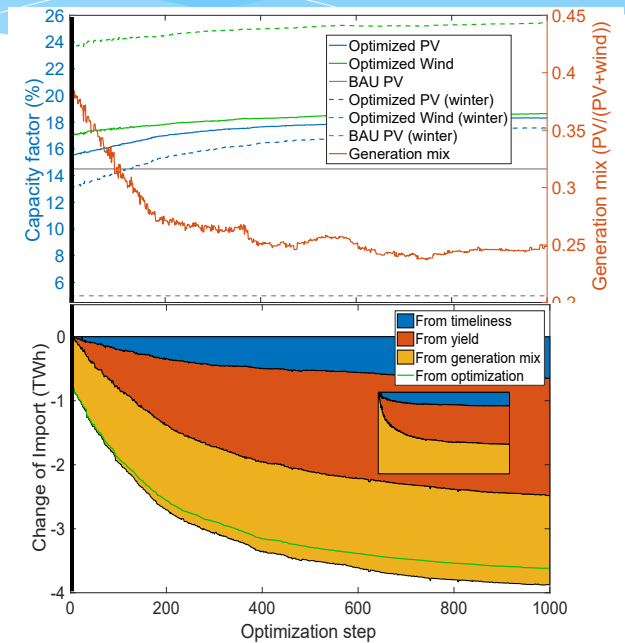
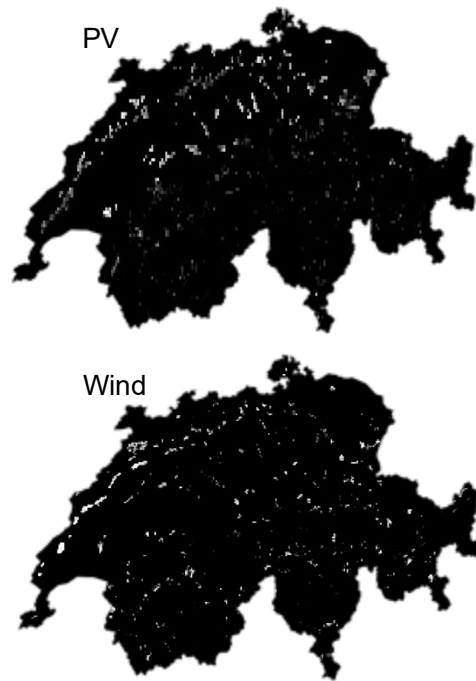
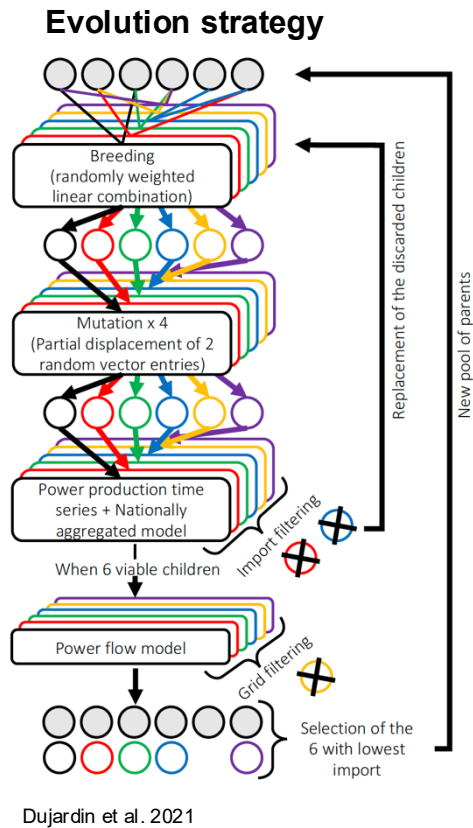
■ Agree
 ■ Rather agree
 ■ Neither nor
 ■ Rather disagree
 ■ Disagree

Technology acceptance is rather stable

- Overall patterns are the same in 2022 and 2024
- A few significant changes (related to recent debates)
 - Lower preferences for open-space PV
 - Electricity imports are still most unpopular but less so in 2024 than in 2022



Optimale Verteilung von PV und Wind in der Schweiz – OREES Model



Dujardin et al. 2021

- Import reduced by 51% compared to initial solution
- 80% less import than a conventional urban PV scenario

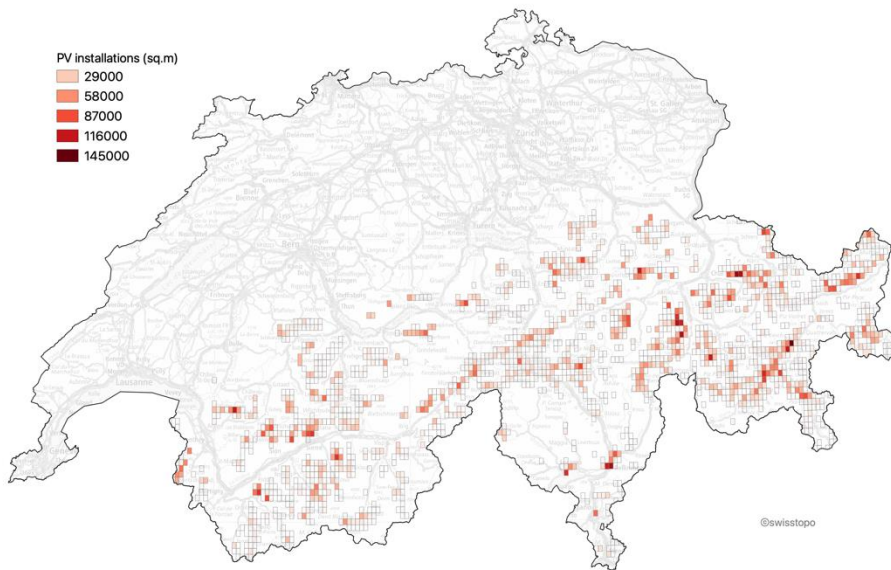
Optimization for minimizing winter deficit (29 TWh generation for the weather of 2016)

Optimal PV installations: 4.44 GW_{peak}

Optimal wind power installations: 13.41 GW_{peak}

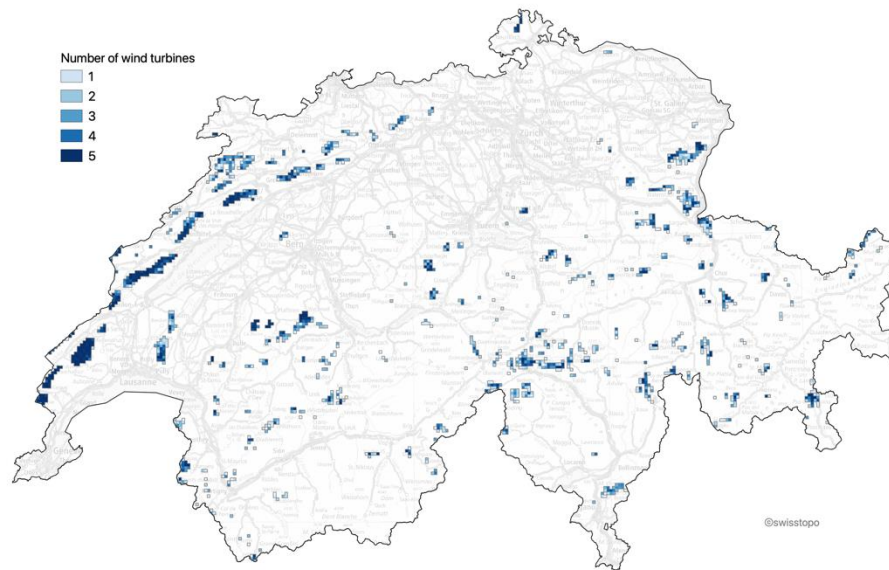
PV installations (sq.m)

- 29000
- 58000
- 87000
- 116000
- 145000



Number of wind turbines

- 1
- 2
- 3
- 4
- 5

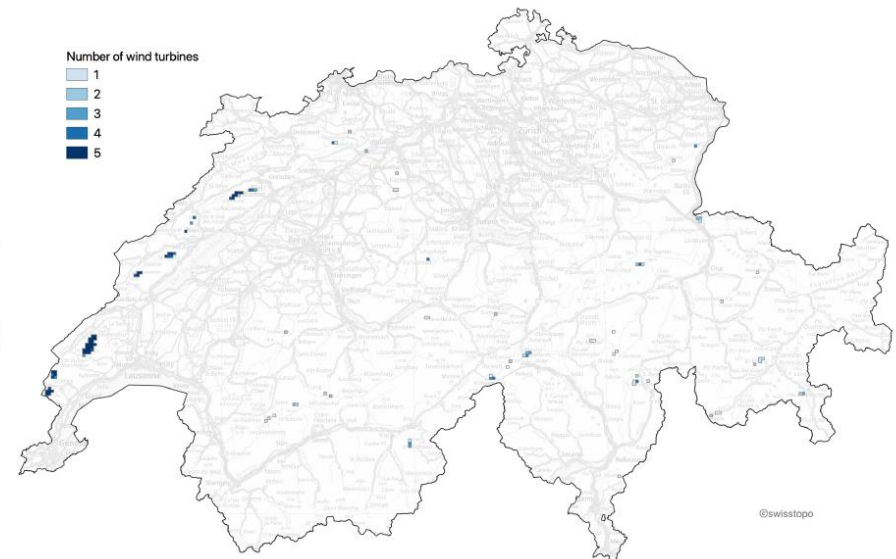
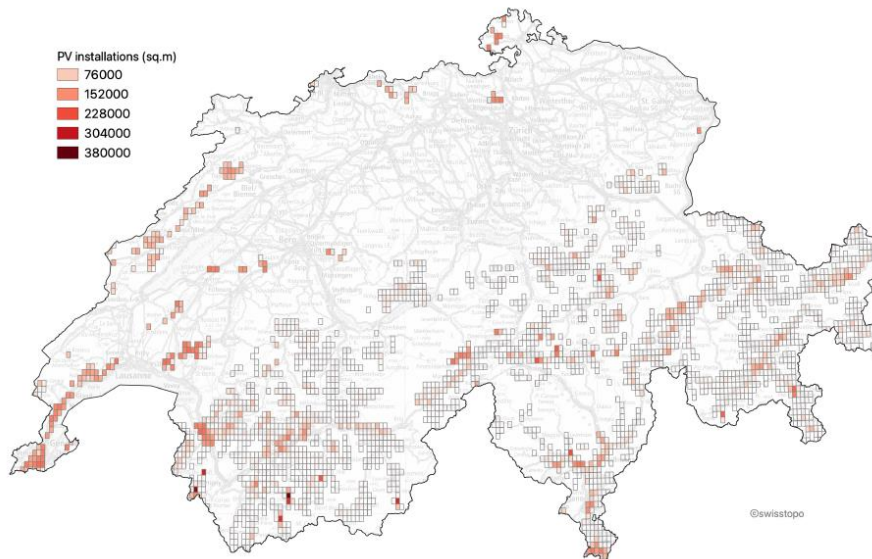


Optimization for revenues but with a stable operation

Optimization for maximizing revenues
(25 TWh generation in 2019)

Optimal PV installations: 13.64 GW_{peak}

Optimal wind power installations: 1.18 GW_{peak}



Where are the best locations for Wind and Solar Installations in Switzerland? (45 TWh Total Production from Wind and Pv – Projection 2050 Weather 2018)

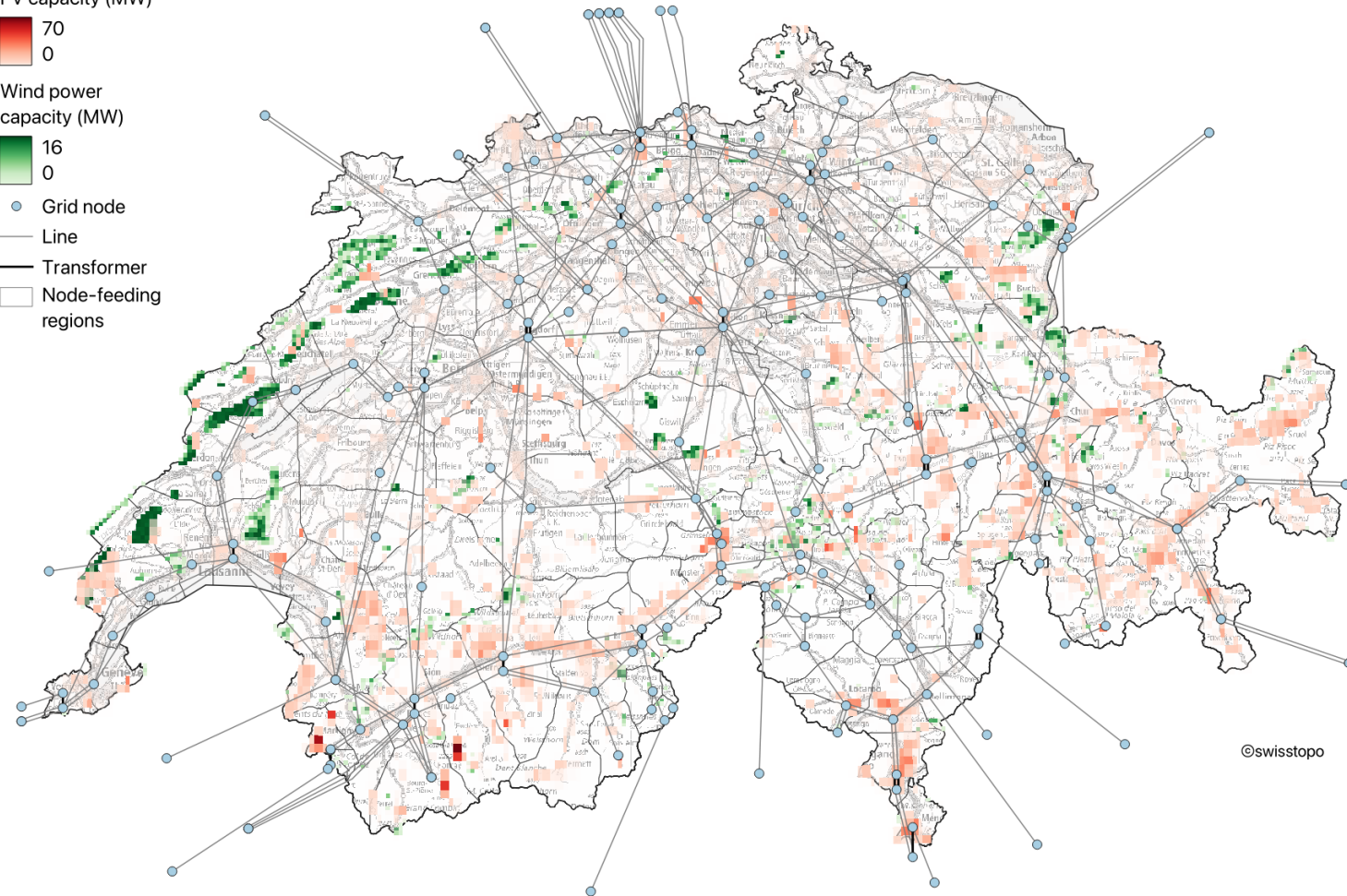
PV capacity (MW)



Wind power capacity (MW)

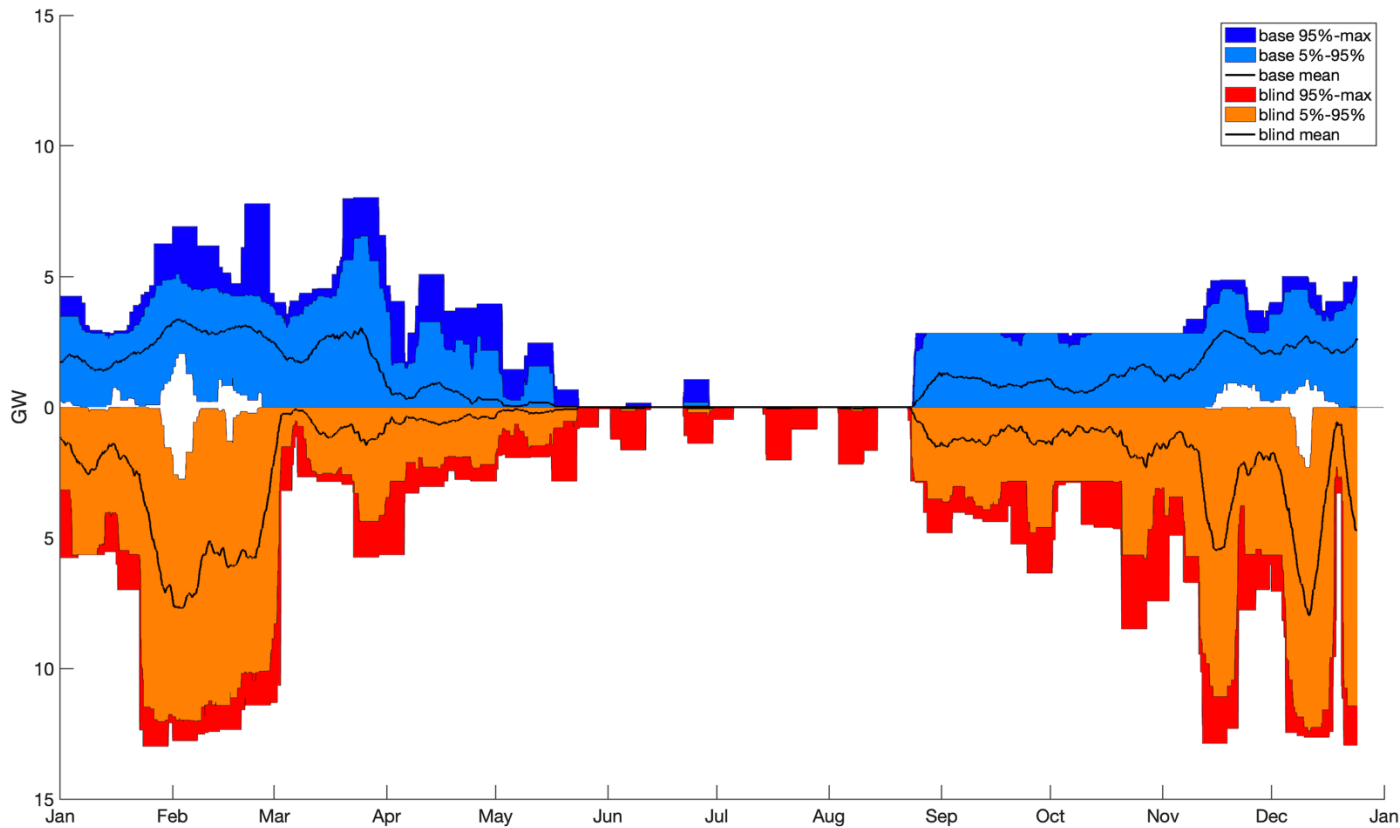


- Grid node
- Line
- Transformer
- Node-feeding regions



©swisstopo

Import and the Value of Weather Forecast



- Import of electricity can be reduced by more than 30% if weather forecast is considered
- Most importantly: peak import values can be avoided
- This is important to stabilise the grid?

Conclusions

- * Existing Infrastructure in the Alps should be used for PV and Wind installations
 - * Reduces the Winter Energy Gap
 - * Reduces Dependency from Import
 - * Solutions for Snow Protection need to be developed
- * Renewable installations are largely compatible with grid 2025
 - Let's produce even more energy in our mountains

Actionable Conclusion: Facilitate High-Mountain Installations of both PV and Wind

Recipe of Success:

100 km² of PV Panels
(50% in the mountains)
– 10 GW

1000 Wind Turbines – 5
GW

→ 10 TWh of
Additional Storage



Wind, Sun and Snow



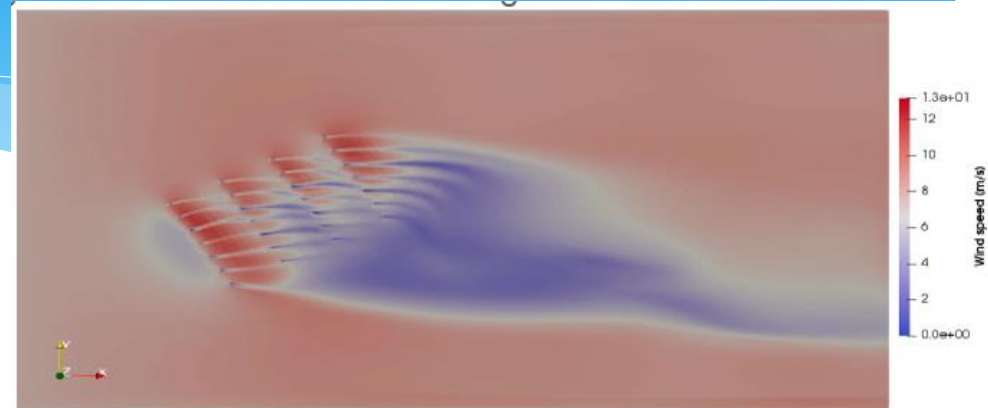
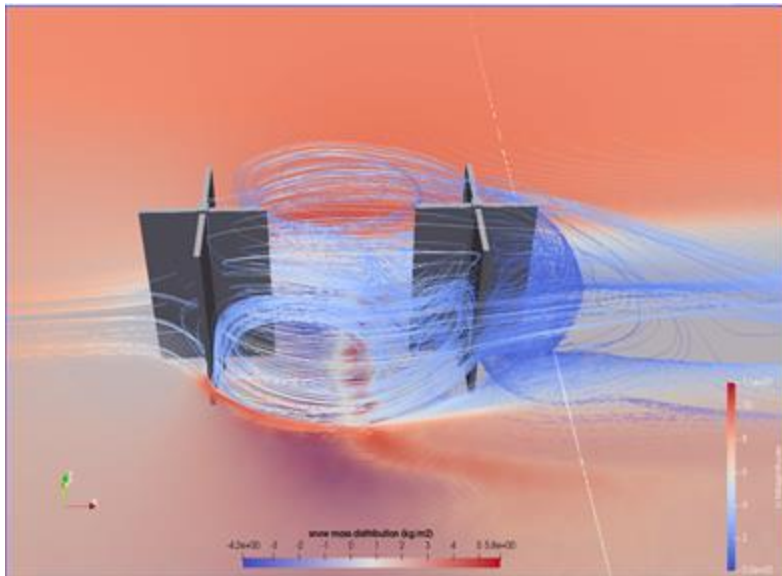
Snow can also be a problem

➔ Need to have new design solutions for high Alpine PV

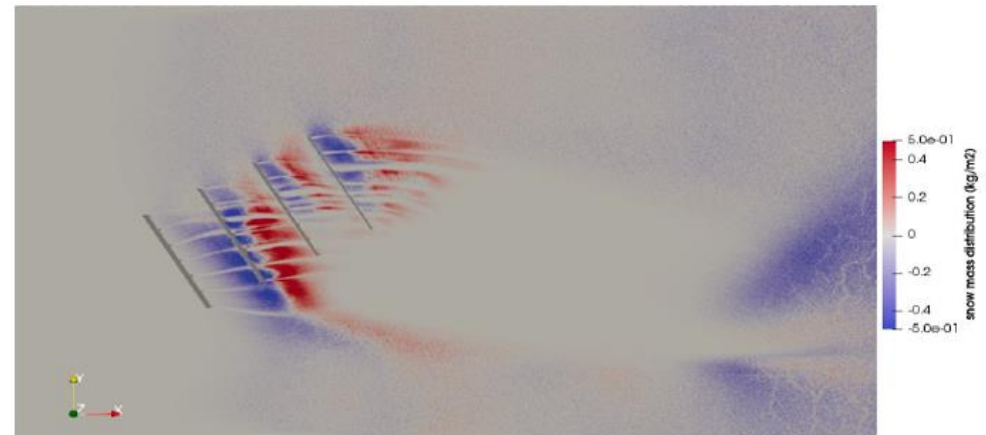


New Tools

Wind loads on Alpine PV



Calculated Snow Deposition



What to do next

- **Some new technology development**
- Models for optimal design of PV plants
- Develop wind turbines for mountains (multi-rotor)
- **Look for optimal placing of infrastructure in Switzerland**

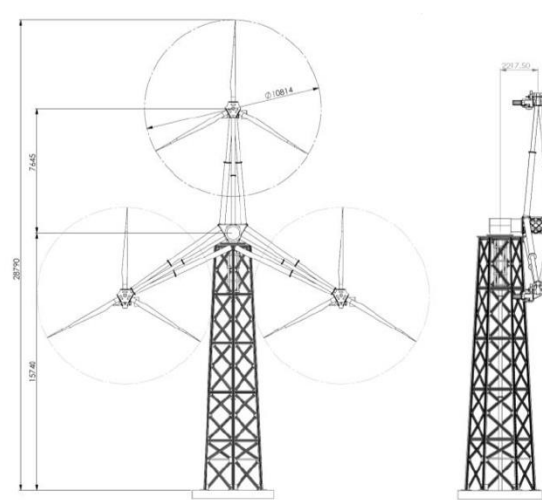


Bild 1...MR30, momentaner Stand der Konstruktion (Aug 22)

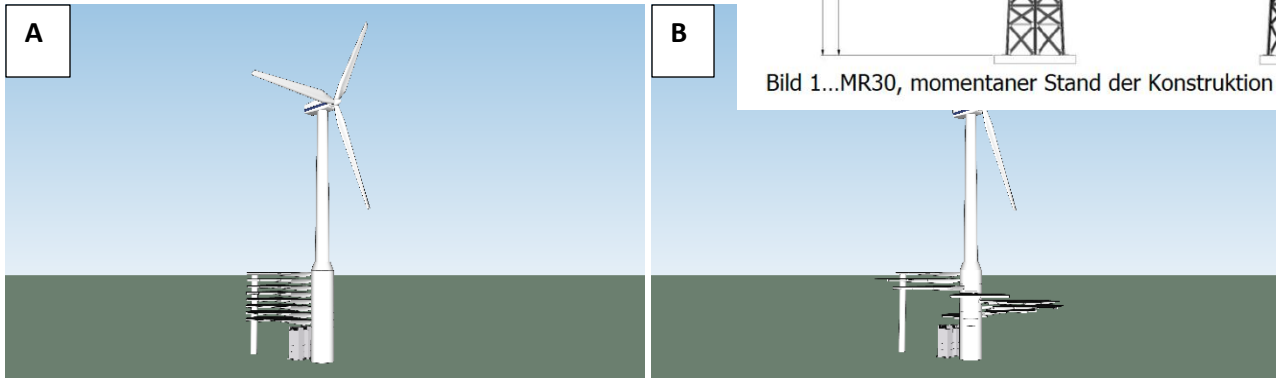


Abbildung 1: Zeichnung des Prototyps in Seitenansicht. **A:** Modus "Unwetter", PV eingefaltet. **B:** "Produktionsmodus", PV geöffnet.