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:
Diffs from the classical setup (south at 39° tilt)

Fig.3. PV orientation (east-west) for maximum yield in each location
Fig.4. PV tilt (horizontal) for maximum yield in each location

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

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

<table>
<thead>
<tr>
<th>Land type</th>
<th>Urban</th>
<th>Industry</th>
<th>Pasture</th>
<th>Agriculture</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max coverage</td>
<td>10%</td>
<td>10%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Constrained to altitudes below 2500m

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

Fig.7. Interannual variation of PV production in each location
Fig.8. Interannual variation of PV winter production in each location

4. Genetic algorithm

Initialization with a pool of homogeneously spread PV + noise

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

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

Failure
- Solution added to the pool

Success
- Enough solutions

Not enough solutions
- Reduction of the pool (best only)

Still improving
- No more improvement

Best solution

Results

Optimization converges to a PV placement scenario that:

- Increases the yield (+18%)*
- Reduces the interannual variations (-37% yearly, -84% in winter)*

Fig.9. Optimal PV location
Fig.10. Max line usage
Fig.11. Mean line usage

- Never exceeds the line capacity

- 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


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 monthly 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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