White Paper:
Sources of Primary Electricity Supply

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Consistent evaluation of electricity generation technologies relevant for Swiss supply

- Current conditions, 2035, 2050
- Domestic and potential import options
- System aspects were not part of the scope of this study (e.g. interactions of technologies, storage options, external costs due to air pollution)
- Contribution to SFOE’s energy perspectives and continuous technology monitoring, key inputs for the JA Scenarios & Modeling
- PSI (Lead), ETHZ, EPFL, WSL, SCCER Biosweet
- Funding: SFOE, SCCER SoE
Potentials, Costs and Environmental Effects of Electricity Generation Technologies

- The White Paper also includes two additional contributions:
  - Mountain PV in a fully renewable Switzerland (CRYOS-EPFL)
  - Role of bioenergy in Switzerland (WSL, SCCER Biosweet)
Contributors

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Content

- Introduction
- Comparative results
- Deep dives:
  - Building-Added PV (BAPV) national scale, alpine PV
  - Biomass
  - Hydropower
  - Deep Geothermal Systems (DGE)
- Challenges and Opportunities
- Conclusions and Recommendations
Potentials, Costs and CO₂ Emissions of Power Generation (2050)

Bauer et al. (2020)
Potential, Costs and \( \text{CO}_2 \) Emissions of Power Generation (2050)

- **PV**: largest by far (up to 50 TWh/a on roofs); though substantial uncertainties
- **Wind**: up to 4 TWh/a, facing social opposition
- **Biomass & hydropower**: low, max. a few TWh/a
- **Geothermal**: high uncertainties

Bauer et al. (2020)
Potentials, Costs and CO₂ Emissions of Power Generation (2050)

Costs
- PV and wind expected to be the cheapest options in 2050
- Large variability for hydropower, depending on specific locations
- Biomass and natural gas based generation mainly driven by fuel costs
- In general: large economies of scale
Impacts on climate change – CO₂ emissions

- Hydropower < wind < PV and geothermal, but all “low-carbon”
- Large variability for biomass, depending on feedstock and conversion
- Natural gas must be combined with CCS to be “low-carbon”

Bauer et al. (2020)
Current low average generation costs are due to existing hydro and nuclear plants.

For new plants today, some biomass, hydro, large PV and natural gas CC would be most economic.

Substantial cost reductions expected for PV, wind, and fuel cells.

Large variabilities for future hydropower, geothermal, natural gas and biomass based generation.
CO₂ Emissions

- **Current life-cycle carbon footprint** is lowest for electricity from hydro, wind and wood power plants.
- **In the future, all renewables are expected to represent** “low-carbon” generation.
- **Natural gas based generation must be combined with CCS in order to be** “low-carbon”.
- **Economy of scale is less important than for generation costs.**
**Solar PV: System Size & Investment Cost**

### Installed System Size Breakdown, 2019

**Switzerland**
- 1%: more than 1000 kWp
- 37%: 20 to 30 kWp
- 31%: 10 to 100 kWp
- 8%: 4 to 20 kWp
- 5%: till 4 kW
- 10%: 100 to 1000 kWp

**Germany**
- 36%: up to 10 kWp
- 34%: 10 to 100 kWp
- 15%: 100 to 500 kWp
- 15%: more than 500 kWp

### System Investment Cost

**Switzerland, 2015-2020**

- Smaller systems in Switzerland, 32% less than 20 kWp, about 50% less than 100 kWp.
- System investment costs continuously decrease with time and size increase.

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*Zhang, X. 2020 (to be published)*
Switzerland can reach 24 ± 9 TWh of annual generation potential (all roofs)

- Large variability, i.e. focus not just on roofs with very good solar irradiance, but there are roofs with less irradiance that are large enough to be economically viable
- Majority of this potential achievable with LCOE below 25 Rp/kWh, half of this potential achievable with LCOE below 20 Rp/kWh
- Electricity tariff in Switzerland: 17 – 25 Rp/kWh

-> Importance of self-consumption
Alpine Photovoltaic

- Less solar radiation is absorbed before it reaches the module surface.
- Fog and cloud cover in winter are often limited to the lowlands.
- Snow cover increases the solar energy reflected back from the ground.
- Steep tilt angles of solar modules; favoring winter production.
- The efficiency of PV systems increases as the module temperature decreases.

Surface area required to produce 12 TWh:
area (y-axis) varies as a function of the tilt angle (x-axis).

- Productivity is higher in the mountains, because for all tilt angles at least ten square kilometers less surface area is needed (difference between red and green line).
- Additional gain due to the influence of the reflecting snow surface (difference between the green and blue lines).
- The winter productivity shows a similar slope dependence.
- Production increase of about 50% in the mountains!
Challenges and Opportunities

Challenges

- Speed of transformation towards 100% renewable
- Temporal (and spatial) mismatch between supply and demand
- System integration and sector coupling
- Large investments required
- Social acceptance

Opportunities

- Reduction of import dependency and use of domestic resources
- Increase of domestic value creation and establishment of high-tech industries
- Improvement of air quality as co-benefit of GHG emission reductions
- Increase of energy system resilience
Summary

- Photovoltaic (PV) power generation exhibits largest potential in Switzerland
- Smart PV installations allow for shifting summer peak generation to winter
- Exploitation of other renewables is crucial for a resilient power sector
- Electricity supply costs are likely to increase, despite of declining costs of renewables
- All renewables are expected to represent “low-carbon” generation by 2050, with hydro, wind and PV performing best
Thank you for your attention

Thanks to all colleagues / contributors