Laboratory of Cryospheric Sciences

UNIGE RES
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

SWEET-EDGE 2021-2027

“Enabling Decentralized renewable GEneration in the (Swiss cities, midlands) and the Alps”

Evelina Trutnevyte, University of Geneva

Jérôme Dujardin, Fanny Kristianti, Annelen Kahl, Hendrik Huwald, Michael Lehning, EPFL & SLF Davos

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15 research teams

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20 implementation partners

swisspower, ewl, eniwa, ZUKUNFTSREGION ARGOVIA, swisspor, SIEMENS, ALPENFORCE ALPINES ENERGIE FORSCHUNGS CENTER, ewb, energie-cluster.ch, LAVEBA, SWL, RIGI TRAC, GEMEINDE DAVOS, ECOCOACH SWITZERLAND, AEW Ihre Energie., south pole, DIE PROJEKT FABRIK, HEIM AG Heizsysteme, axpo, EVTEC QUALITY

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+ 42 support partners

SWEET-EDGE objectives

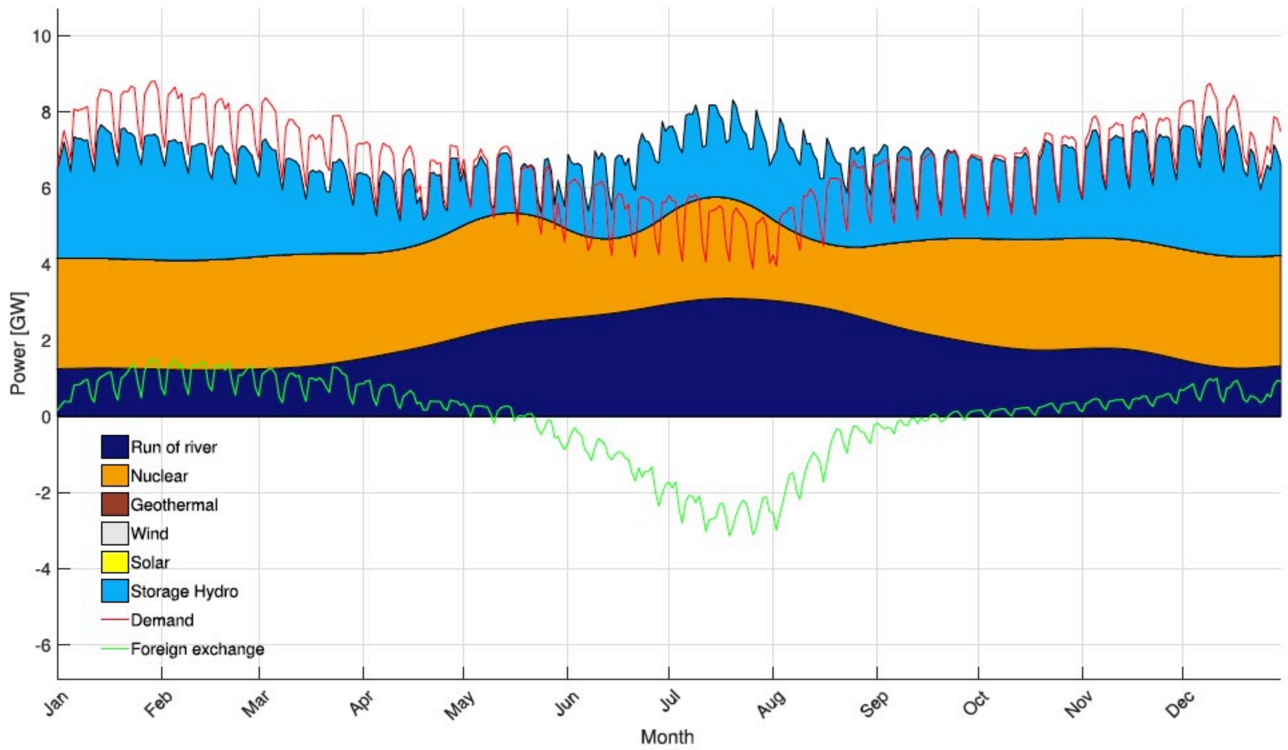
VISION: fast-track the growth of locally-sourced decentralized renewable energy in Switzerland

- develop new national-level scenarios and implementation pathways with high shares of decentralized renewable energy by 2050, including options for nearly or fully renewable Switzerland
- ensure that by 2050, when ambitious shares of renewable energy are reached, the Swiss energy system is designed and operated in a technically and economically optimal and secure way, and that it is well positioned in the European markets
- identify tailor-made solutions for the Swiss cities, midlands, and the Alps for largely electrified and multi-carrier energy systems
- combine research with innovation in three Pilot and Demonstration project clusters (P&Ds)

Content of this Talk

- Kraftwerk Schweiz: Quantitative Rechnungen
- Towards a better estimation of solar energy in mountains
- Towards a better estimation of wind energy in mountains
- Going from National Scenarios to Regional and Local Solutions

Starting from National Scenarios for PV and Wind



(a) Current

Bartlett, et al. (2018), Charting the course: A possible route to a fully renewable Swiss power system, *Energy*.

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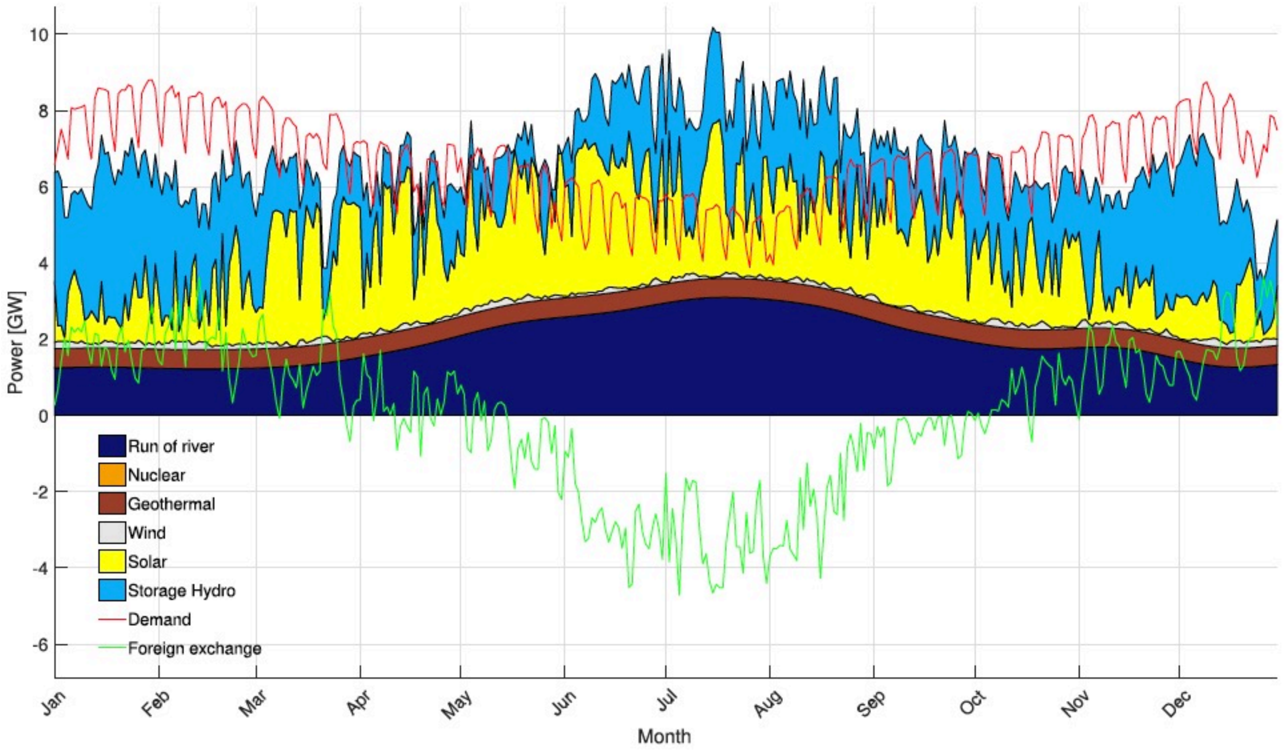
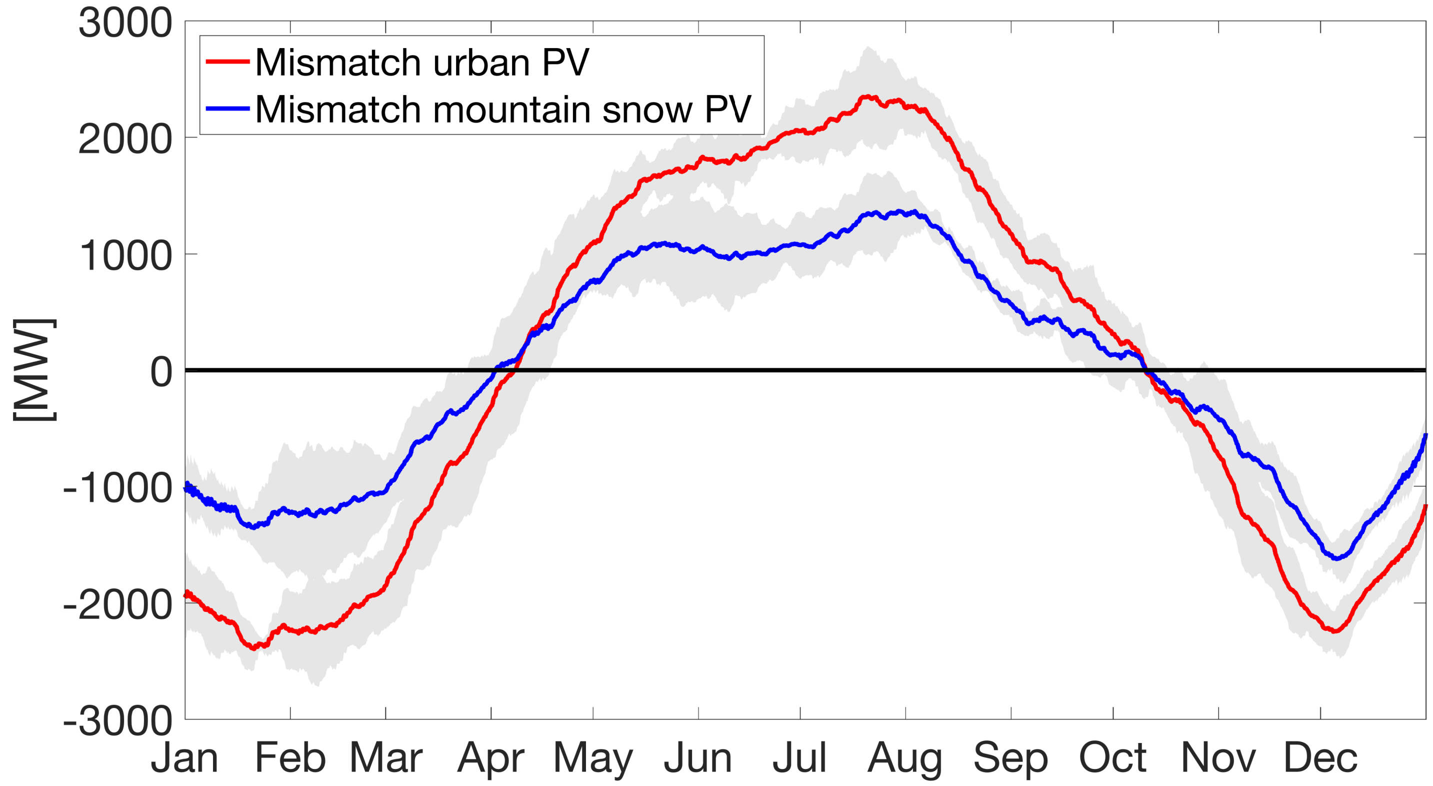
Nuclear Power replaced by wind (little) and PV



(c) Renewable

Bartlett, et al. (2018), Charting the course: A possible route to a fully renewable Swiss power system, *Energy*.

How to reduce the seasonal mismatch?



→ Need to fully understand potential of mountain PV:

- Incoming Radiation
- Existing Infrastructure
- Acceptance
- Finance

Annelen Kahl, Jérôme Dujardin, Michi Lehning, PNAS 2019;116:4:1162-1167

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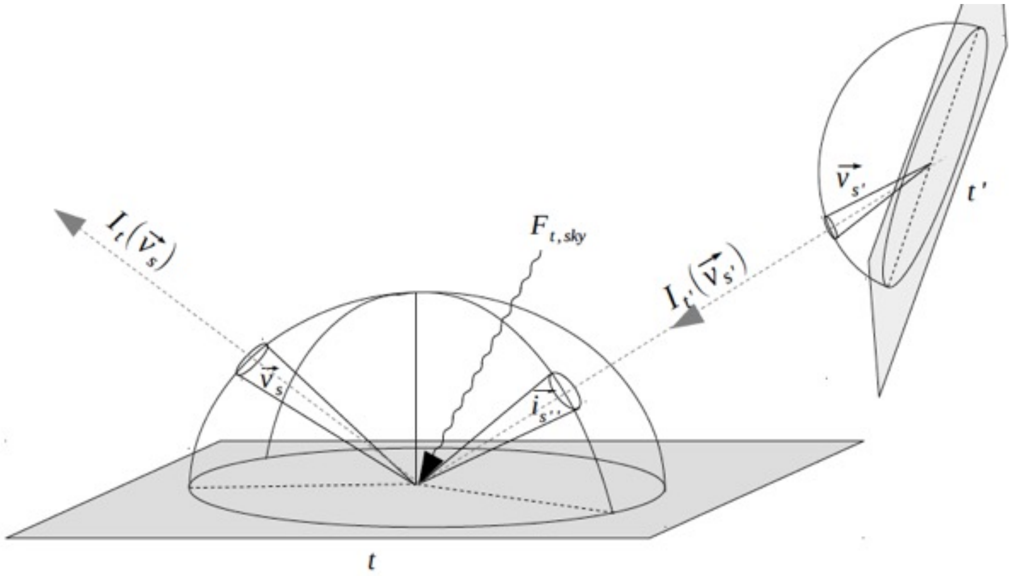
Consider the role of Snow in Radiative Transfer

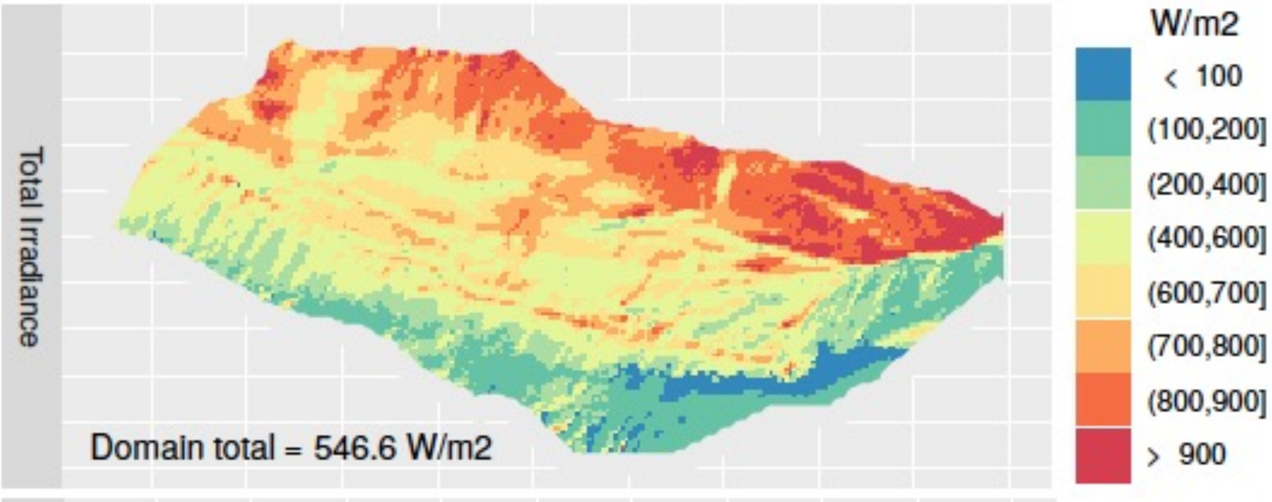
- **Snow scatters** light (high albedo) but does so **anisotropically**
- Not considered in any model of radiative transfer
- Combine snow modelling with near surface atmospheric modelling to assess influence on **surface energy balance** and yield of **solar panels** (PV) in snow environments
- Current models perform poorly
- Use for **potential assessment** and **operational forecasting**



$$I_t(\vec{v}_s) = \overbrace{\frac{\alpha}{\pi} R(\vec{v}_s, \vec{i}_{sun}) F_{direct,t} + \frac{\alpha}{\pi} F_{diffuse,t}}^{I_{t,sky}(\vec{v}_s)} + \sum_{s''=1}^{S} I_{t'(t,s'')}(\vec{v}_{s'(t,s'')}) R(\vec{i}''_s, \vec{v}_s) \alpha f_{s''}$$

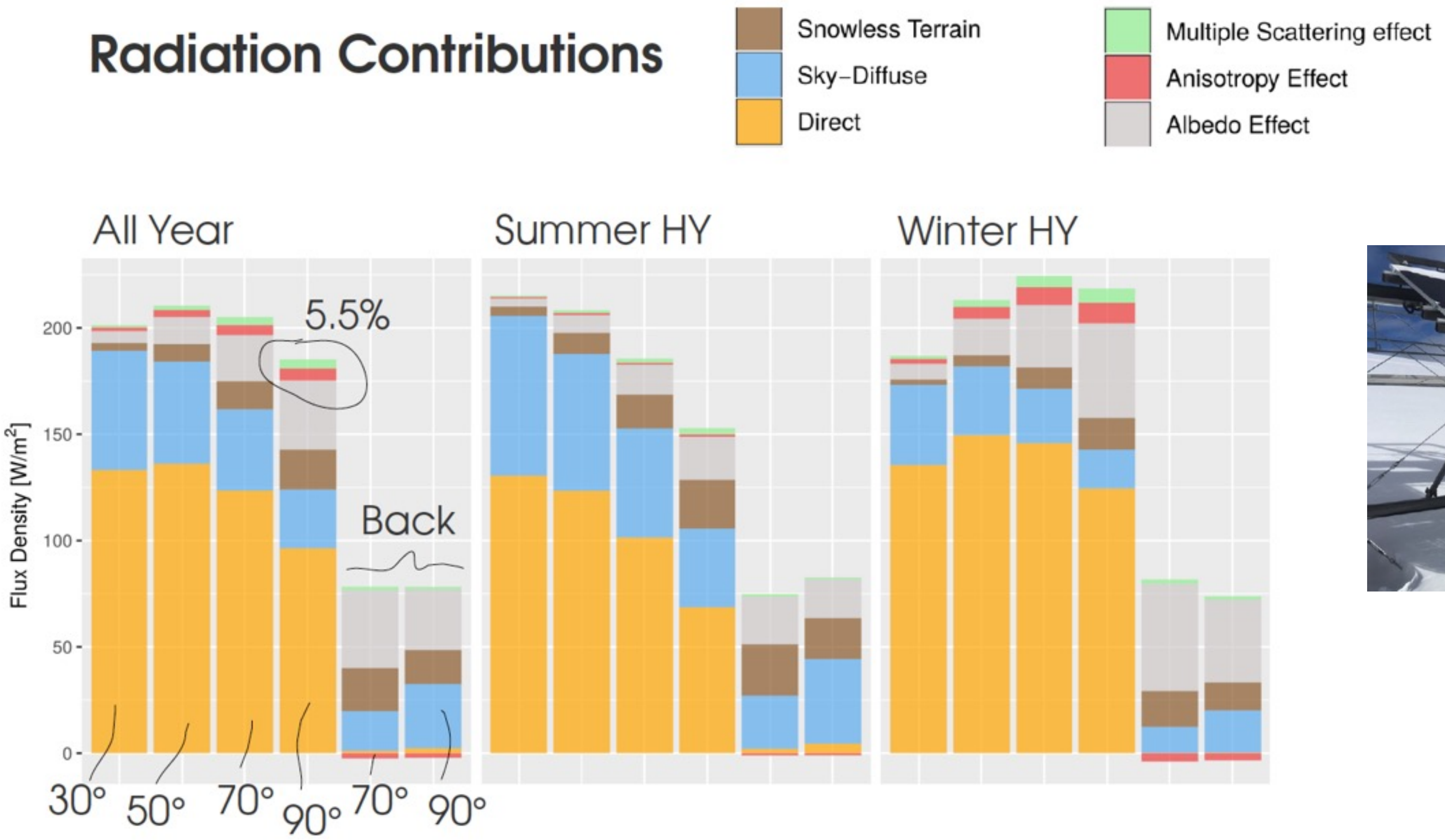
Iterative Solution

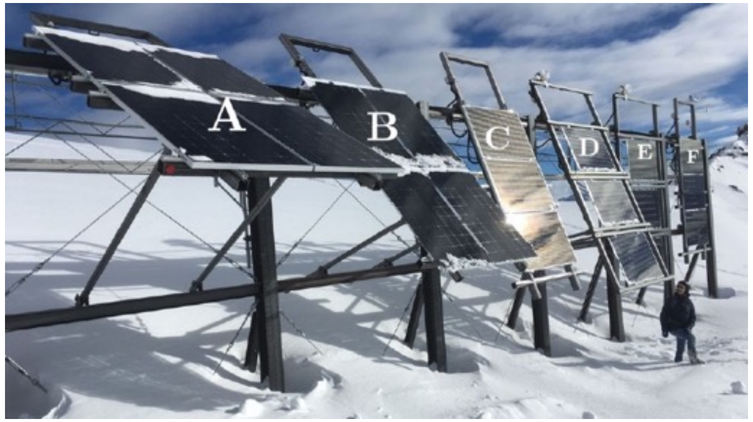
$$I_{t,k+1}(\vec{v}_s) = I_{t,sky}(\vec{v}_s) + \sum_{s''=1}^{S} I_{t'(t,s''),k}(\vec{v}_{s'(t,s'')}) R(\vec{i}''_s, \vec{v}_s) \alpha f_{s''}$$



Von Rütte, Kahl and Lehning, JGR, 2021

Consider the role of Snow in Radiative Transfer





Von Rütte, Kahl and Lehning, JGR, 2021

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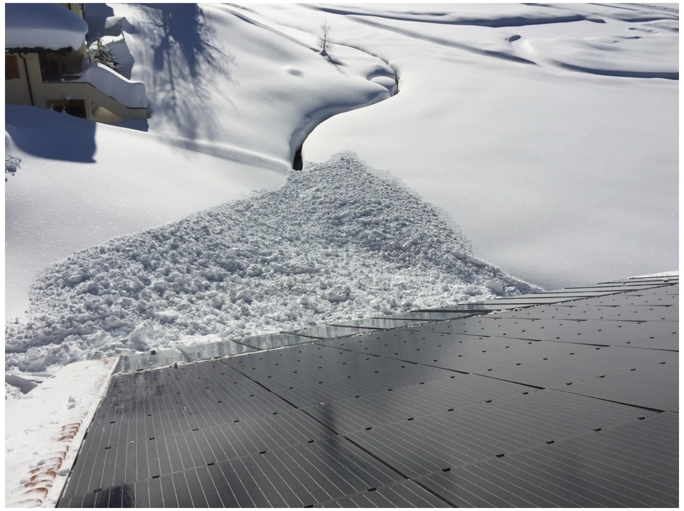
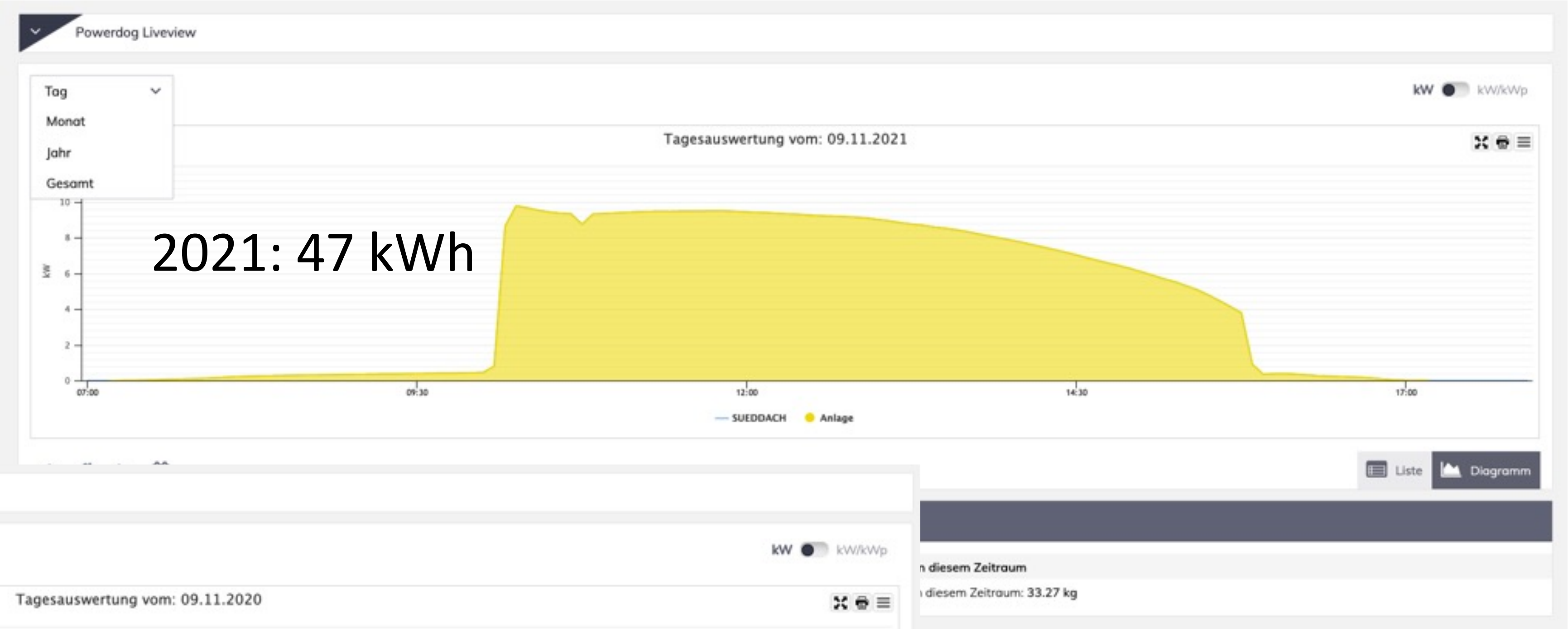
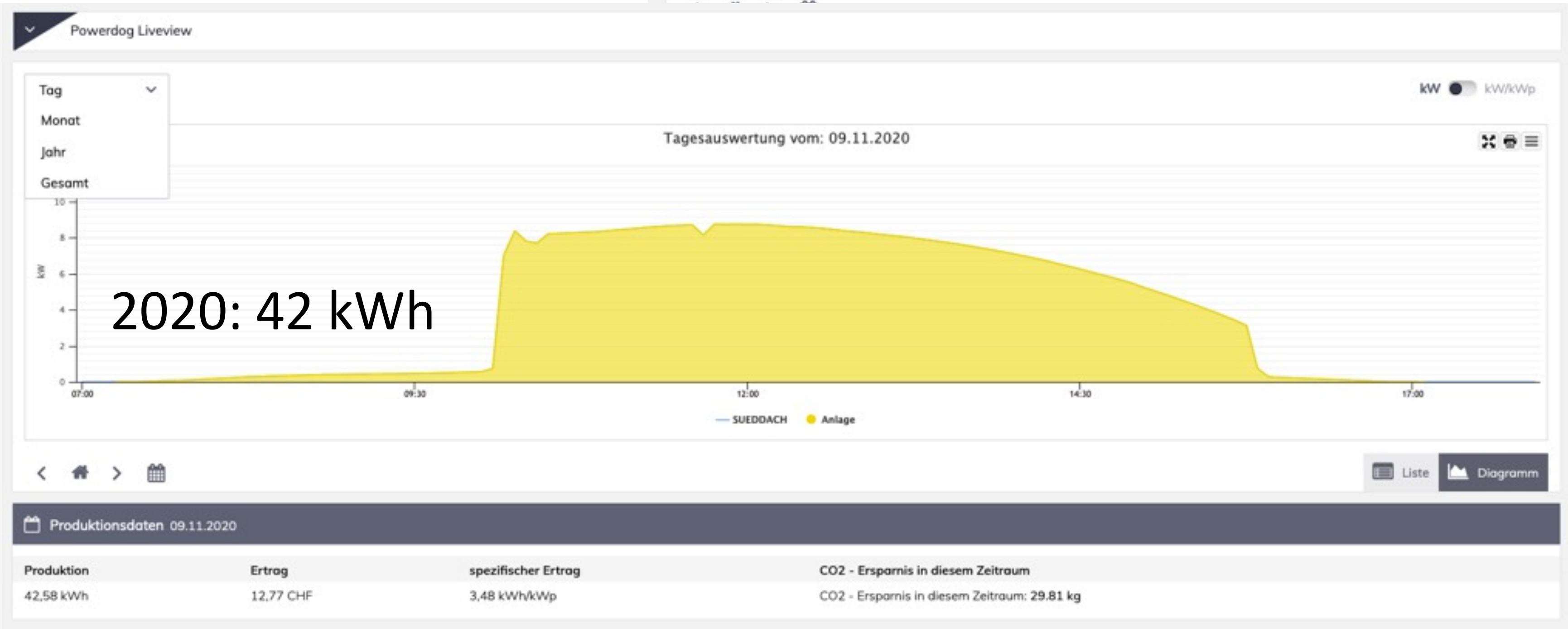
Does it matter in practice ?







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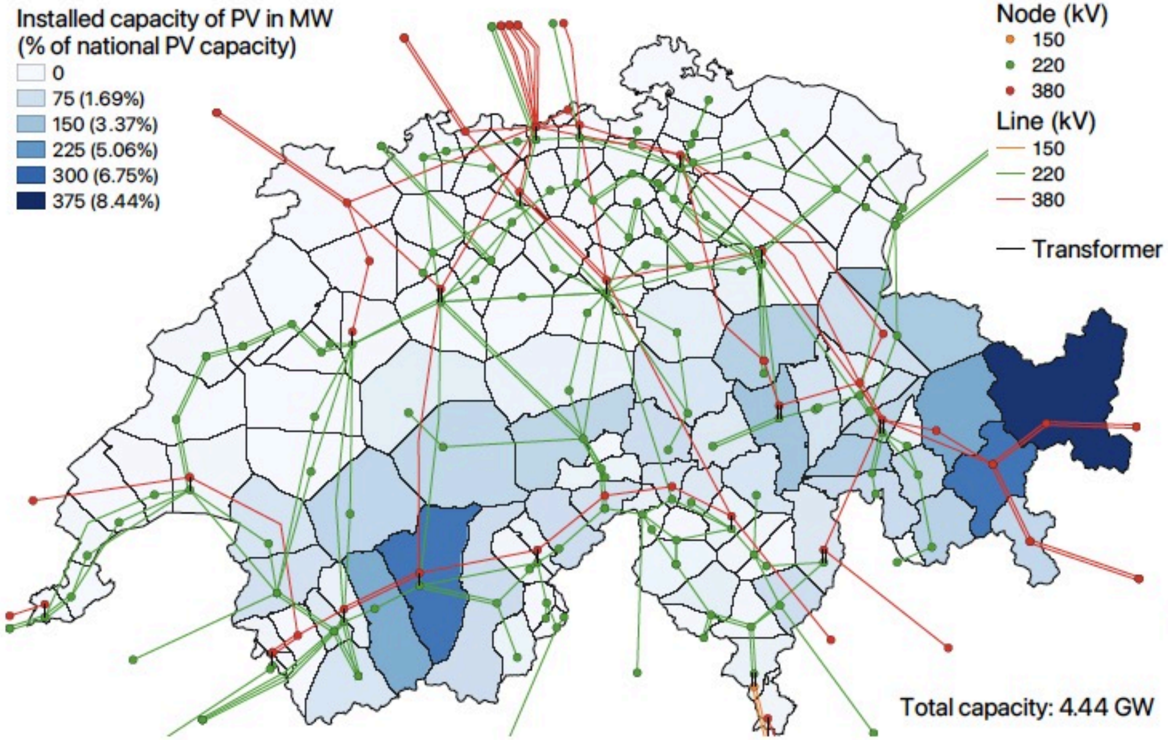
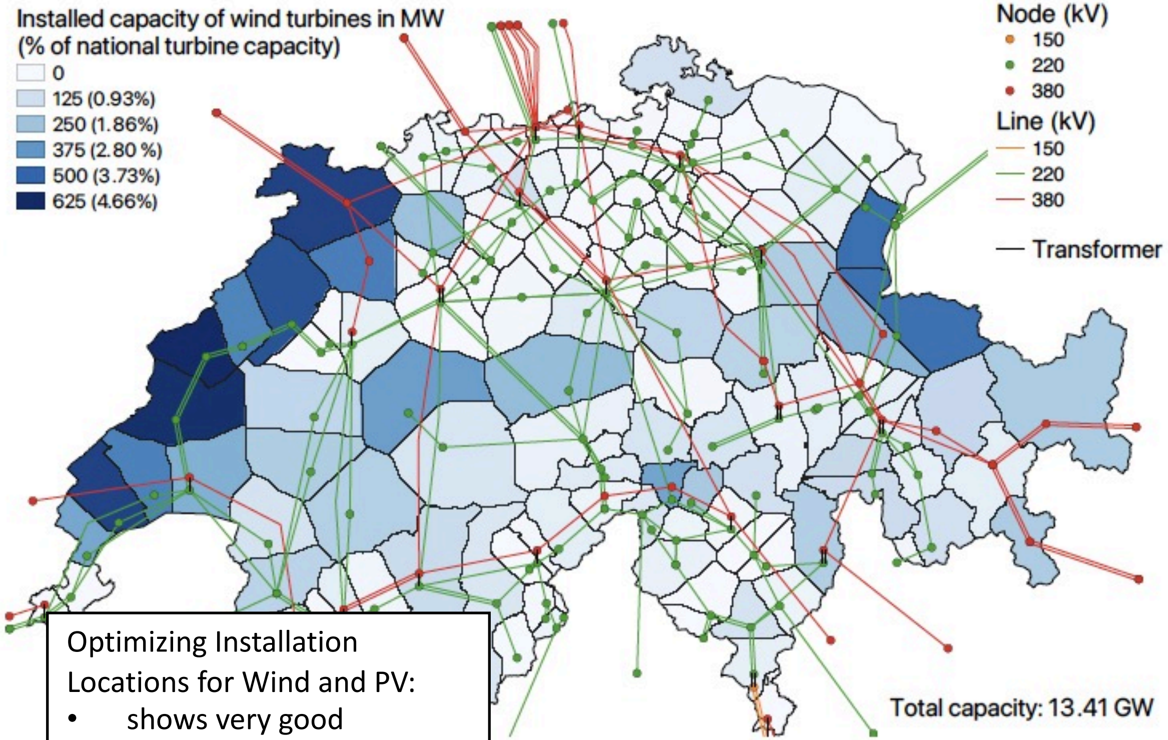
The dark side of snow

What is the optimal placement of PV and Wind? (for self-sufficiency)





Optimizing Installation Locations for Wind and PV:

- shows very good **complementarity** between wind and PV
- considers grid constraints
- favors the mountains especially for PV
- favors Jura for wind (but also Alps)

Dujardin, J., A. Kahl, and M. Lehning (2021), Synergistic optimization of renewable energy installations through evolution strategy, *Environ Res Lett*, *16*(6), doi: ARTN 064016, 10.1088/1748-9326/abfc75.

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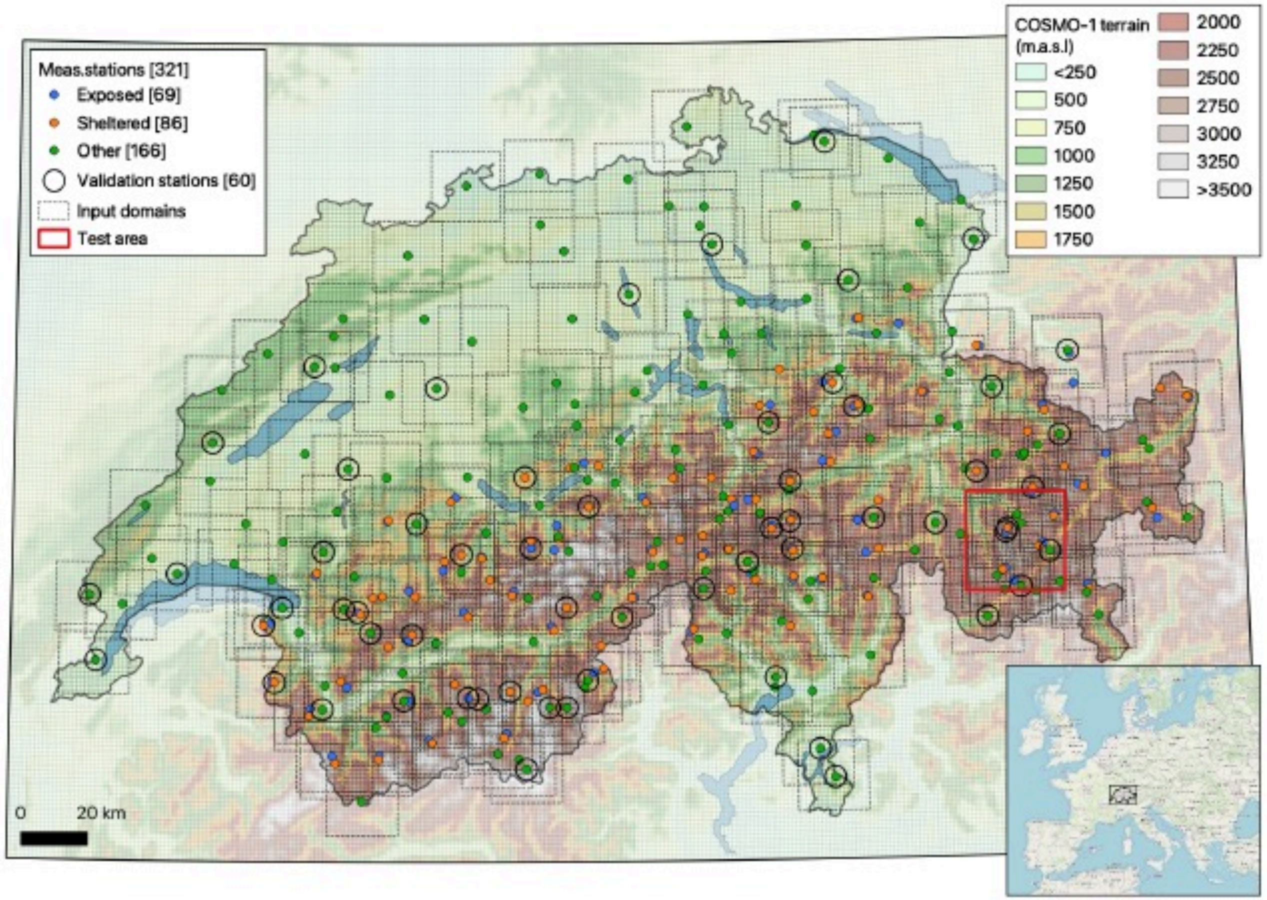
Make HR Wind Fields Computationally Affordable with ML



- Try **machine learning** (ML) and specifically convolutional neural networks with training on weather station data (MeteoCH and IMIS)

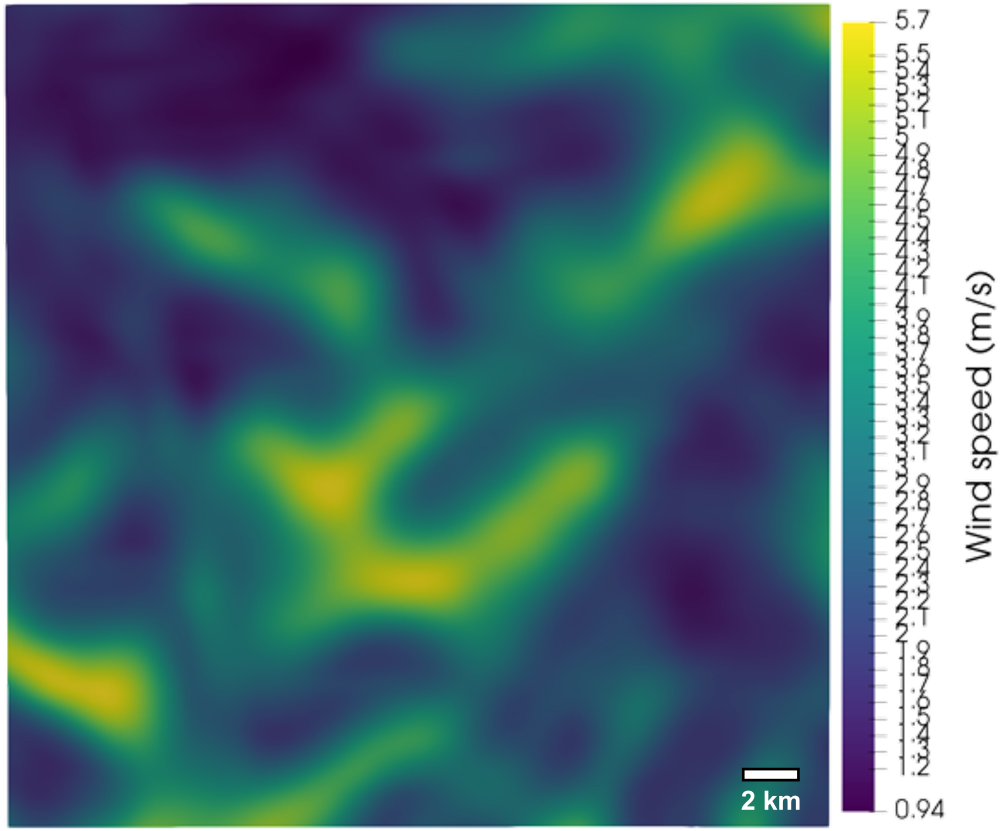
- **Topographic Parameters** determined in an environment around the grid point of interest and characterizing wind exposure → make the wind turn as it hits topography

- Find a suitable **Loss Function,** which not only minimizes the error but also preserves the distributions of modelled winds as expressed by e.g. Weibull parameters

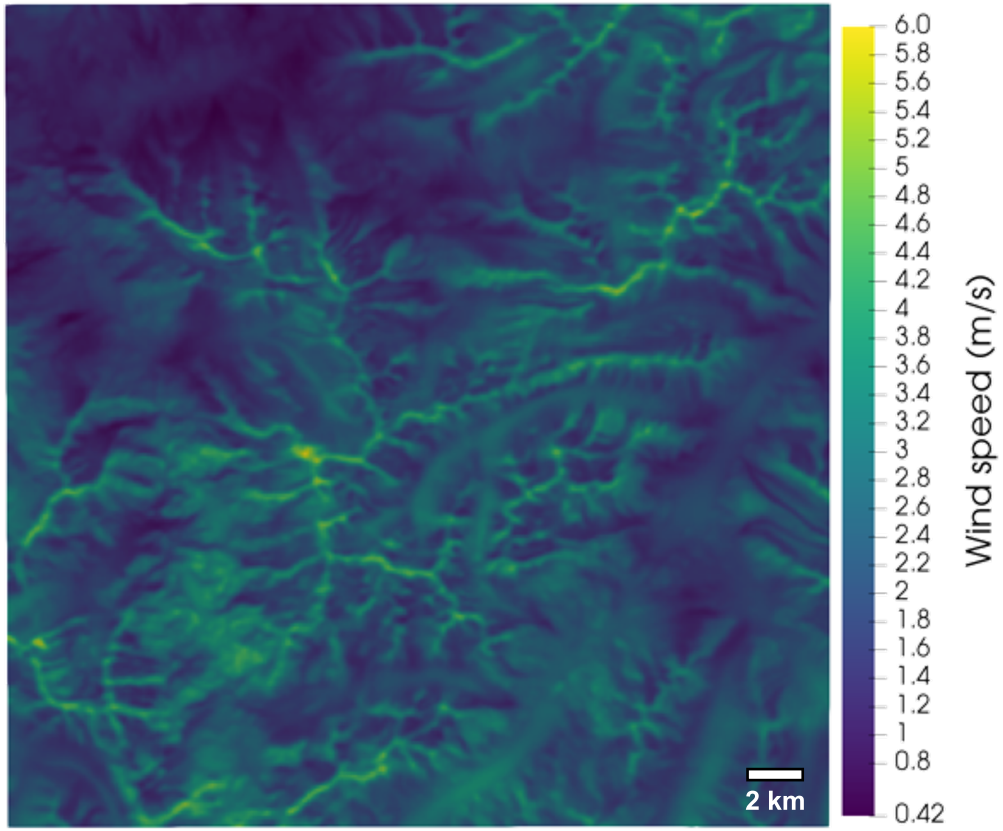
WindTopo brings out local features and wind maxima

Average wind speed (1 year, hourly)

COSMO-1



Wind-Topo



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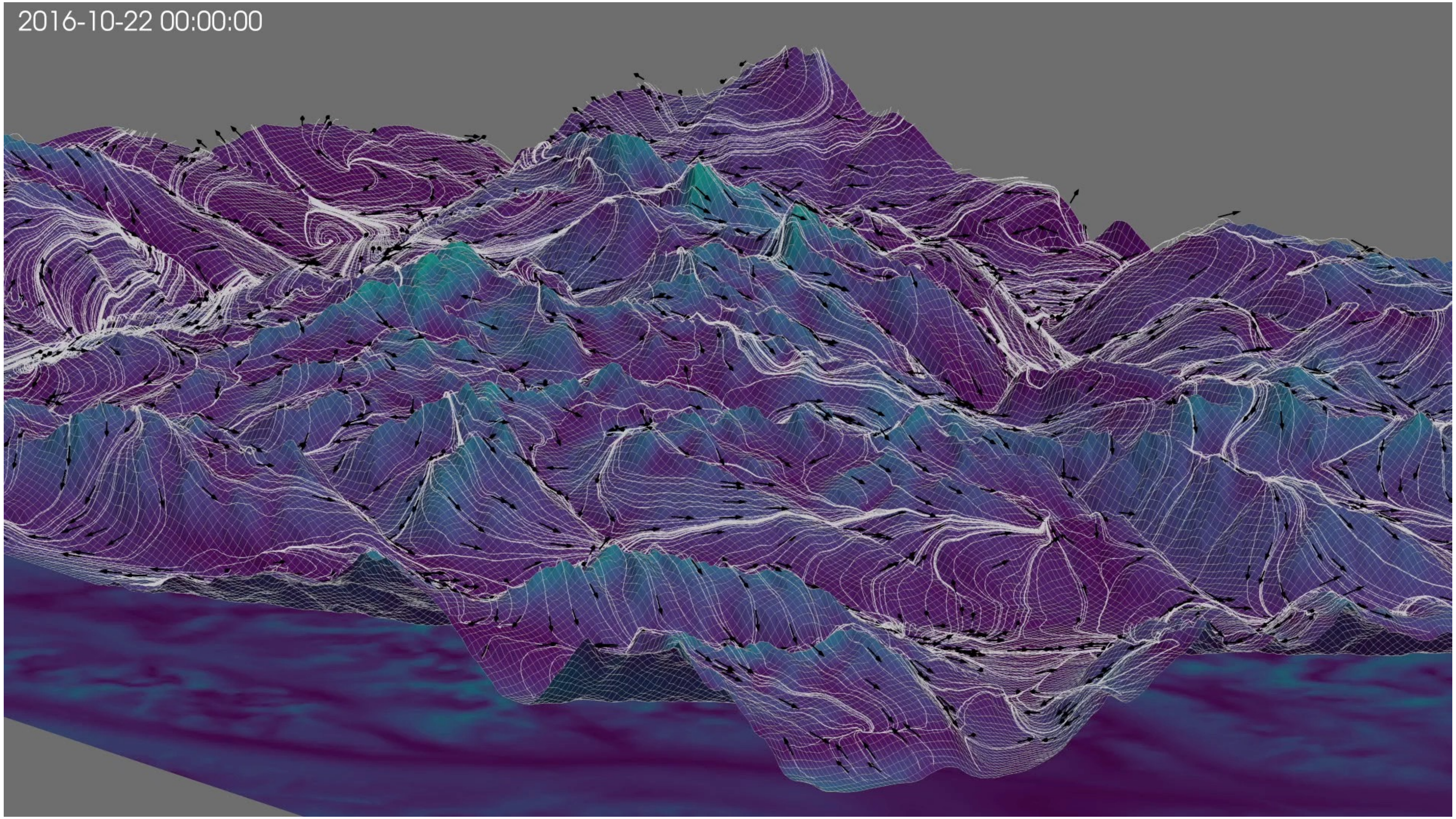
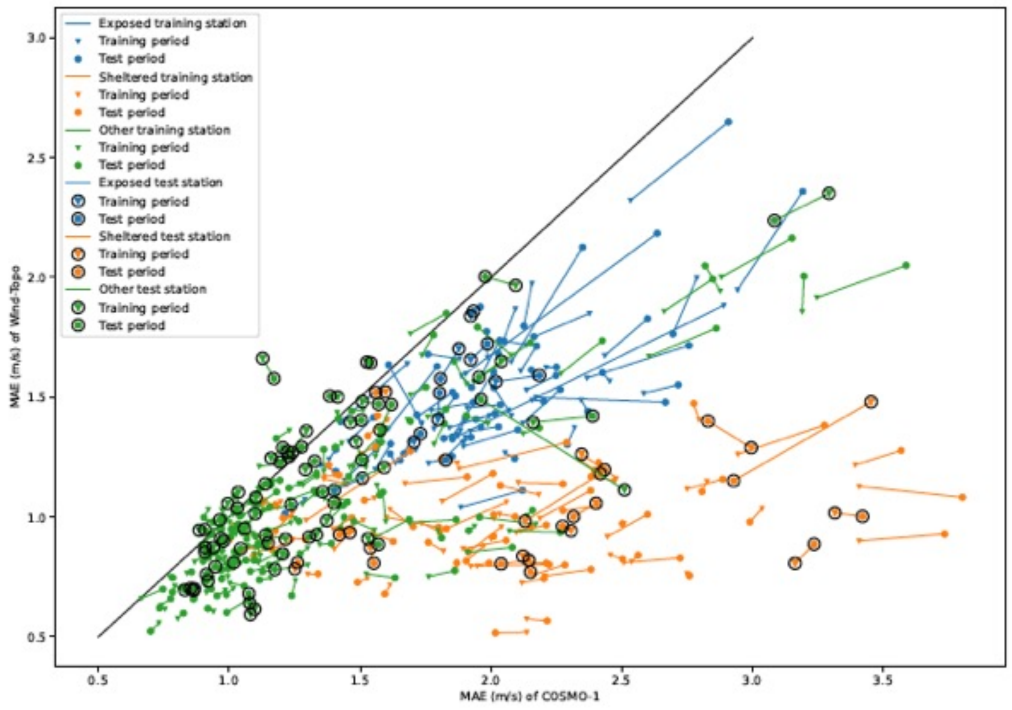


Make HR Wind Fields Computationally Affordable with ML

- The machinery behind is still quite complicated and still requires significant resources
- A **spatial and temporal cross-validation** gives good results
- Ongoing tests for completely new environments (India), other topographic settings (passes) and for «height above ground» extrapolation
- Use for **potential assessment** and **operational forecasting**



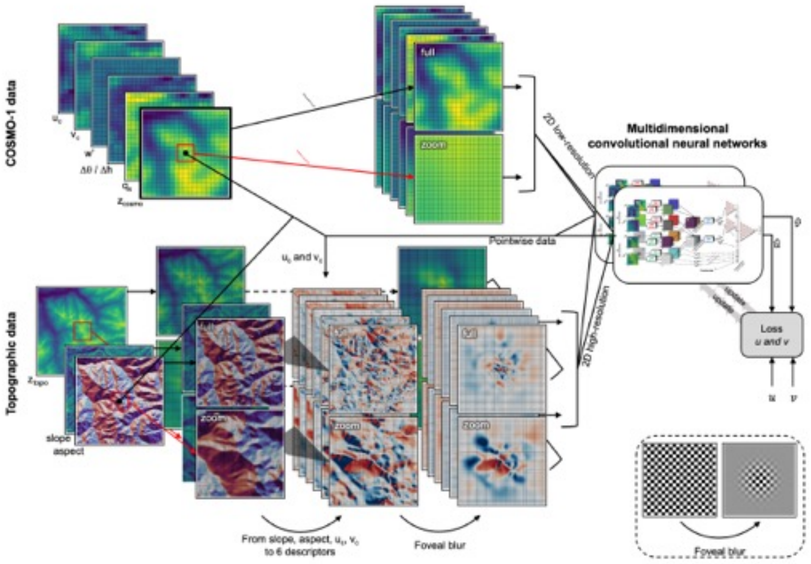
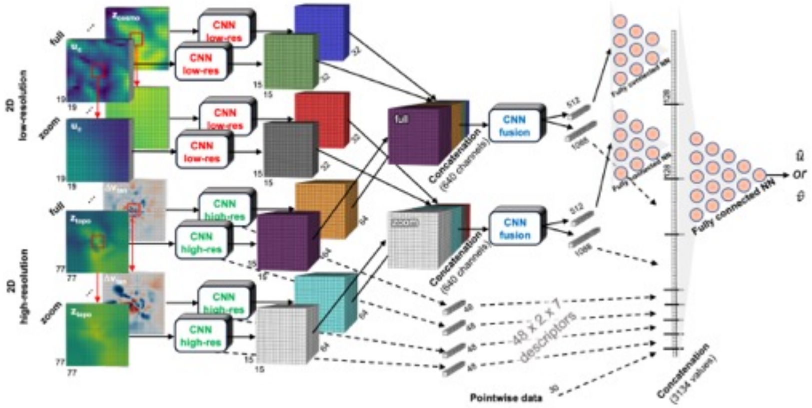


Figure 5.3: Chain of operations to obtain the predicted $\hat{u}$ and $\hat{v}$ at the center of the patch of input data.



Dujardin and Lehning, QJRMS, in review

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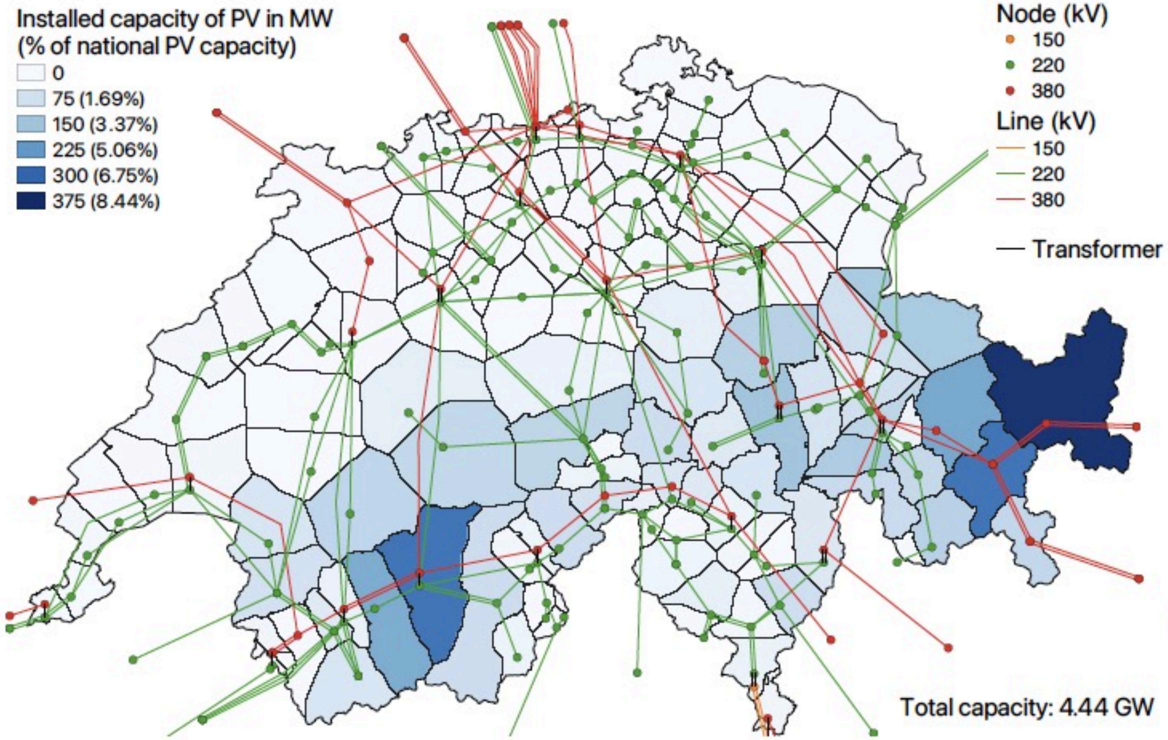

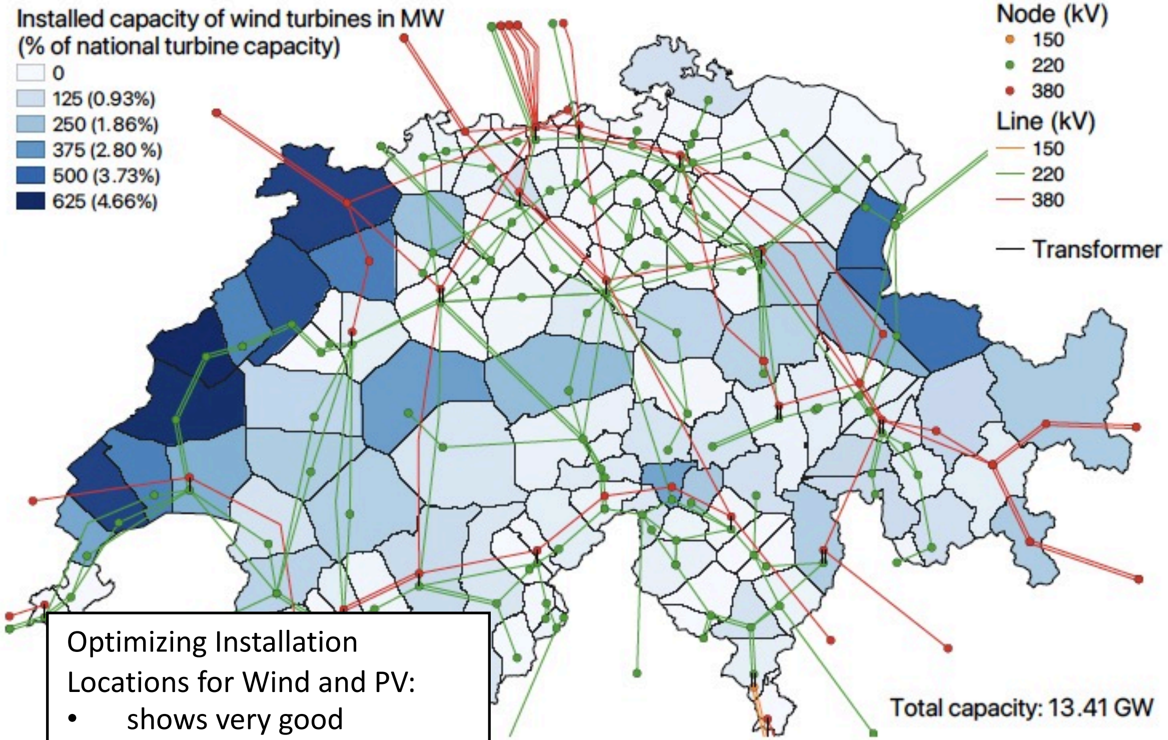

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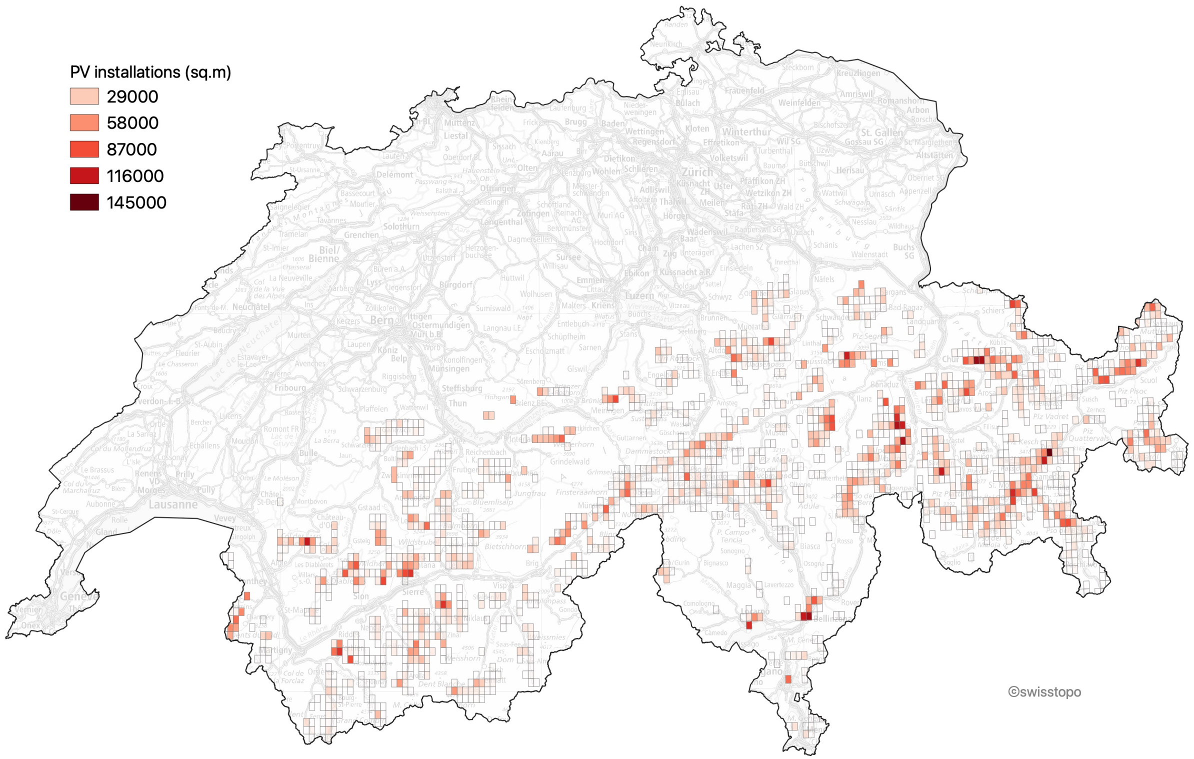
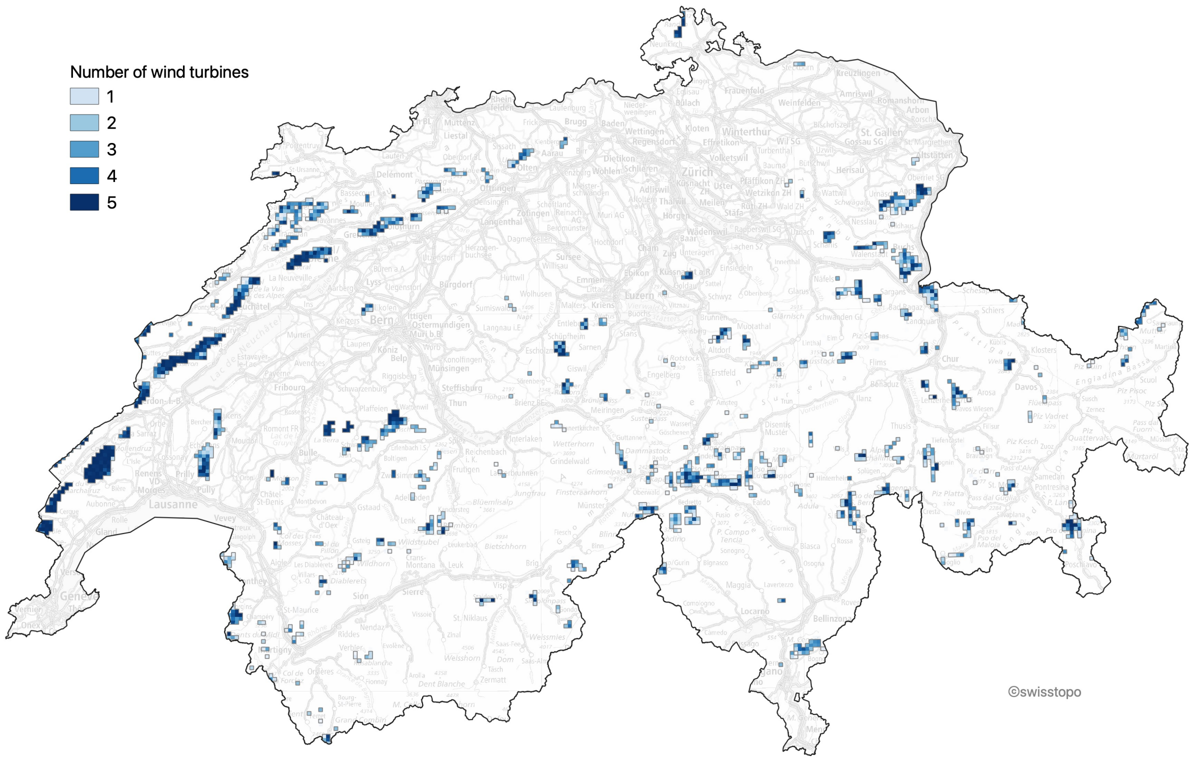
Optimization for minimizing winter deficit
(29 TWh generation in 2016)

Optimal PV installations: 4.44 GW_{peak}



Optimal wind power installations: 13.41 GW_{peak}



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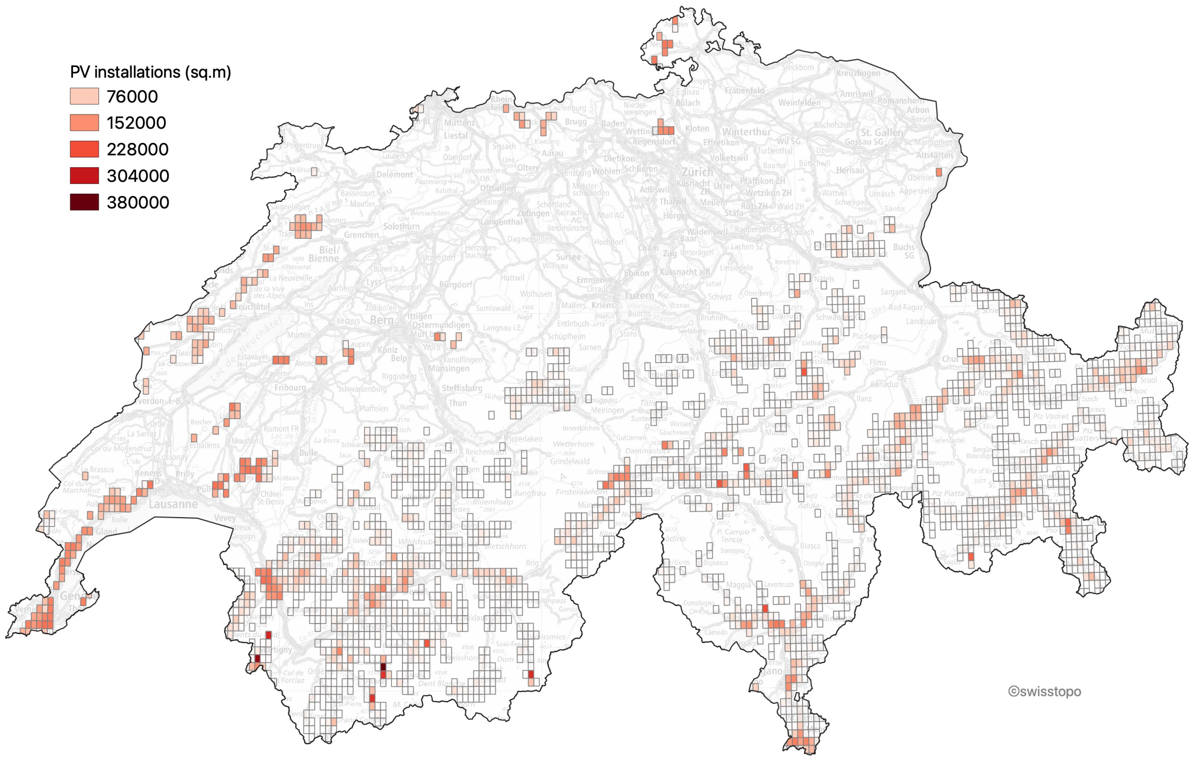
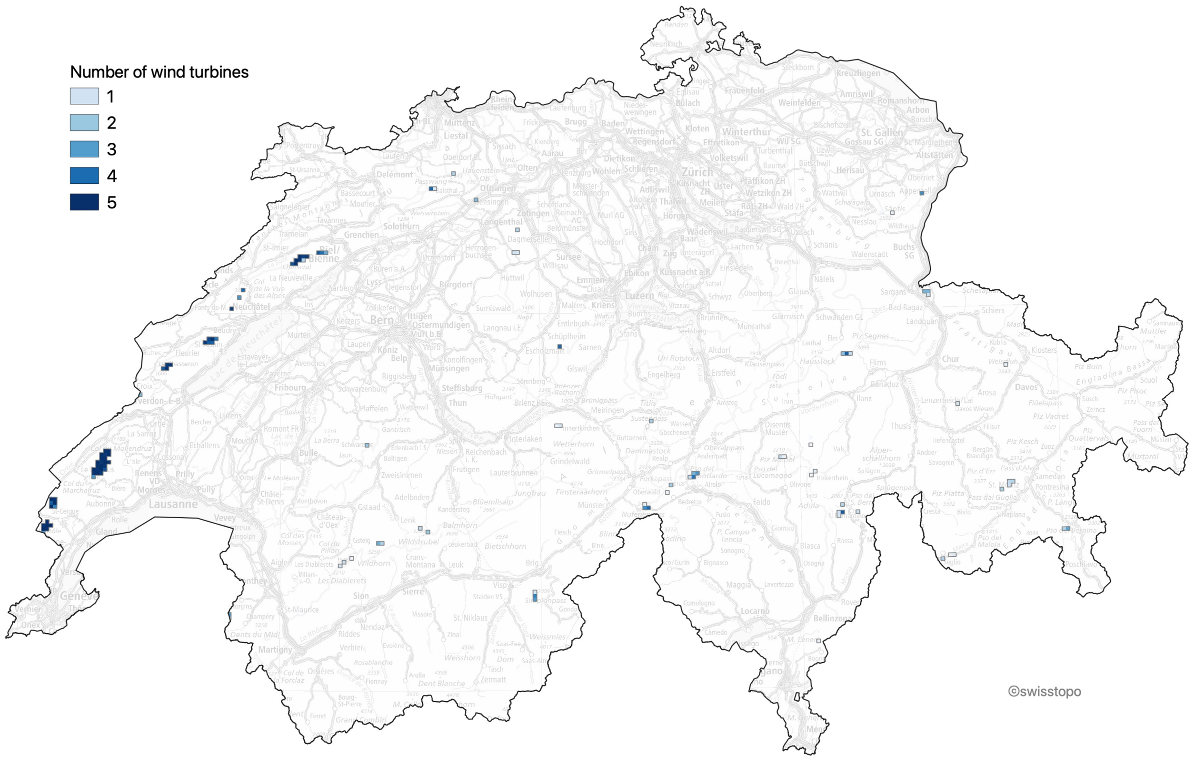
Optimization for maximizing revenues
(25 TWh generation in 2019)

Optimal PV installations: 13.64 GW_{peak}



Optimal wind power installations: 1.18 GW_{peak}



Fresh from the Press: Jérôme Dujardin

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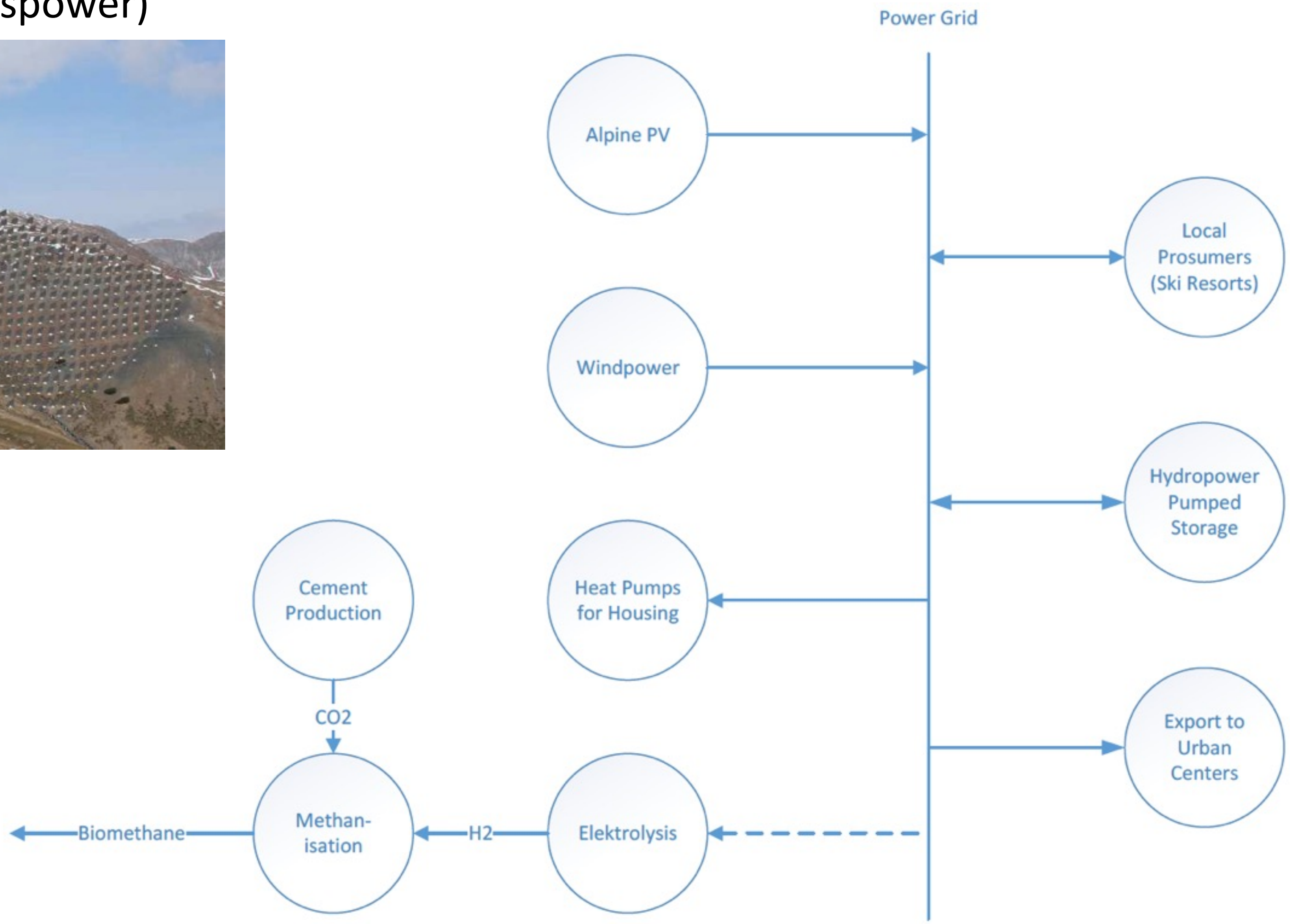
SWEET-EDGE WP 6 – Demo Alps

Totalop Site Davos (Swisspower)



Alpine Wind: La Stadera Lukmanier

Reasons for more wind than currently known:

- Channeling
- Speed-up
- Mountain Waves

<u>How can we find the best spots?</u>

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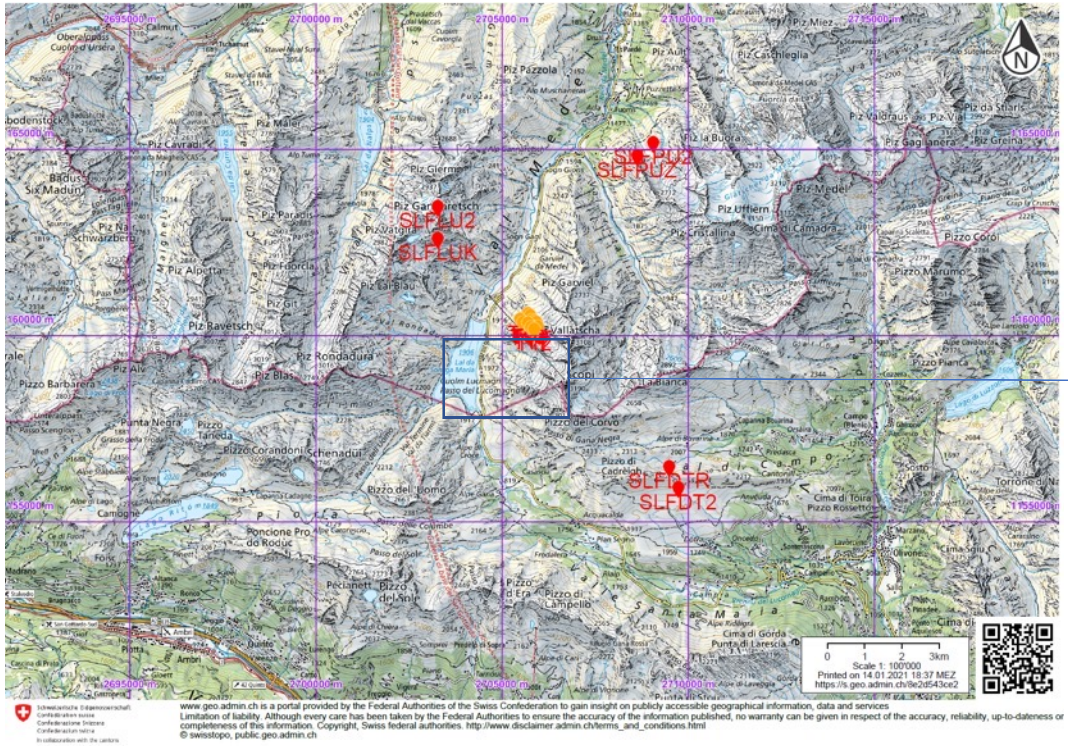
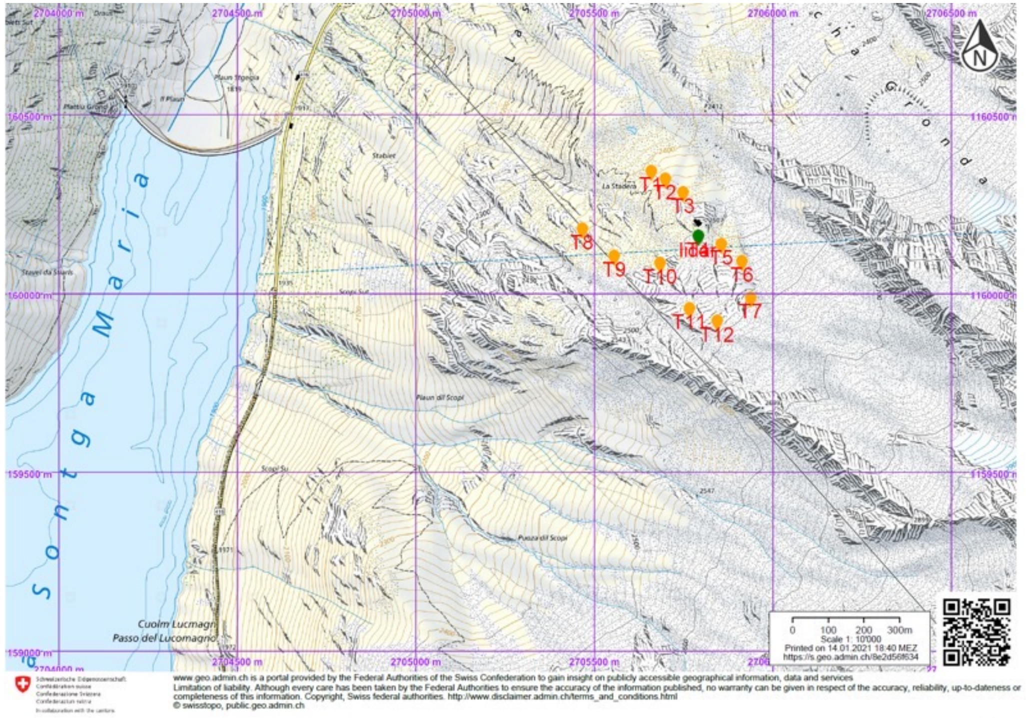
Alpine Wind: La Stadera Lukmanier

How good is this location?

Weather station
Planned turbines location
Lidar location

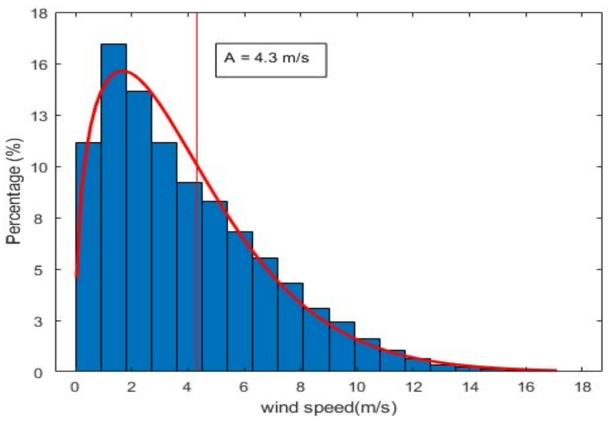




Alpine Wind: La Stadera Lukmanier

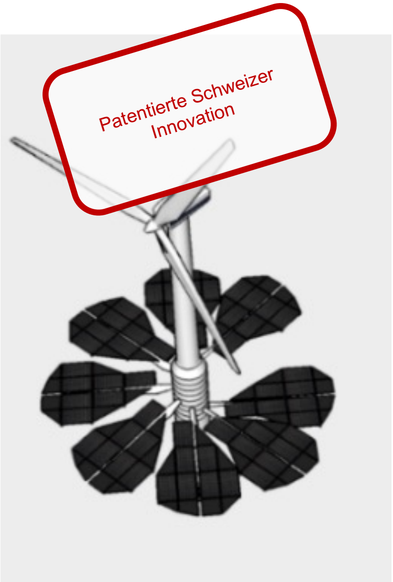
Innovative Solution

Machine Learning Approach



Weibull distribution from 10 years trained data at lidar location

K = 1.4 , A = 4.3 m/s



Conventional Measurements

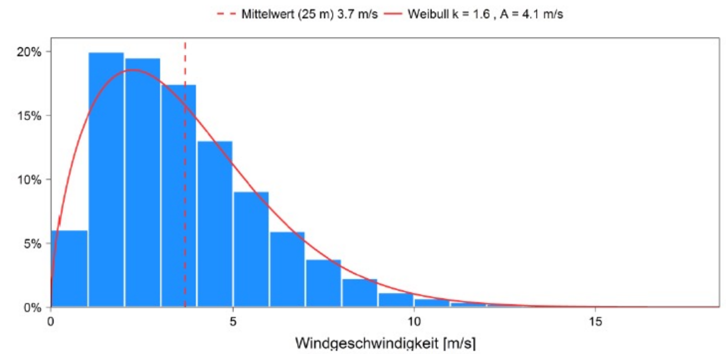


Abbildung 4: Häufigkeitsverteilung der Windgeschwindigkeit auf 25 m mit der entsprechenden approximierten Weibull-Verteilung.

Weibull distribution from meteotest

K = 1.6, A=4.1 m/s

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“First Conclusions”

- Increasingly analysing more detail of PV and wind contributions to a fully renewable Switzerland confirm feasibility and stability
- Mountain PV remains ”best choice”
- Wind needs more work – first steps have been presented
- Need to get it built
    - Community (prosumer) involvement
    - Business models
    - Legal frameworks