FEASIBILITY STUDY FOR 100% RENEWABLE ENERGY MICROGRIDS WITH MEDIUM-SIZED WIND TURBINES IN SWITZERLAND

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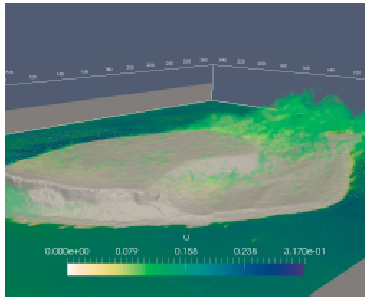
Wind energy research programme at HSR

1. DIGITALISATION

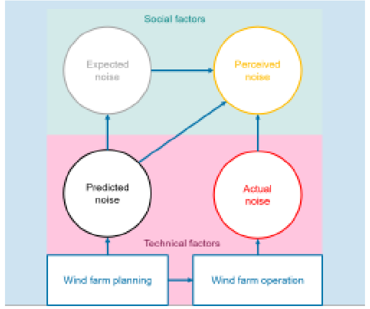


Computational Fluid Dynamics: high-fidelity Large Eddy Simulations and application of the Lattice Boltzmann Method to wind flow in complex terrain (BFE, WindForS).

Internet of Things: design of wireless, smart pressure and acoustic measurement systems for wind turbine blades.

Machine Learning: power curve predictions and SCADA data analysis.

2. HUMAN FACTORS

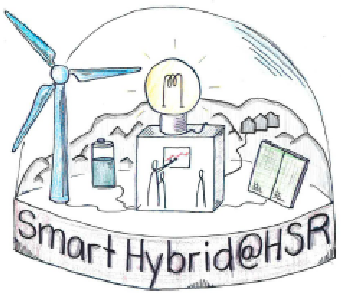


Acceptance: understanding the technical and behavioural factors related to wind turbine noise perception and reality (together with the University of St. Gallen).

Skills: supporting young professionals in leadership skills development (in collaboration with mindspire).

Teaching: developing and applying e-learning methods for wind energy education.

3. SYSTEM INTEGRATION



Microgrids: investigating the possibility of integrating wind energy, photovoltaics and storage systems into closed microgrid systems for improving grid stability.

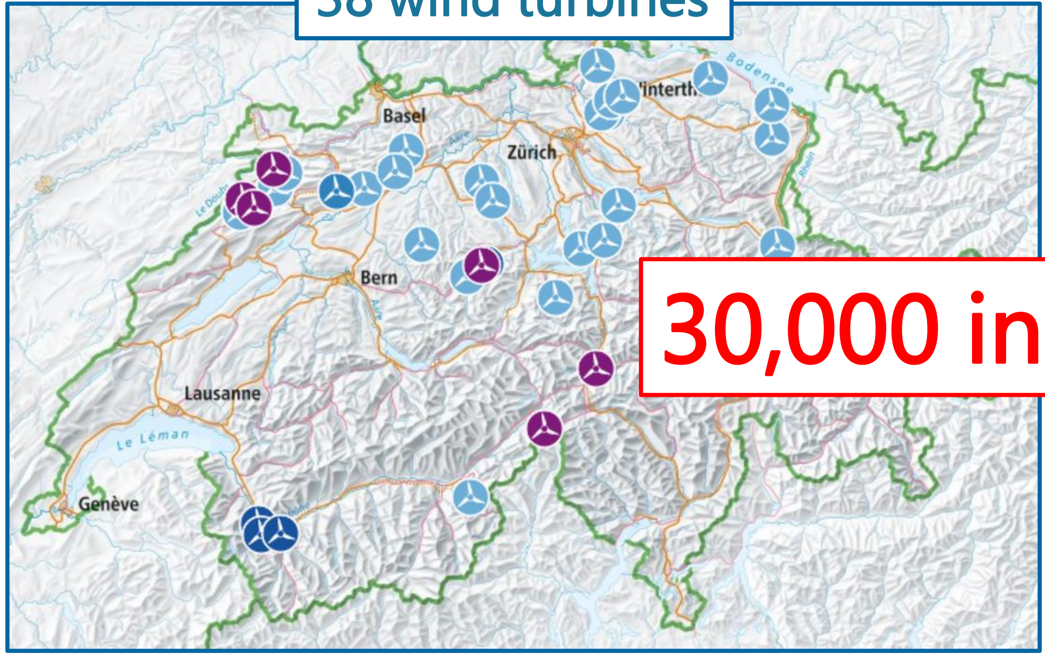
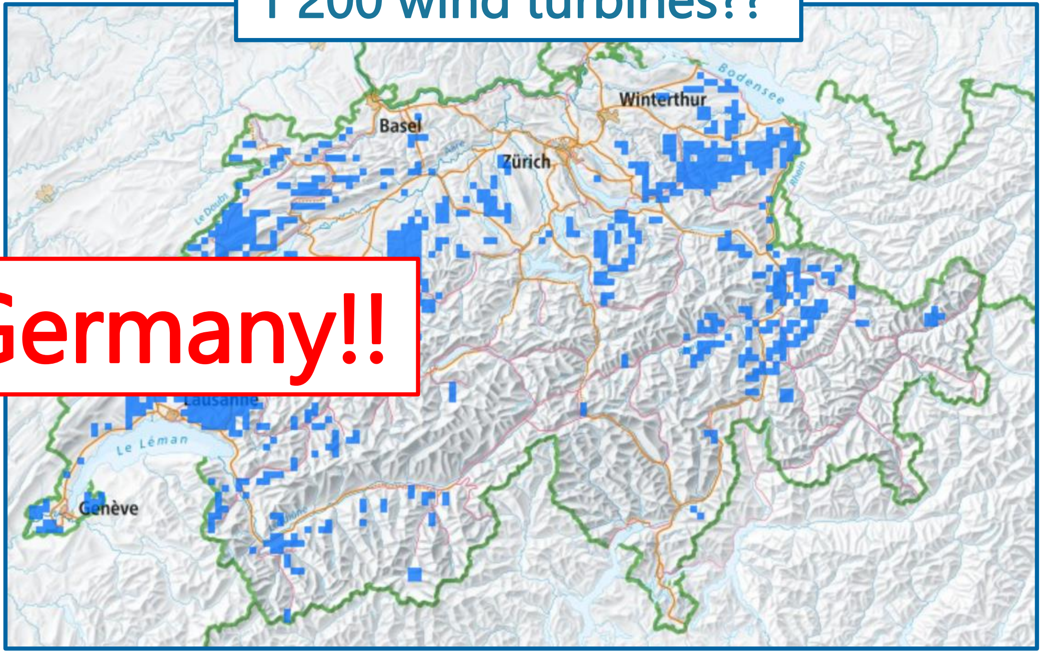
Innovation: novel energy supply solutions such as kite wind power and building-integrated systems.

Recycling: designing and testing new bio-materials for wind turbine blades.

Contents

- **Wind energy in Switzerland.**
- **Goal of this work.**
- **Method.**
- **Results and analysis.**
- **Conclusions.**

Wind energy in Switzerland

2018	Energy strategy 2050
38 wind turbines 	1’200 wind turbines?? 

30,000 in Germany!!

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Wind energy in Switzerland

- **Current situation:**
  - Switzerland does not yet have a large number of installed wind turbines (0.2% penetration level in 2016).
  - Despite the ambitious Energy Strategy 2050, not a single wind turbine was installed in 2018!
- **Why not??**
  - Mainly large delays, costs and risks associated with the permitting procedure for wind turbines higher than 30 m.
- **What about wind turbines lower than 30 m?**
  - Much easier permitting procedure.
  - Less economically viable than large wind turbines: average installed costs of about 4,400 $/kW compared to 1,400 $/kW for MW-size wind turbines[1].

→ Combination of wind turbines < 30 m with PV and storage in microgrids??

[1]*International Renewable Energy Agency (2012): RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES*

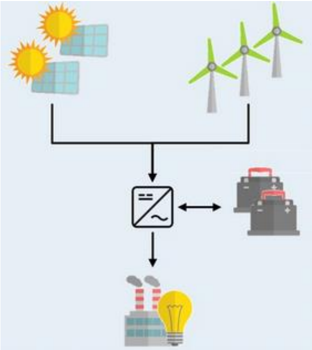
Goal of this work

- **Goal = to investigate the feasibility of 100% renewable microgrids in Switzerland.**

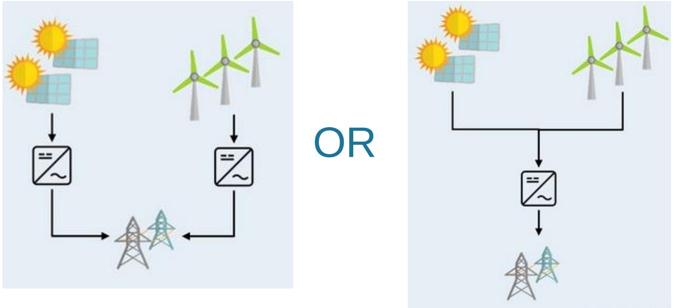
- **The United States Department of Energy Microgrid Exchange Group defines a microgrid as:**

  "*A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both connected or island-mode*".

Independent island solutions



Grid-connected solutions



→ **Only island-mode microgrids are investigated in this work.**

Method

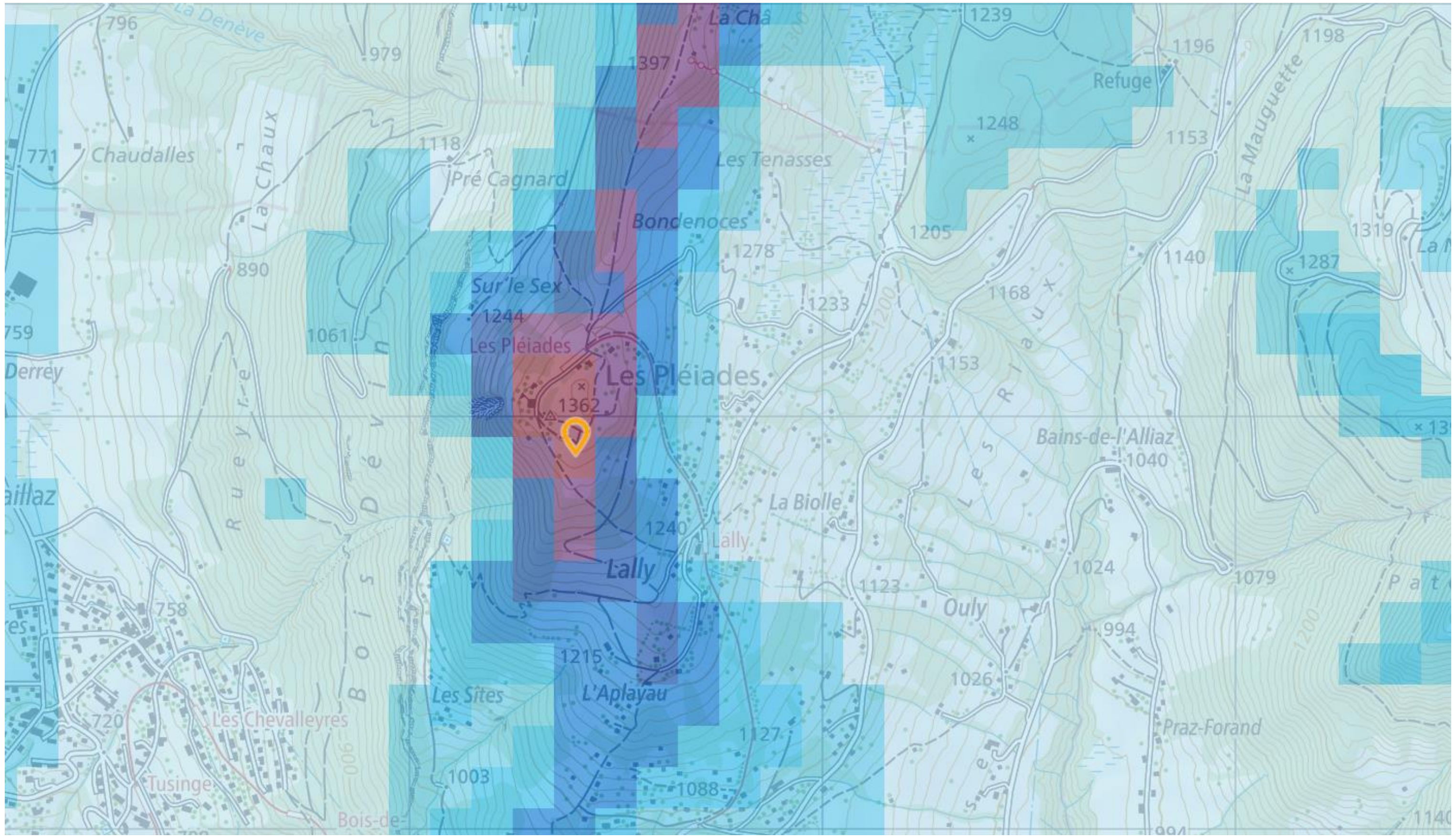
Commercial software HOMER PRO

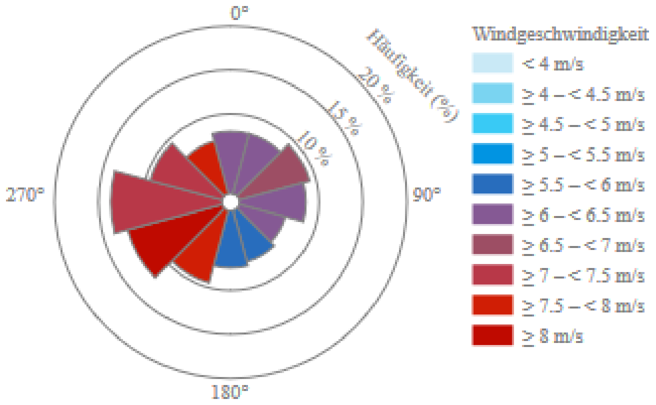
SITES	RESOURCES	MICROGRID	LOADS	ALGORITHM	OPTIMISATION
Choose sites based on wind speed, terrain and nearby villages.	Obtain and input solar radiation and wind speed distribution data for each site.	Define microgrid layout, set-up and components.	Choose a range of suitable load profiles.	Choose the most suitable optimisation algorithm.	Run the optimisation algorithm to calculate the optimal amount of PV, wind and storage.

Choice of sites

https://map.geo.admin.ch

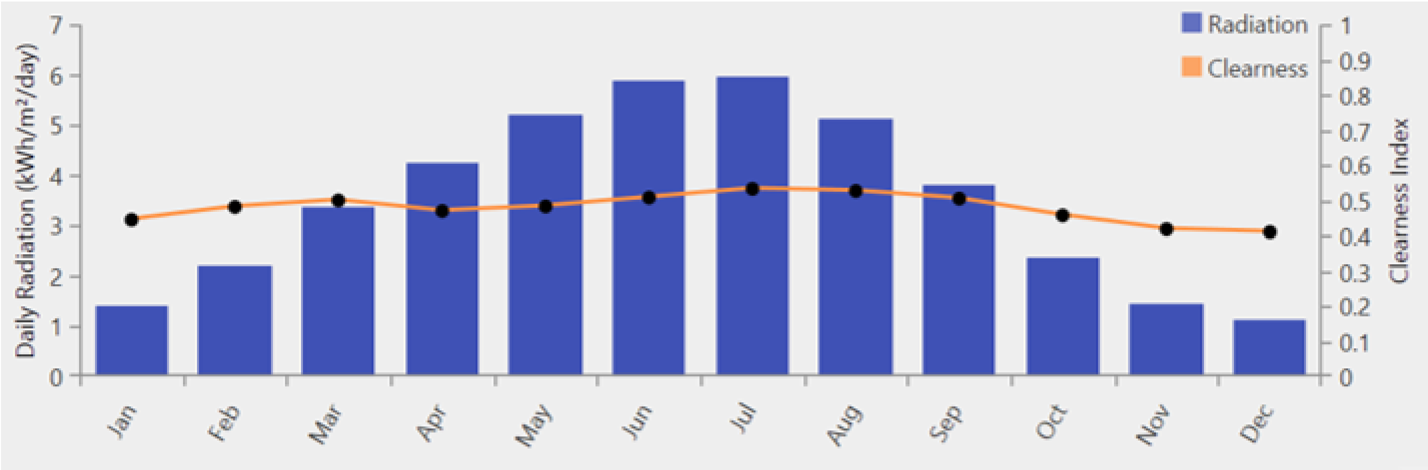
Example site – Les Pléiades





Resources

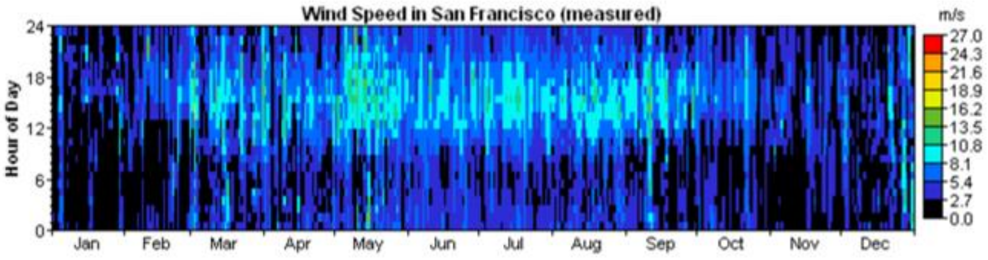
- **Solar Global Horizonatal Irradiation (GHI) resource = sum of beam radiation, diffuse irradiance and ground-reflected radiance:**
  - Monthly averages downloaded from the NASA Surface meteorology and Solar Energy database based on the latitude and longitude (averages from 1983 – 2005).
  - HOMER builds a set of 8'760 solar radiation values (one for each hour) and creates synthesised values using the Graham algorithm[1] → realistic day-to-day and hour-to-hour variability and auto-correlation.

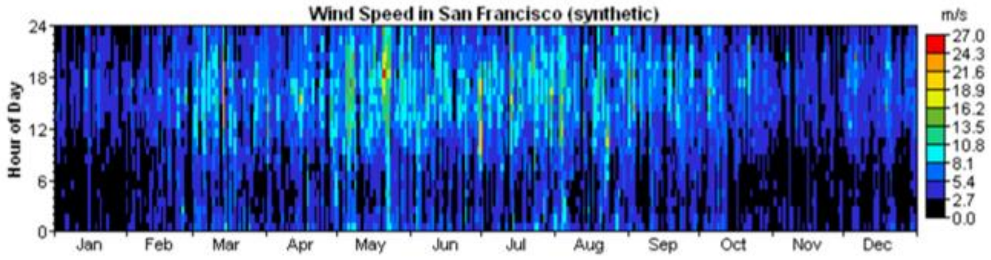


[1]*Graham VA, Hollands KGT (1990), A method to generate synthetic hourly solar radiation globally, Solar Energy, 44(6), 333-341*

Resources

- **Wind resource:**
  - Monthly average wind speed downloaded from the HOMER website based on the latitude and longitude.
  - Yearly average at 50 m obtained for each site from www.wind-data.ch.
  - Monthly averages then scaled manually for each site and for the WTG height using a power law profile with a shear factor of 0.2.
  - HOMER generates synthetic wind data using the **Weibull factor**, the **1-hour autocorrleation factor**, the **dirunal pattern strength** and the hour of the **peak wind speed**.

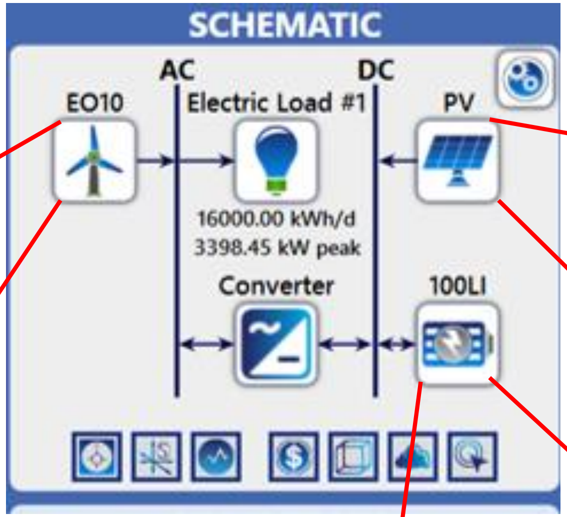




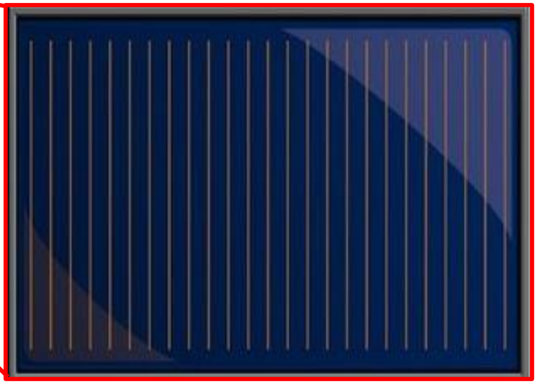
Microgrid set-up

Rated power = 10 kW
Rotor diameter = 15.81m
Hub height = 16 m
(Total height = 23.81 m)
Capital costs (CAPEX) = $44,000[1]
Operating costs (OPEX) = $4,000/year[2]
3% availability losses
5% wake effect losses
2% electrical losses

EO10 Eocycle wind turbine



Rated power = 1 kW
DC with MPPT
Derating factor = 80%
Capital costs (CAPEX) = $3,000/kW[4]
Operating costs (OPEX) = $10/year



Generic flat plate PV

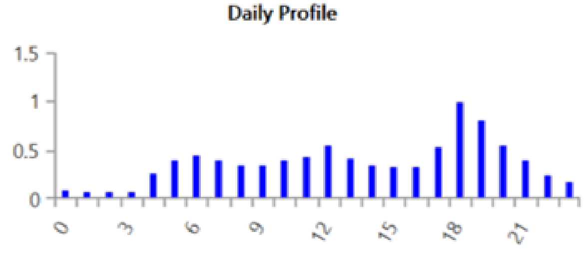
Nominal capacity = 100 kWh
Maximum charge current = 167 A
Maximum discharge current = 500 A
Time = 15 years
CAPEX = $20,000/kWh[3]
Replacement costs = $20,000/kWh
OPEX = $1,000 / year

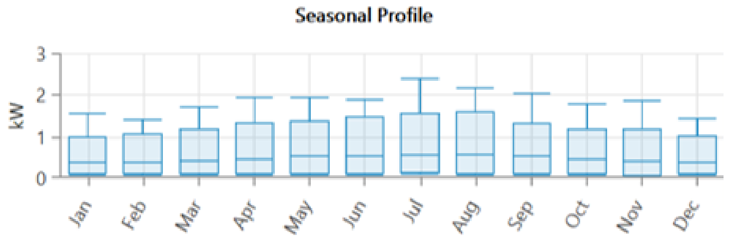
Idealized Li-ion battery

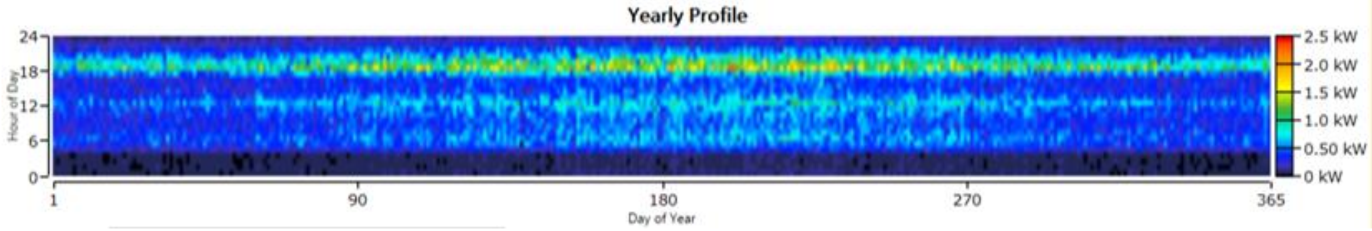
[1]International Renewable Energy Agency (2012): RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES
[2]Estimated as CAPEX/10
[3]Bloomberg
[4]http://www.energie.ch/photovoltaik

Load profiles

- **Synthetic load created from a profile → hourly values for each month.**
- **Load magnitude scaled to a range of values:**







Load profile	Electricity demand per day (kWh/day)	Number of 4-room houses[1]
1	500	73
2	1,000	146
3	3,000	438
4	4,000	584
5	5,000	730
6	10,000	1,460
7	16,000	2,336

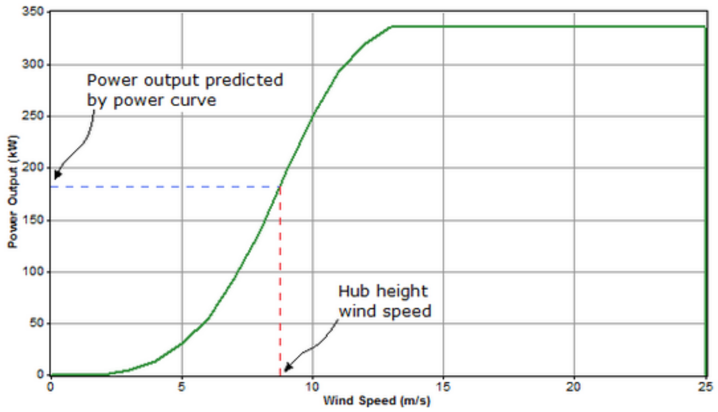
[1]*Assumption: average electiicty demand of a four-room house = 2,500 kWh/year (average in CH)*

Algorithm

- **PV array output:** $$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) \left[1 + \alpha_P \left(T_c - T_{c,STC} \right) \right]$$

Y_{PV} = the rated capacity of the PV array, meaning its power output under standard test conditions [kW]
f_{PV} = the PV derating factor [%]
$\bar{G}_T$ = the solar radiation incident on the PV array in the current time step [kW/m^2]
$\bar{G}_{T,STC}$ = the incident radiation at standard test conditions [1 kW/m^2]
α_P = the temperature coefficient of power [%/°C]
T_c = the PV cell temperature in the current time step [°C]
$T_{c,STC}$ = the PV cell temperature under standard test conditions [25°C]

- **Wind turbine power output:**
  - Corrected hub-height wind speed and manufacturer's power curve with density correction:



- **Maximum battery charge and discharge power: Kinetic Battery Model**

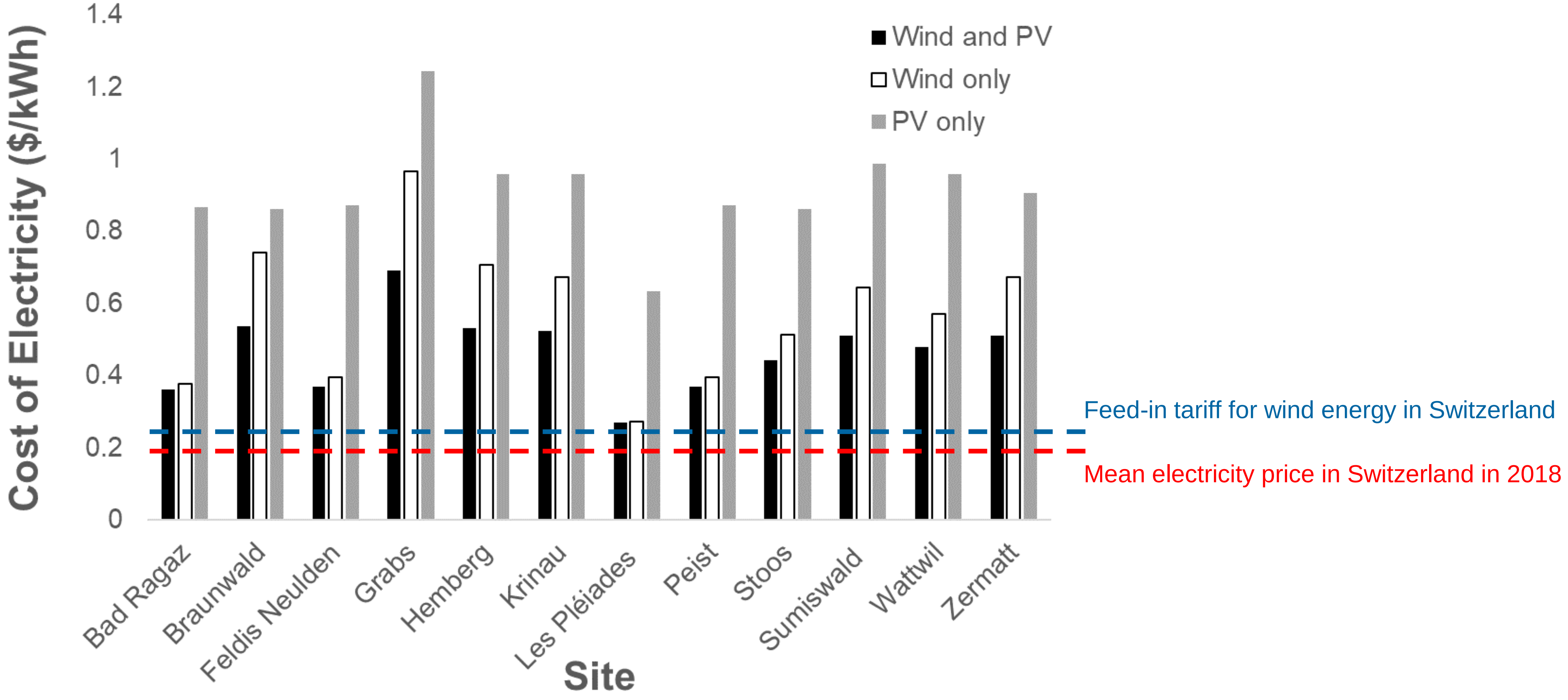
Algorithm

- **Optimization settings:**
  - 60 minutes per time step.
  - Optimization goal = minimise Net Present Cost.
  - Variables = installed capacity of PV, wind turbines and storage.

- **Other settings:**
  - Nominal discount rate = 6.00%.
  - Project lifetime = 20 years.
  - $ and CHF are interchangeable (exchange rate = 0.99).

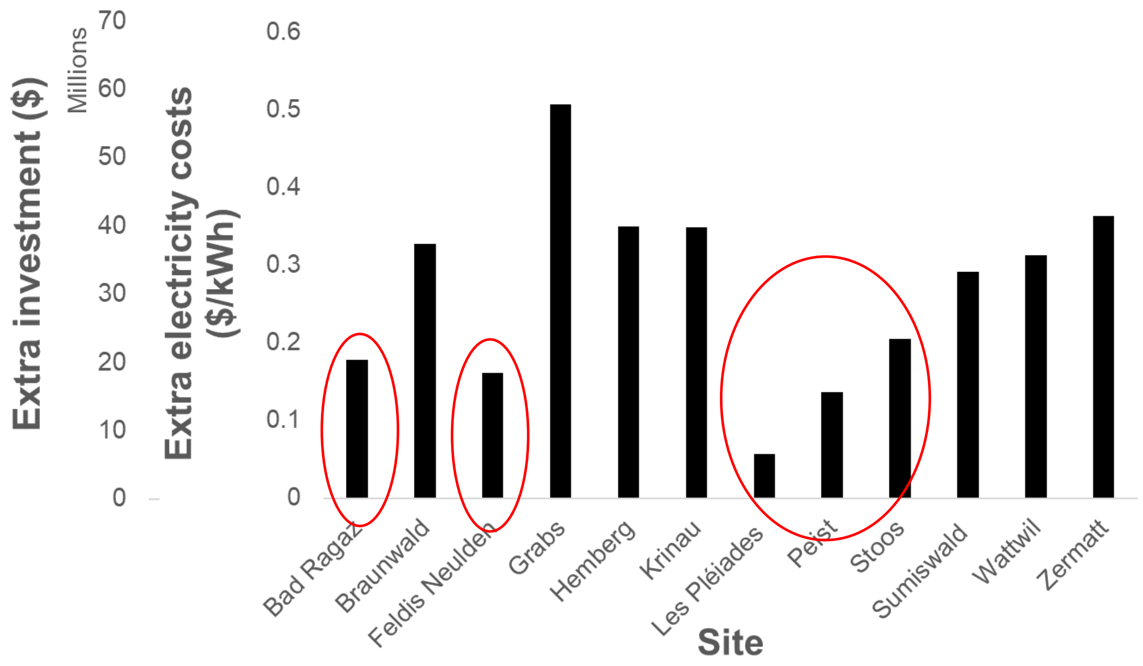
Wind & PV combination significantly better than separate

Results for 16'000 kWh/day load profile (COE hardly depends on load profil):



Significant extra investment necessary

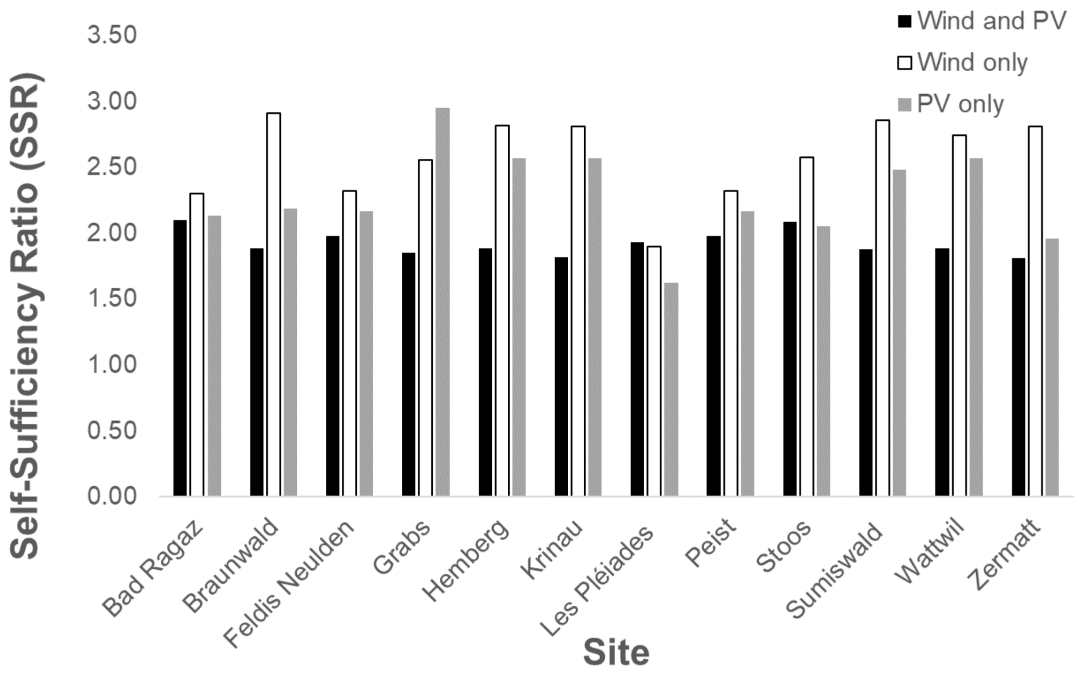
Results for 16,000 kWh/day load profile (COE hardly depends on load profil):



Five "economically feasible" sites assuming that companies / states are willing to pay up to 0.2 $/kWh for electricity independence.

Self-sufficiency ratio significantly reduced by combination of wind and PV

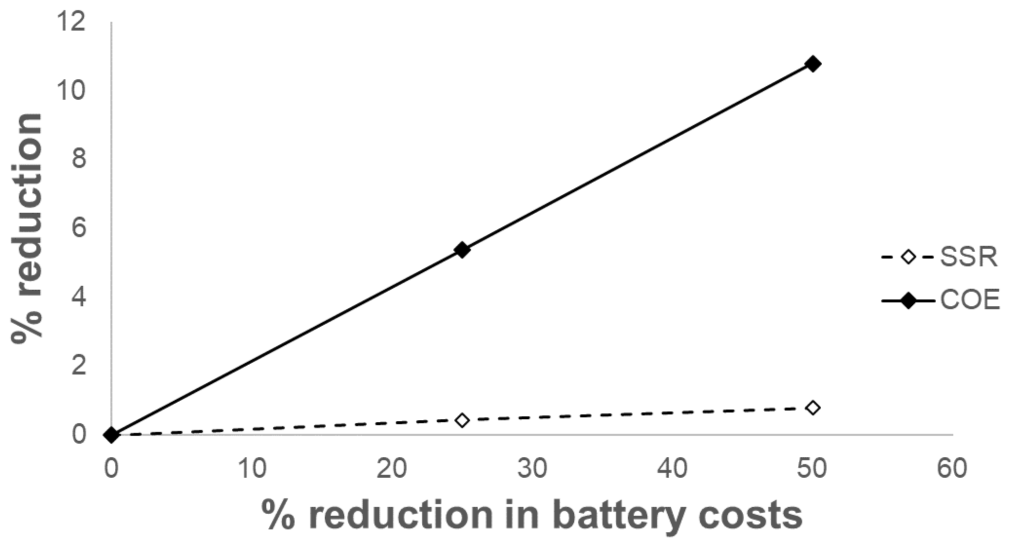
Self-Sufficiency Ratio: $SSR = \frac{Actual\ wind\ and\ PV\ production\ (kWh)}{Production\ demanded\ (kWh)}$



- SSR > 1 due to varying hourly demand not matching varying wind and sun resource.
- Reduced by combination of wind and PV with battery.
- Could be reduced further by:
  - Connecting to grid when required.
  - Lower battery / storage costs.

Reducing battery costs reduces SSR and therefore COE

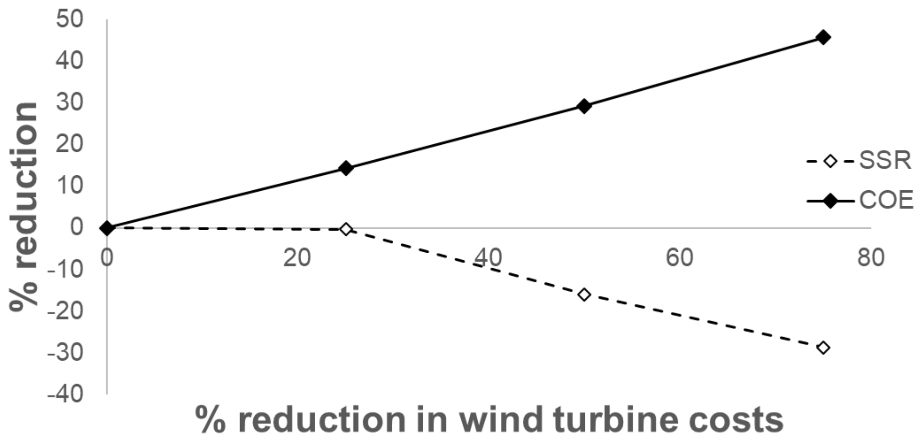
- **Les Pléaides 16,000 kWh/day case:**



- **For wind and PV combined, effect of reduced battery costs on SSR is minimal.**

Reducing capital cost of wind energy reduces COE but increases SSR

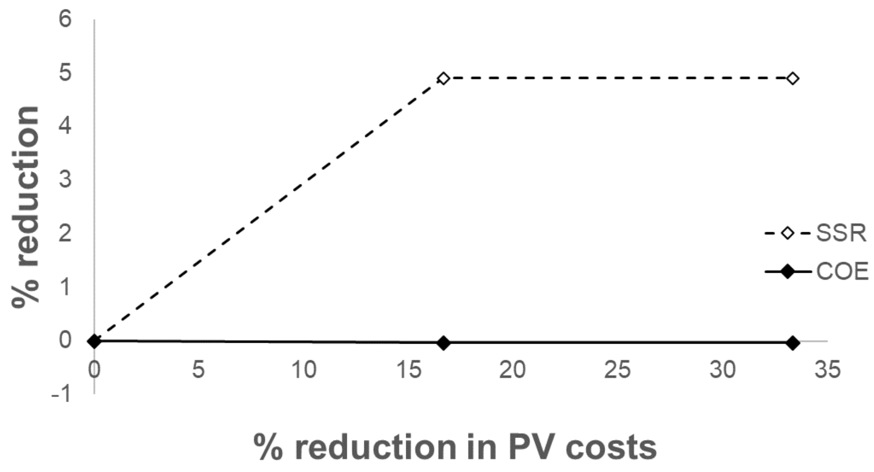
- **Les Pléaides 16,000 kWh/day case:**



- **For wind and PV combined, reduced wind energy costs decrease COE but increase SSR (because of more wind turbines).**

Reducing capital cost of PV hardly affects COE but increases SSR

- **Les Pléaides 16,000 kWh/day case:**

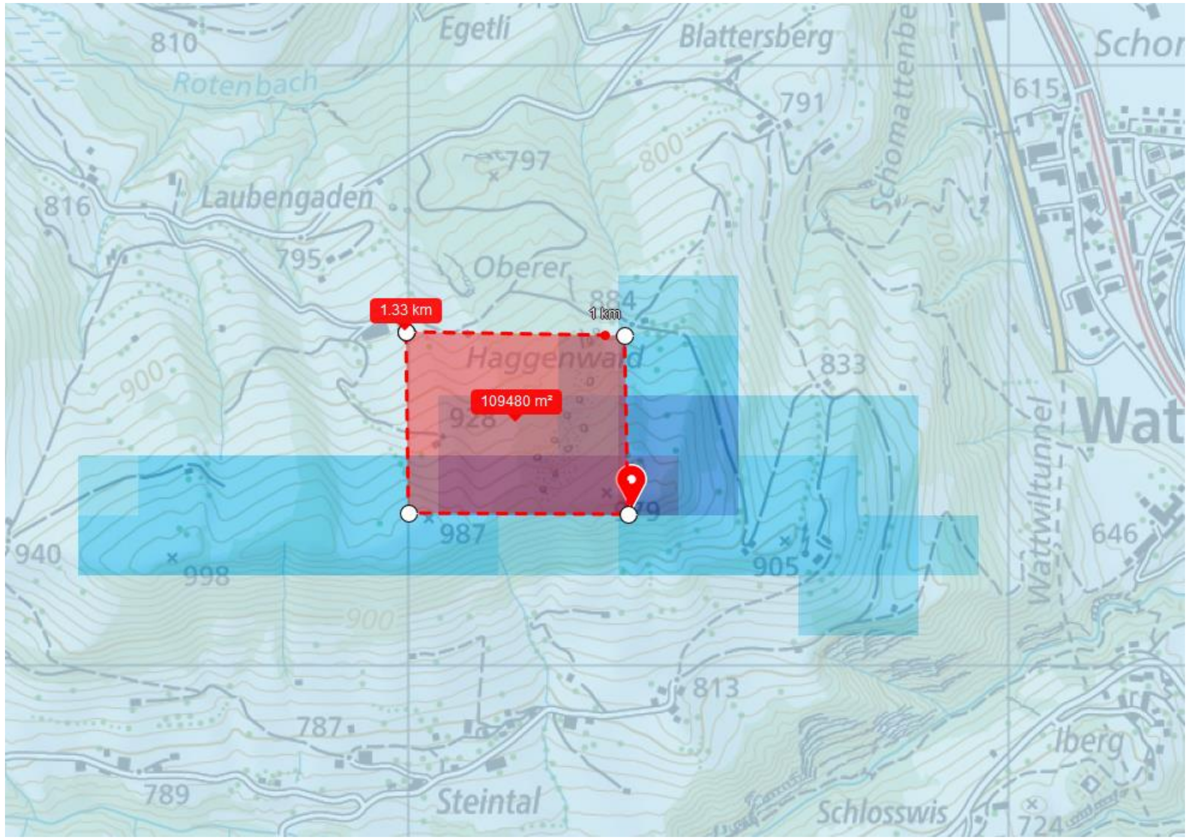


- **For wind and PV combined, reduced PV costs hardly affects COE but increases SSR (because of more PV).**

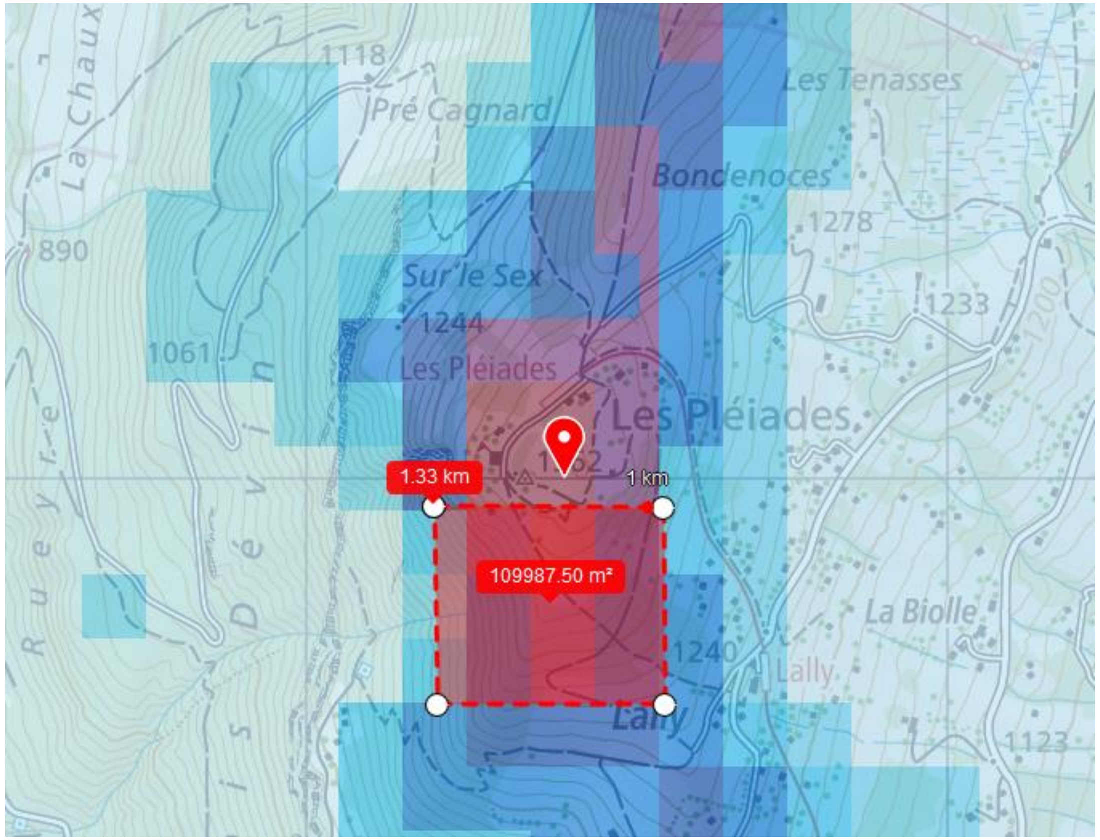
Approximate "acceptable" space estimated from map

- **Approximate acceptable ground area for PV and WTG = 100,000 m²:**

Example Wattwil

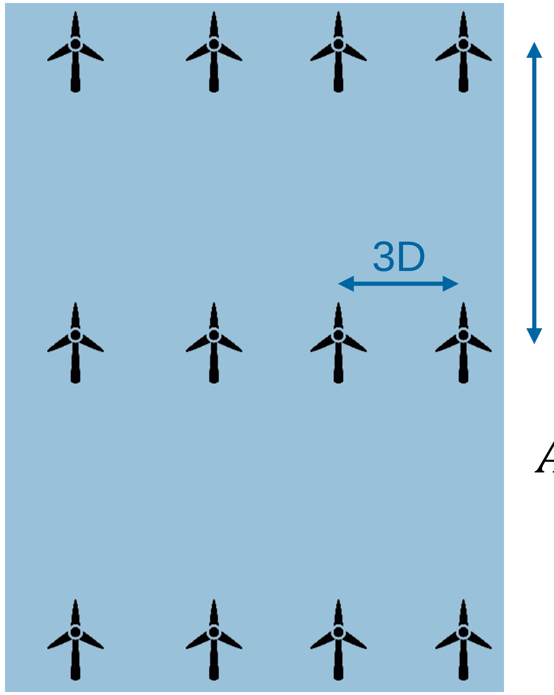


Example Les Pléades



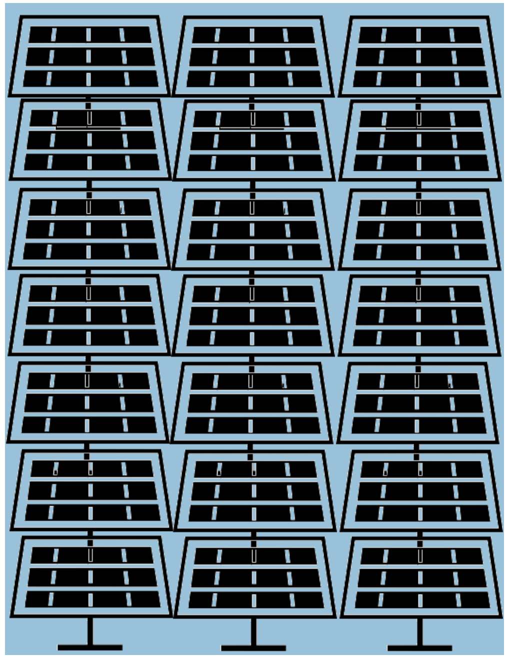
Assumptions for area calculations

- **Wind turbines:**

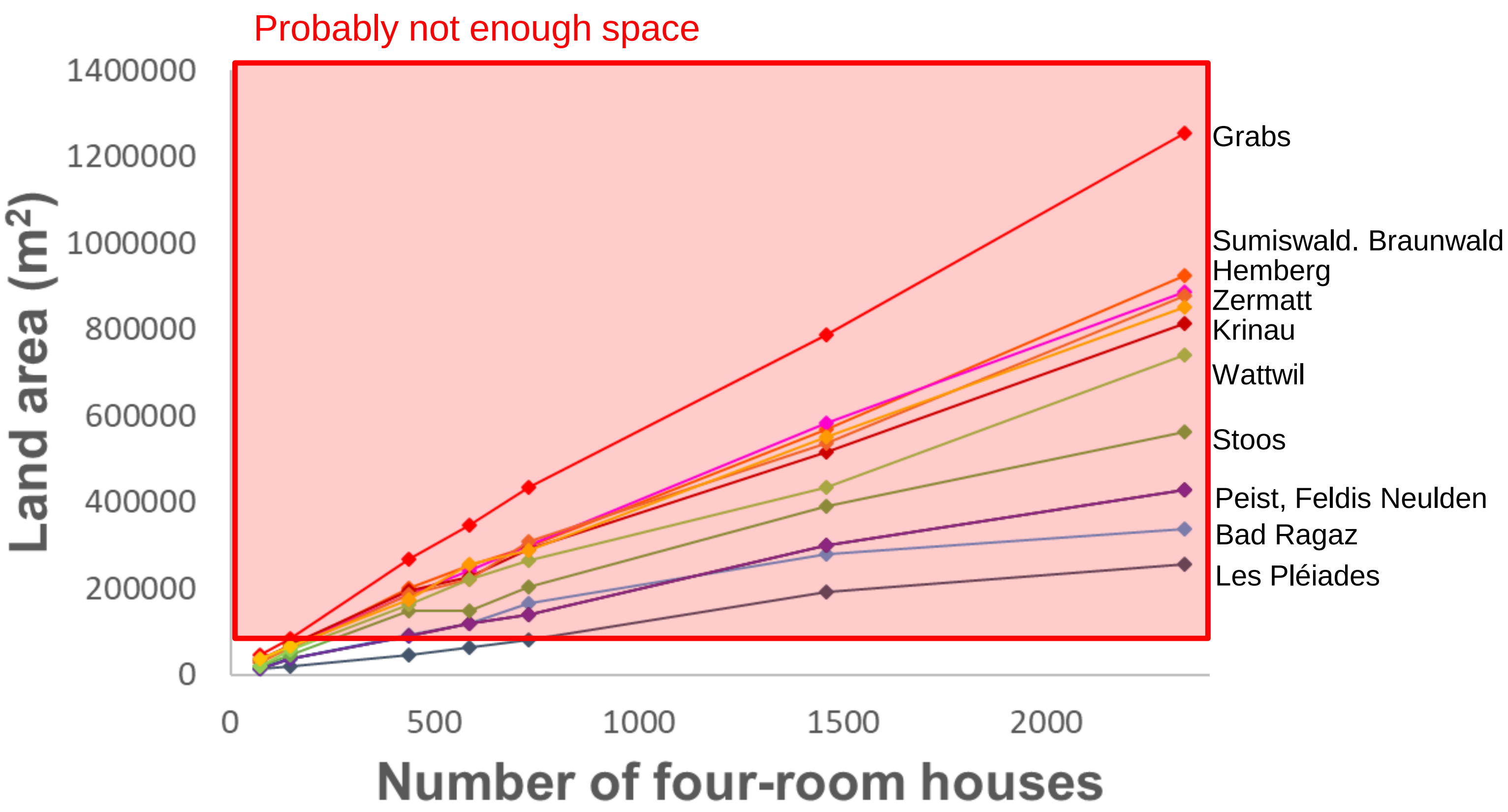


$$A = \sqrt{N-1} \times 10D \times 3D$$

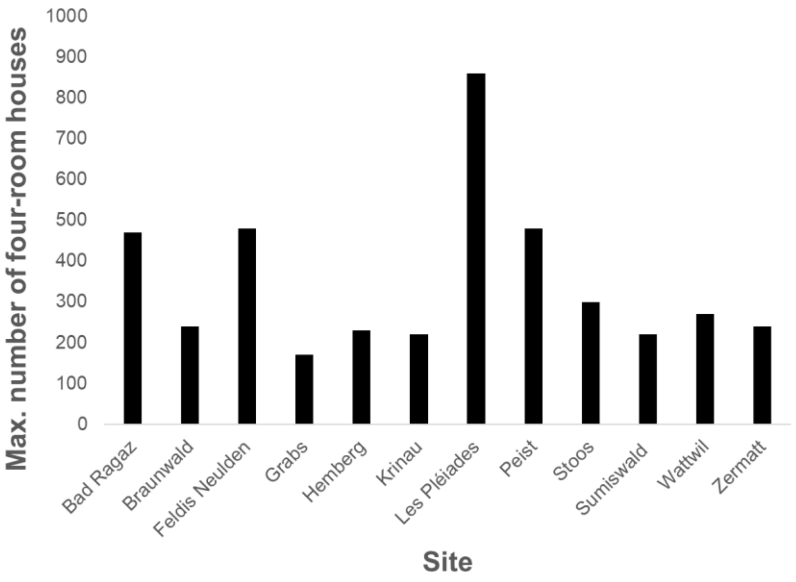
- **PV: assumption = 200 m² / kW**



This solution is greatly limited by available space!



Probably the maximum size possible:



→ More detailed investigations needed.

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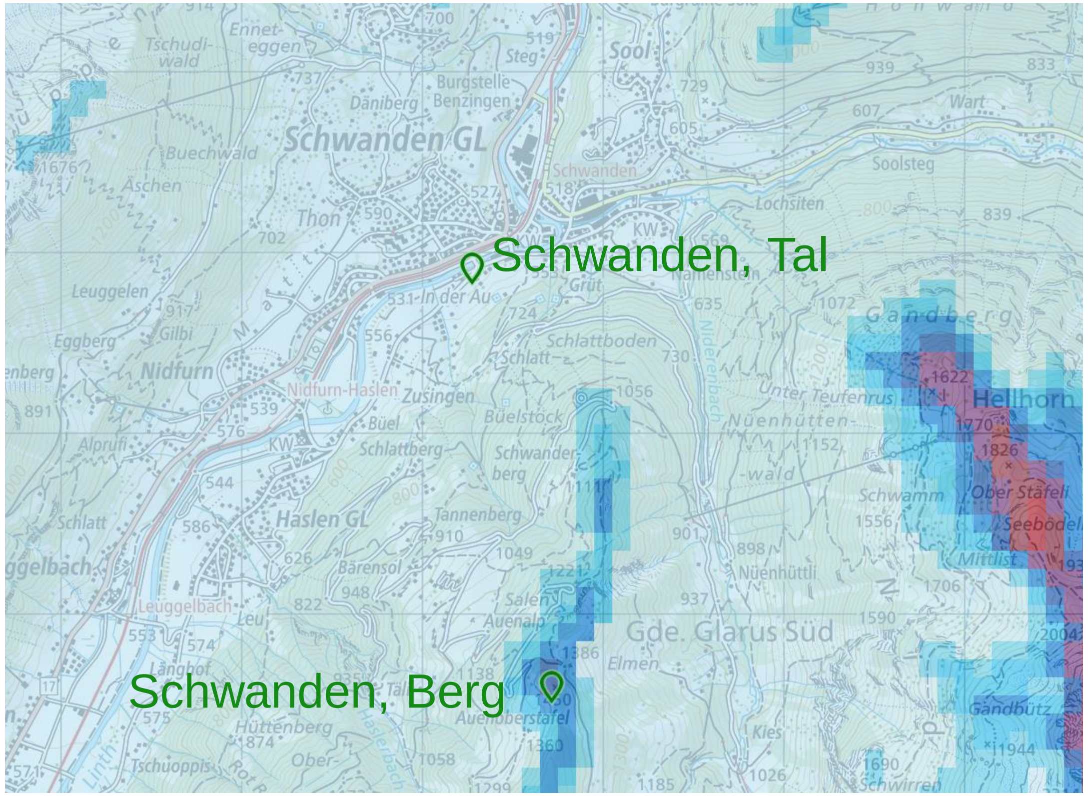
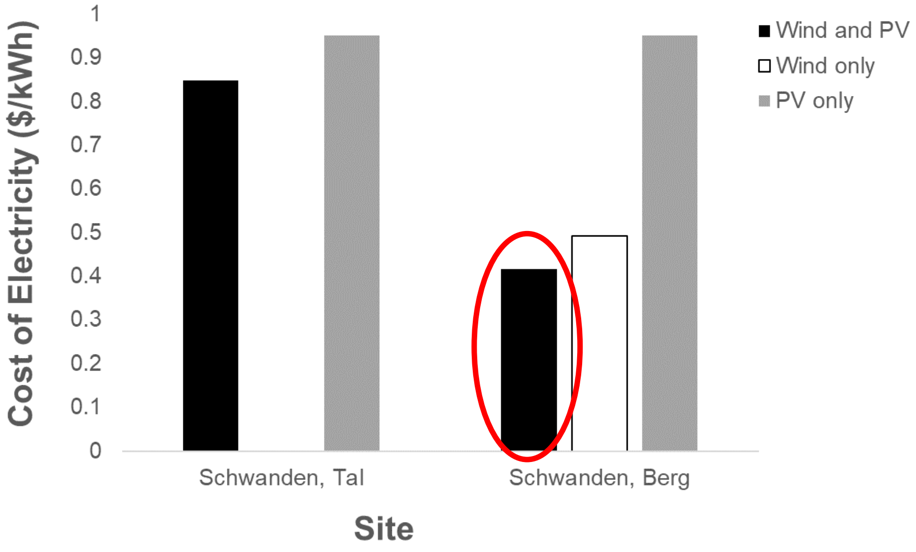
Test case for High Performance Computing Centre near Schwanden



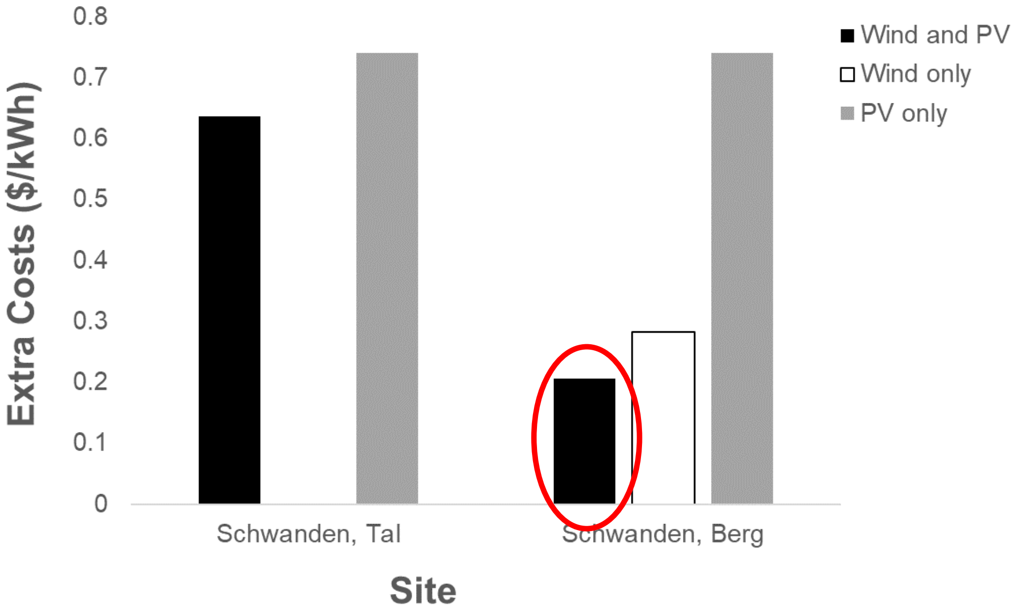
- **High Performance Computing Center in Canton Glarus "ungleich".**
- **Wants to runs 100% on renewable energy.**
- **Prepared to pay ca. 0.15 $/kWh extra.**
- **30 servers, each 1.1 kW peak → 440,000 kWh / year constant demand.**

Test case for High Performance Computing centre

- **Wind speed too low in valley but OK on hill:**



- **Extra costs only 0.05 $/kWh higher than acceptable:**



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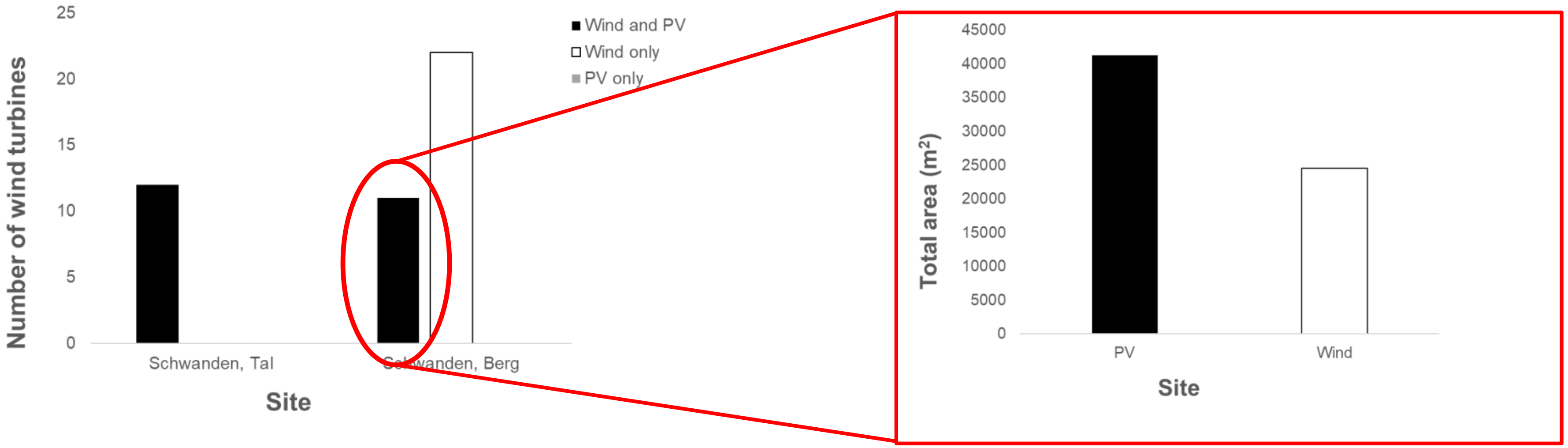
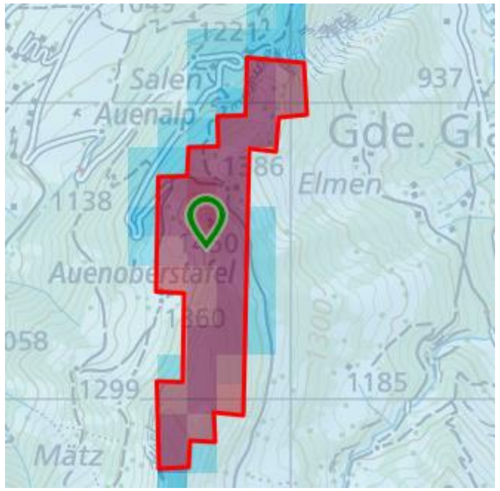
Test case for High Performance Computing centre

- **10 wind turbines over 25,000 m² seems reasonable:**



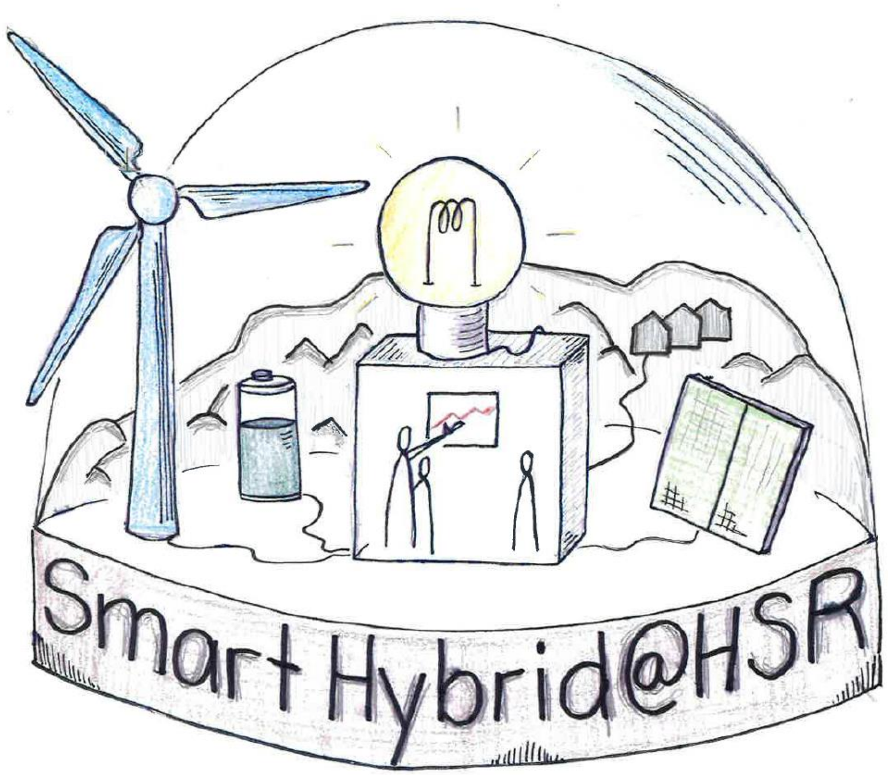


→ Resonable solution successfully found for this test case!

Conclusions

- Twelve sites in Switzerland were chosen for a 100% renewable energy microgrid feasibility study.
- Five of these sites were found to be economically viable, assuming that organisations / municipalities are prepared to make extra investments up to 0.2 $/kWh for electricity independence.
- The Self-Sufficiency Ratio (SSR) was between 1 and 2 for each site, reflecting the extra installed capacity required in order to fully cover every hour of demand (island operation).
- Reduced battery costs (up to 50%) reduce COE (up to 11%) but reduce SSR only minimally (<1%).
- Reduced wind turbine costs (up to 75%) reduce COE (up to 46%) but increase SSR (up to 30%).
- Reduced PV costs (up to 33%) reduce COE (up to 66%) but increases SSR (up to 81%).
- The implementation of 100% renewable energy microgrids is strongly limited by the area required / available.
- A suitable solution was found for a High Performance Computing Centre test site in Canton Glarus.
- The next step is to look at some real test cases with real costs and wind measurements.

Thank you!



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