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SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

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White Paper:
Sources of Primary Electricity Supply

Peter Burgherr – WP4 Coordinator – Paul Scherrer Institute (PSI)

SCCER SoE Annual Conference, 02.11.2020

Potentials, Costs and Environmental Effects of Electricity Generation Technologies

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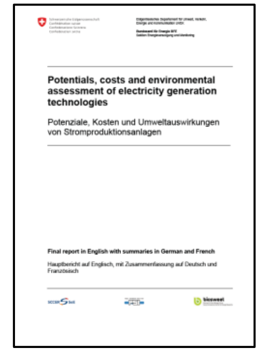
Can renewables fill the power gap?

April 2018 - by Christian Bauer

Sooner or later Switzerland must get by without nuclear power plants. This has been determined by the adoption of the Energy Strategy 2050. But how can the power gap be filled? Is there enough space and acceptance for photovoltaic installations and wind turbines in Switzerland, or will we have to import electricity from abroad? How much will the alternatives cost and what effects will they have on the environment? The Paul Scherrer Institute (PSI) has recently attempted to answer these and other questions for the Swiss Federal Office of Energy (SFOE).

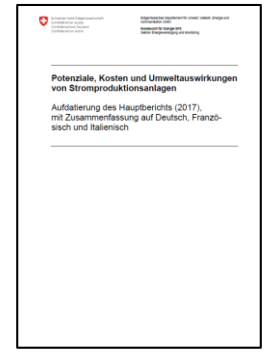


Potentials, costs and environmental assessment of electricity generation technologies

Potenziale, Kosten und Umweltauswirkungen von Stromproduktionsanlagen

Final report in English with summaries in German and French

Hauptbericht auf Englisch, mit Zusammenfassung auf Deutsch und Französisch



Potenziale, Kosten und Umweltauswirkungen von Stromproduktionsanlagen

Aufdatierung des Hauptberichts (2017), mit Zusammenfassung auf Deutsch, Französisch und Italienisch

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:**


PNAS

The bright side of PV production in snow-covered mountains


Heft 57, 2017

WSL Berichte

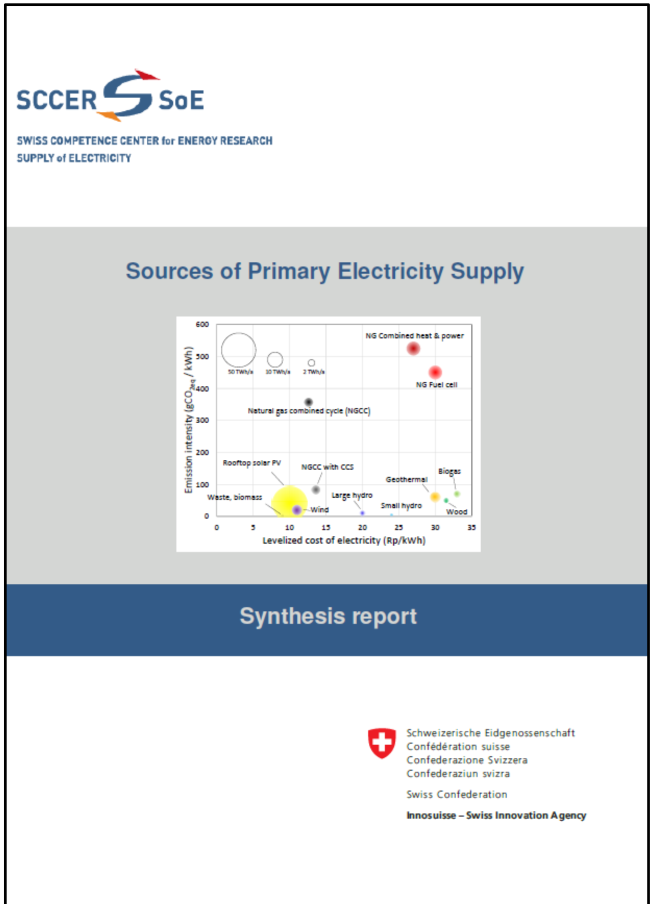
Biomassenpotenziale der Schweiz für die energetische Nutzung

Ergebnisse des Schweizerischen Energiekompetenzzentrums SCCER BIOSWEET

Oliver Thees, Vanessa Burg, Matthias Erni, Gillianne Bowman, Renato Lemm

- **Mountain PV in a fully renewable Switzerland (CRYOS-EPFL)**
- **Role of bioenergy in Switzerland (WSL, SCCER Biosweet)**

White Paper Contributors and Content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Sources of Primary Electricity Supply

Synthesis report

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  *editors

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 CO_2 Emissions of Power Generation (2050)

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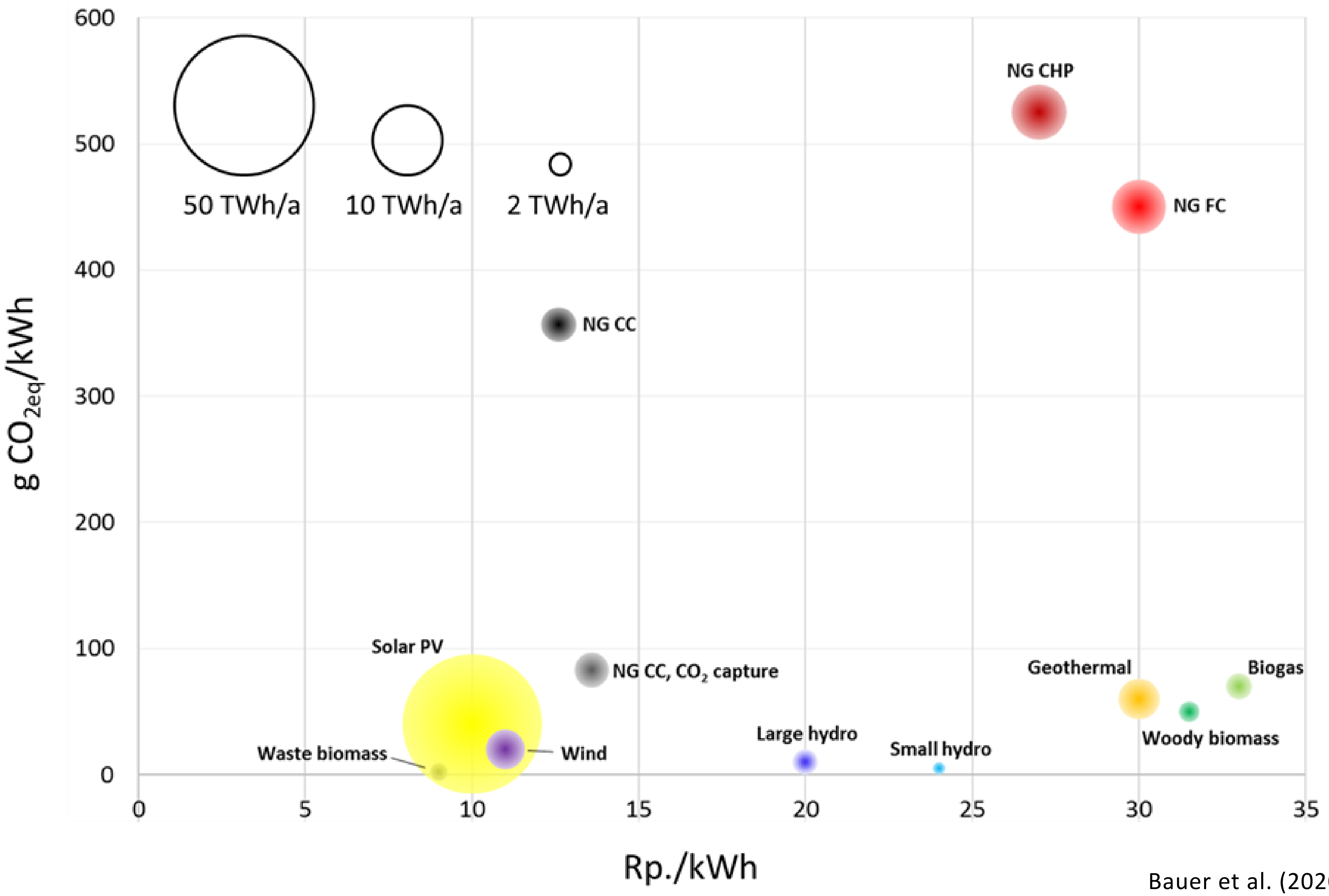

Bauer et al. (2020)

Potentials, Costs and CO_2 Emissions of Power Generation (2050)

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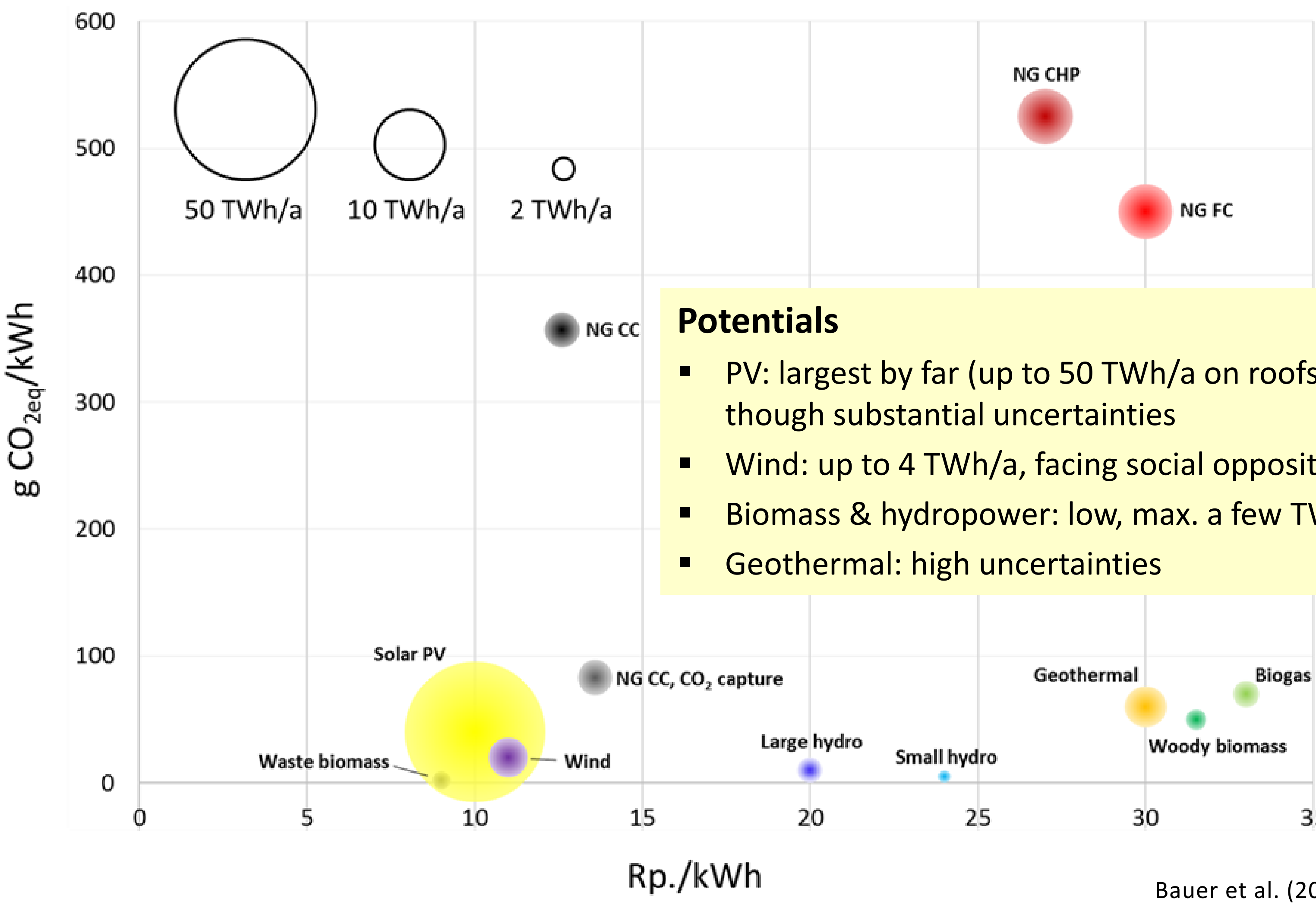
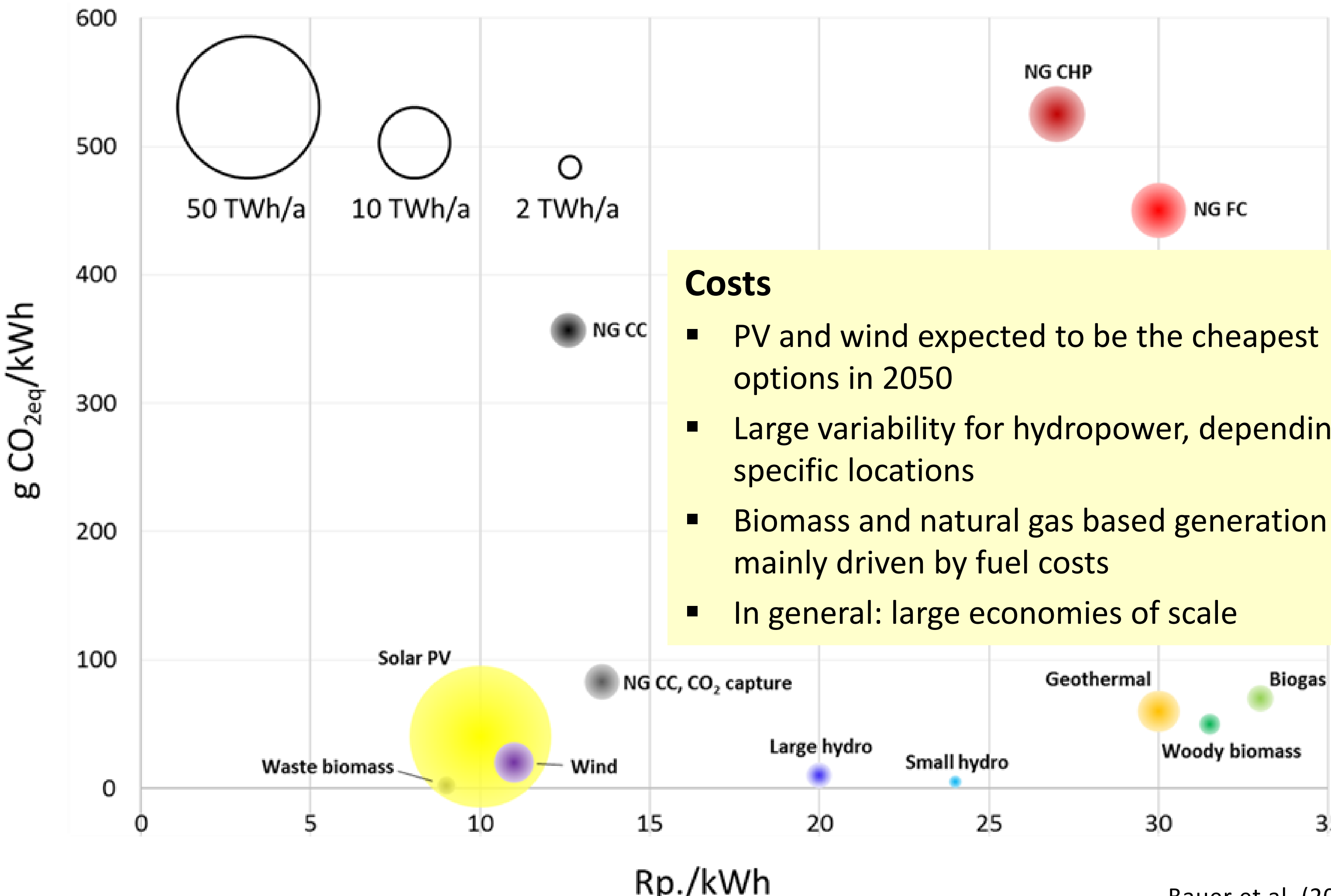


Potentials

- 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 CO_2 Emissions of Power Generation (2050)

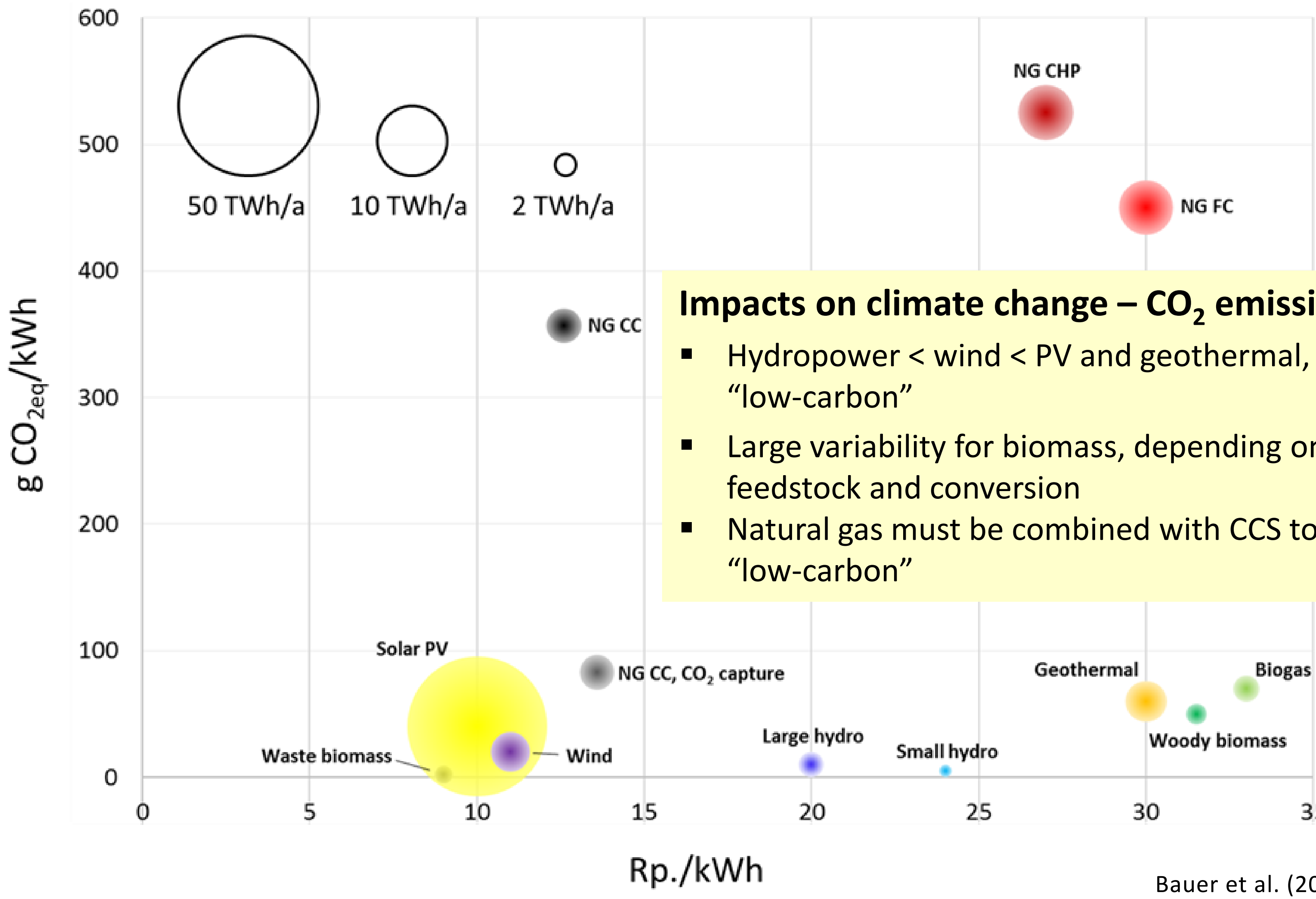


Costs

- 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

Bauer et al. (2020)

Potentials, Costs and CO_2 Emissions of Power Generation (2050)

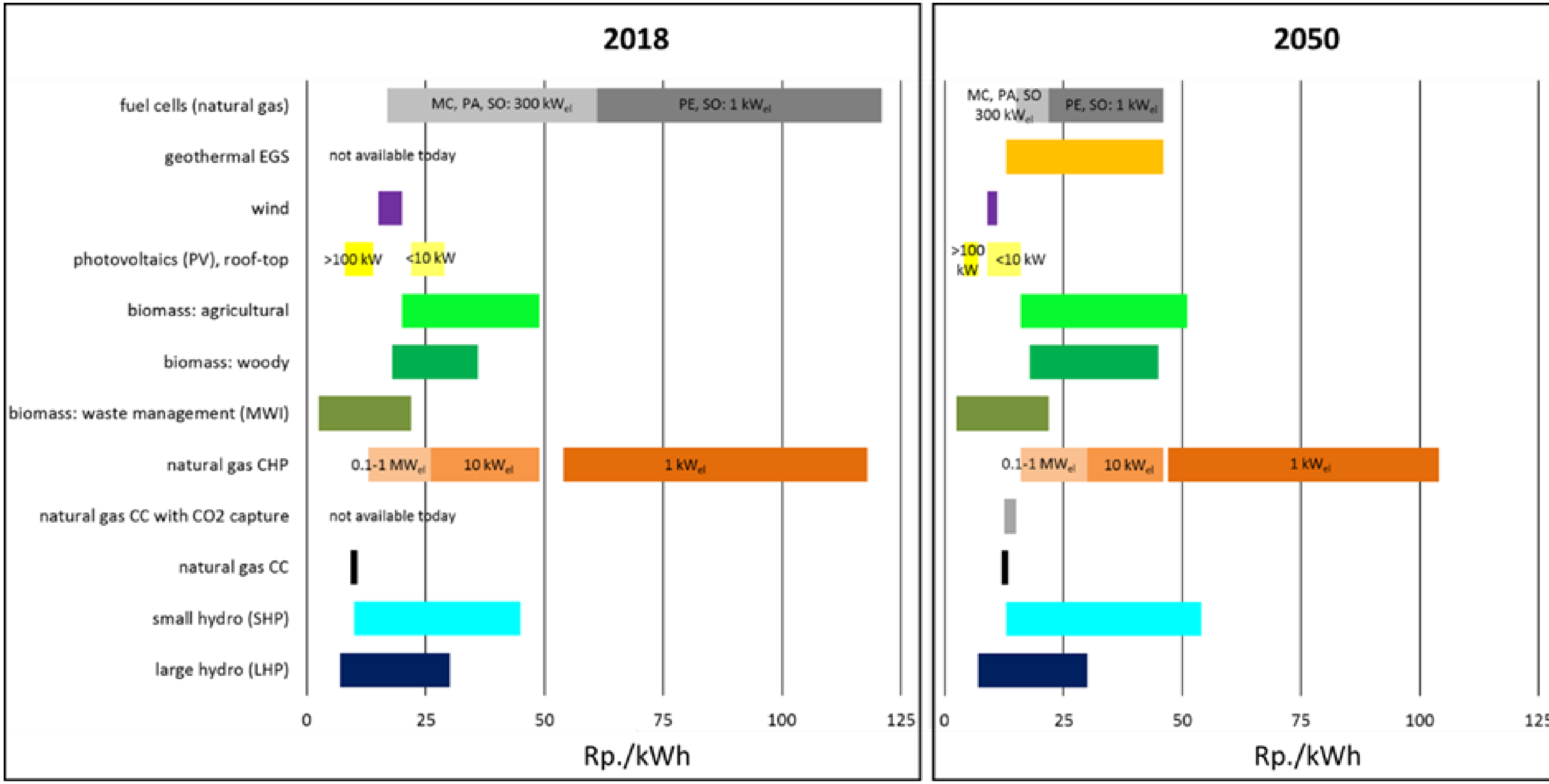


Impacts on climate change – CO_2 emissions

- 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)

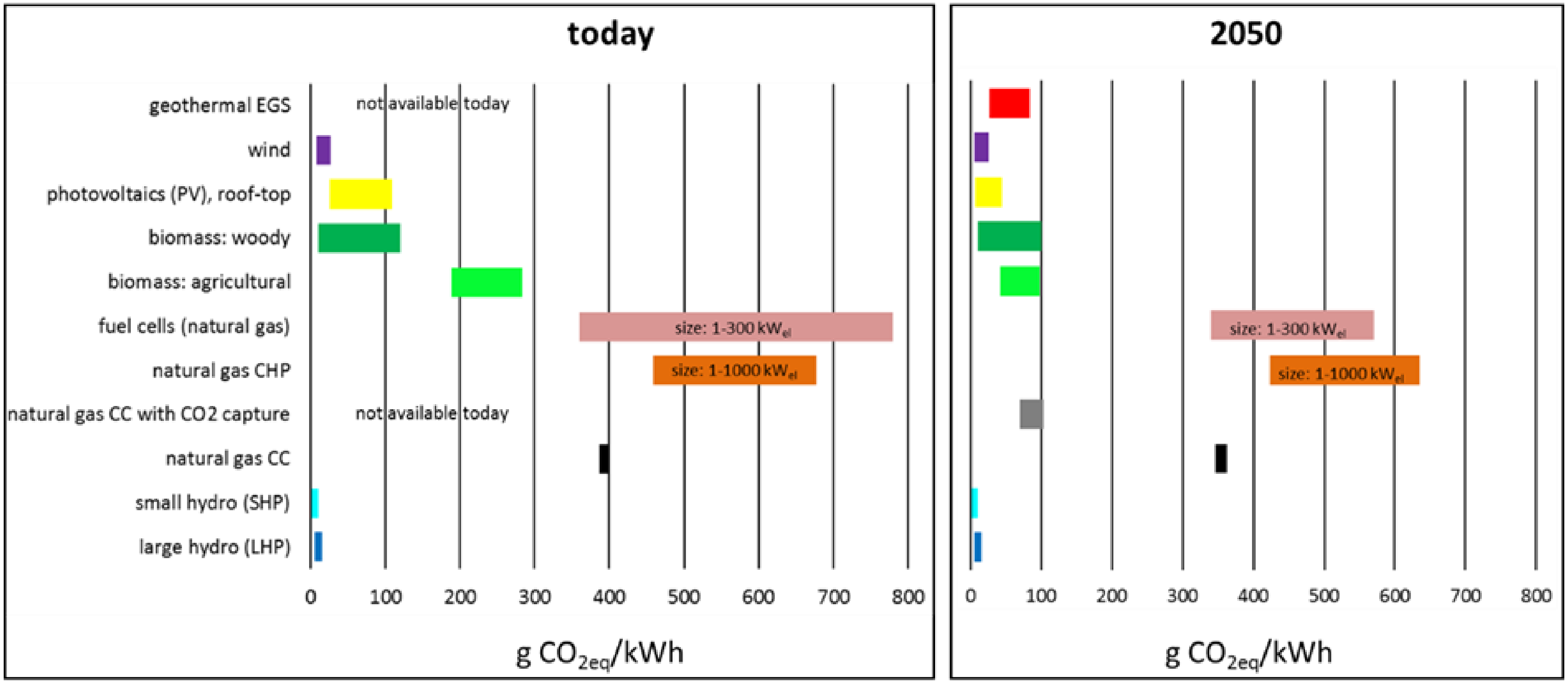
Costs



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

CO_2 Emissions



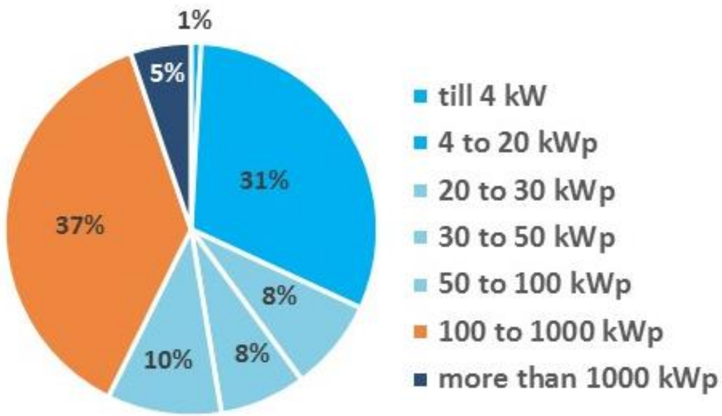
Bauer et al. (2020)

- 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

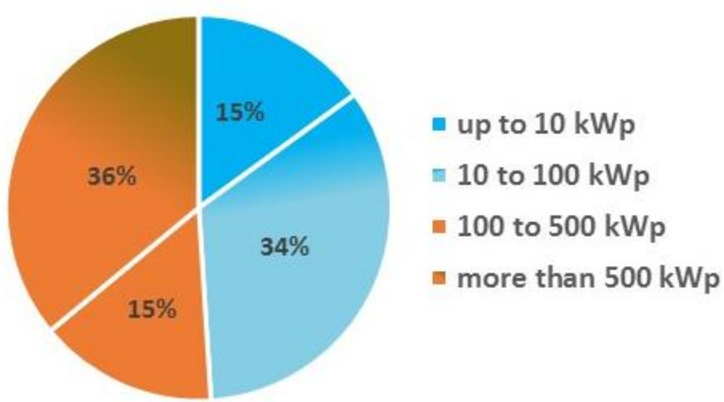
Solar PV: System Size & Investment Cost

Installed System Size Breakdown, 2019

Switzerland

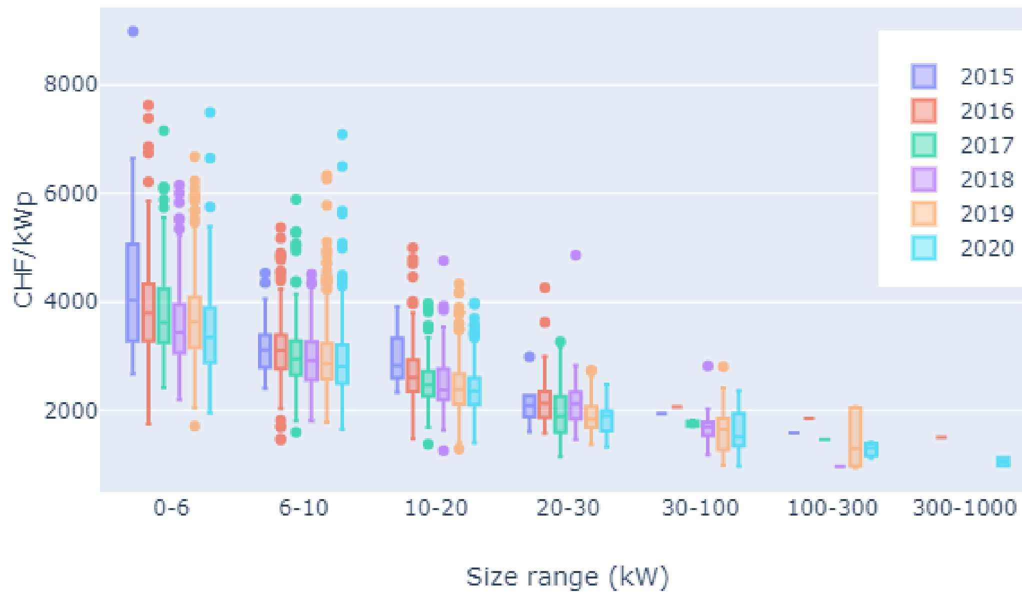


Germany



System Investment Cost

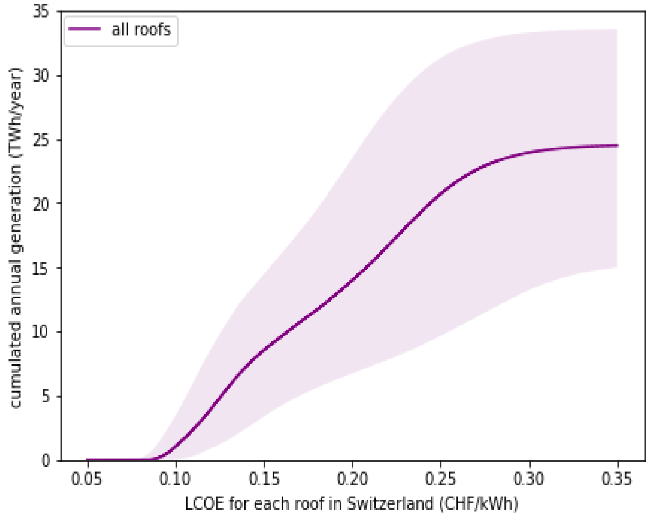
Switzerland, 2015-2020



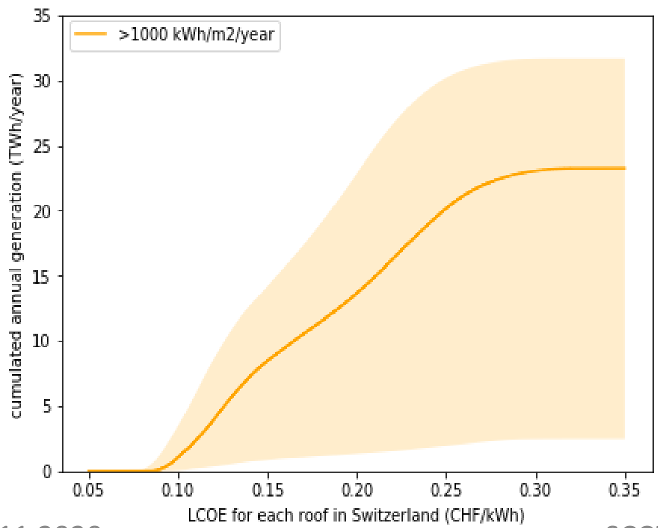
Zhang, X. 2020 (to be published)

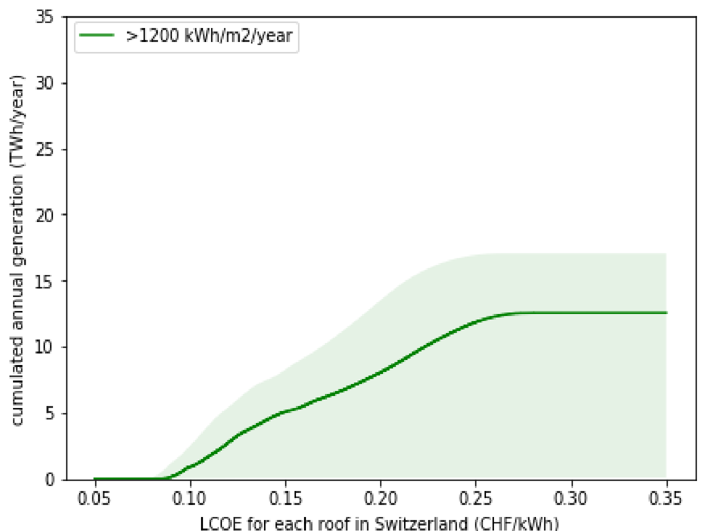
- Smaller systems in Switzerland, 32% less than 20 kWp, about 50% less than 100 kWp.
- System investment costs continuously decrease with time and size increase

Solar PV: Annual Generation Potential & LCOE



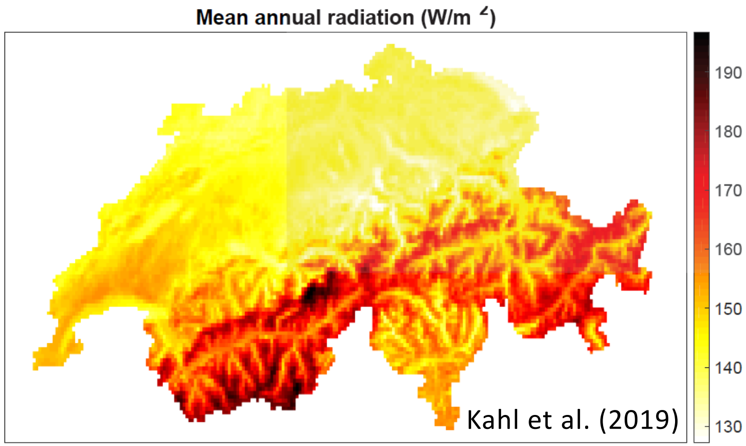
- Switzerland can reach 24 ± 9 TWh of annual generation potential (all roofs)
- Large variability, i.e. focus not just on roofs with very good solar irradiance, but there are roofs with less irradiance that are large enough to be economically viable
- Majority of this potential achievable with LCOE below 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

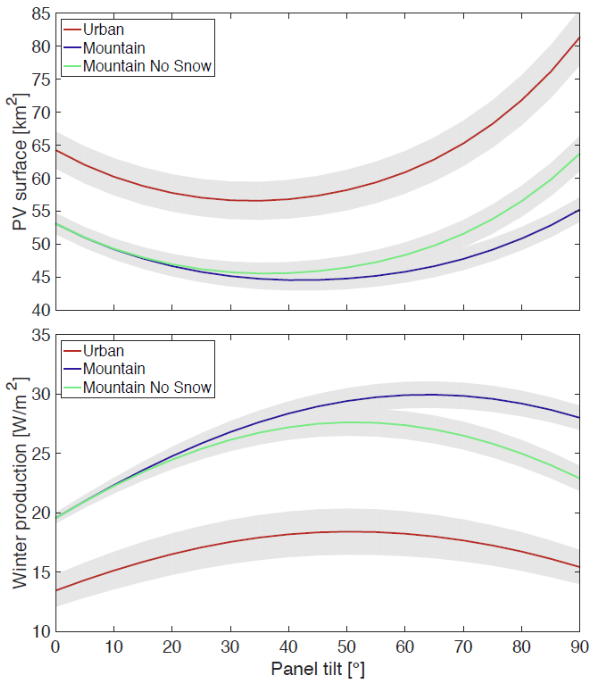




Zhang, X. 2020 (to be published)

Alpine Photovoltaic





Kahl et al. (2019)

- **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 r**eflecting 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

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Challenges

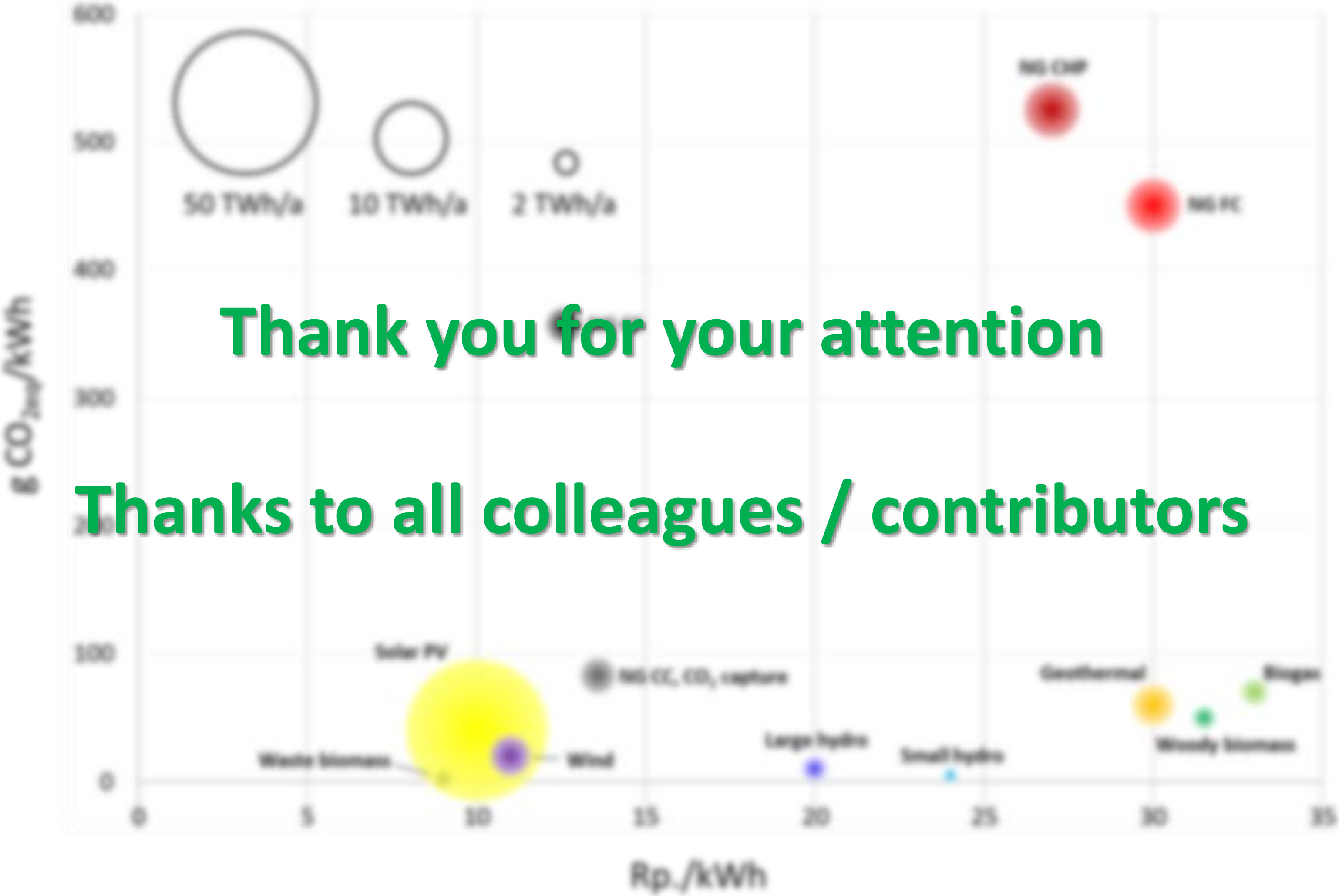
- Speed of transformation towards 100% renewable
- Temporal (and spatial) mismatch between supply and demand
- System integration and sector coupling
- Large investments required
- Social acceptance

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