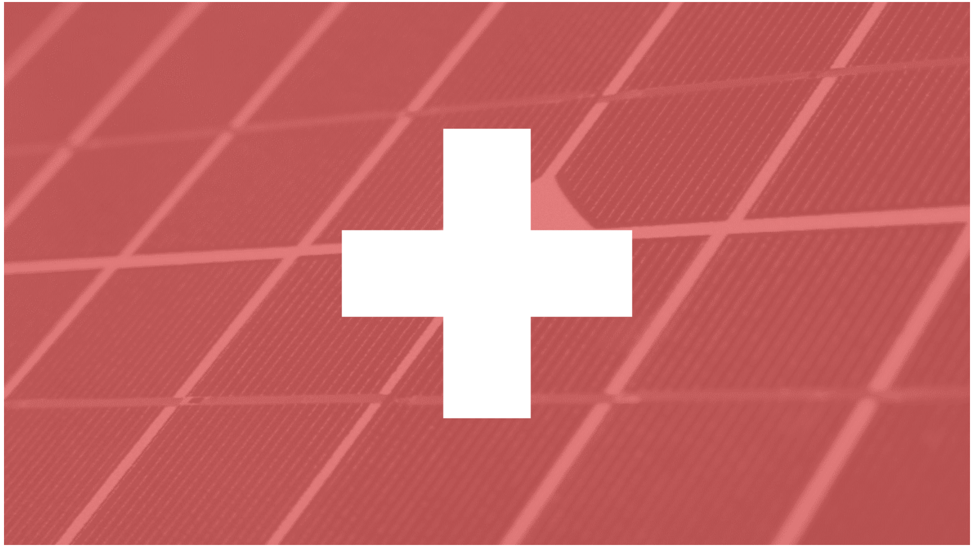


Firm PV Power Switzerland

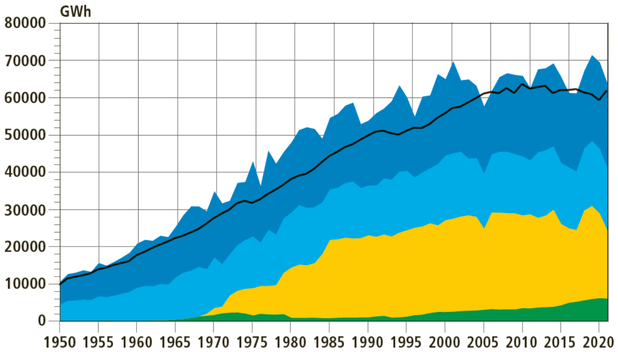
Jan Remund, Meteotest AG, IEA PVPS Task 16

ISES Webinar, 16.08.2022

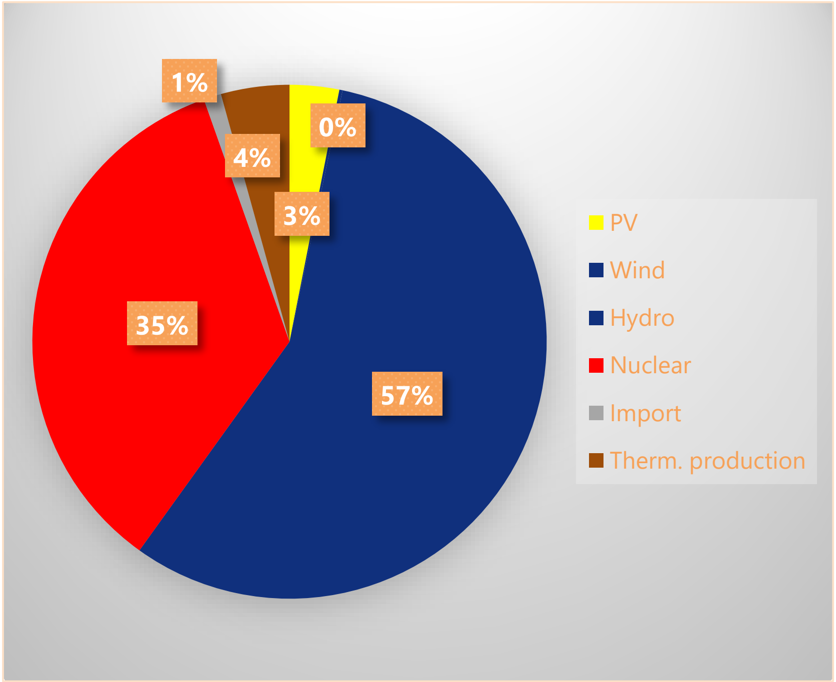
Contents

Swiss situation 2018-2020

- PV:
  - Share is small: 3% (2018-2020)
  - but growing strongly: 30% / year
    [share is 5% in 2021]
- Consumption trend: stable (60 TWh)



BFE, Schweizerische Elektrizitätsstatistik 2021 (Fig. 9)
OFEN, Statistique suisse de l'électricité 2021 (fig. 9)



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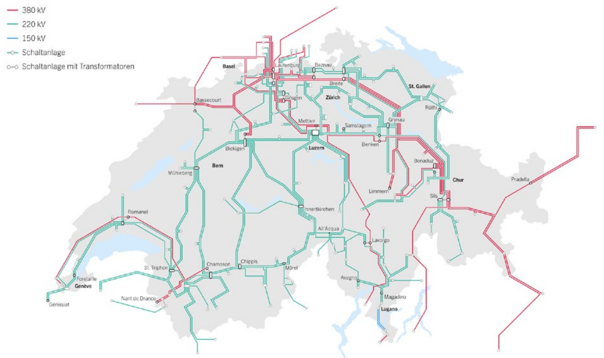
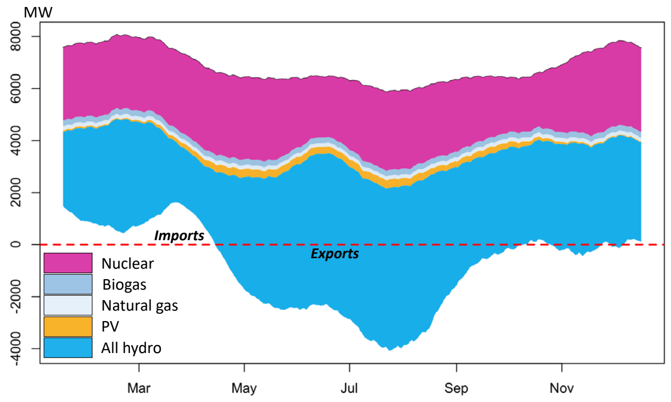
Swiss case

- Strongly integrated in Europe
  - Import during winter
  - Export during summer
  - Very small net import/export annually
- Not coupled to EU market system any more
  - missing framework & electricity agreement "in the centre – but left out"

  → scenarios with autonomous grid and restricted import
- No grid modelling, no climate change taken into account



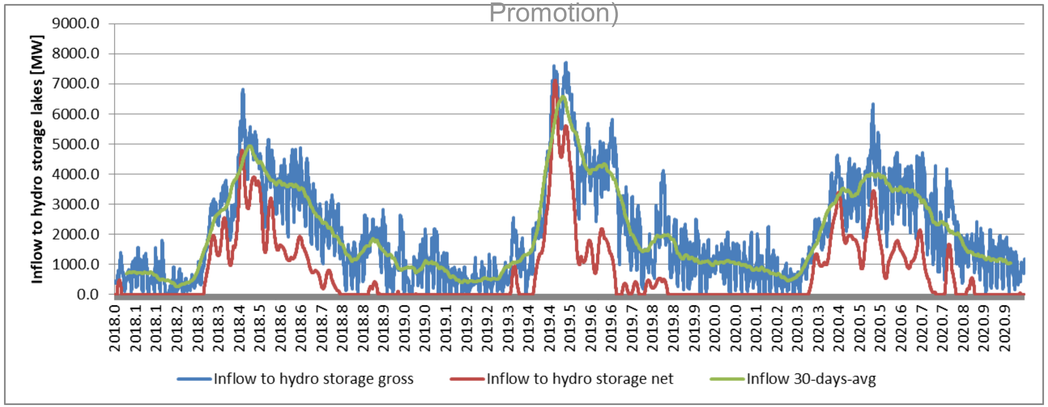


Swiss Case - Hydro

- Three types of hydro power
  - Run of river
  - Hydro seasonal storage lakes → long term storage (months, 10 TWh storage)
  - Pumped hydro storage (PHS) → short term storage (days)

Grande Dixence (Foto: Valais/Wallis Promotion)

Modelled inflow to seasonal storage lakes: hardly no inflow during winter due high altitude (snow) (modelled based on hydro storage filling states and ENTSO-E timeseries)



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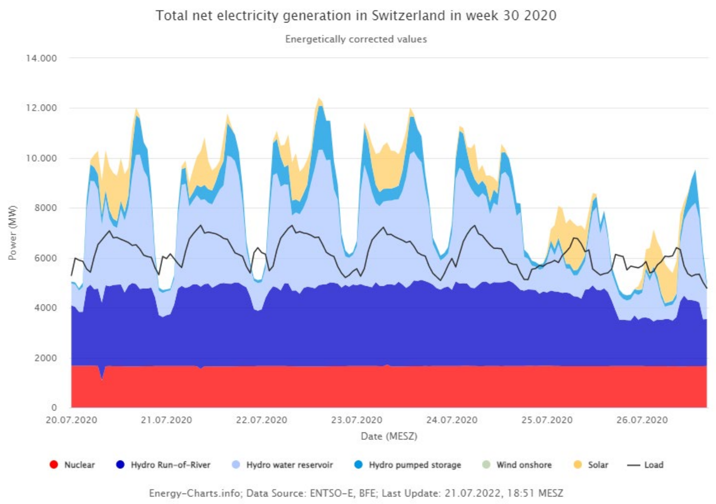
Input data

- Based on ENTSO-E hourly timeseries[1] 2018 – 2020
- Corrections:
  - Correction to annual production data of Swiss Fed. Office of Energy (SFOE)
  - One hour gaps: filled linearly
  - Longer Gaps: PV filled with average GTI (15°S) of Swissmetnet
- Scaled up linearly to 2050 scenario levels



Issue for modelling:
CH production doesn't fit load – it's produced for EU (EEX) markets (DE/FR/IT/AT)
Source: energy-charts.info

[1] https://transparency.entsoe.eu

ENTSO-E is the European association for the cooperation of transmission system operators (TSOs) for electricity

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Scenarios

- Energy perspectives 2050+, Net Zero (CO2) Basis, state of **2050**
  - Growth: +30% till 2050 (to 85 TWh)
  - Nuclear: phased out (power stations would be 66-83 years active in 2050)

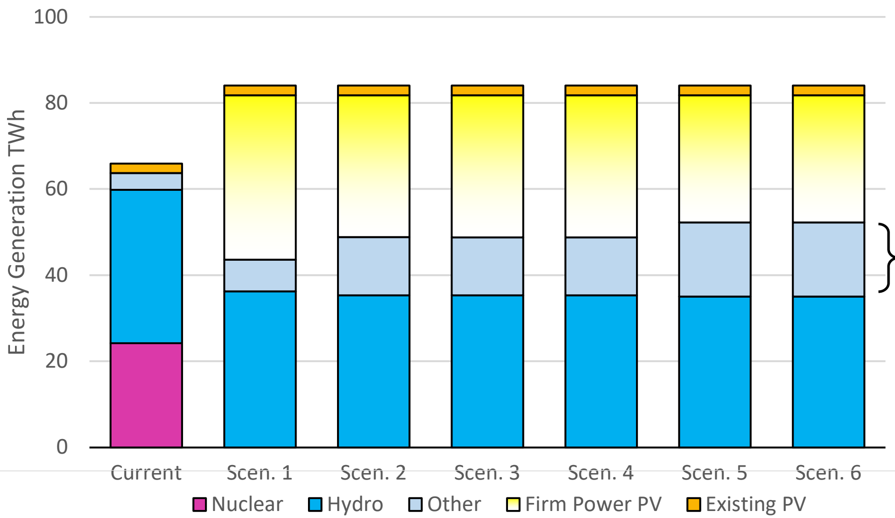
  → **Exchange of nuclear with PV**
- 6 sub-scenarios (→ next slide)
- 4 options:
  - CH as an island (stand-alone/autonomous) or linked to the EU electricity market
  - CH or USA cost levels

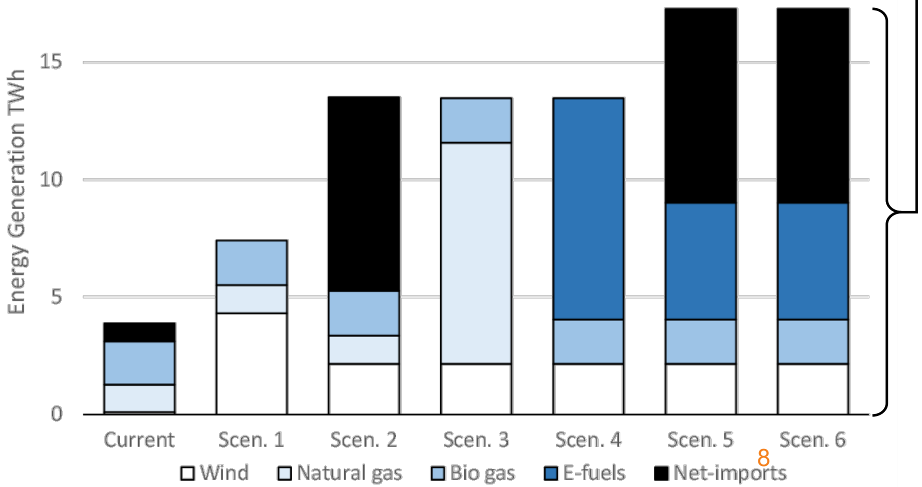
  → **24 scenarios**

* https://www.bfe.admin.ch/bfe/en/home/policy/energy-perspectives-2050-plus.html/

Six main Scenarios

1. E-Perspectives, zero net import
2. 10% net annual import
3. 10% renewable gas power plants, restricted import
4. 10% e-fuels power plants, restricted import
5. 10% net annual import, 6% e-fuels power pl.
6. 10% import, 6% e-fuels pp., agri-PV





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Cost levels: CH and USA (2050)

In brackets: US levels

- US: optimistic, large scale
- CH: conservative, small scale

Source: NREL ATB

- https://atb.nrel.gov/electricity/2021/data

Nr	Installation costs in CHF/kW	Approx. energy costs in cts/kWh
PV avg. on buildings	860 [786] (390)	6.9
Agri PV (farm land)	660	5.2
Battery storage[10]	330 (45)	9.2
Wind		11.0
Hydro		6.0 (mix of new and existing)
Hydrogen[11]		10.0
Gas power station (gas and investment)	2000 CHF/kW	8.5
ETS	100 CHF/tCO_2	
Thermal electricity cost incl. certification		11.1 – 16.8
Thermal electricity costs based on H_2 (e-fuels)		17.9 – 19.7
Imported electricity		6.0
Exported electricity		5.0

Current price levels much higher:

- Electricity: 40 cts/kWh
- Gas: 20 cts/ kWh

(higher than foreseen green H2 based electricity)

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Method

- Asumption: s > p (storage costs are higher than production costs)
- Optimisation of LCOE based on installation costs
- Optimimum between curtailment and storage

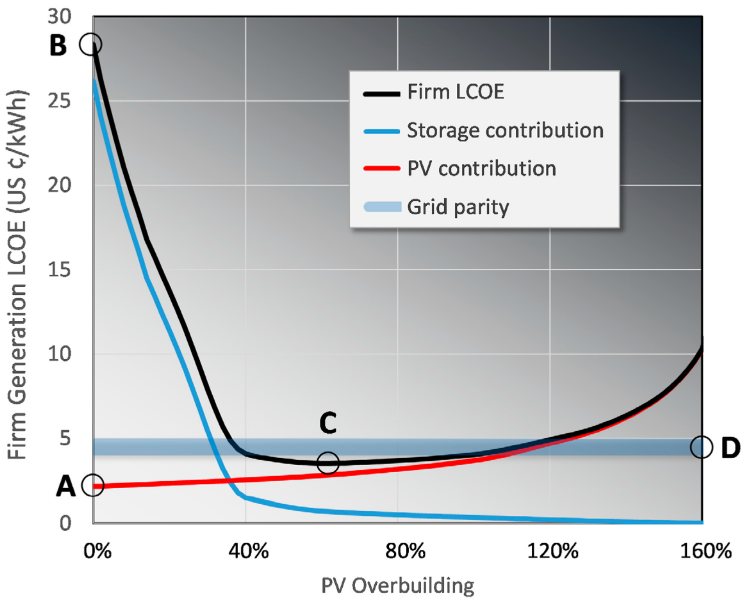
(A) LCOE of uncurtailed PV

(B) LCOE without any curtailment (all is stored)

(C) Sweet spot

(D) Current market price

100% overbuilding means, that 50% of the theoretical PV production is curtailed.



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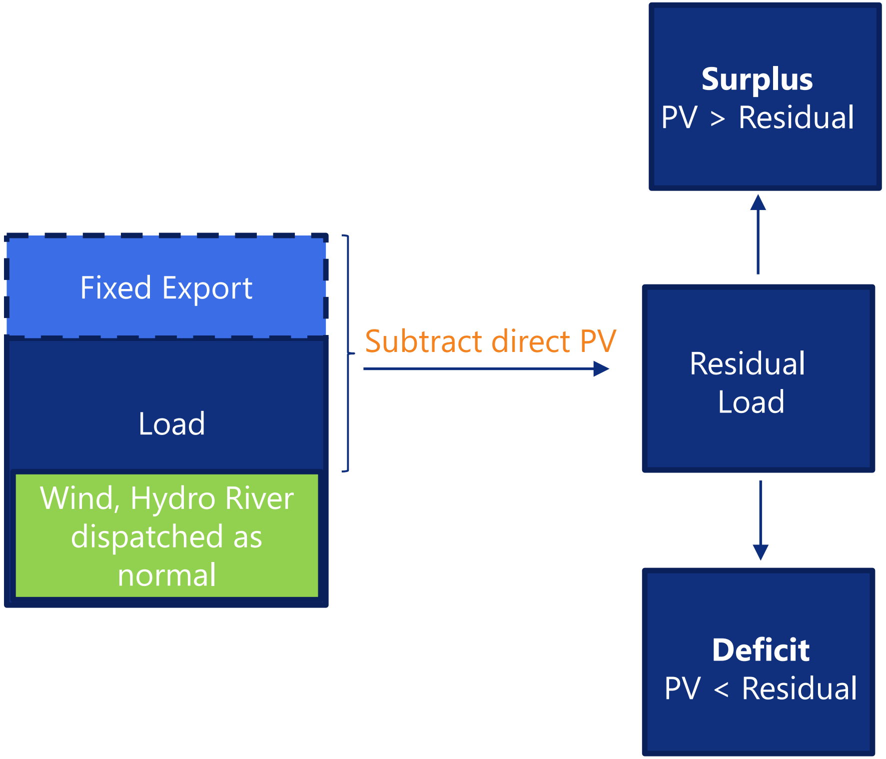
Dispatch model



Surplus:

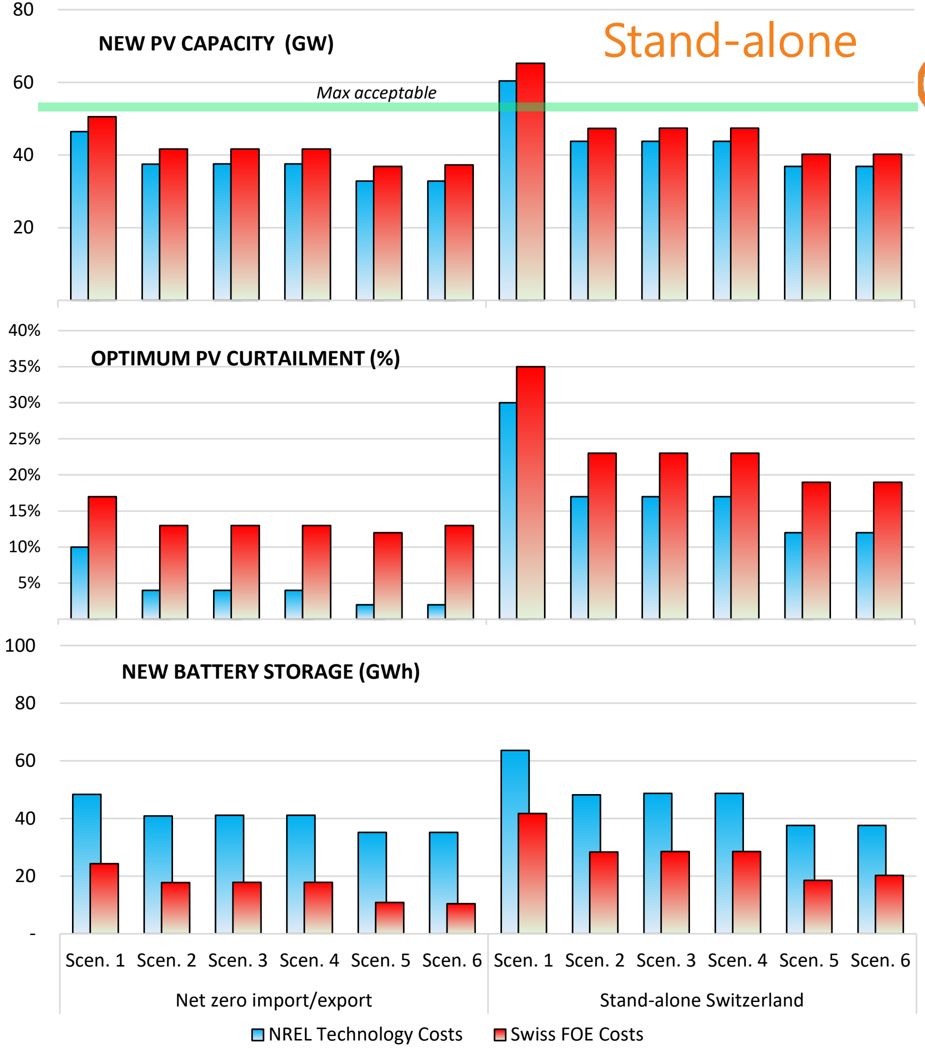
1. Fill storage: PSH then electrochemical within cap. limits
2. Then, curtail if additional excess

Deficit:

1. Discharge storage: PSH then electrochemical within cap. limits
2. Then discharge dispatchable resources within cap. limits: hydro storage, natural gas, biogas and/or e-fuels

Results

- New PV capacities
- Optimum curtailment
- New battery storage



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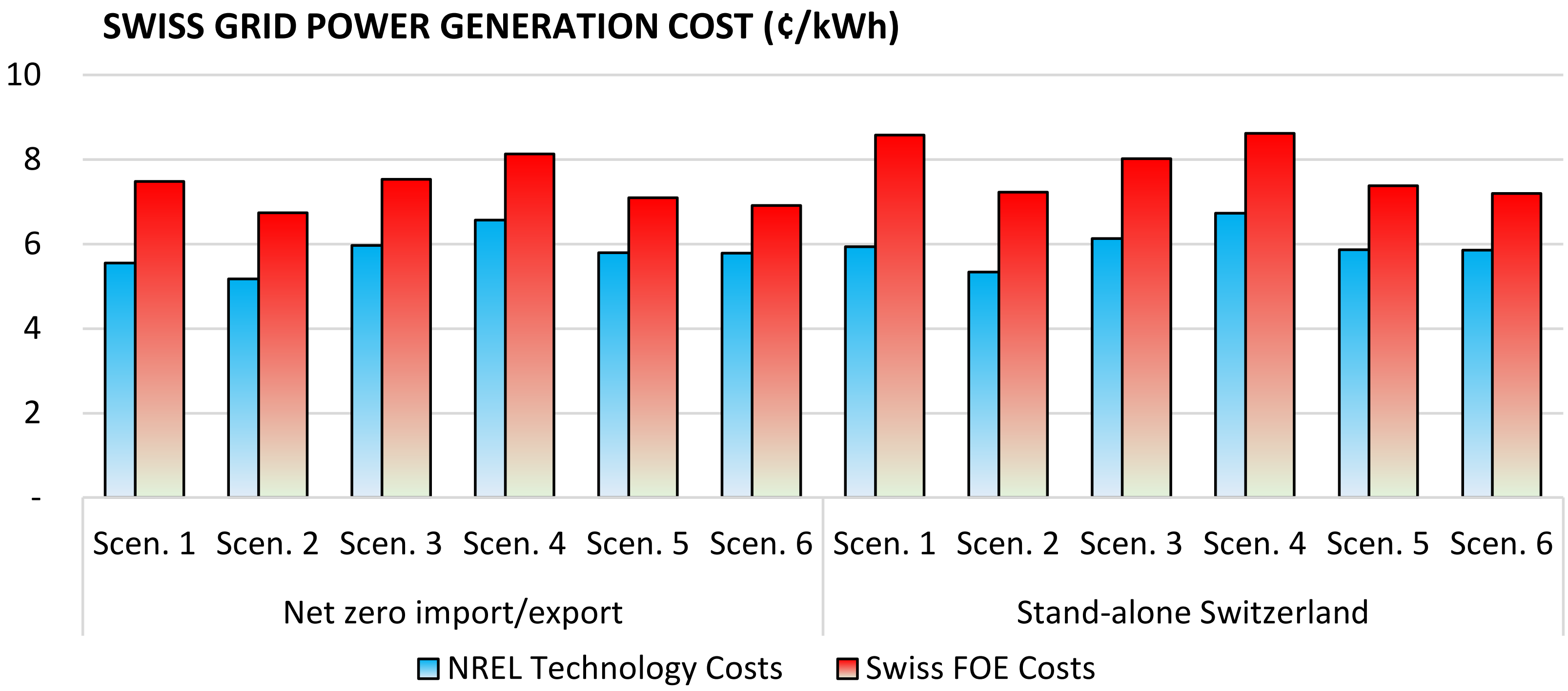
Generation costs for all scenarios

Cost level 2015-19



Stand-alone

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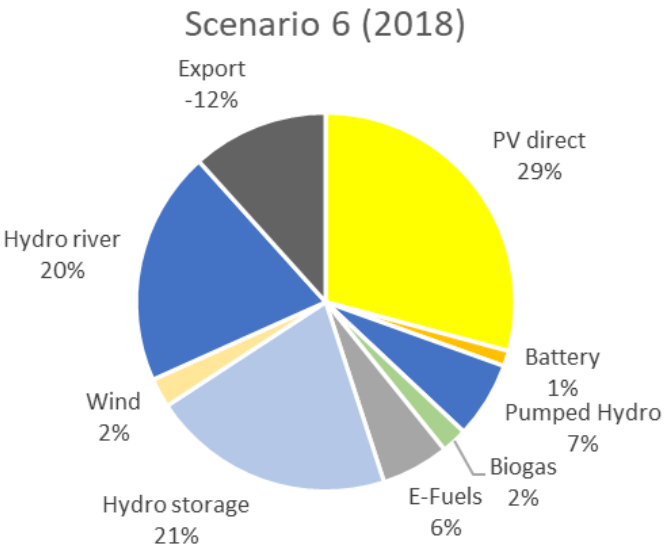
Capacities and production

Share of electricity production



Installed capacities (CH cost levels)

	CH integrated						Stand-alone
Parameter	**Sc. 1**	**Sc. 2**	**Sc. 3**	**Sc. 4**	**Sc. 5**	**Sc. 6**	**Sc. 4a**
PV installed capacity [GW]	50.1	41.0	41.0	41.0	36.6	37.0	48.1
PV curtailment [TWh]	7.9	4.7	4.7	4.7	4.1	4.5	11.1
LCOE [cts/kWh]	7.5	6.7	7.5	8.1	7.1	6.9	8.6
Battery Capacity [GWh]	24.8	19.8	19.9	19.9	11.9	11.6	26.6
Imports [TWh]	10.0	18.3	10.0	10.0	18.3	18.3	0.0

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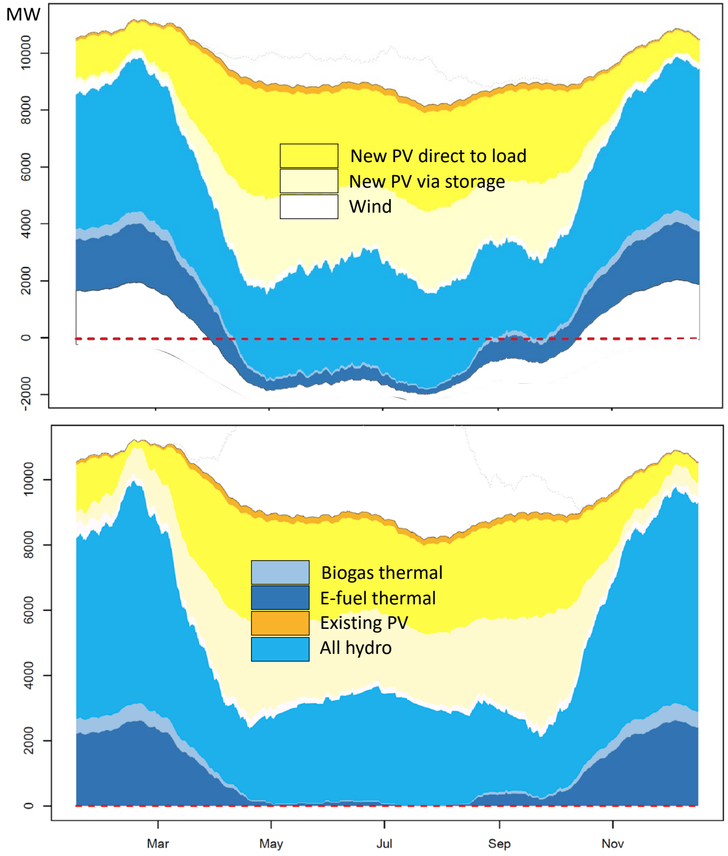
Seasonal Production (Scenarios 4 / 4a)

Production: integrated / autonomous

- With import/export (4)

- No import/export (4a)

Stand-alone



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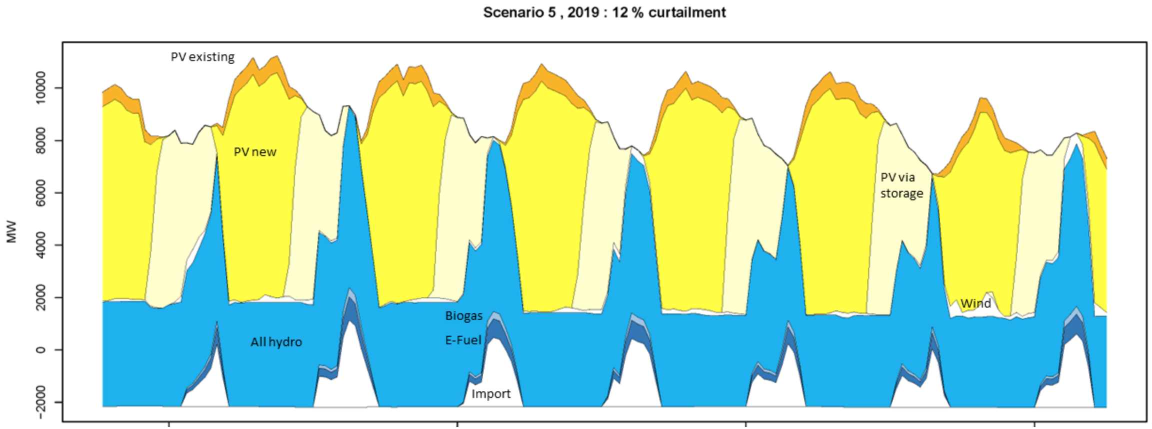
Hourly production patterns (Scenario 5)

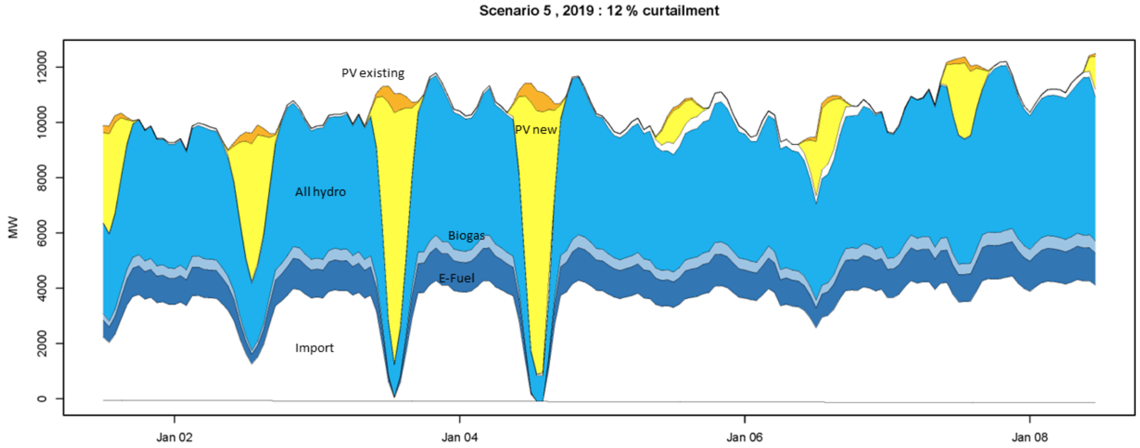
Summer:

- PV at day
- Batteries in evening
- Hydro at night
- Export at day

Winter:

- PV at day – when sunny
- Hydro all day
- E-fuels all day
- Import (if not sunny)





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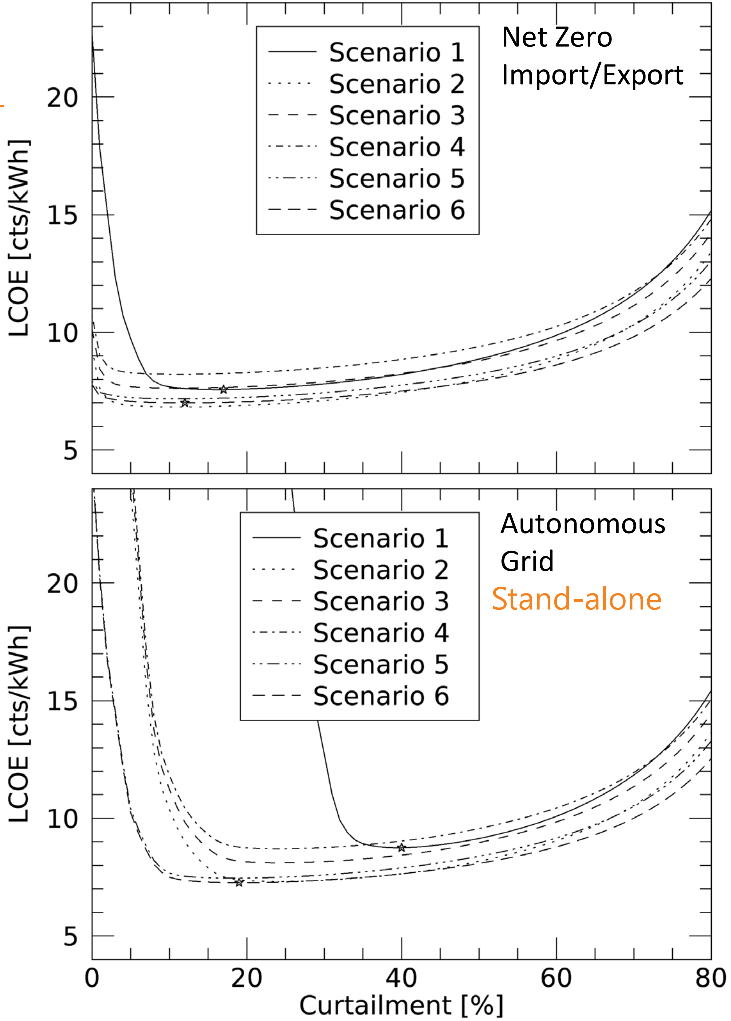
Results: Minimal costs

Optimal levels of curtailment

- 6-8 cts/kWh reached in any case
- lowest costs are reached (CH cost levels):
  - Scenario 2
  - 40 GW PV
  - 15% energy curtailment
  - 15 GWh batteries,
  - 10% net imports (18 TWh during winter)
  - 10% rise of hydro power generation and storage (plus 1 TWh)
  - a rise in pumped hydro from 2.9 to 5.7 GW
  - import of 5 TWh of e-fuels for electricity generation



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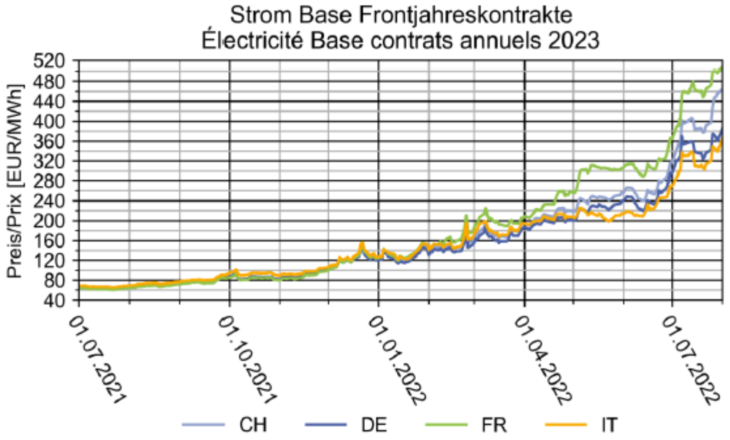
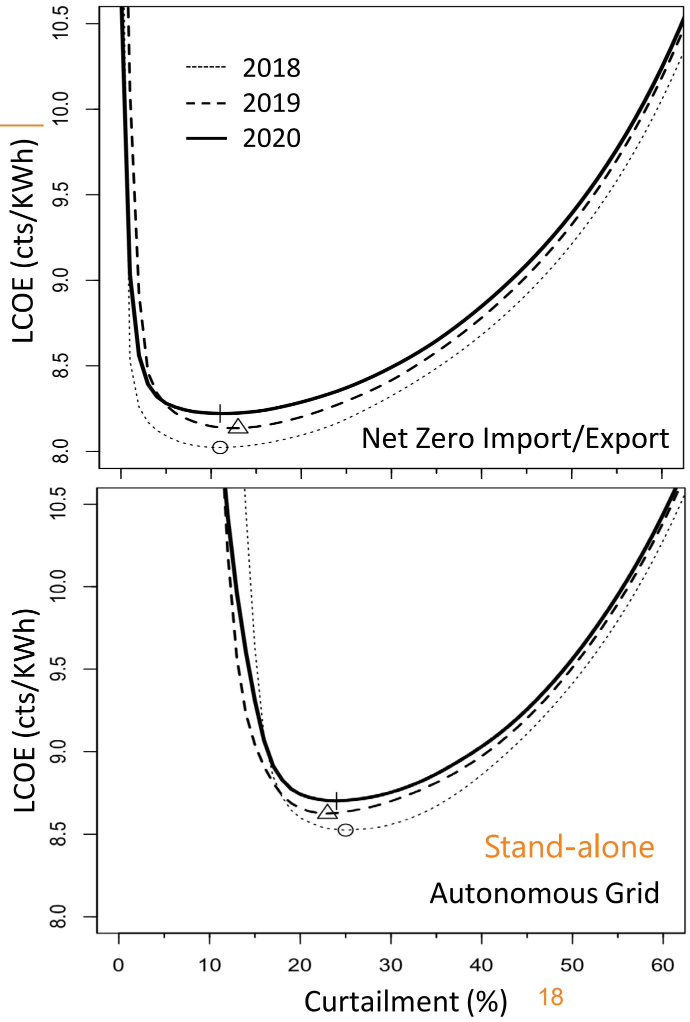
Sensitivity to meteo

Low sensitivity of meteo years 2018, 2019 and 2020

Current price levels much higher:





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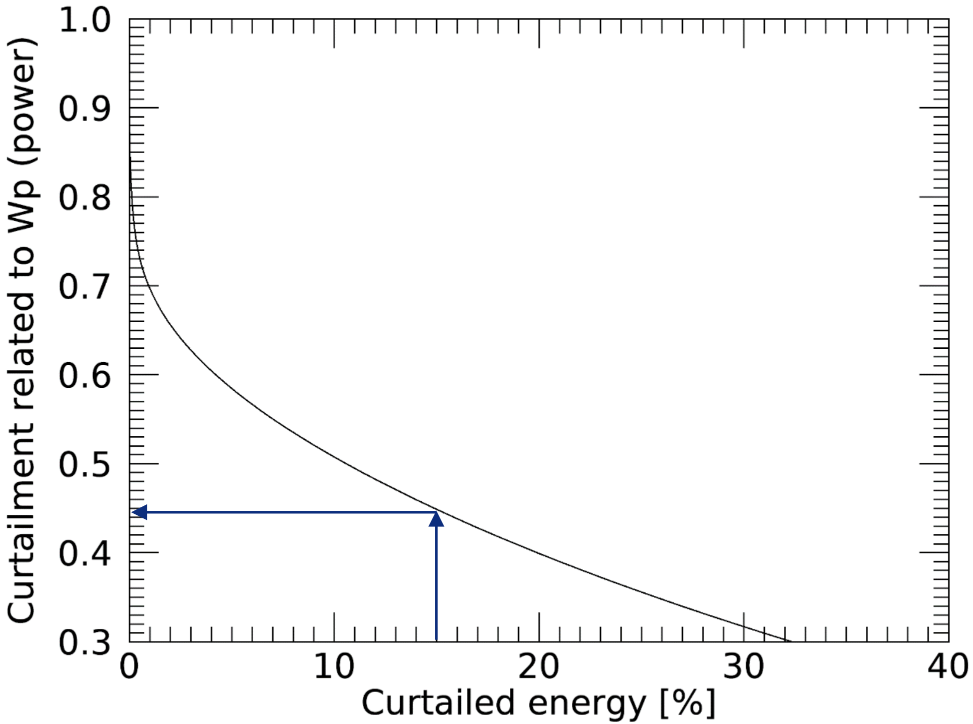
Curtailments: Power vs Energy

Curtailment of 15% energy → power curtailed to 45%

Modelled based on one minute data (Meteonorm) for Bern



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Conclusions

- Overall, the results of the Energy Perspectives 2050+ could be confirmed
- Expensive E-fuel based thermal generation, can play a pivotal catalyst role
- 10–85 GWh of batteries are feasible compared to the expected electrical vehicle batteries (about 200 GWh of battery storage)
- Stand-alone grid operation would increase these costs by an average of 7%
- Curtailment lowers production costs by 63% for import/export configuration, and 450% for stand-alone
- Overbuilding and curtailment of PV is “the enabler” of the energy transition
- No net zero modelling without curtailment taken into account

Take home messages & outlook

- **Renewables are securing costs and climate**

  → The quicker we get to 100% renewables, the stabler the system and the less it depends on imported energy

- There is no fast track:
  - It will take 20 years with 2 GW installed / year to achieve 40 GW
- Current support and market system have to be re-modelled to obtain the optimum for the economy
  - How to adopt the political and technical regulations to achieve the optimal values of overbuilt PV is an open question and needs to be investigated
  - A market system based on marginal costs seems unlikely to fit

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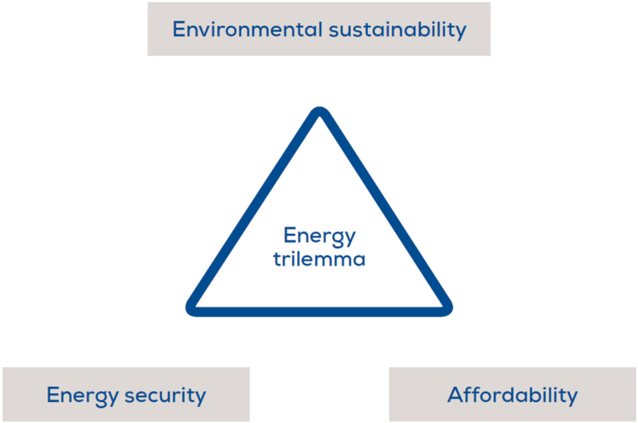
Firm PV concept solves energy trilemma

- Firm PV power concept eases heavily the energy trilemma:
  - Affordability → all scenarios show low prices
  - Sustainability → net zero is possible
  - Security → scenarios with and without import show low price

Different levels of security of supply can be reached without neglecting the net zero CO_2 targets and still keeping electricity costs affordable.
The higher the level of security the higher the installed PV and the higher the share of curtailment is needed



Energy trilemma according Gove et al., 2016