Trade-offs between regionally equitable and cost-efficient allocations of renewable electricity generation

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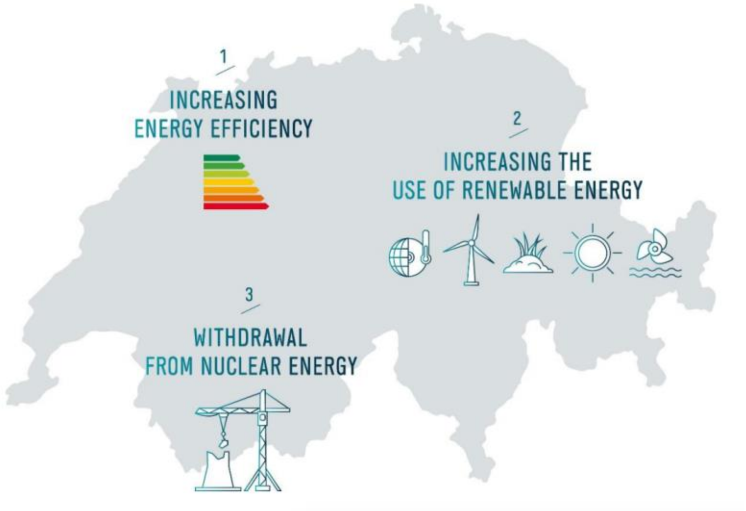
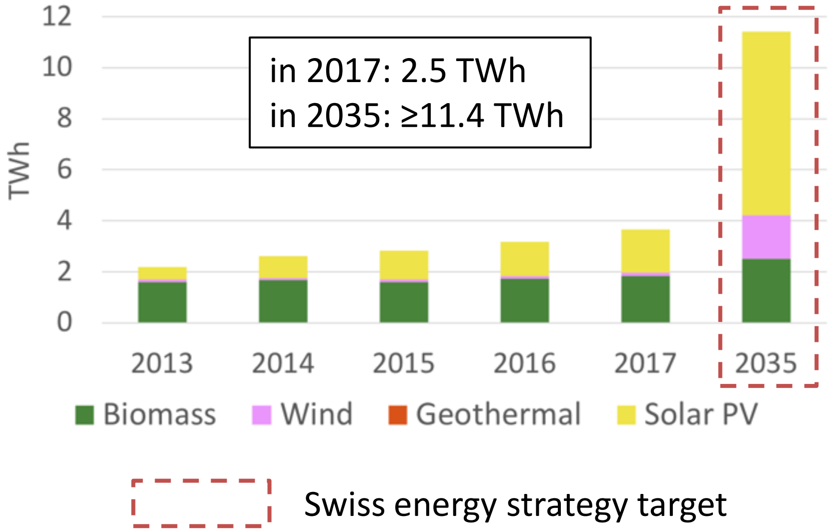
Swiss Energy Strategy requires drastic increase in renewable electricity until 2035



Renewable electricity (without hydro)

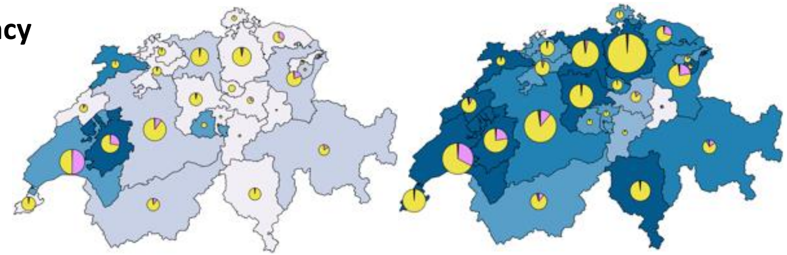


Source: Swiss Federal Office of Energy (SFOE) 2018; Swissolar market analysis 2012-2017; PSI – Paul Scherrer Institut (2017)

What are the regional distributional impacts of allocating decentralized renewable electricity generators (DREG)?

Spatial allocation of DREG

- ➕ Higher el. generation efficiency
- ➕ Higher profits for investors
- ➕ Fewer installations needed
- ➖ Clustering of installations
- ➖ Higher risk of disturbances (e.g. from wind turbine noise)
- ❓ Lower public acceptance



Cost-optimal | Regionally equitable

- ➕ Lower balancing power needed
- ➕ Higher whole-system efficiency
- ❓ Higher public acceptance
- ➖ Lower el. generation efficiency
- ➖ More installations needed

Goal:
Assess tradeoffs between cost-optimal and regionally equitable allocation of DREG

Based on: Grunewald (2017); Drechsler *et. al.* (2017); Langer *et. al.* (2016); Tsoutsos *et. al.* (2005); Knoblauch *et. al.* (2018); Fell *et. al.* (2019); Budischak *et. al.* (2013); Fuchs *et. al.* (2017); Wüstenhagen *et. al.* (2007); Klagge *et. al.* (2012); Dobbins *et. al.* (2019)

Method: EXPANSE spatially-explicit bottom-up power system model with Modeling to Generate Alternatives (MGA) approach

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Pre-processing (GIS-based)

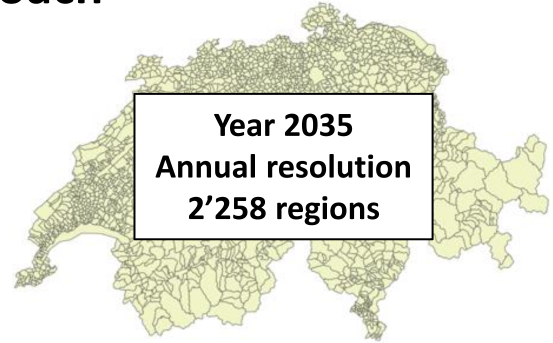
- **Resource assessment** (e.g. solar potential)
- **Power plant data** (e.g. LCOE, capacity)
- **Electricity demand** (per municipality)

Optimization run (on HPC cluster)

- **Cost-optimal scenario** (1 scenario)
- **Near-optimal scenarios (MGA)** (2’000 scenarios)

Trade-off analysis

- **Regional equity**
- **Generation costs**
- **Investment**
- **Installed capacity**

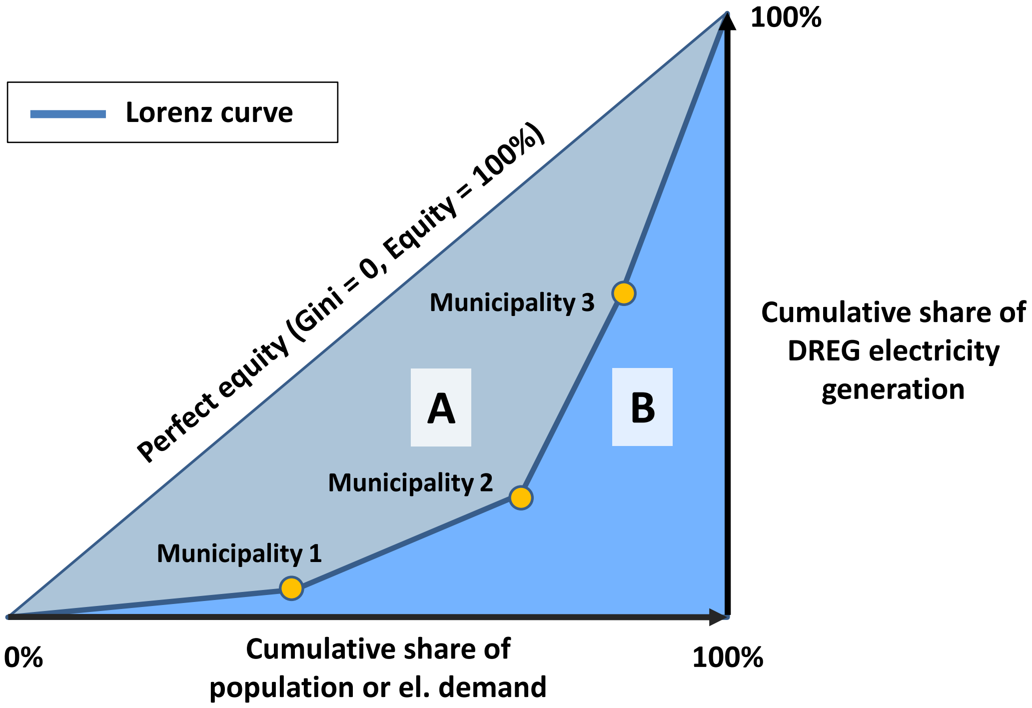


Modelled Technologies

Hydro, Solar PV, Wind, Gas, Geo-Thermal, Woody biomass, Biogas, Waste incineration, Imports, Efficiency

Model references: Trutnevyte, E. (2013); Berntsen, P. B., et. al. (2017); Trutnevyte, E. (2012)

Measuring regional equity: Gini index

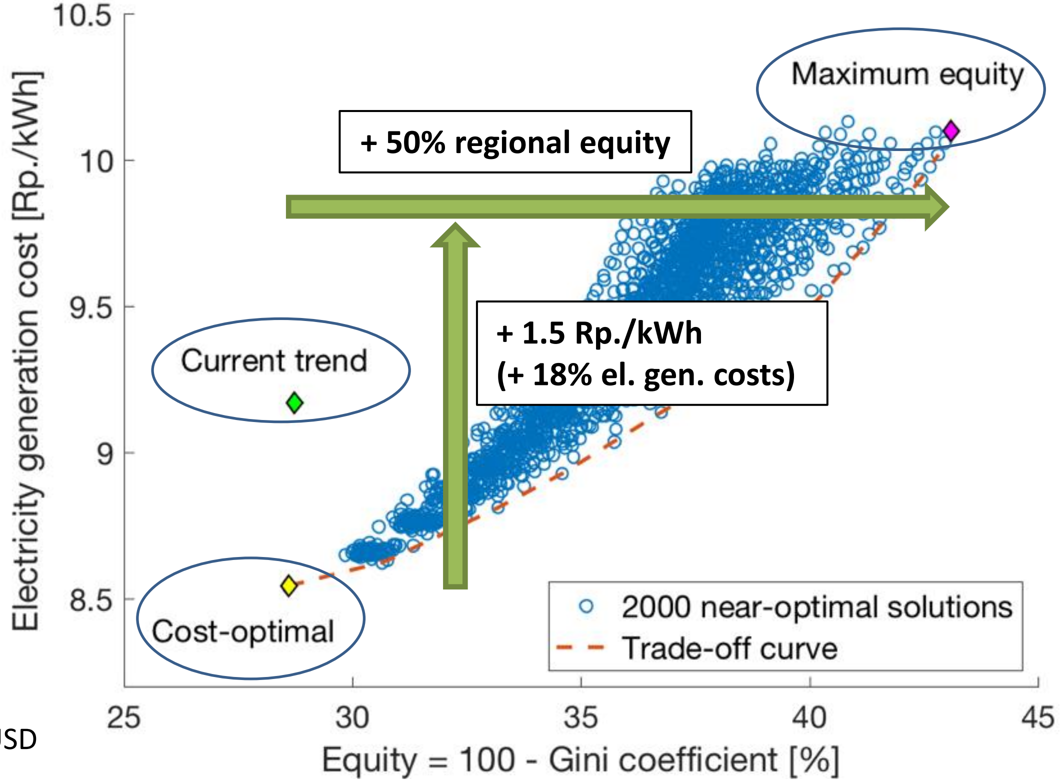


$$Gini = \frac{A}{A+B}$$

$$Equity = 100 - Gini\ [\%]$$

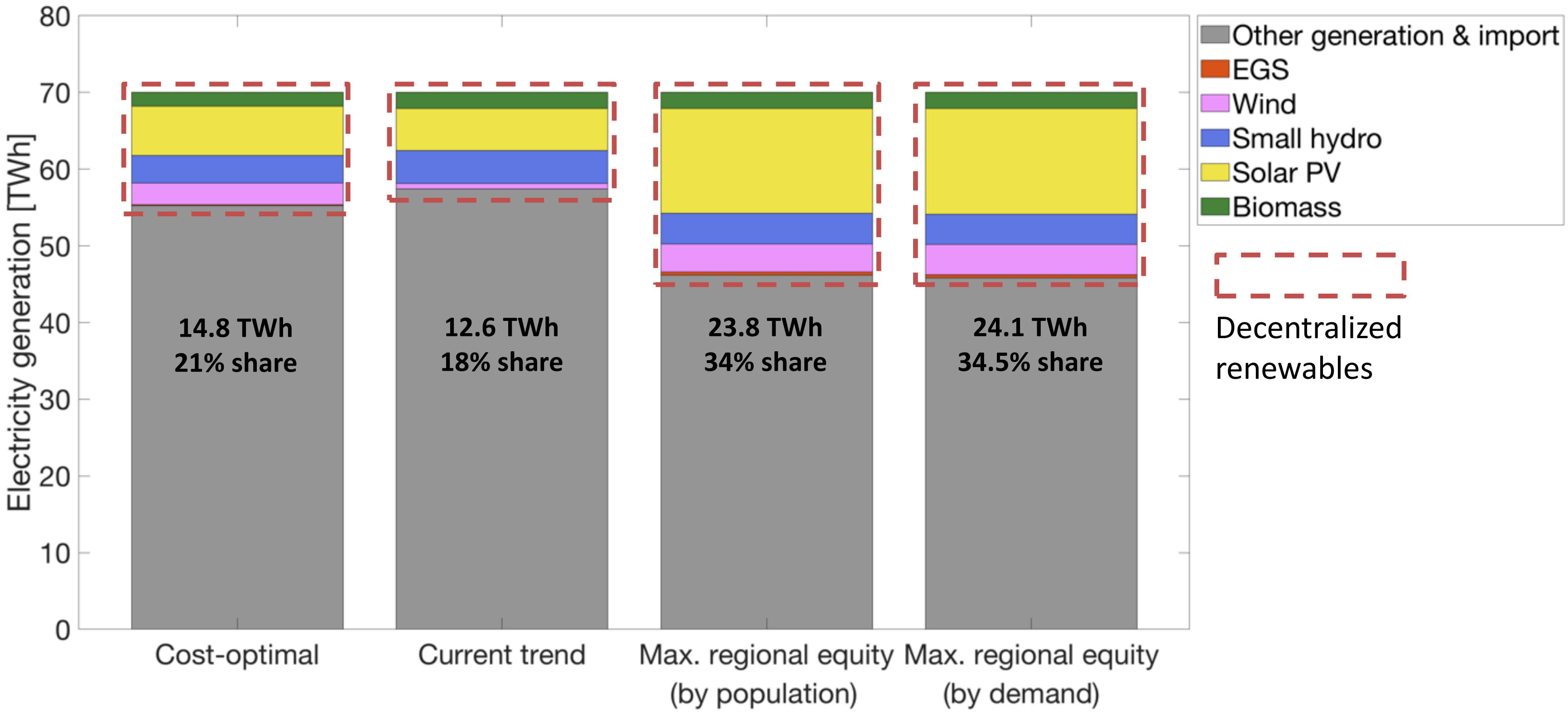
Reference: Drechsler *et. al.* (2017); Gini (1912)

Results: Regional equity and cost trade-offs

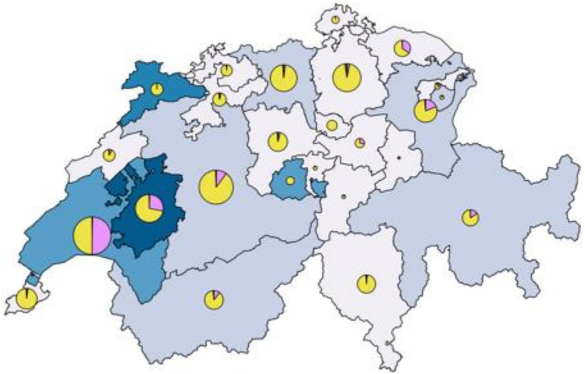


Note: 100 Rp. ≈ 1 USD

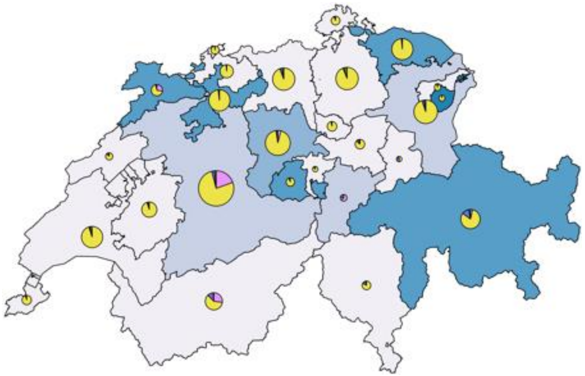
Results: Share of decentralized renewables in electricity mix



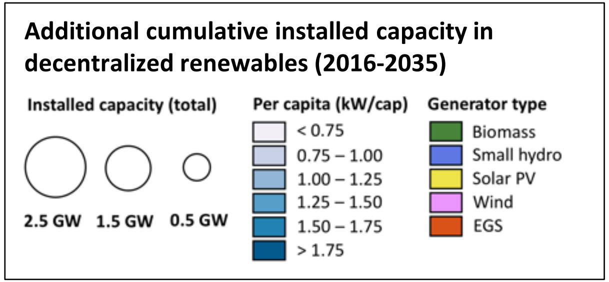
Results: Spatial distribution of installed capacity



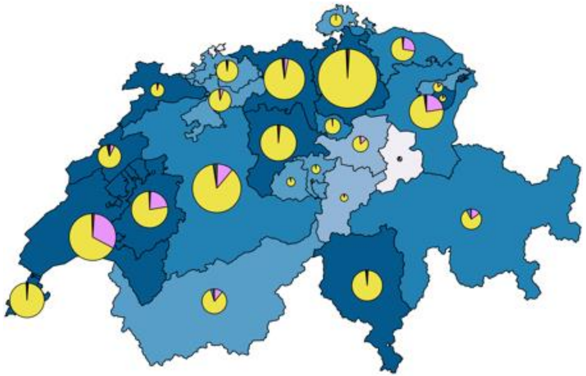
Cost-optimal scenario
(Cost* = 8.54Rp./kWh, Equity = 28.5%)



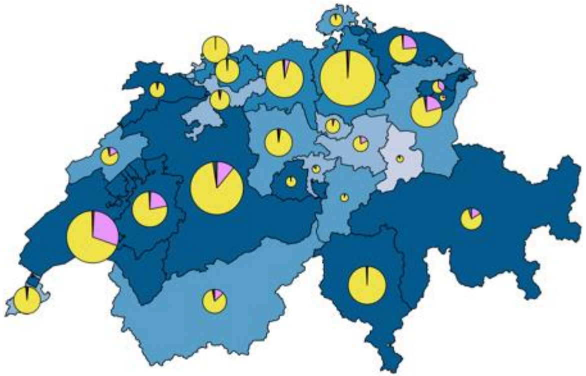
Current trends scenario
(Cost* = 9.17Rp./kWh, Equity = 28.7%)



***Cost = Electricity generation cost**

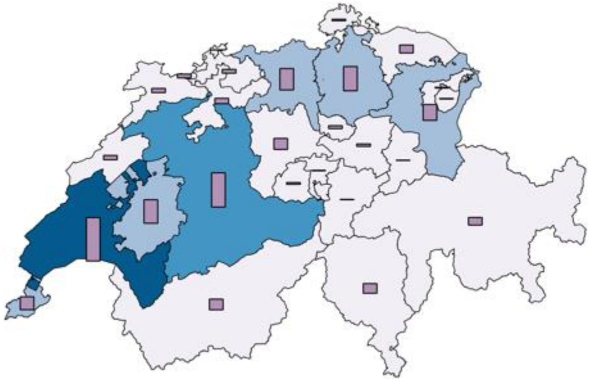


Max. regional equity (by population)
(Cost* = 10.1Rp./kWh, Equity = 43.1%)

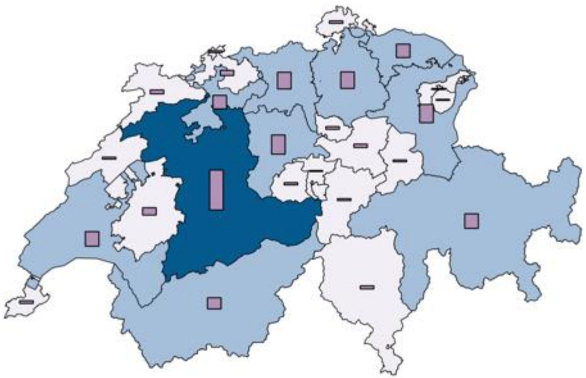


Max. regional equity (by demand)
(Cost* = 10.03Rp./kWh, Equity = 43.0%)

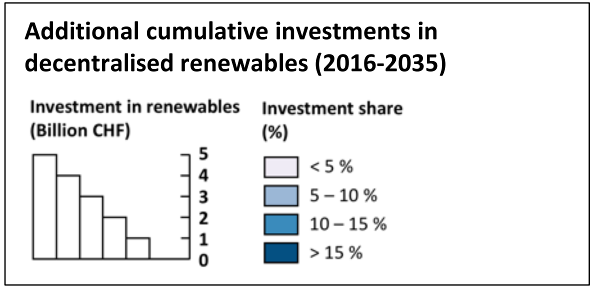
Results: Spatial distribution of investments



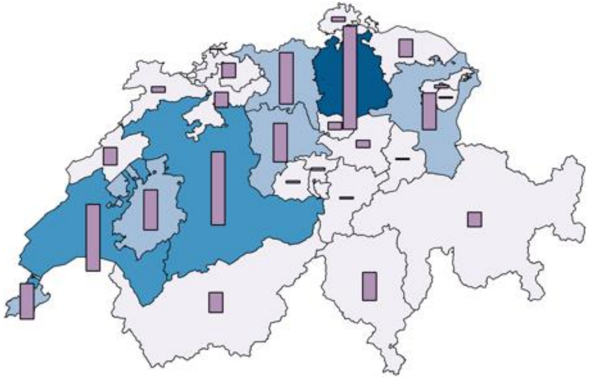
Cost-optimal scenario
(Investments = CHF 11.5 bn, Ø CHF 605m/year)



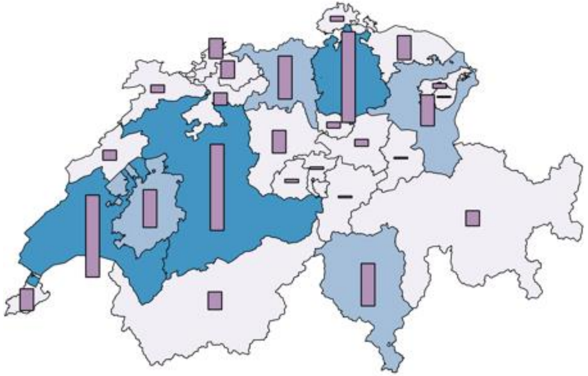
Current trends scenario
(Investments = CHF 13 bn, Ø CHF 684m/year)



***Investments = Capital expenditures (CAPEX)**



Max. regional equity (by population)
(Investments = CHF 31.1 bn, Ø CHF 1'636m/year)



Max. regional equity (by demand)
(Investments = CHF 31.5 bn, Ø CHF 1'657m/year)

Conclusions

Key findings:

- **Significant cost-equity trade-off in Switzerland:**
  - +50% regional equity -> +18% total electricity generation cost
- **Current trend is neither on cost-optimal or regionally equitable path**
  - Observed trend risks fortifying regional disparities that are not cost-optimal
- **Increasing share of solar PV with increasing regional equity:**
  - Possible key technology for equitable and cost-efficient energy transition
- **Focus on cost-optimality leads to spatial concentration of investments:**
  - Spatial concentration of renewables to few locations (such as canton Vaud)

Implications for Energy Strategy 2050:

- Spatial allocation of renewables has significant impact on costs and regional equity
- Reallocation of renewables is difficult, therefore it is important to start thinking about spatial allocation impacts in advance

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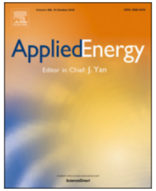

Check for updates

Distributional trade-offs between regionally equitable and cost-efficient allocation of renewable electricity generation

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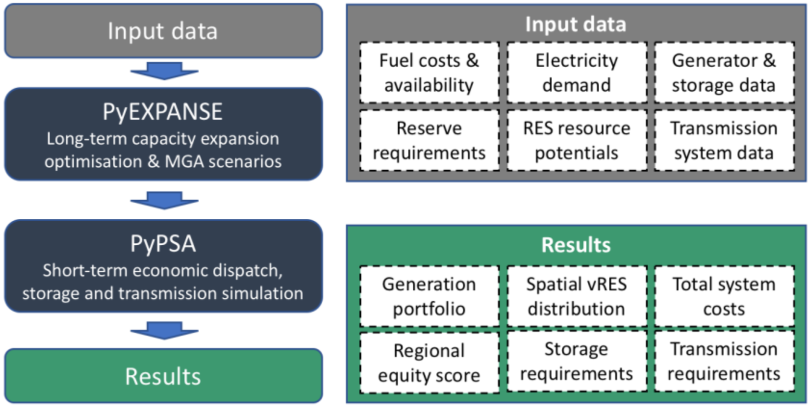
Future work: European model to assess equitable low-carbon transitions for various equity indicators and “effort-sharing” approaches

- **Models:** PyEXPANSE + PyPSA
- **Area**:
  - EU-28 + Switzerland (CH) + Norway (N)
  - 1’369 regions (NUTS 3)
- **Technologies**:
  - Conventional electricity generation
  - Renewable electricity generation
  - Transmission
  - Storage
- **Data**: Aim for open-source data

Study regions



Overview of methodology

Thank you!

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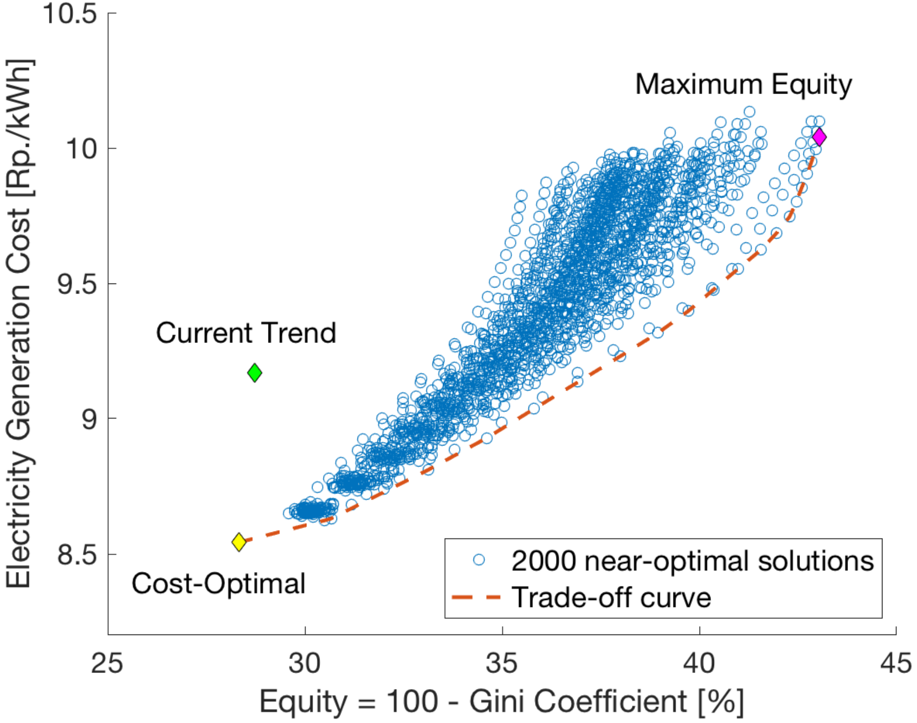
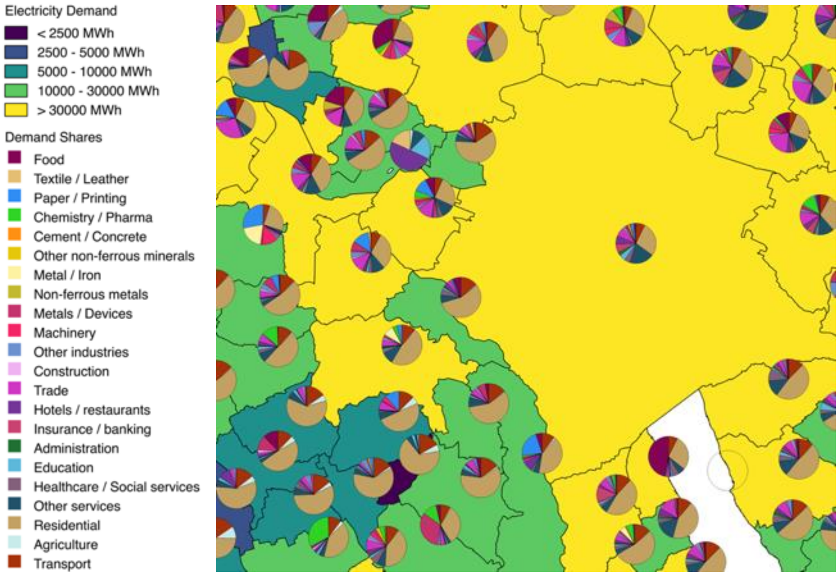
Regional equity (by demand) and cost trade-offs

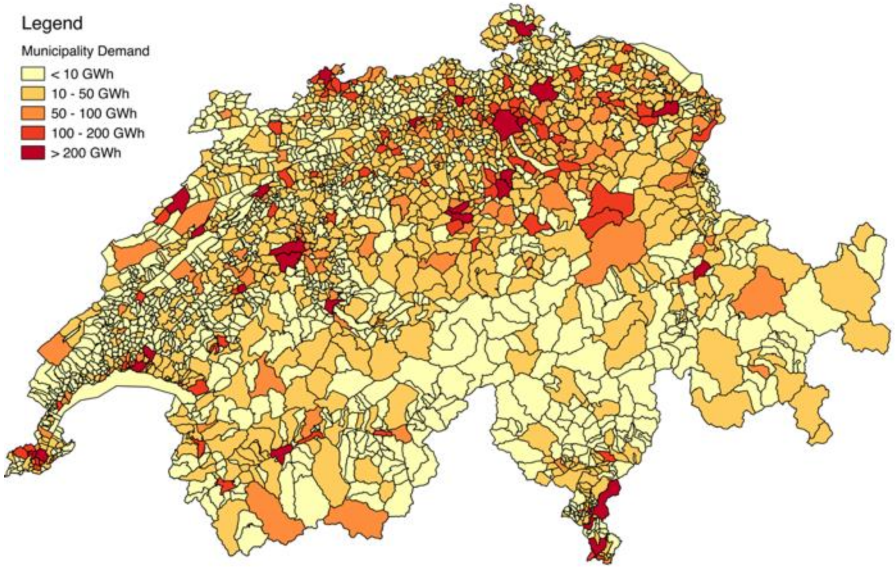


Electricity Demand Model

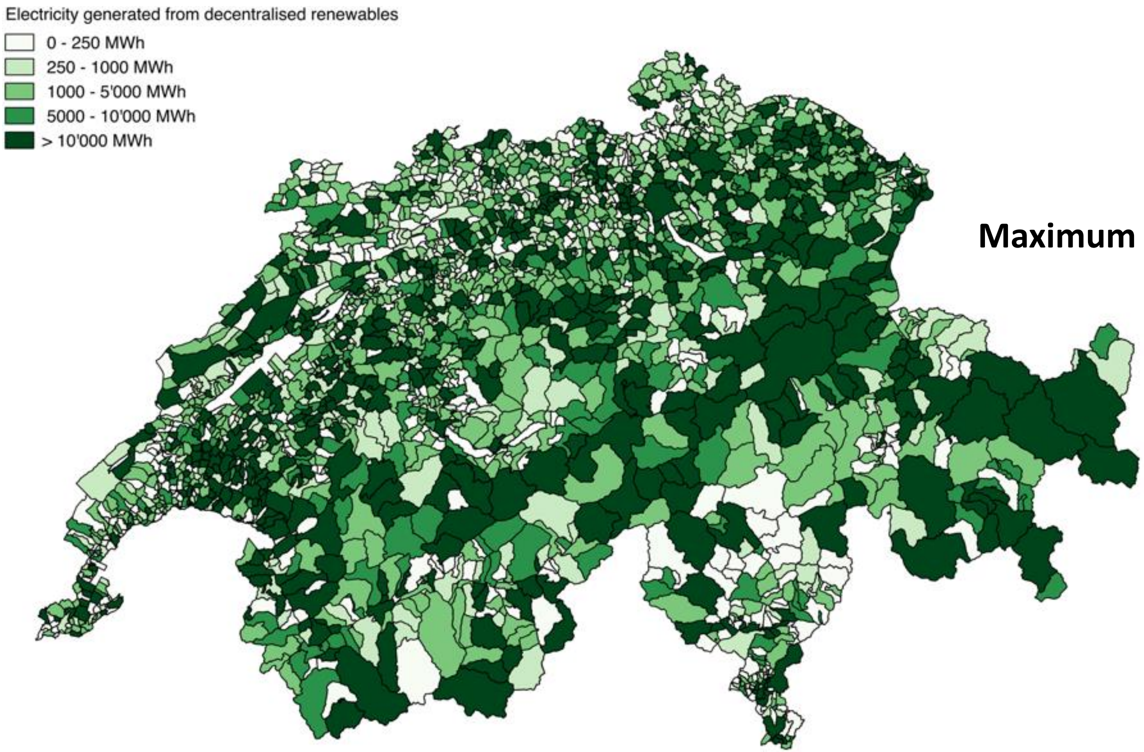
Approach

- NOGA # of employees as a proxy for el. demand from 19 Industry & Commerce sectors
- Number of inhabitants as proxy for demand from Households and Transport



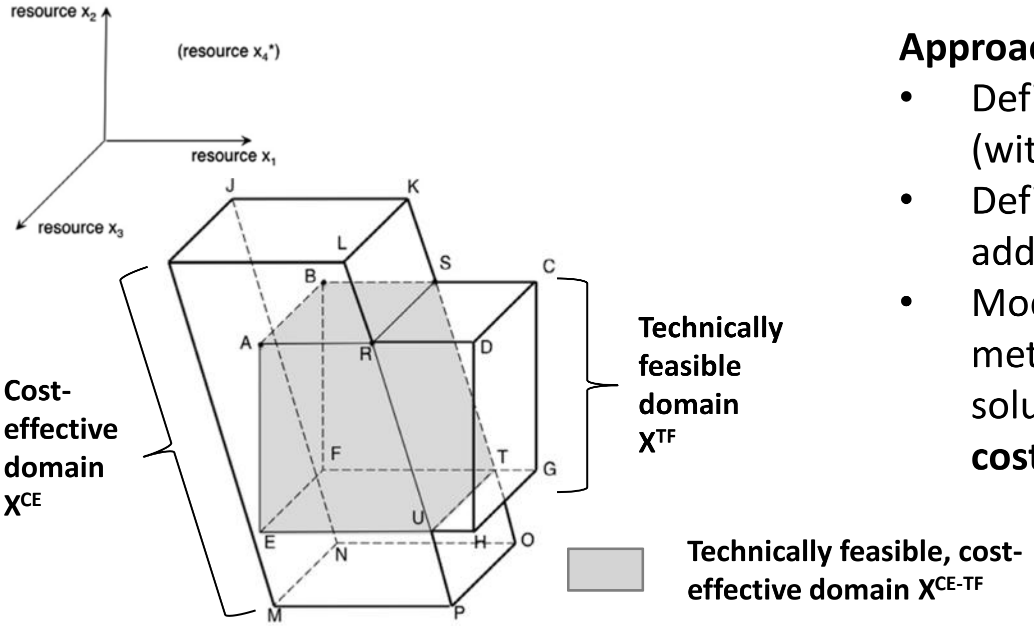


Electricity generated by decentralised renewables



Maximum equity scenario

EXPANSE power system model with Modeling-to-generate-alternatives method (MGA)



E. Trutnevyte (2013), EXPANSE methodology for evaluating the economic potential of renewable energy from an energy mix perspective, Applied Energy, ISSN: 0306-2619, Vol: 111, Page: 593-601

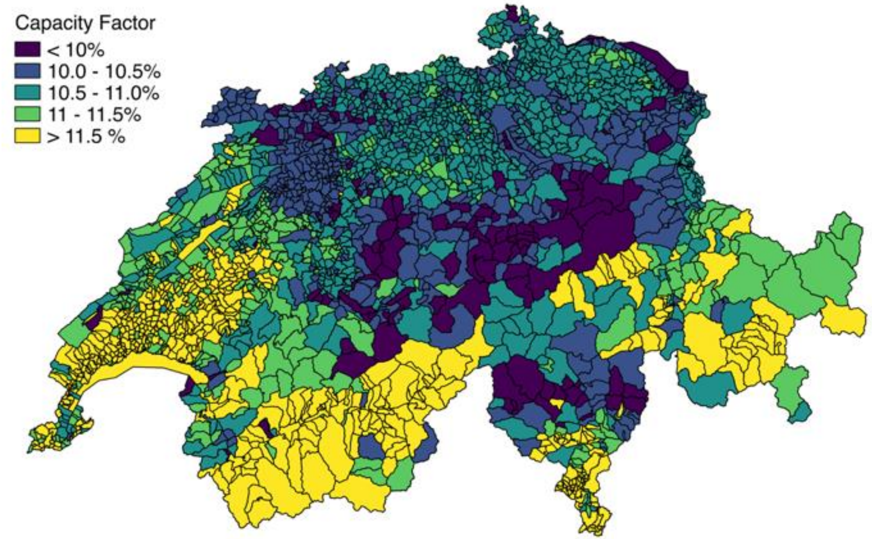
Approach:

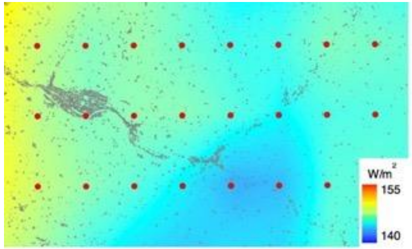
- Define **technically feasible domain X^{TF}** (with demand and supply potentials)
- Define **cost-effective domain X^{CE}** by adding a varying cost constraint
- Modeling-to-generate-alternatives method: Sample large defined number of solutions within the **technically feasible, cost-effective domain X^{CE-TF}**

Estimation of Solar Rooftop PV potentials and cost

Solar Power Database (Existing & Remaining Potential)

- Existing solar panels (capacity, el. gen. and location (Source: KEV List))
- Performance parameters (Costs, el. efficiency (source: PSI report *Bauer et. al.*)
- Remaining potential: BFE “Sonnendach” study (60%) + modelling (40%) (Source: 3D Building Data, BFE study)





Available Rooftop Area and Angle

+

Solar Irradiation [kWh/year]

+

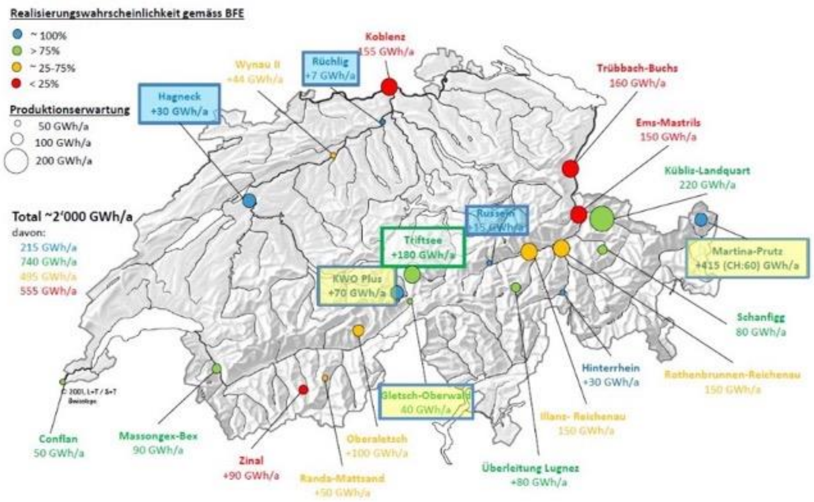
Reduction Factor by Building Type

Energy Resource & Powerplant Database

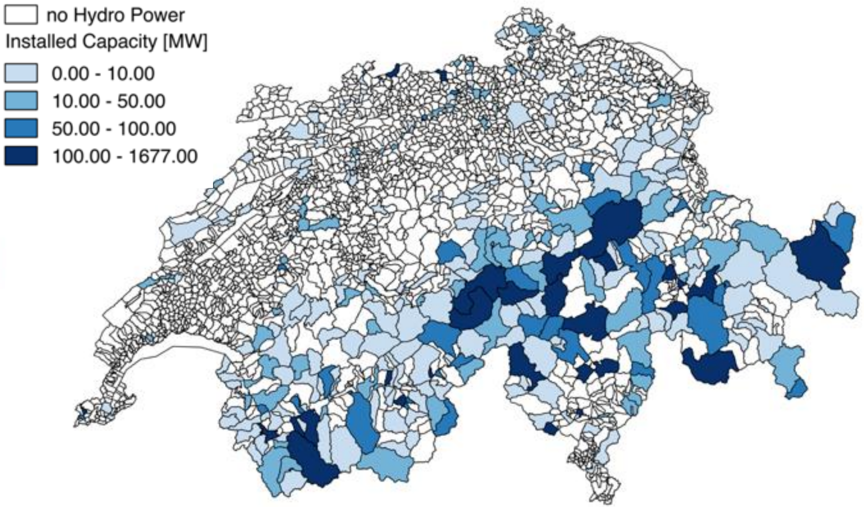
Hydro Power Database (Dams, RoR and Small Hydro)

- Type, capacity, annual production and location (Source: BFE)
- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)

Hydro Plants in Construction



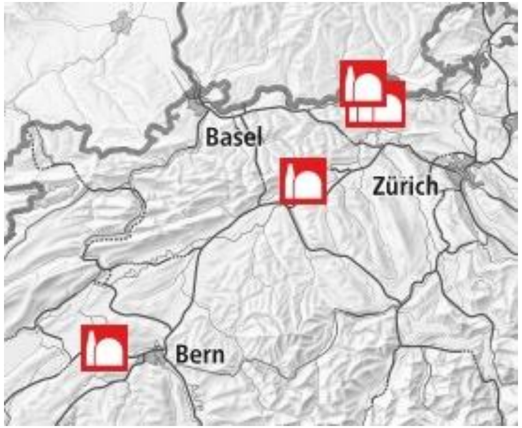
Installed Hydro Power Capacity



Energy Resource & Powerplant Database

Nuclear Power Database

- Capacity, annual production and location (Source: BFE)
- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)
- Assumption: no Nuclear power after 2034 (Grants will not be extended)
- Therefore: **Modelled available capacity is ZERO for year 2035**



Expected Decommissioning

- Beznau I & II: 2030 (Source: NZZ)
- Mühleberg: 2019 (Source: BKW)
- Gösgen: 2029 (not confirmed yet)
- Leibstadt: 2034 (not confirmed yet)

Energy Resource & Powerplant Database

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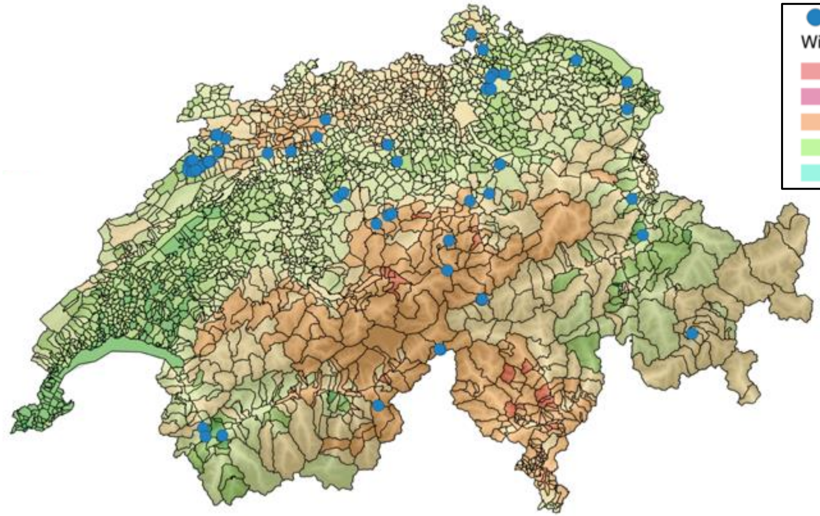
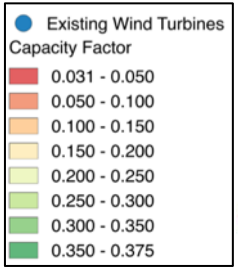
Wind Power Database

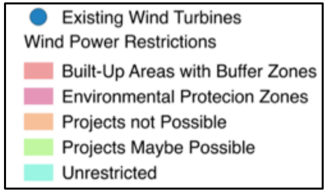
- Type, capacity, annual electricity production and location (Source: BFE)
- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)

Wind Resource Assessment





Wind Farm Spatial Restrictions



Energy Resource & Powerplant Database

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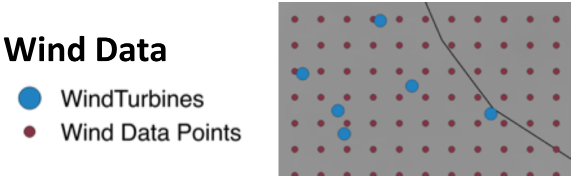
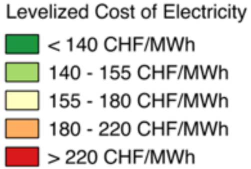
Wind Power Database

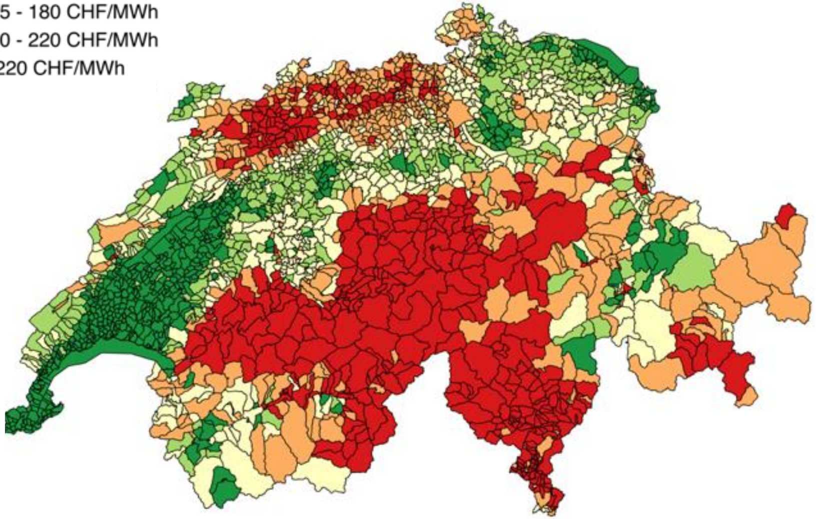
- Modelling of Turbine Performance and LCOE with Wind Data (BFE, MeteoSchweiz)

Wind Data

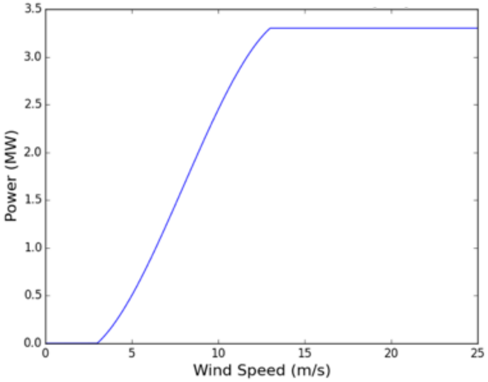




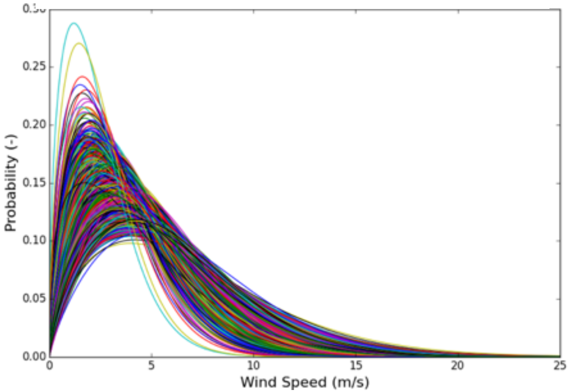
Modelled LCOE



Turbine Data



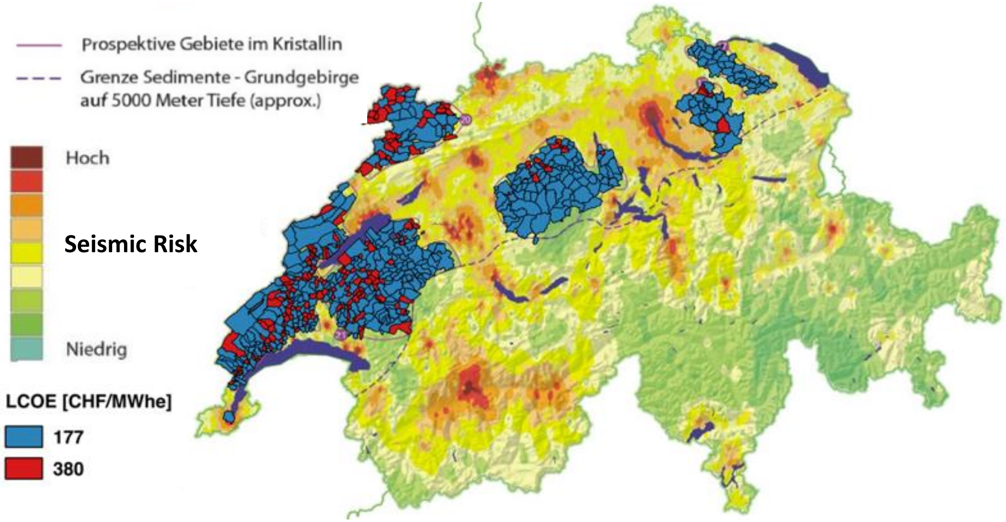
Wind Speed Distribution



Energy Resource & Powerplant Database

Enhanced Geothermal Power Database

- Status: Currently no operational EGS power plants in Switzerland
- Potential areas for EGS construction from reports (Geoenergie Suisse)
- LCOE, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)



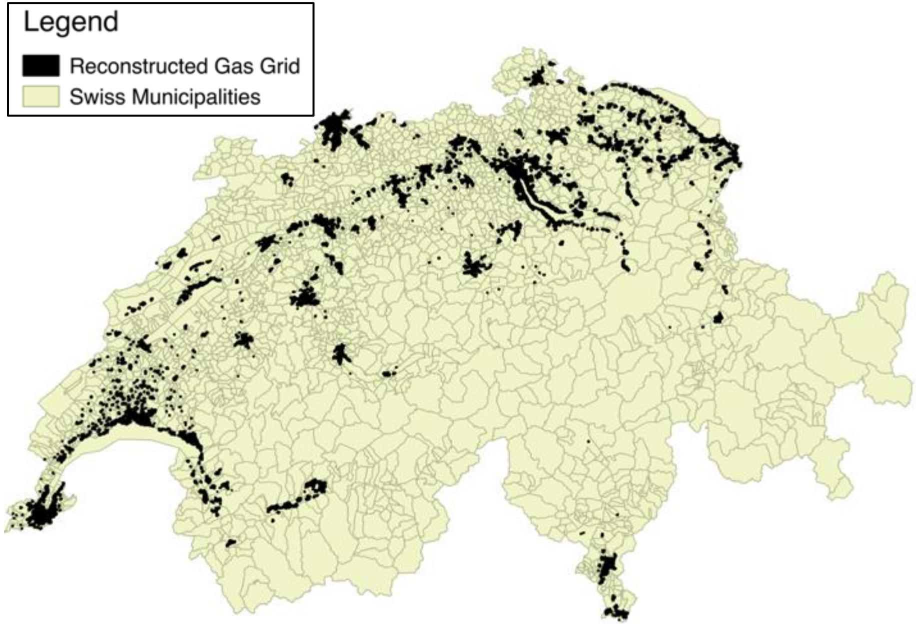
Approach to select EGS sites

- Areas with Crystalline Layer @5000m depth
- Areas with industrial zones (easy building rights)
- Exclude areas with high seismic risk
- Assume 5MW plants. 30GWh yearly production
- Cost model based on TA Swiss Base cost model
- Two LCOE cost levels which includes or excludes heat credits from heat sold through district heating grid
- District heating data obtained from GWR data

Energy Resource & Powerplant Database

Gas Power Database

- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)



Approach to select potential Gas power plant sites

- Reconstruct gas grid from two data sources:
  - Register of buildings and dwellings (identify buildings with gas heaters)
  - Verband der Schweizerischen Gasindustrie (VSG) list of postal codes with available gas grid

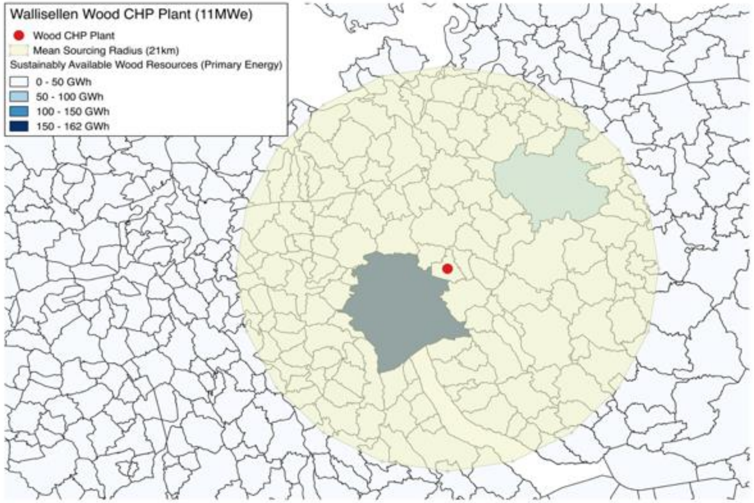
Existing and Planned power plants (Source: VSE report)

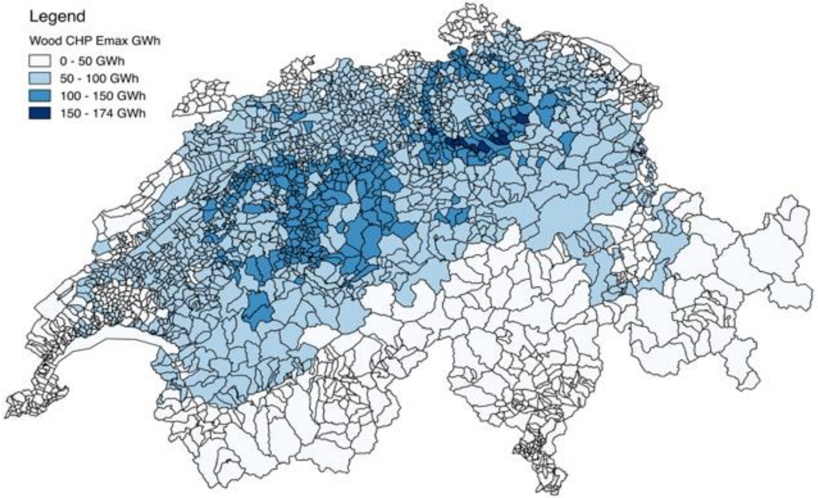
	MW	GWh
Total (Existing)	132	608
Total (Planned)	1'652	9'528
Total (Potential 2035)	3'000	20'000
Total (Potential 2035)	5'250	35'000

Energy Resource & Powerplant Database

Wood CHP Database

- Capacity, annual electricity production and location (Source: KEV List)
- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)
- Modelling Approach: Limit resources to 30km radius around each site



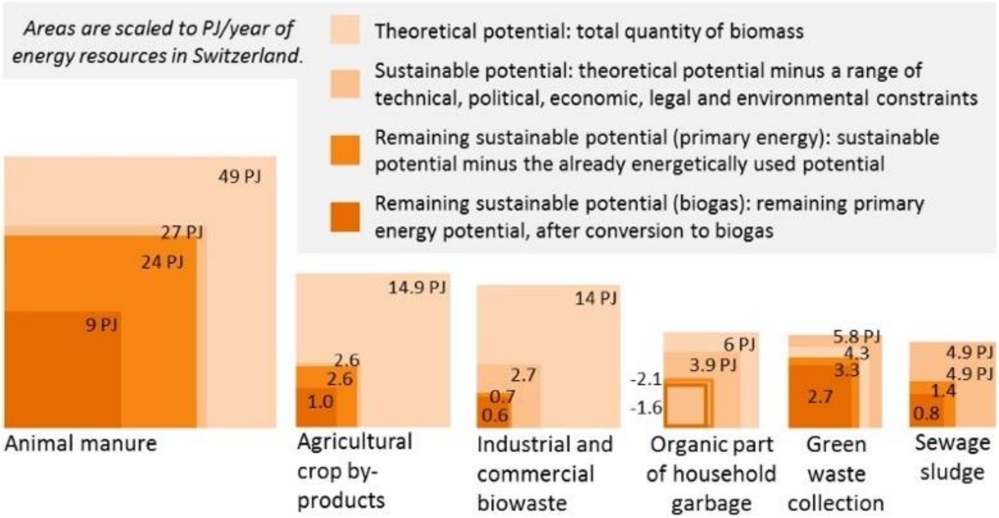


Energy Resource & Powerplant Database

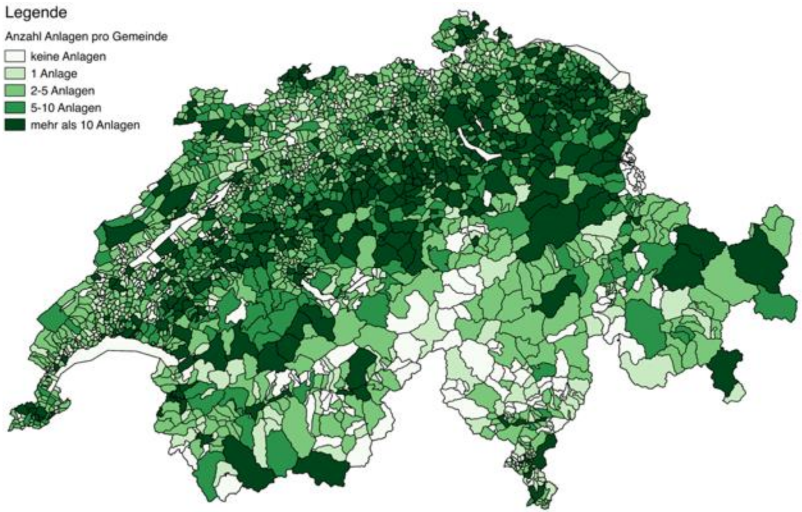
Biogas Database

- Capacity, annual electricity production and location (Source: KEV List)
- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)

Sustainable Biogas Potential



Potential no. of 25kW power plants



Energy Resource & Powerplant Database

Waste Incineration Plant Database

- Type, capacity, annual electricity production and location (Source: VBSA)
- Costs, electrical efficiency and technical constraints (source: PSI report *Bauer et. al.*)

Existing Waste Incineration Plants

Assumptions (For years up to 2035)

- No new Waste Incineration plants will be built
- Current Waste incineration plants will have maximum added electricity production of 197GWh
- This is mainly due to efficiency gains from more efficient steam generation
- Based on current supply of 1065, this equals max. 18% increase in power production