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Optimization of photovoltaic potential and its integration in Switzerland using genetic algorithm and optimal power flow

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How to harvest solar energy effectively?

Given the natural resources? Given the transmission grid?

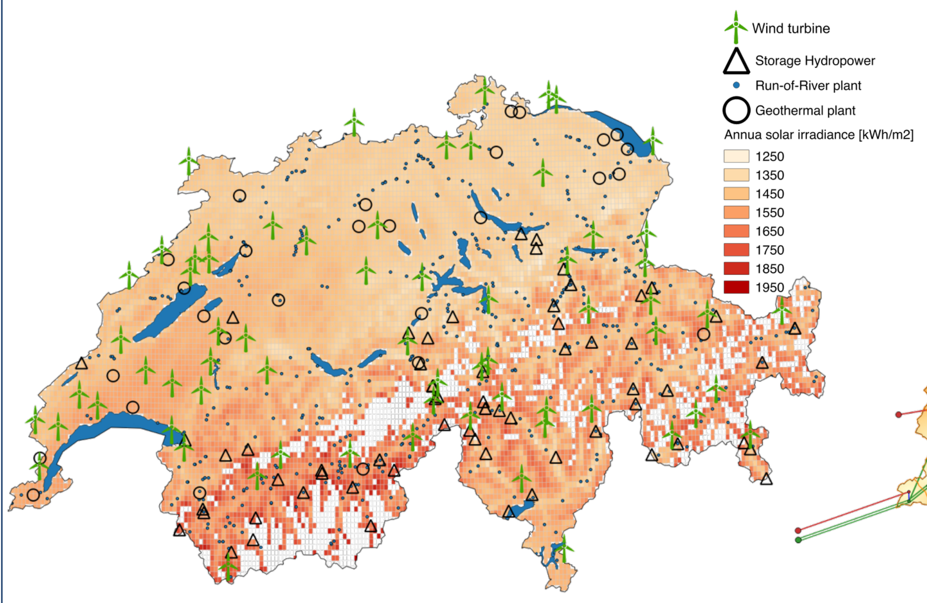


Fig.1. Annual solar irradiance and other electricity generation sources

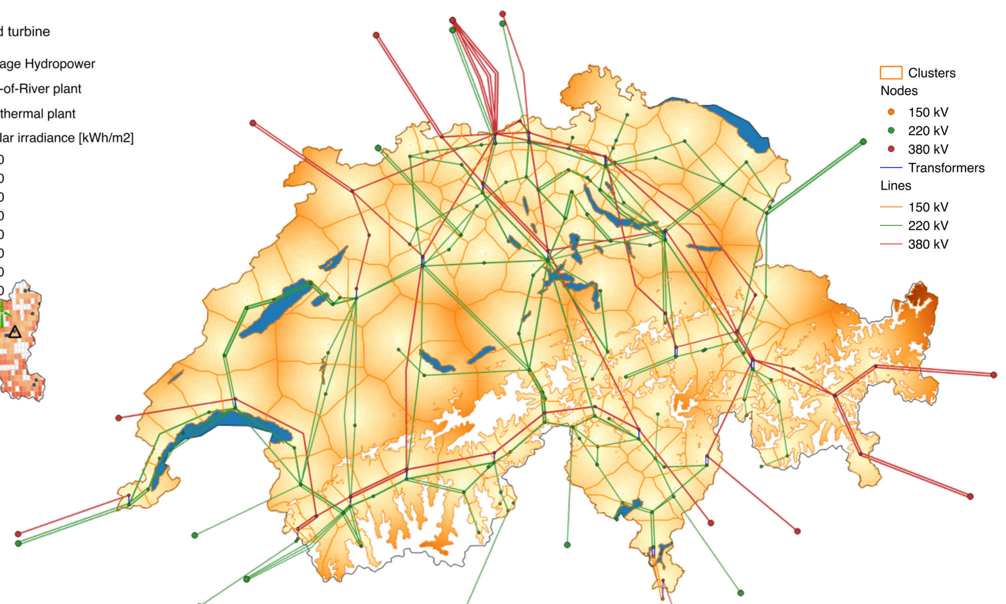


Fig.2. Transmission grid (as planned for 2025)

Hybrid deterministic / stochastic approach

1. Local photovoltaic (PV) configuration for **maximum yield**:
Differs from the classical setup (south at 39° tilt)

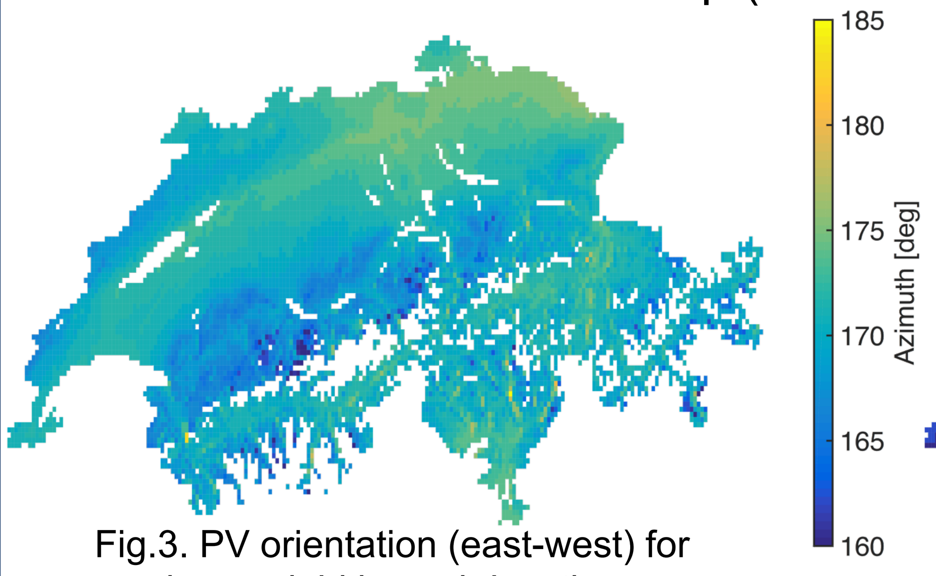


Fig.3. PV orientation (east-west) for maximum yield in each location

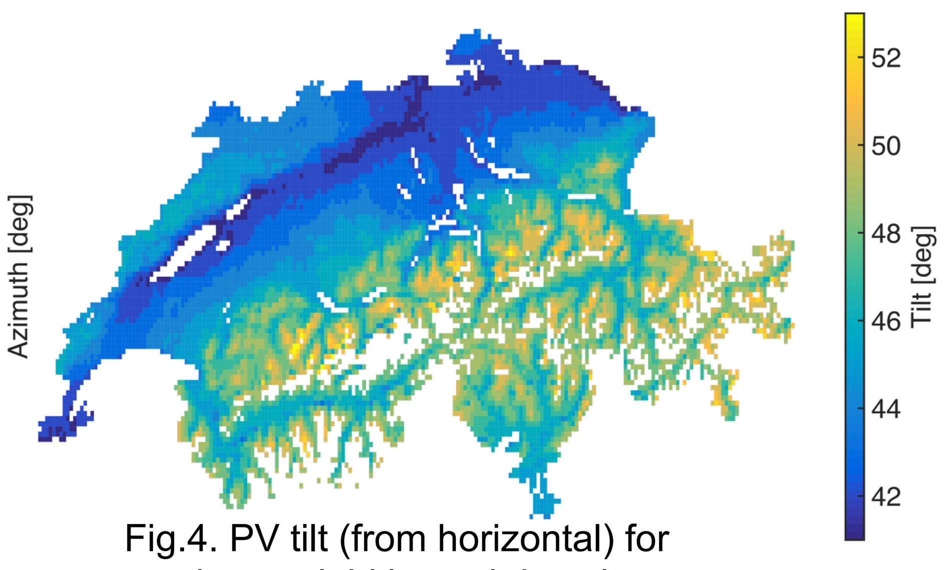


Fig.4. PV tilt (from horizontal) for maximum yield in each location

→ **Local settings** of PV panels are set, independently of the global configuration (locations within the country)

2. Local specificities of PV production:
- Annual yield
- Reduction of annual required import, due to higher winter production [1]
- Stability of annual production
- Stability of winter production

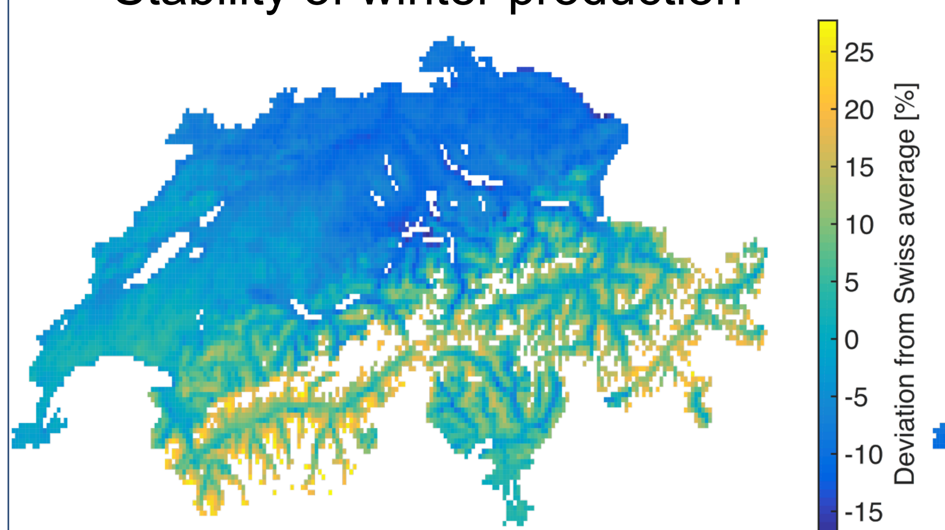


Fig.5. PV production in each location relative to the national average

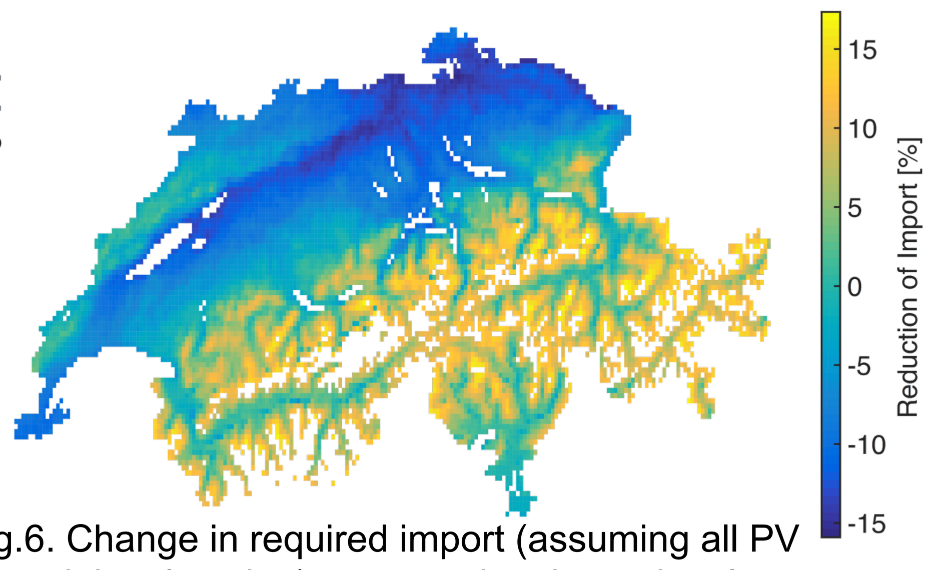


Fig.6. Change in required import (assuming all PV placed in a location) compared to the national average

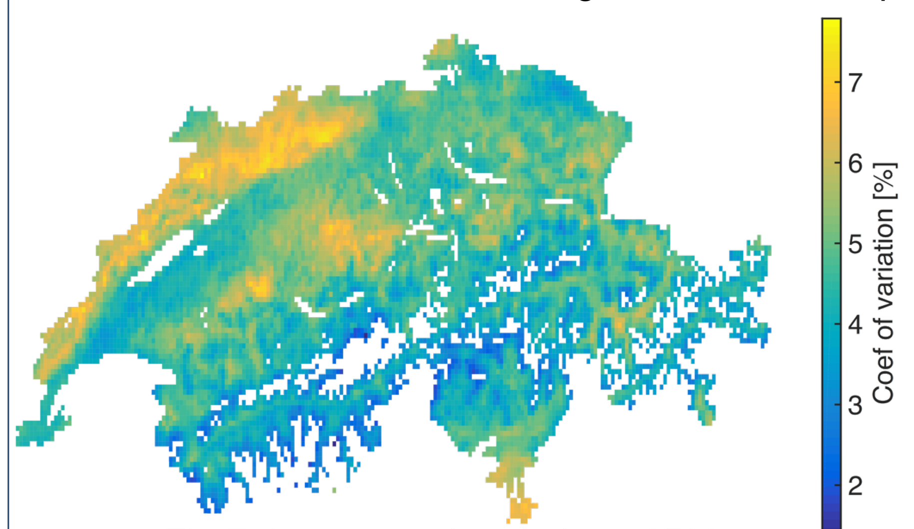


Fig.7. Interannual variation of PV production in each location

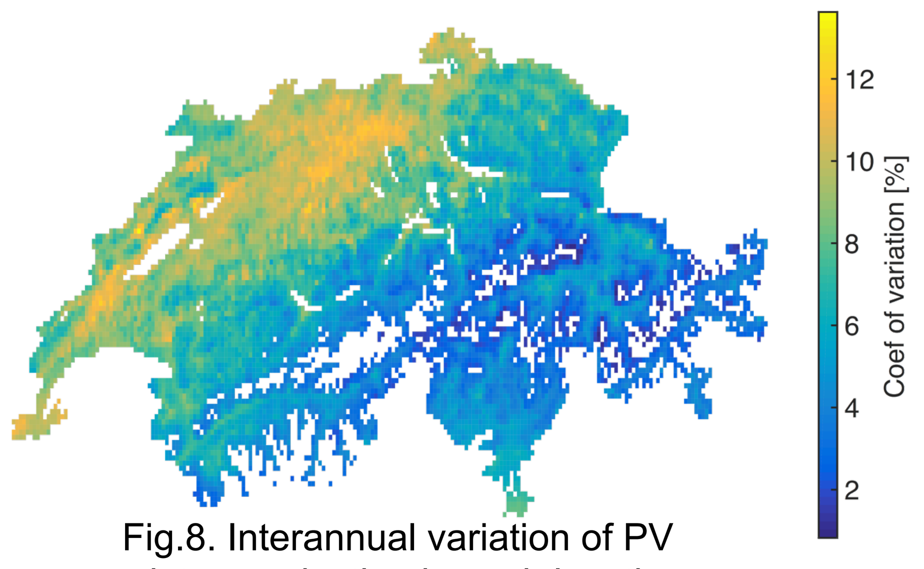


Fig.8. Interannual variation of PV winter production in each location

→ Multi-**objective function** for the genetic algorithm
→ Selection of the best locations within the clusters

3. Maximum PV coverage in each pixel based on CORINE land surface cover type.

Land type	Urban	Industry	Pasture	Agriculture	Open
Max coverage	10%	10%	5%	5%	5%

Constrained to altitudes below 2500m

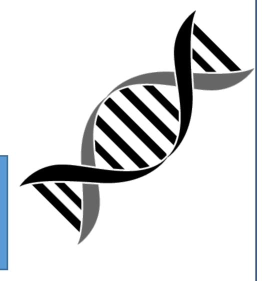
→ Amounts to 670 km2 (~10 times the required PV area)
→ Leaves freedom to the genetic algorithm

→ **Constraints** on the solutions found by the genetic algorithm (upper limit of PV installed in each cluster)
→ Selection of the available locations within the clusters

4. Genetic algorithm

Initialization with a pool of homogenously spread PV + noise

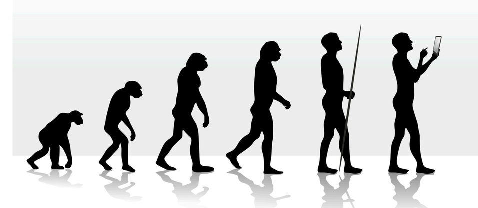
Generation of a new solution from 2 random parents (random linear combination + random mutation)



Enough space in each cluster?
No / Yes

Test the solution with power flow model
Failure / Success

Solution added to the pool



Not enough solutions / Enough solutions

Reduction of the pool (best only)

Still improving / No more improvement

Best solution

Results

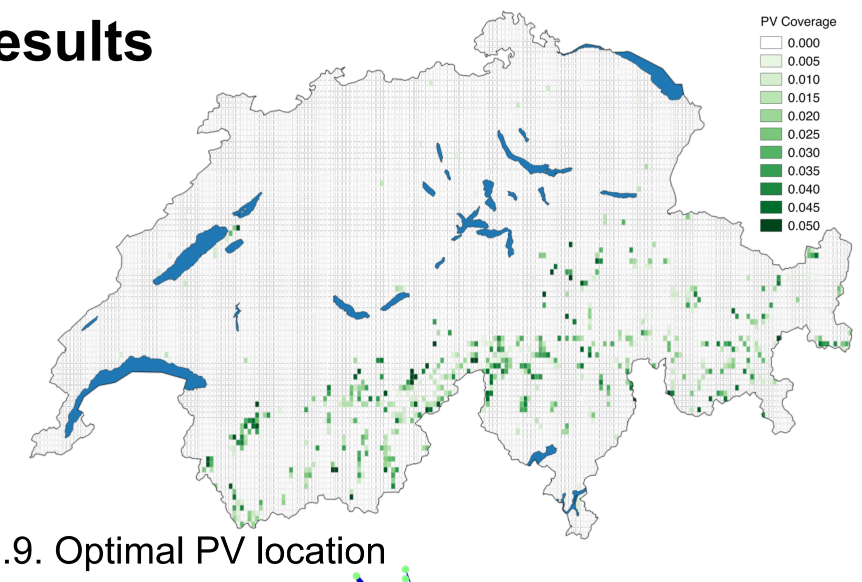


Fig.9. Optimal PV location

Optimization converges to a PV placement scenario that:

- **Increases the yield** (+18%) *
- **Reduces the interannual variations** (-37% yearly, -64% in winter) *

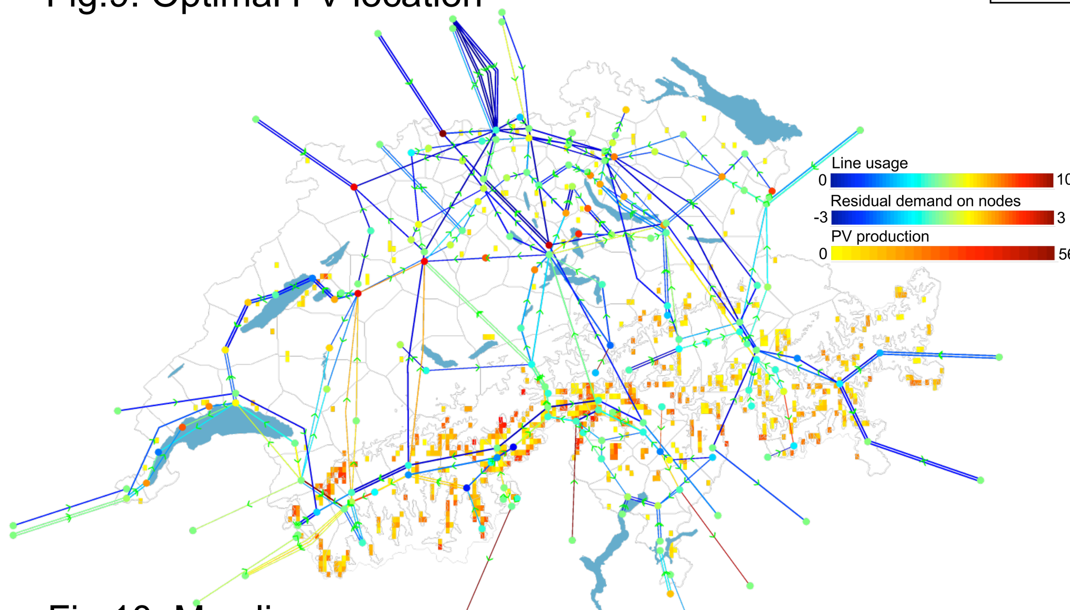


Fig.10. Max line usage

- **Never exceeds** the line capacity

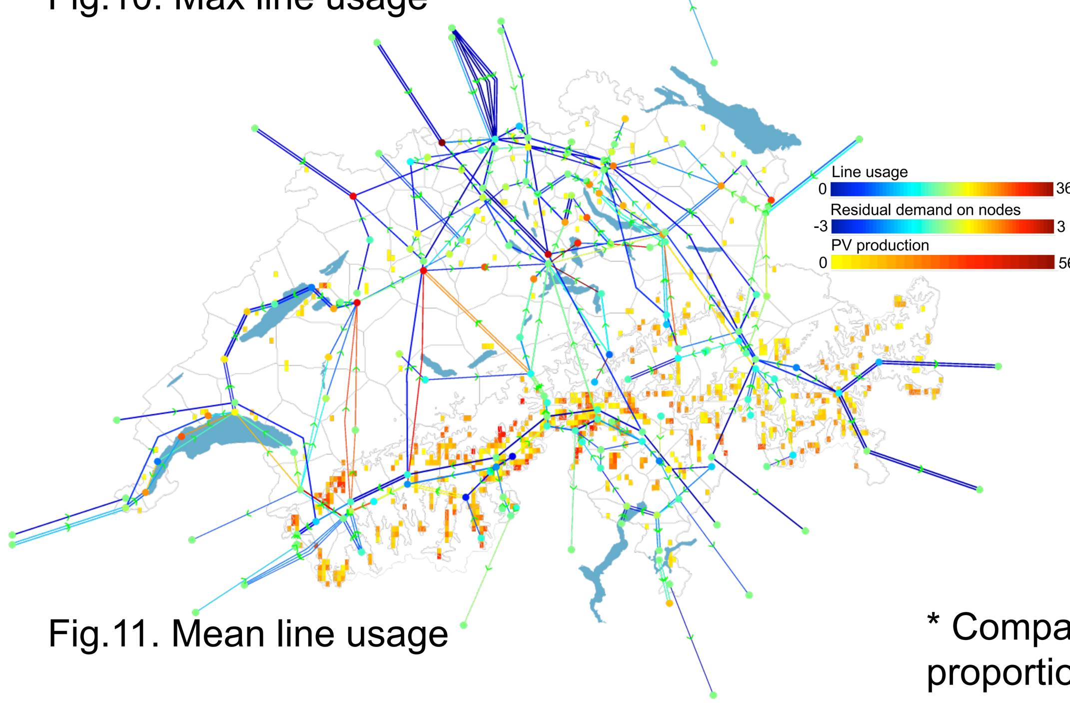


Fig.11. Mean line usage

- **Reduces the required import** (-17%) *

* Compared to a PV placement scenario proportional to population density

Perspectives

- Improvements on the definition of potential PV area by using more GIS products (access from road, complexity of the terrain).
- Increase resolution of topographic shading for better irradiance computation in **complex terrain**.
- Apply optimization strategies to **wind energy** as well.

References

[1] National energy balance model from:
J Dujardin et al. Interplay between photovoltaic, wind energy and storage hydropower in a fully renewable Switzerland. Energy, vol135, p513-525, 2017

Data

- PV production time series based on satellite-derived irradiance (MeteoSwiss)
- Wind production time series based on wind speed measurements (MeteoSwiss)
- Demand time series from Swissgrid (publicly available on their website)
- Run-of-the-river montlhy production and reservoirs' inflow from the Swiss Federal Office of Energy (SFOE) and PREVAH model (WSL)
- Storage / pumped hydropower characteristics from WASTA database (SFOE)

Acknowledgments

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