

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

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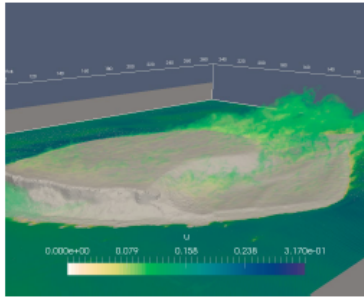
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# Wind energy research programme at HSR

## 1. DIGITALISATION

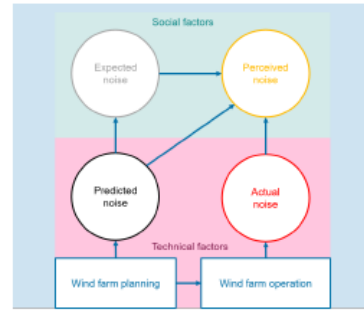


**Computational Fluid Dynamics:** high-fidelity Large Eddy Simulations and application of the Lattice Boltzmann Method to wind flow in complex terrain (BFE, WindForS).

**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

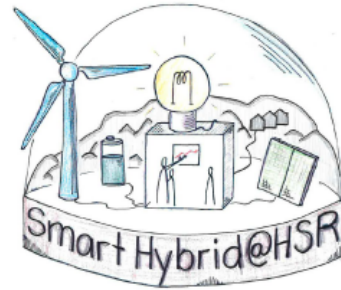


**Acceptance:** understanding the technical and behavioural factors related to wind turbine noise perception and reality (together with the University of St. Gallen).

**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 micro-grid 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.

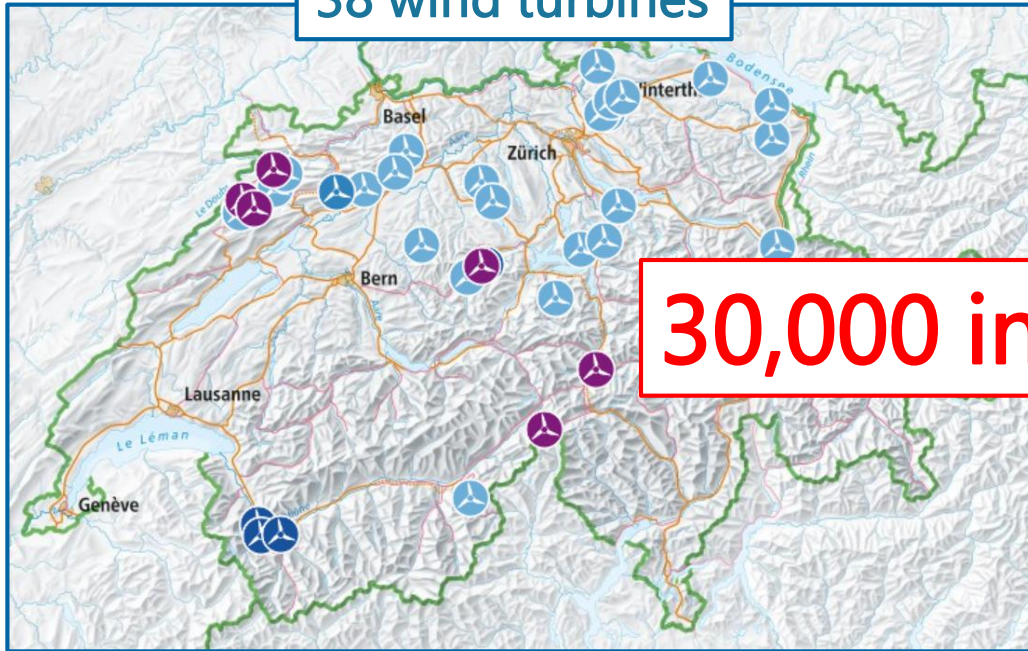
# Contents

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

# Wind energy in Switzerland

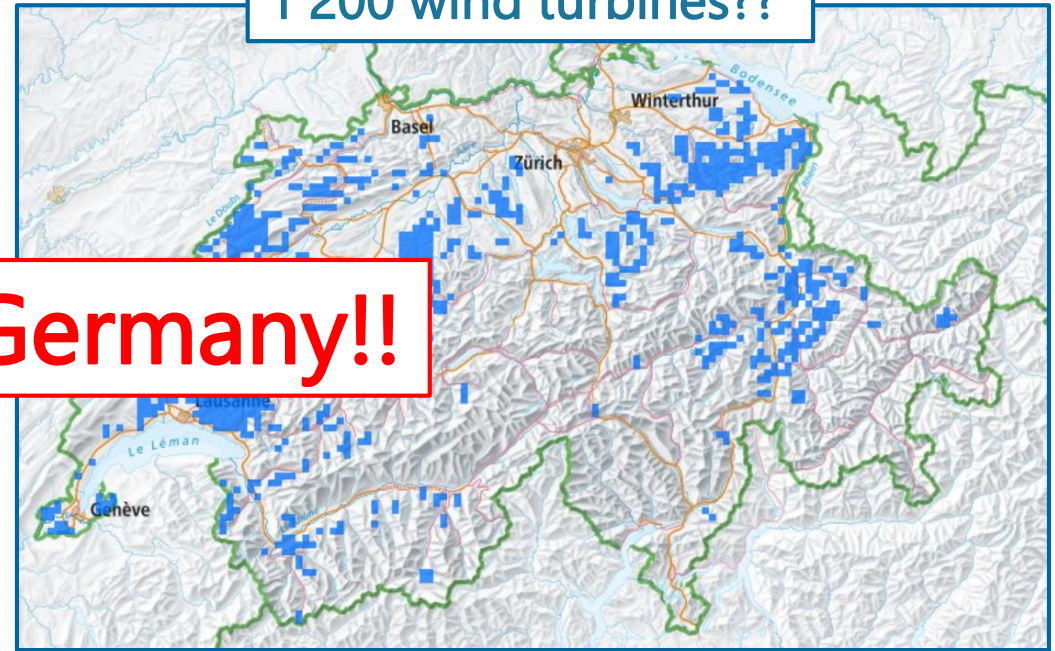
2018

38 wind turbines



Energy strategy 2050

1'200 wind turbines??



30,000 in Germany!!

## ■ 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<sup>1</sup>.

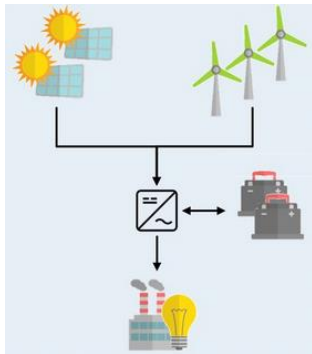
→ **Combination of wind turbines < 30 m with PV and storage in microgrids??**

<sup>1</sup>International Renewable Energy Agency (2012): RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES

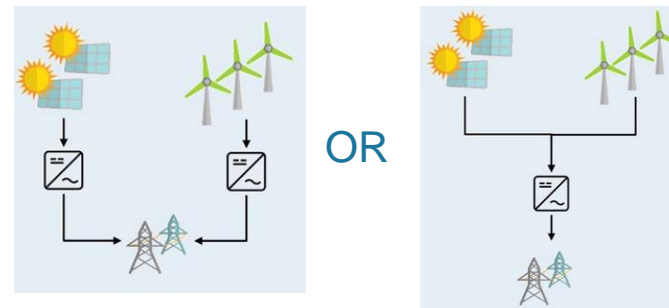
# Goal of this work

- **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

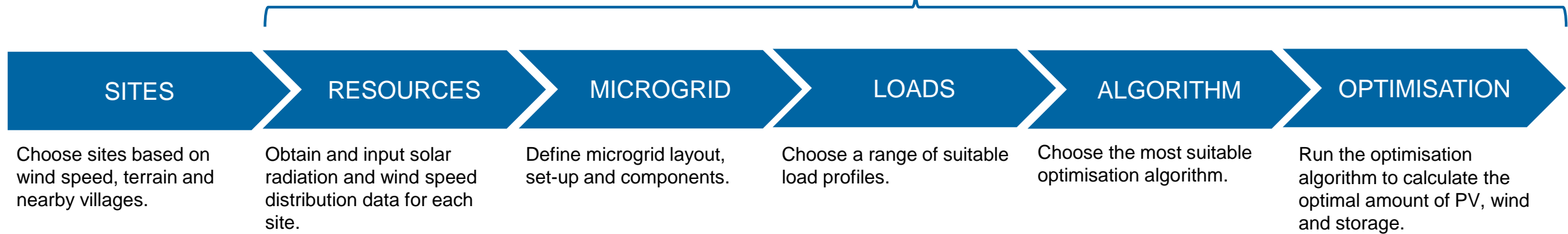


## Grid-connected solutions



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

## Commercial software HOMER PRO



# Choice of sites

SITES




RESOURCES

MICROGRID

LOADS

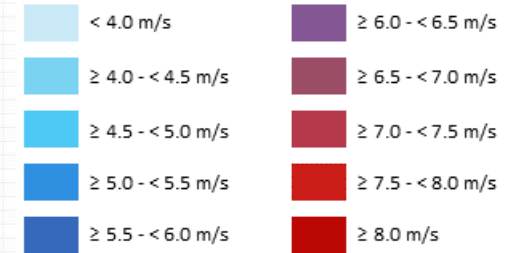
ALGORITHM

OPTIMISATION

-  **Four sites in Canton St. Gallen**
-  **Six other sites in Switzerland**
-  **Test case sites**



Wind speed at 50 m height



<https://map.geo.admin.ch>



# Example site – Les Pléiades

SITES

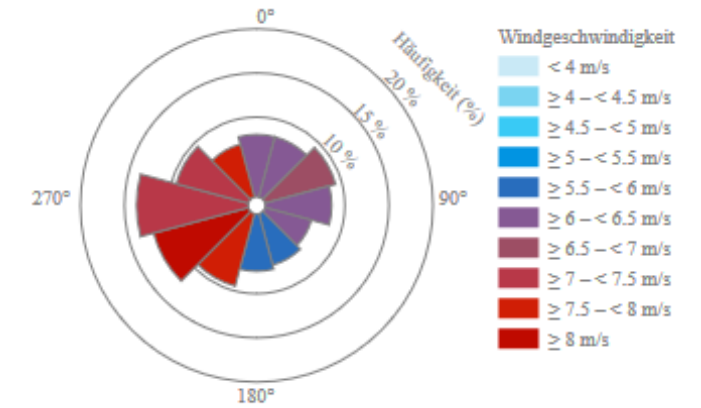
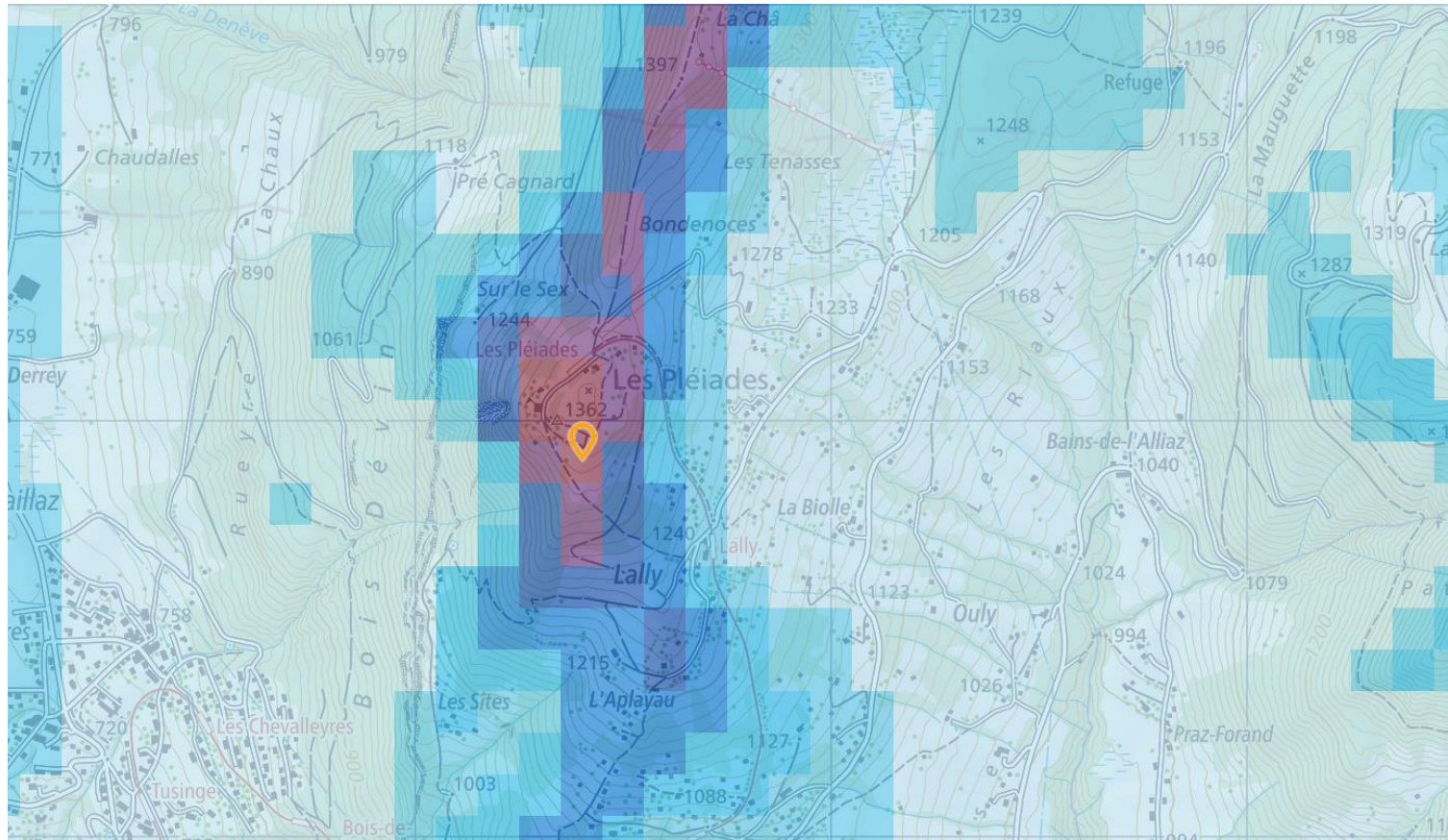
RESOURCES

MICROGRID

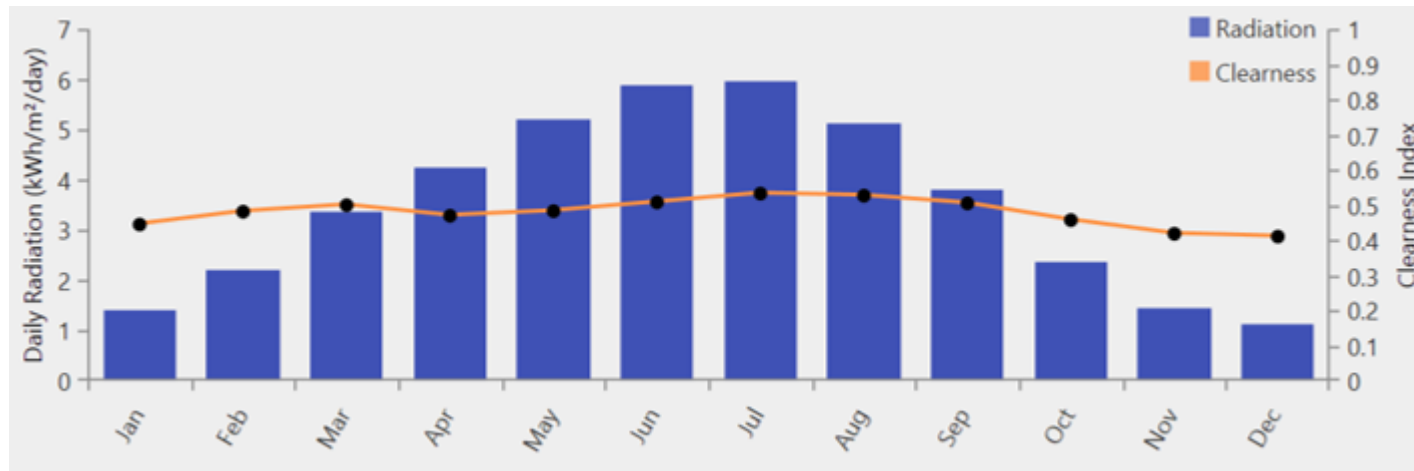
LOADS

ALGORITHM

OPTIMISATION



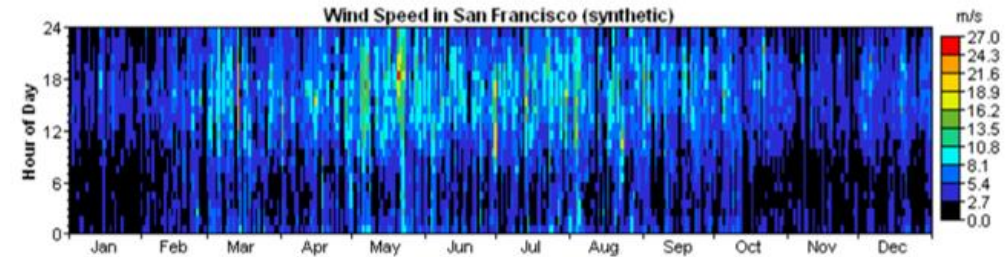
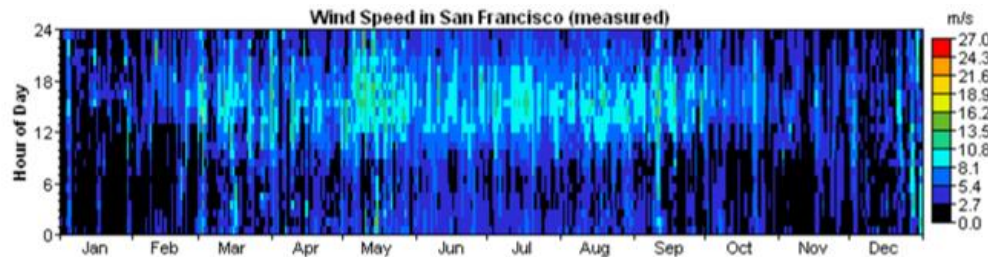
- **Solar Global Horizontal Irradiation (GHI) resource = sum of beam radiation, diffuse irradiance and ground-reflected radiance:**
  - Monthly averages downloaded from the NASA Surface meteorology and Solar Energy database based on the latitude and longitude (averages from 1983 – 2005).
  - HOMER builds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



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

## ■ 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](http://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 autocorrelation factor**, the **diurnal pattern strength** and the hour of the **peak wind speed**.

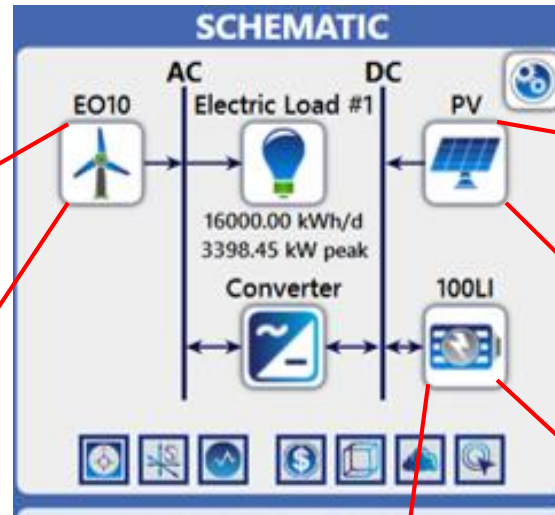


# Microgrid set-up

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



EO10 Eocycle wind turbine

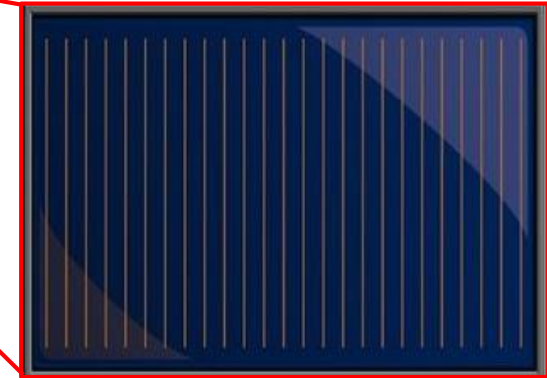


Nominal capacity = 100 kWh  
 Maximum charge current = 167 A  
 Maximum discharge current = 500 A  
 Time = 15 years  
 CAPEX = \$200/kWh<sup>3</sup>  
 Replacement costs = \$200/kWh



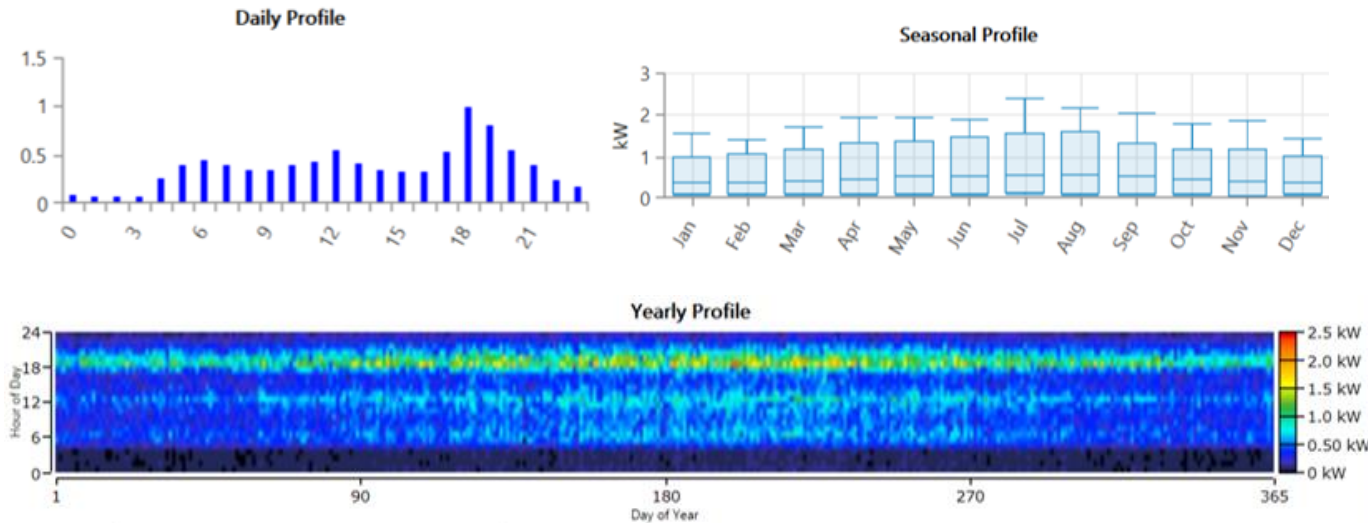
Idealized Li-ion battery

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



Generic flat plate PV

- 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 <sup>1</sup>
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

<sup>1</sup>Assumption: average electricity demand of a four-room house = 2,500 kWh/year (average in CH)

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

$Y_{PV}$  = the rated capacity of the PV array, meaning its power output under standard test conditions [kW]

$f_{PV}$  = the PV derating factor [%]

$\overline{G}_T$  = the solar radiation incident on the PV array in the current time step [kW/m<sup>2</sup>]

$\overline{G}_{T,STC}$  = the incident radiation at standard test conditions [1 kW/m<sup>2</sup>]

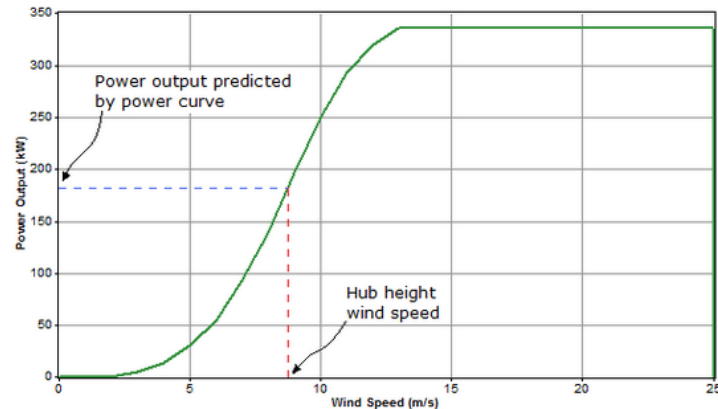
$\alpha_P$  = the temperature coefficient of power [%/°C]

$T_c$  = 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**

## ■ Optimization settings:

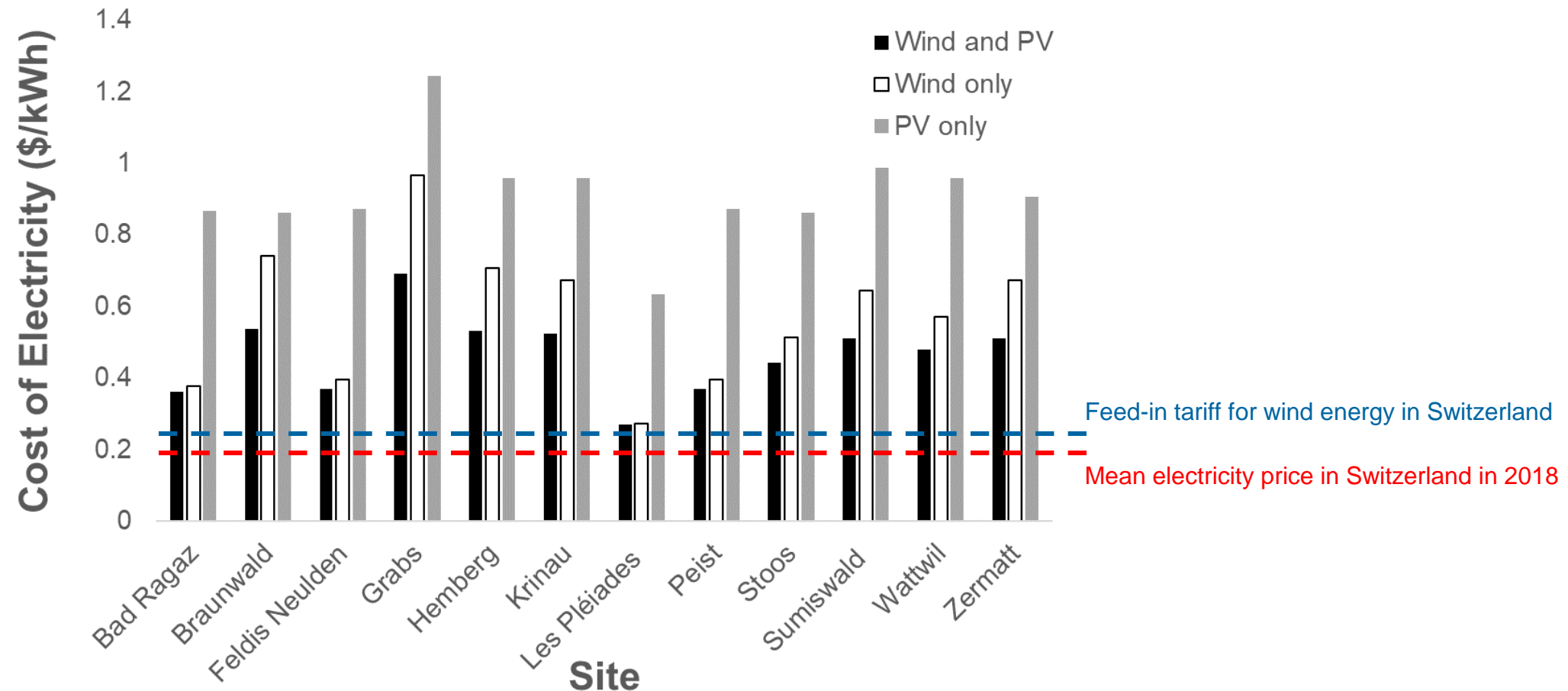
- 60 minutes per time step.
- Optimization goal = minimise Net Present Cost.
- Variables = installed capacity of PV, wind turbines and storage.

## ■ 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

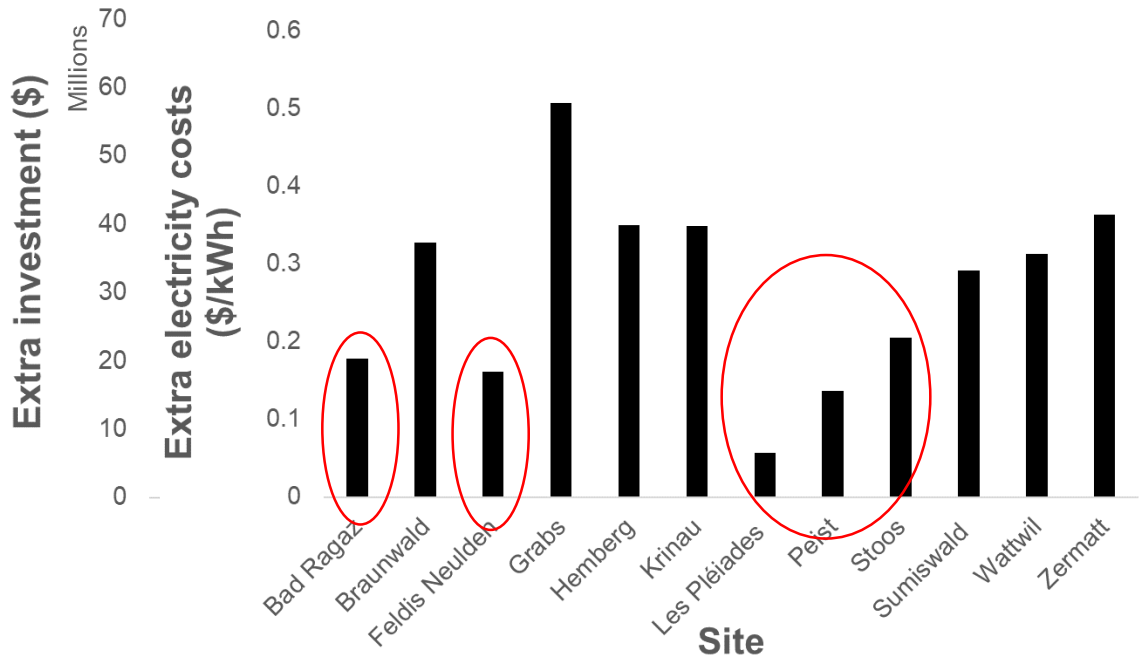
Results for 16'000 kWh/day load profile (COE hardly depends on load profil):





# Significant extra investment necessary

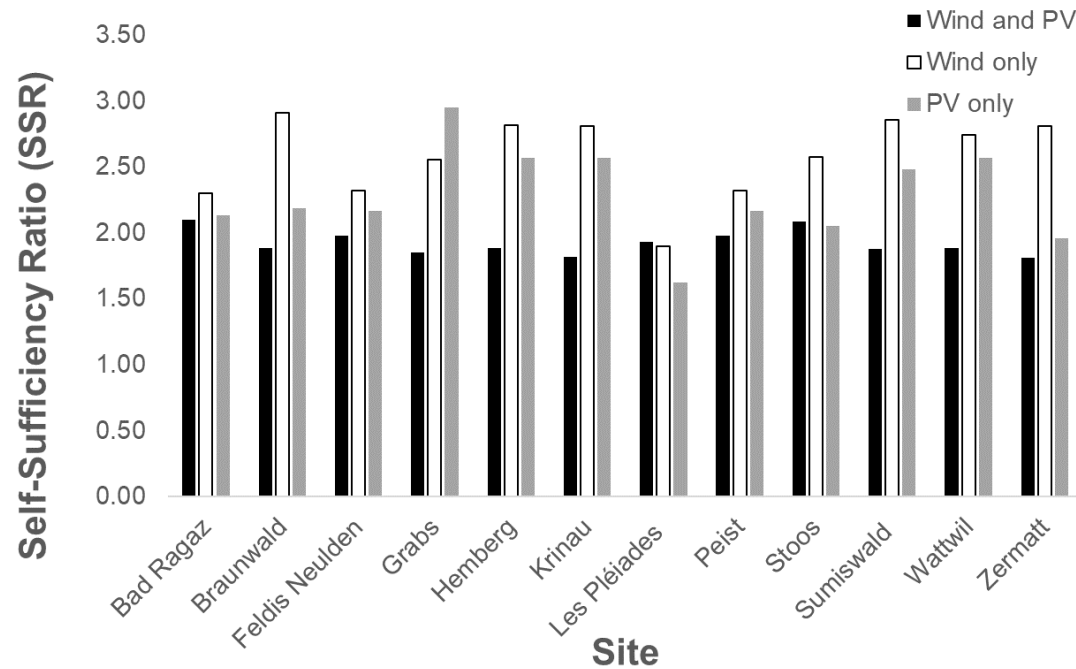
Results for 16,000 kWh/day load profile (COE hardly depends on load profil):



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

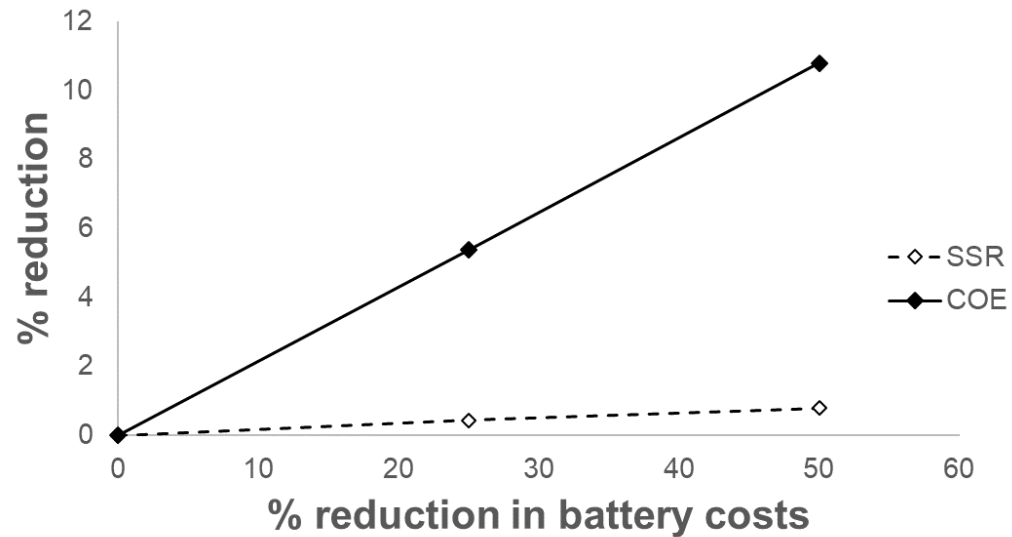
Self-Sufficiency Ratio:  $SSR = \frac{\text{Actual wind and PV production (kWh)}}{\text{Production demanded (kWh)}}$



- 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

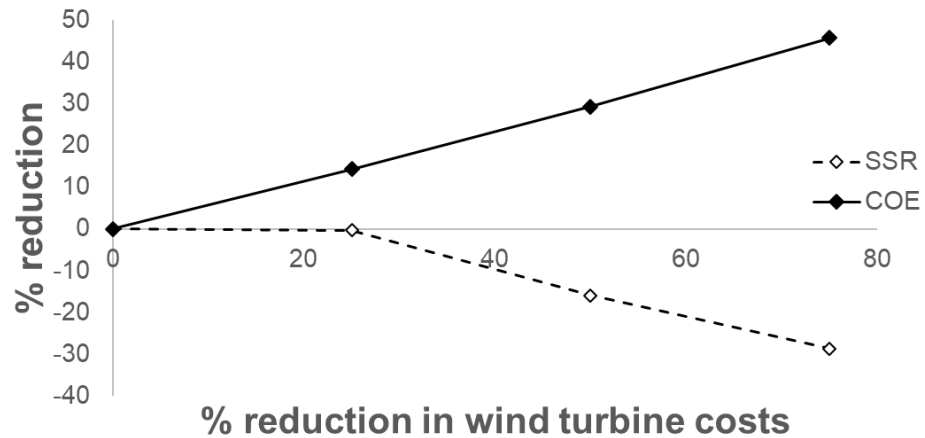
## ■ Les Pléaides 16,000 kWh/day case:



## ■ 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

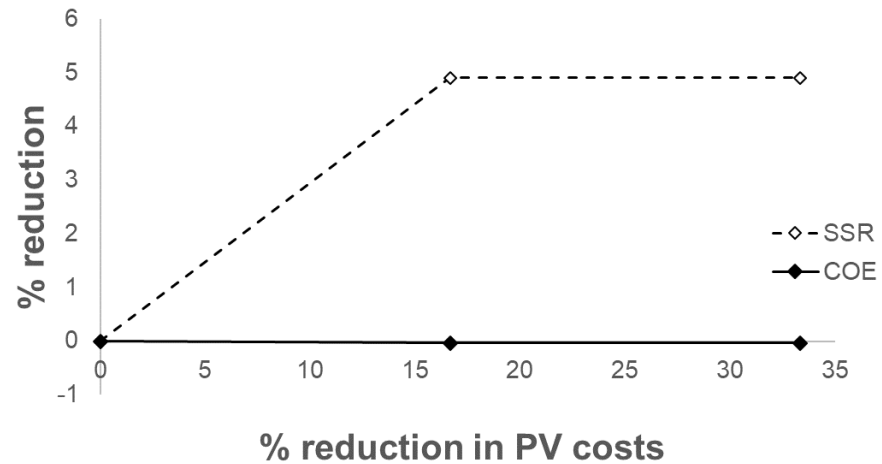
## ■ Les Pléaides 16,000 kWh/day case:



## ■ 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:

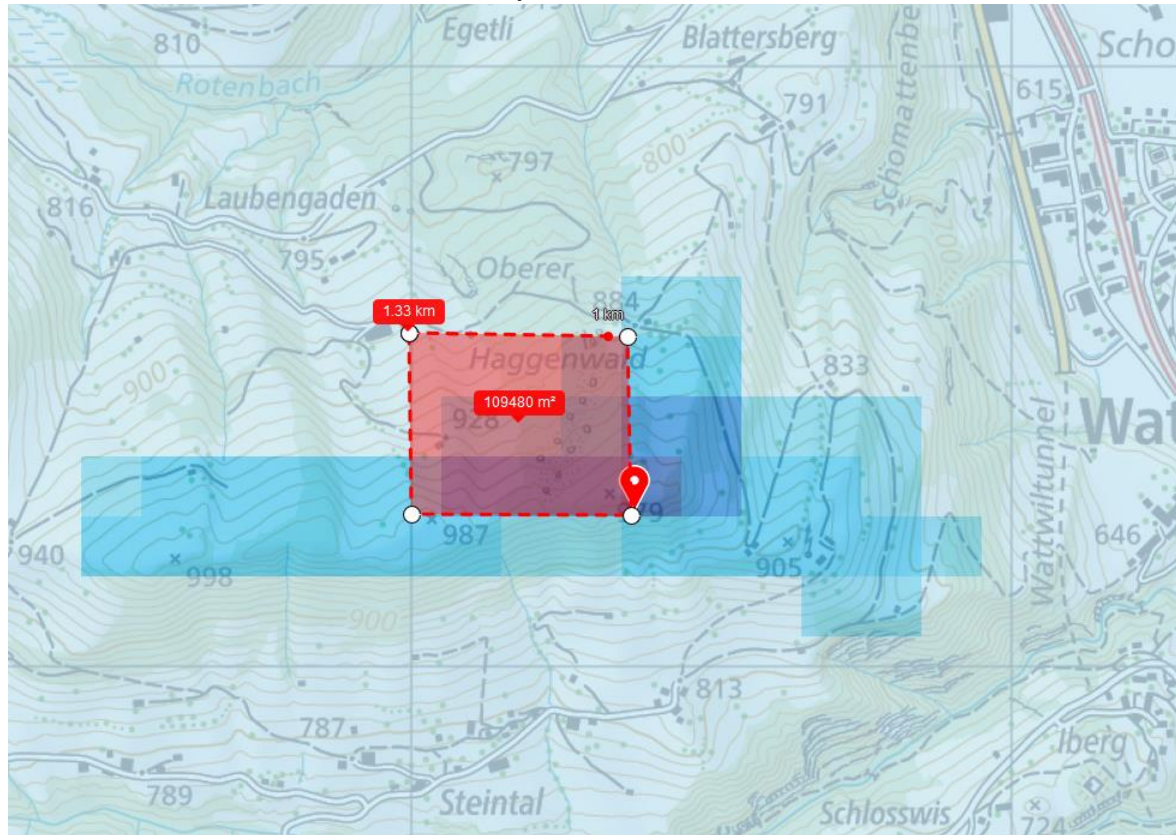


## ■ For wind and PV combined, reduced PV costs hardly affects COE but increases SSR (because of more PV).

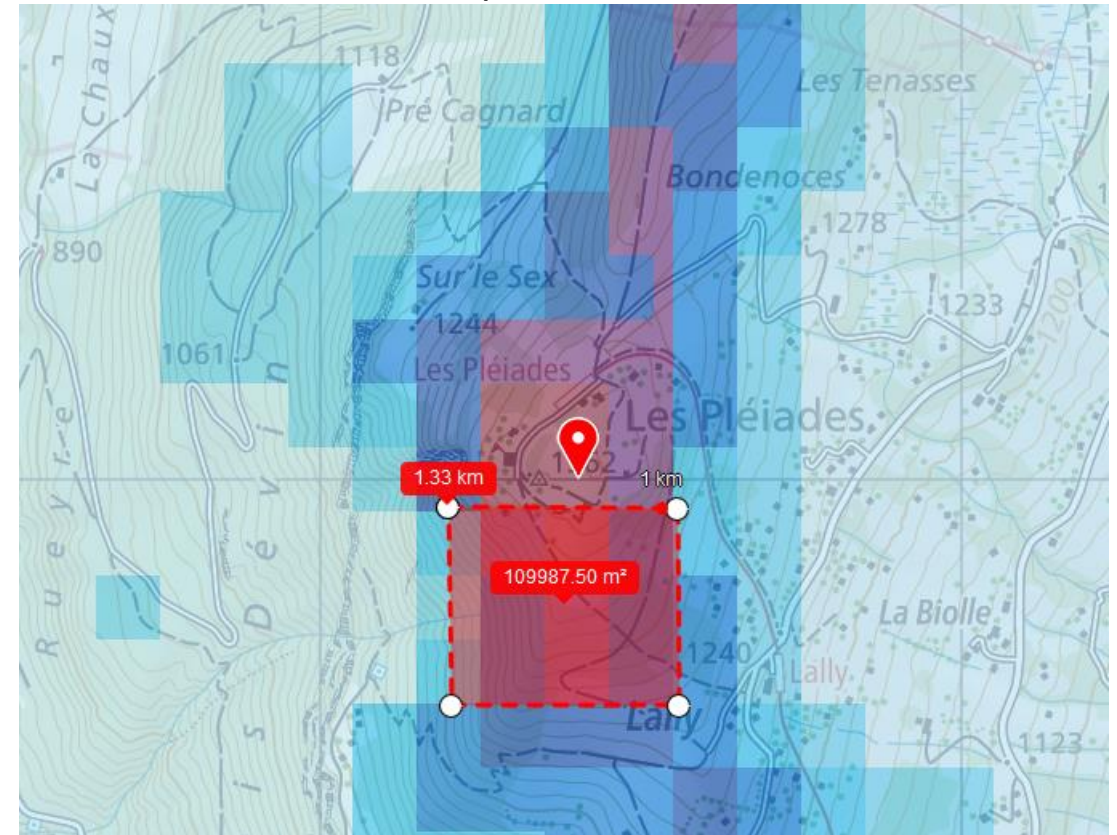
# Approximate "acceptable" space estimated from map

- Approximate acceptable ground area for PV and WTG = 100,000 m<sup>2</sup>:

Example Wattwil

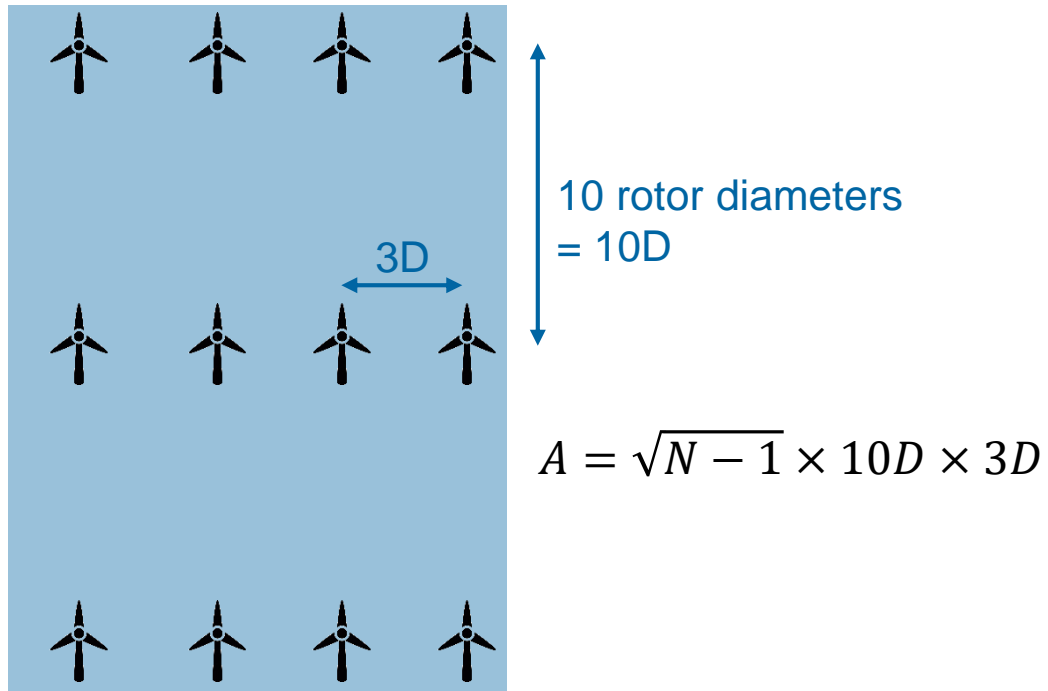


Example Les Pléiades

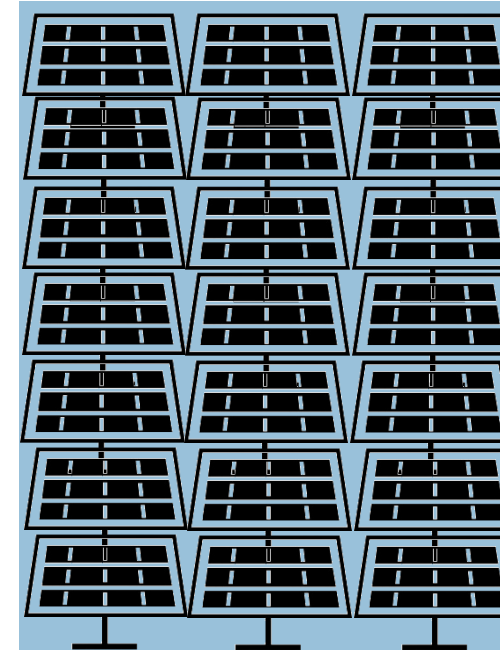


# Assumptions for area calculations

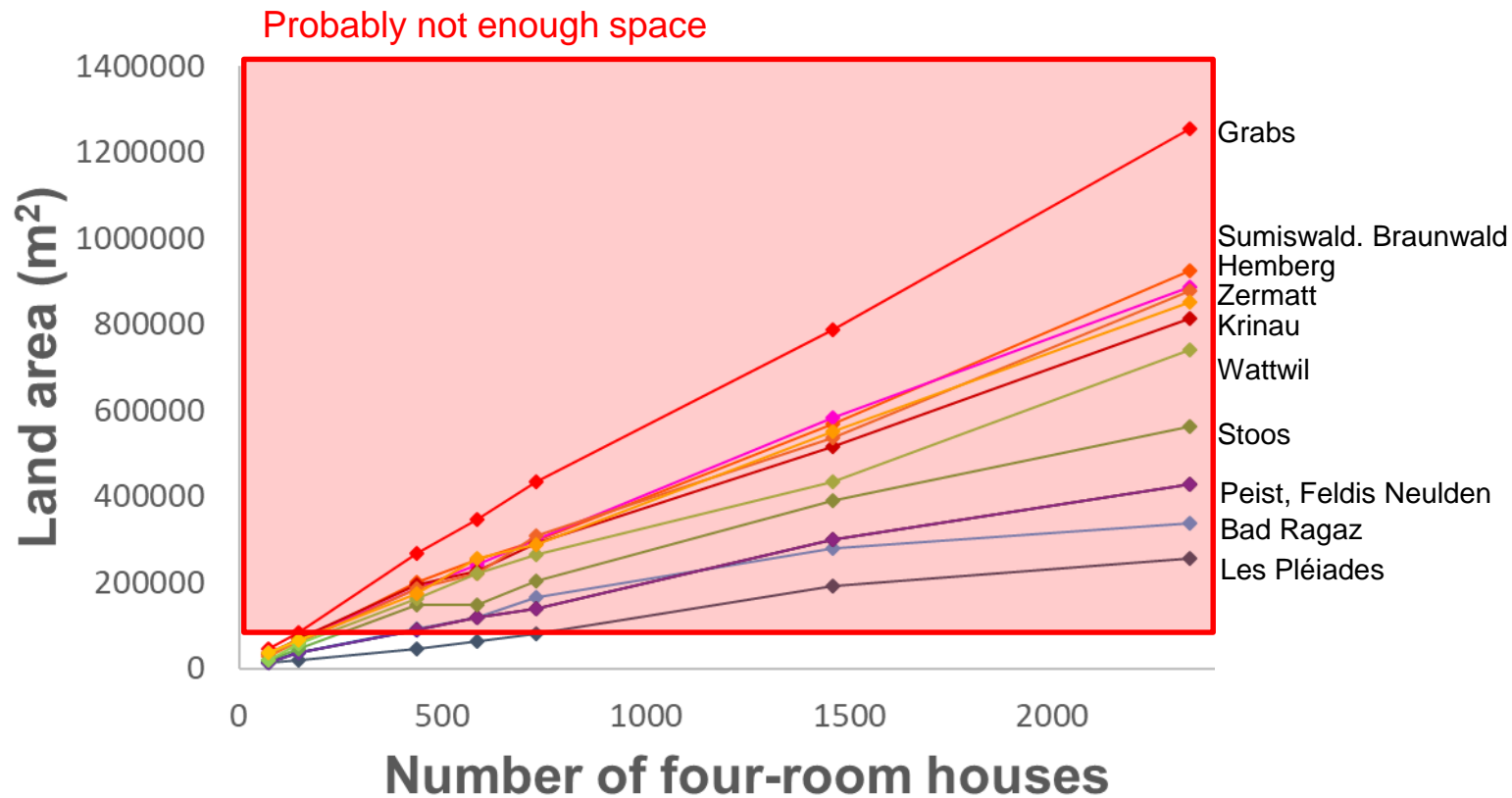
## ■ Wind turbines:



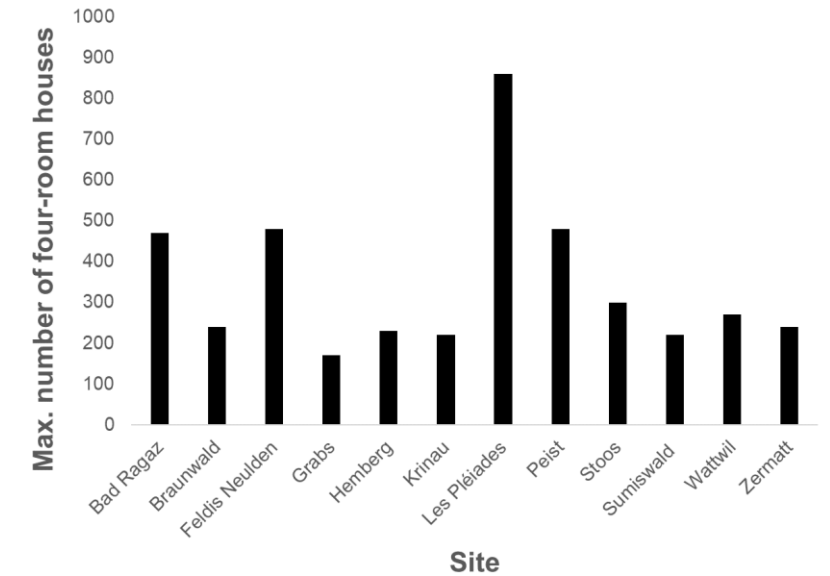
## ■ PV: assumption = 200 m<sup>2</sup> / kW



# This solution is greatly limited by available space!



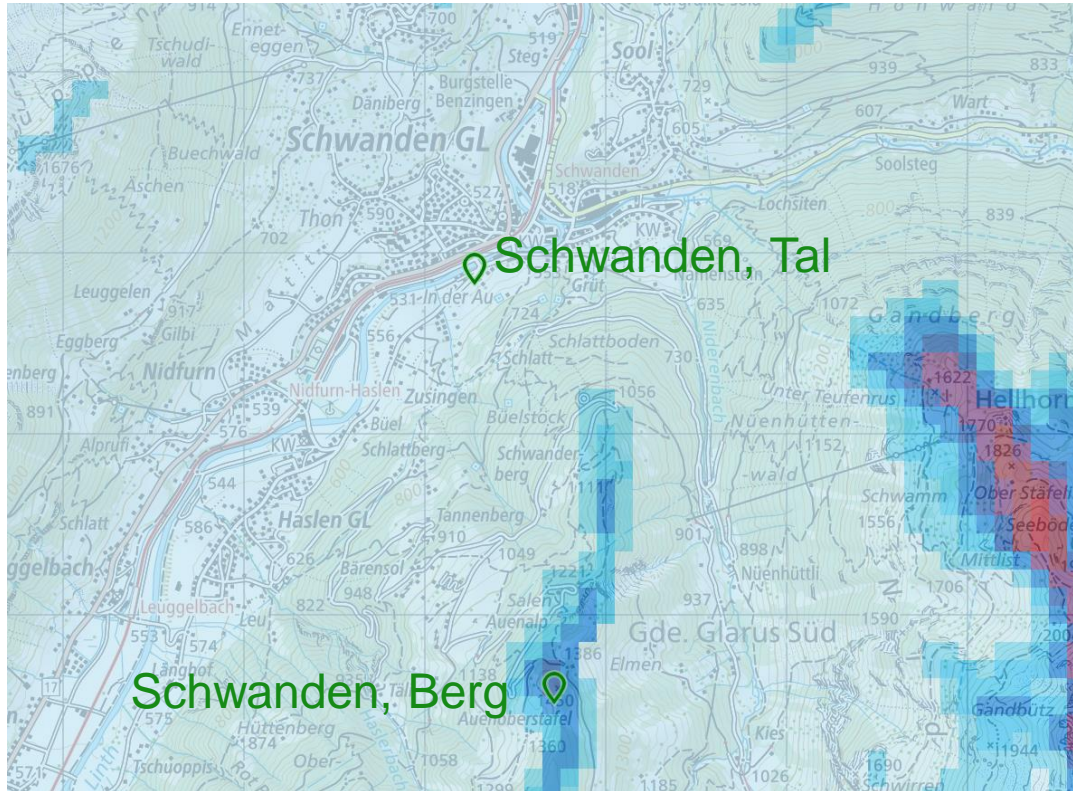
## Probably the maximum size possible:



→ More detailed investigations needed.



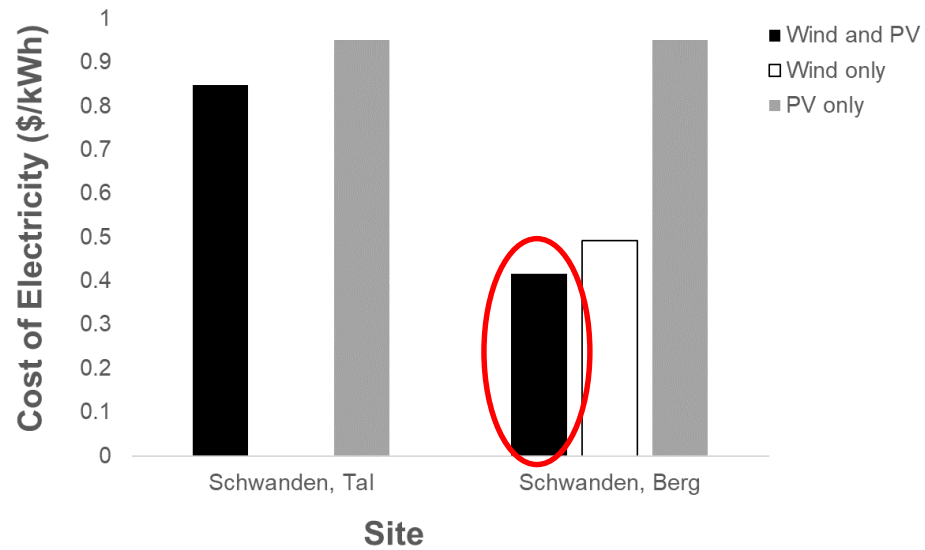
# Test case for High Performance Computing Centre near Schwanden



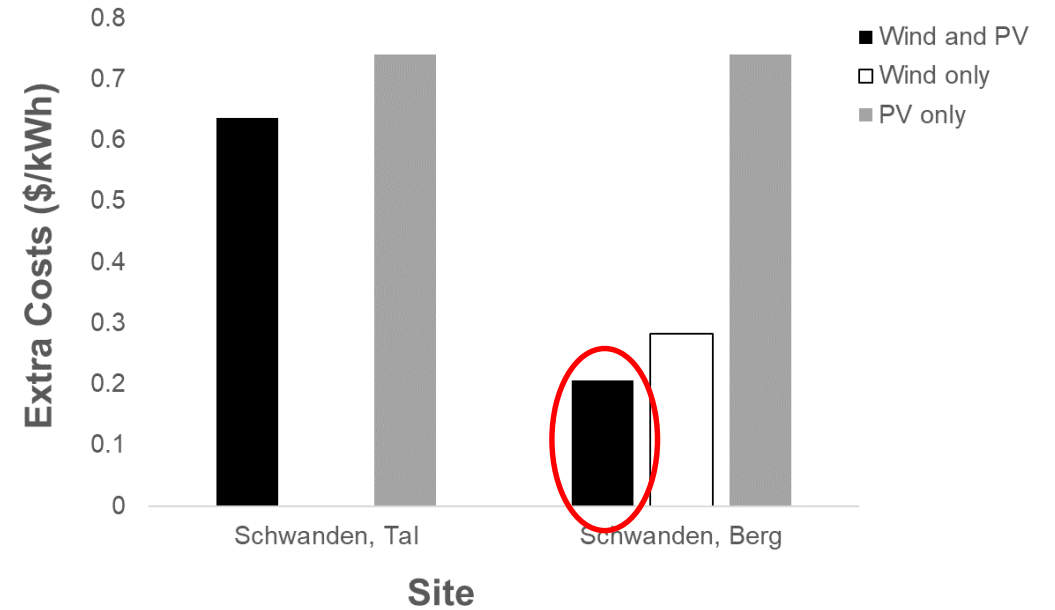
- High Performance Computing Center in Canton Glarus "ungleich".
- Wants to runs 100% on renewable energy.
- Prepared to pay ca. 0.15 \$/kWh extra.
- 30 servers, each 1.1 kW peak → 440,000 kWh / year constant demand.

# Test case for High Performance Computing centre

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

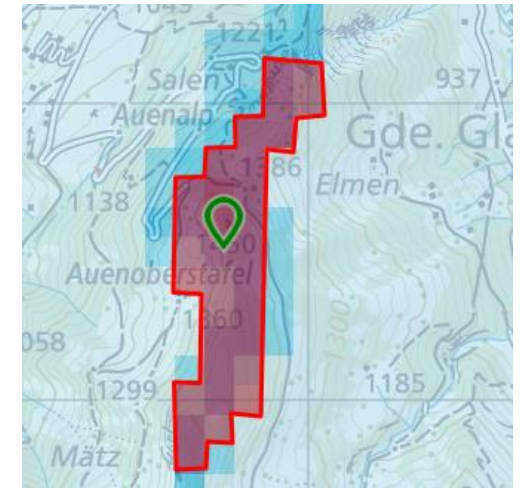
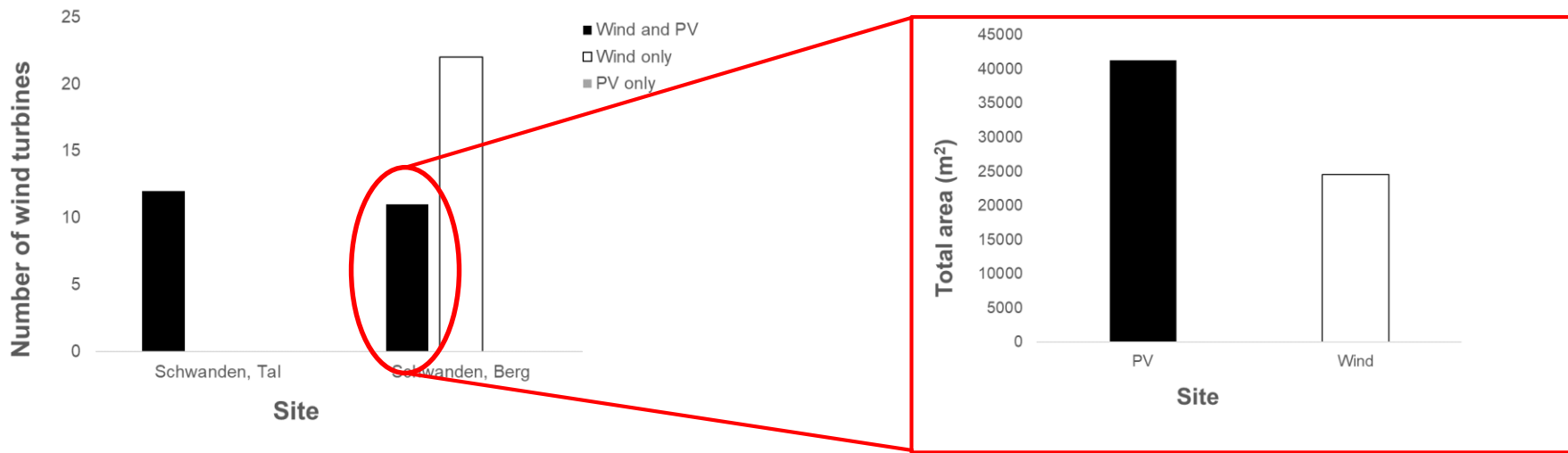


- Extra costs only 0.05 \$/kWh higher than acceptable:



# Test case for High Performance Computing centre

- 10 wind turbines over 25,000 m<sup>2</sup> seems reasonable:

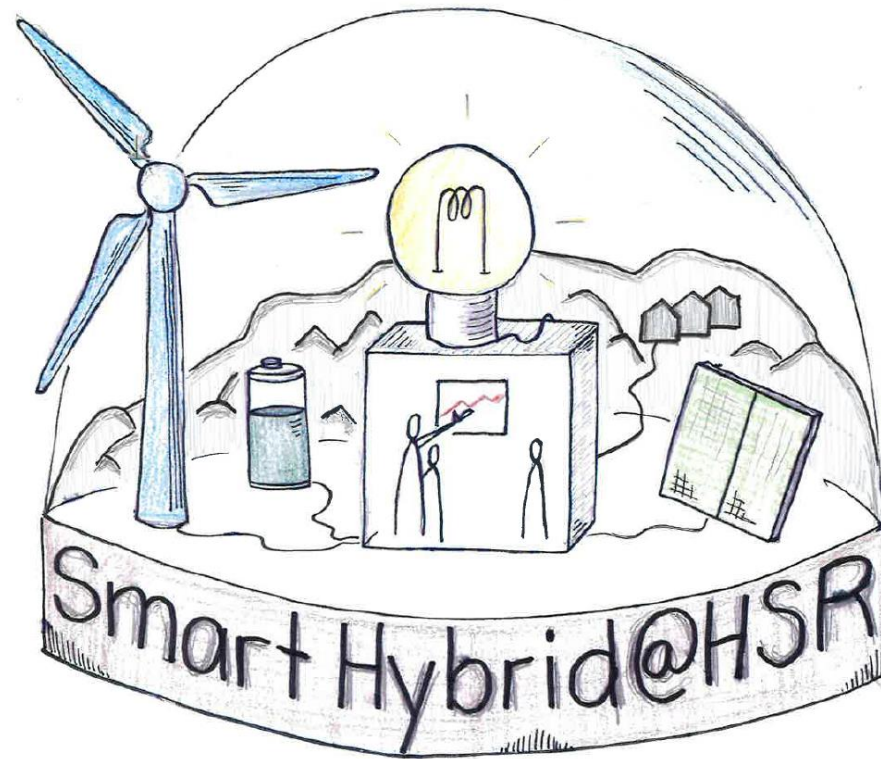


→ Reasonable solution successfully found for this test case!

# 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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