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The impacts of climate change on Swiss hydropower

IAEE International Conference, Groningen, 11.06.2018

Motivation

- Hydropower is the dominant source of electricity in Switzerland
- Contributes 60% to overall electricity supply
- Hydropower is subject to an environment of change
  - Swiss nuclear phase-out
  - Large-scale expansion of renewables domestically and abroad
  - Climate change
- Hydropower operators are asking: How will hydropower make money in the future? What are the driving influences of future revenue?
- Here, focus on one aspect: Climate change

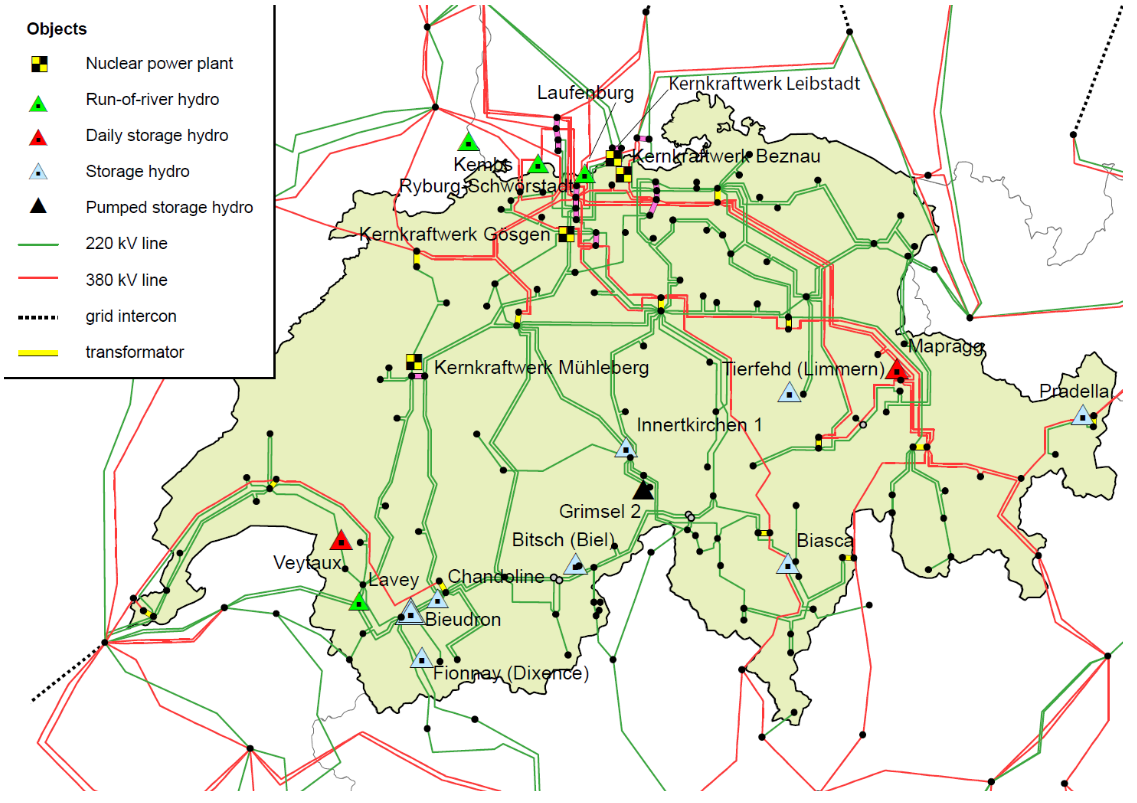
Research questions

How will climate change impact Swiss hydropower?

What’s the impact on the overall electricity system?

Model

Model: Swissmod



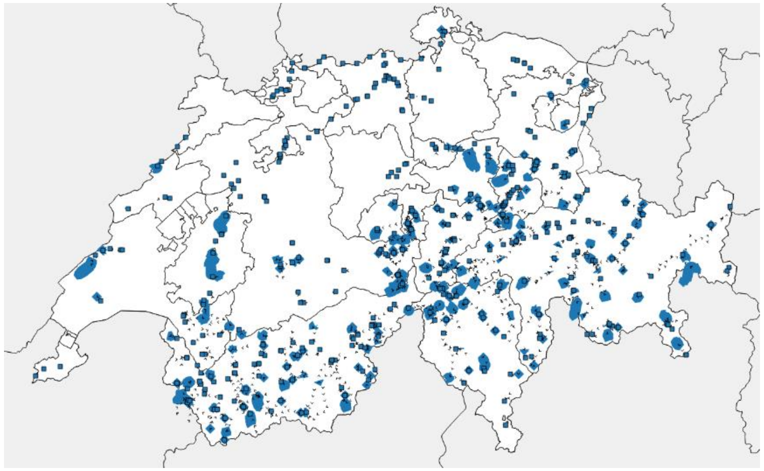
Transmission System Model:

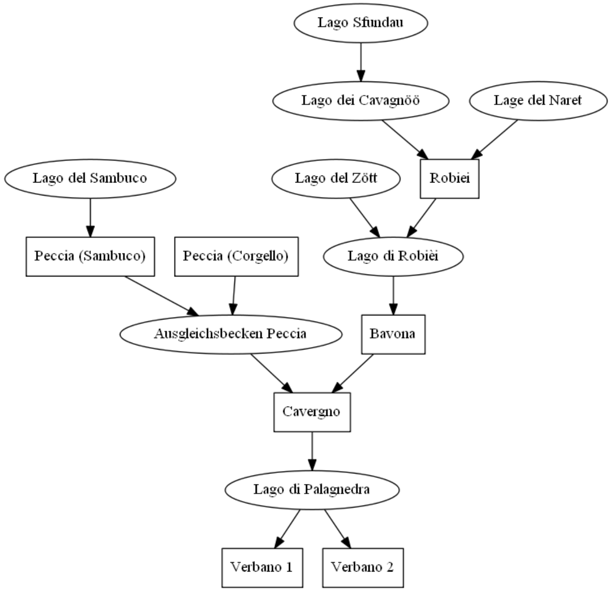
- ca. 230 nodes (150 in Switzerland)
- ca. 400 lines

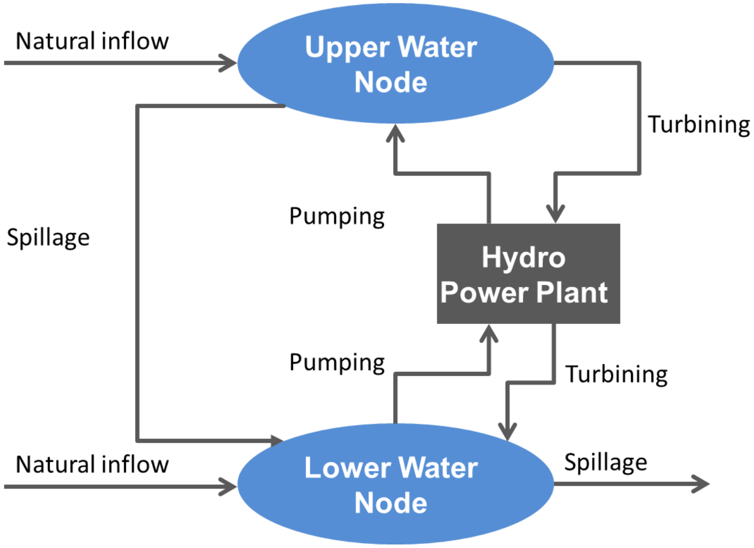
Neighboring countries included in simplified representation

Swissmod is a DC load flow, dispatch, cost-minimization model with particular detail on hydropower

Model: Hydropower representation

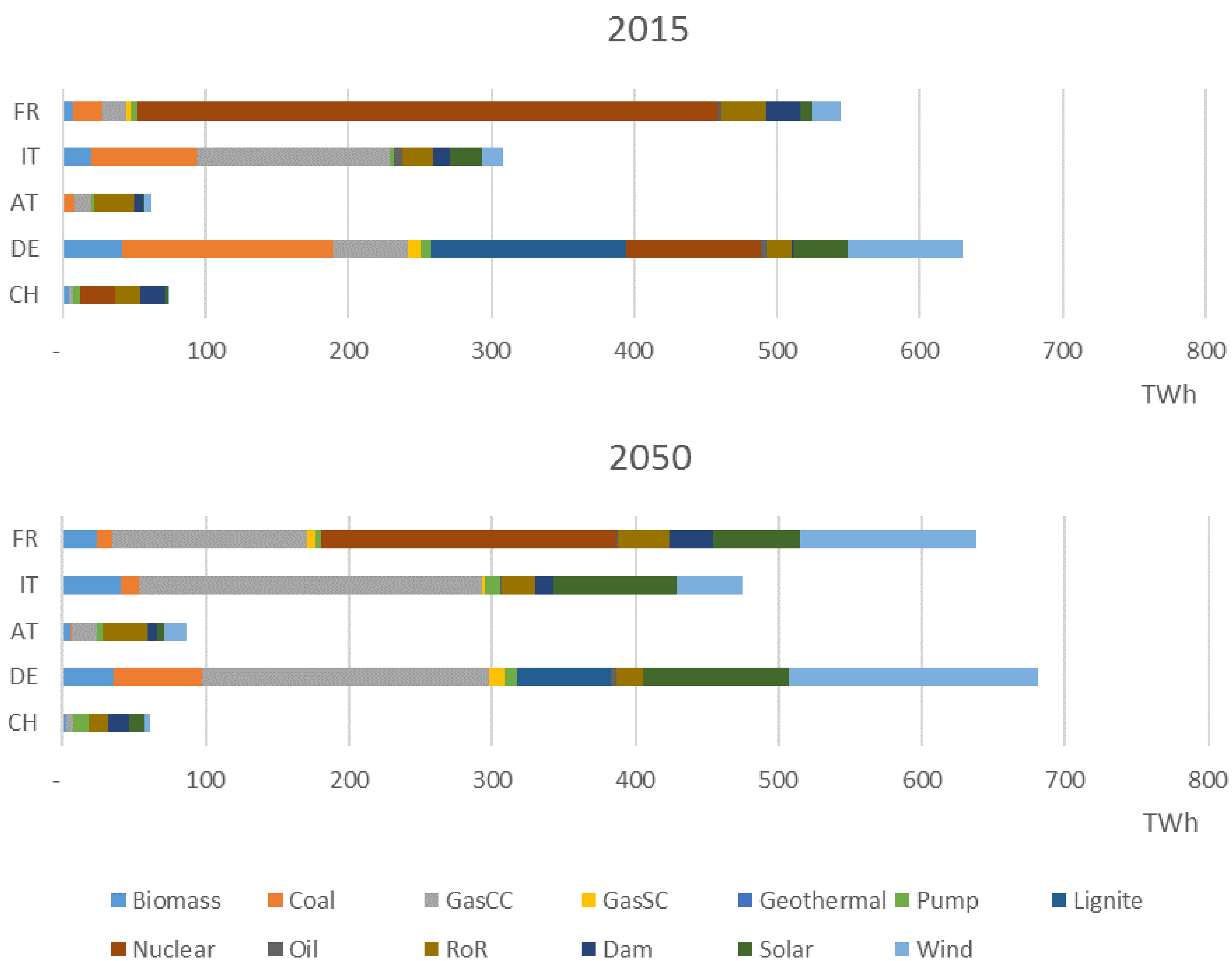






Data

Electricity system data



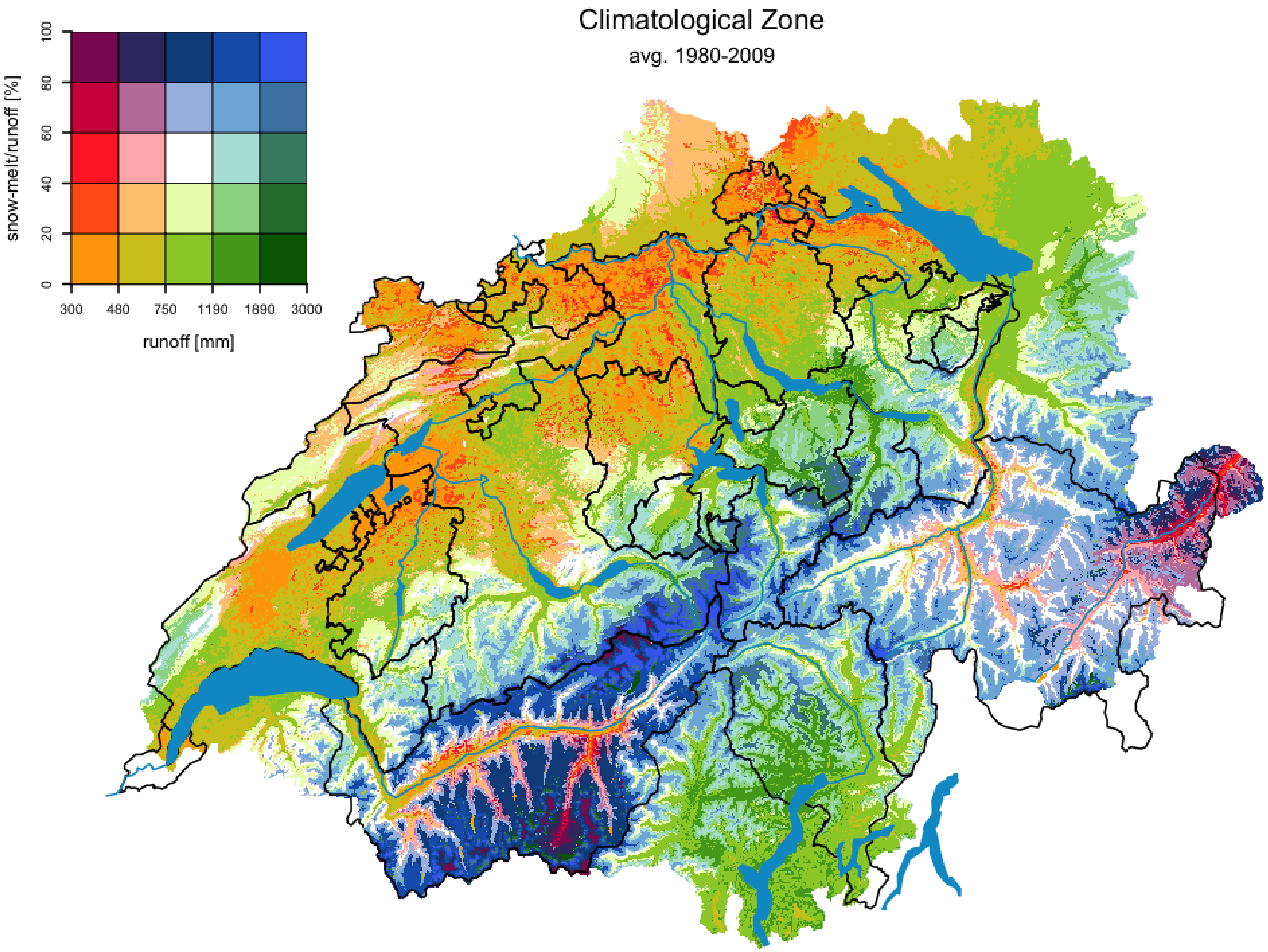
Climate data: Runoff

- We use runoff data by Speich et al. (2015) using delta change method
- High geographical and temporal resolution
- Climate periods

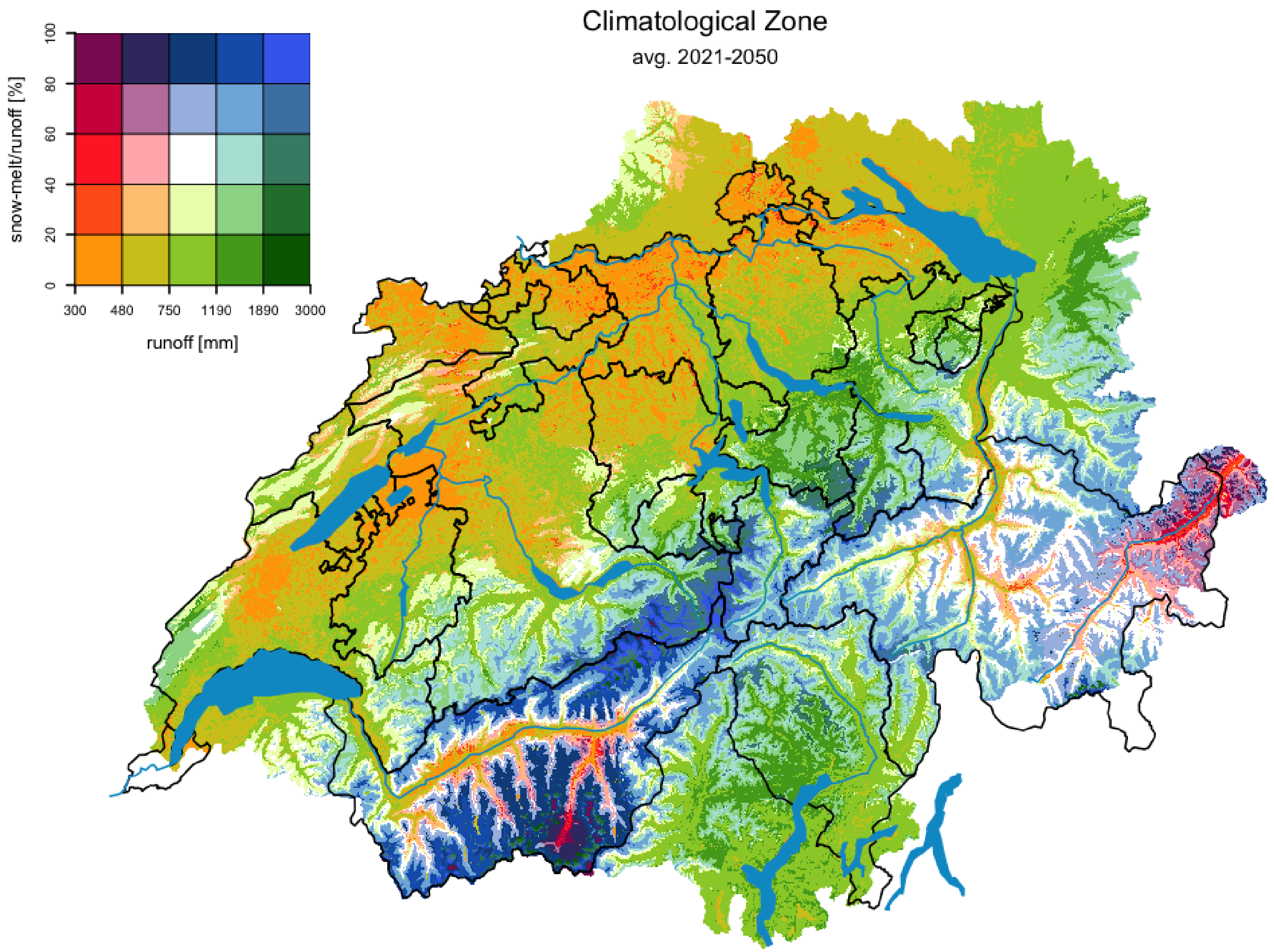
Label	Climate period
0 (=historic)	1980 - 2009
‘21	2021 - 2050
‘70	2070 - 2099

- All these use the “weather” of 1980-2009, just in a different climate setting

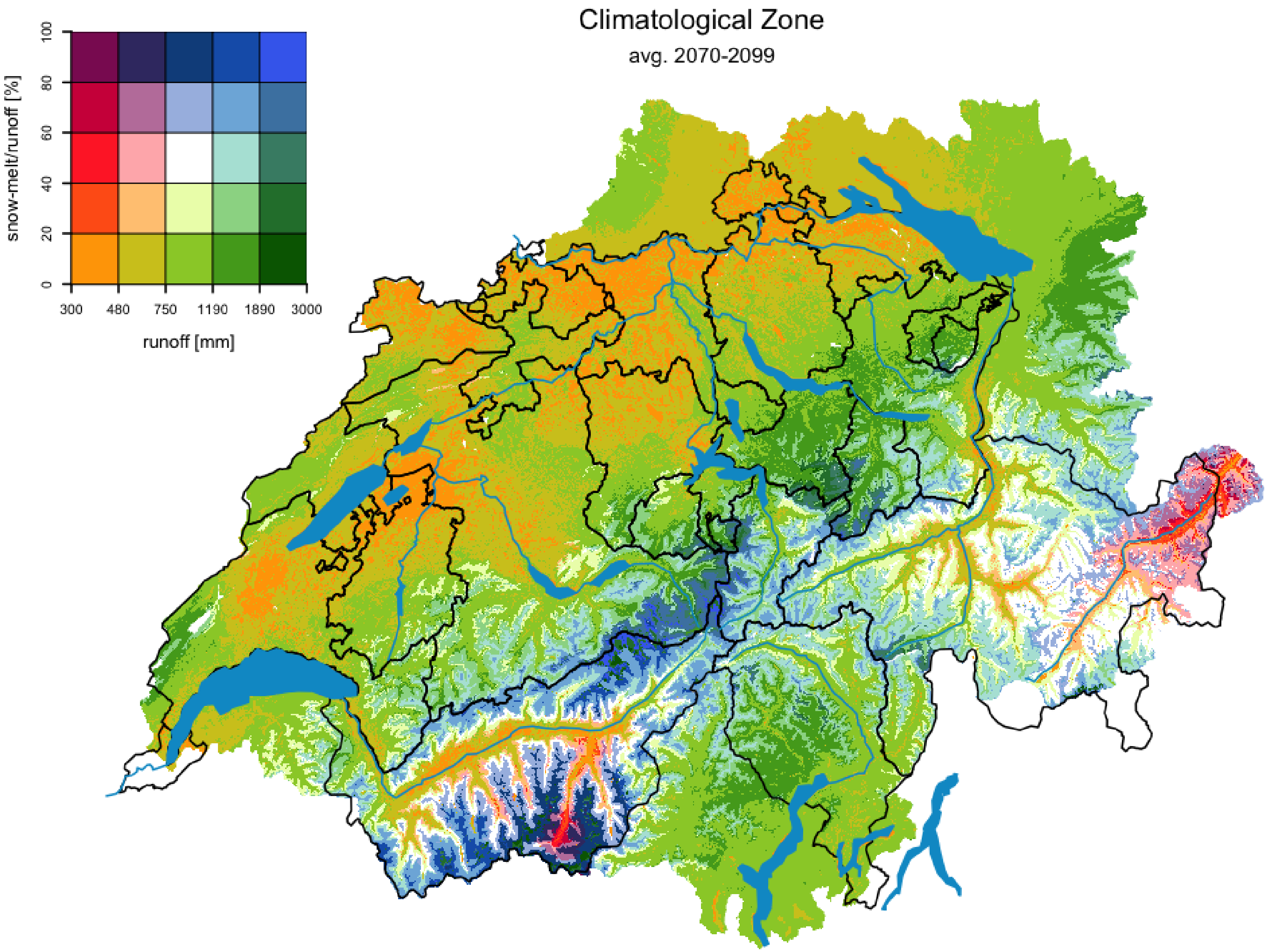
Climate data: Runoff (historic)



Climate data: Runoff (2021-2050)



Climate data: Runoff (2070-2099)



Scenario set-up

Electricity systems

2015

2050

X

Reference

historic inflow

Global climate model

BCM

ECHAM

HadCM3Q3

X

Climate period

2021-2050

2070-2099

X

Hydrologic year

avg → 2008

dry → 2003

wet → 1999

X

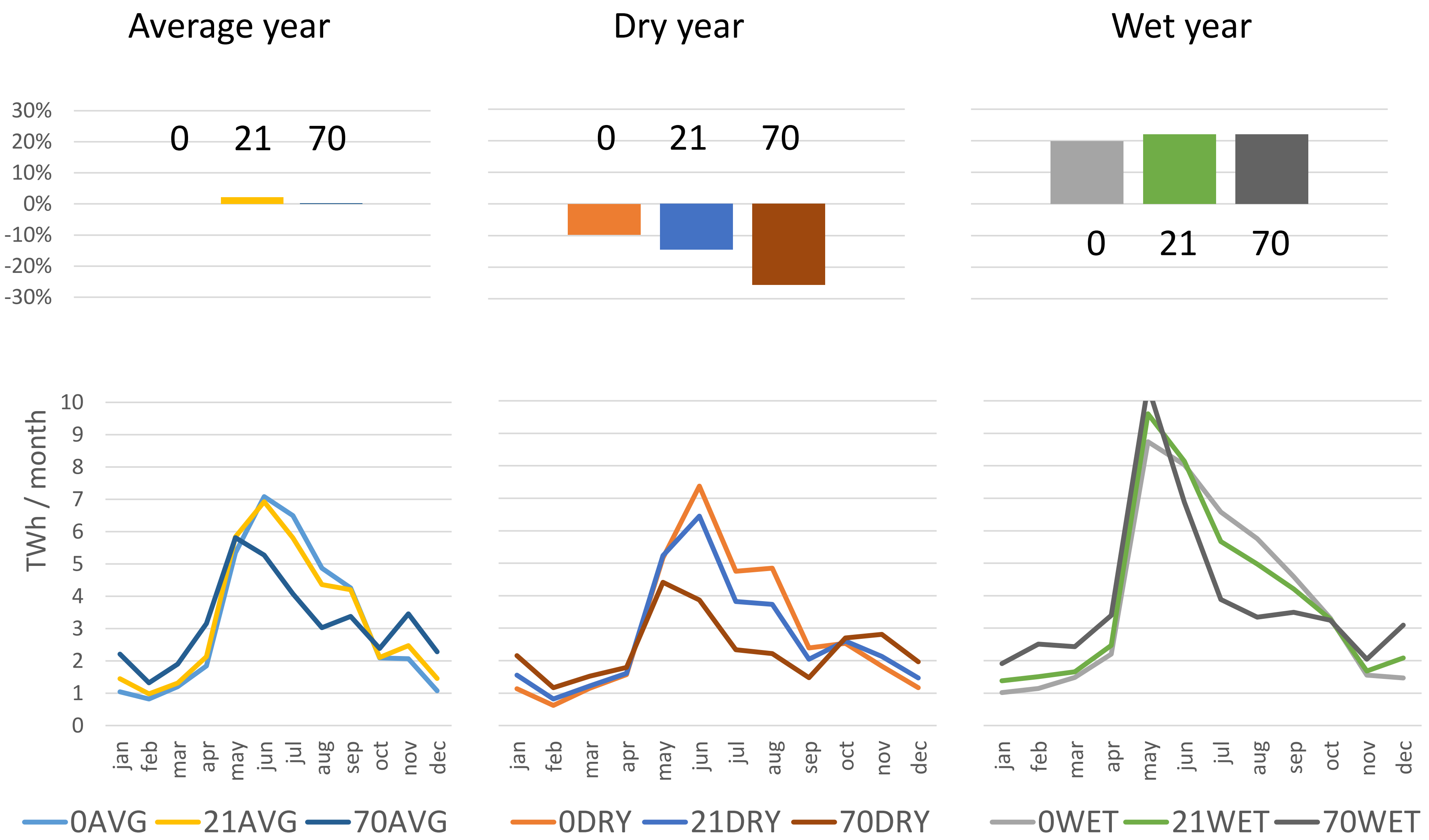
2 electricity systems

3 historic discharge patterns (1 x 3)

18 future discharge patterns (3 x 2 x 3)

42 scenarios

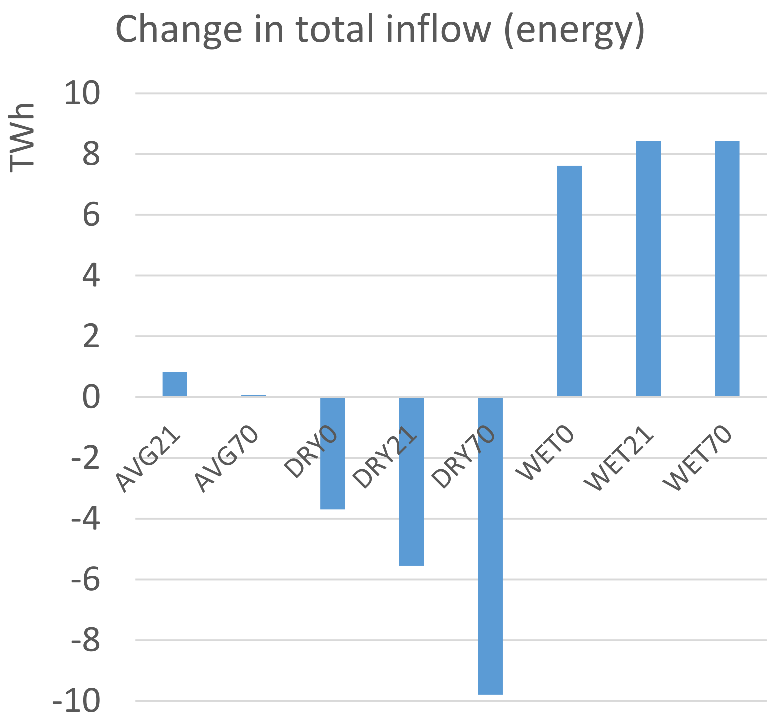
Data: Inflow changes

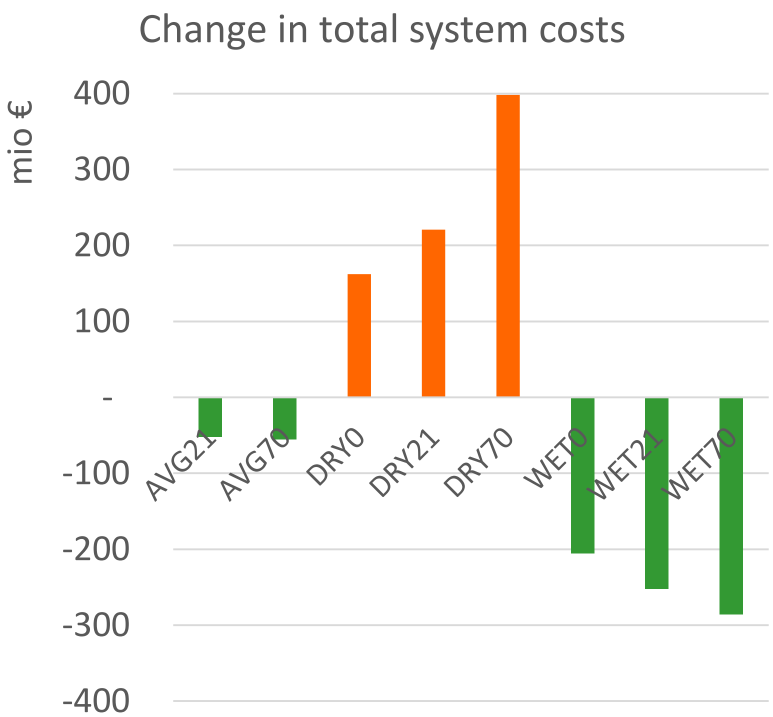


Results for 2015 electricity system

Results: Overall impact

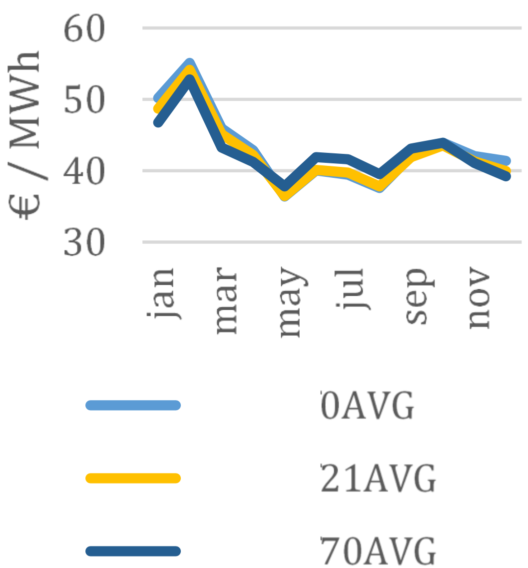
Absolute difference in Total System Cost relative to historic base year





Results: Prices

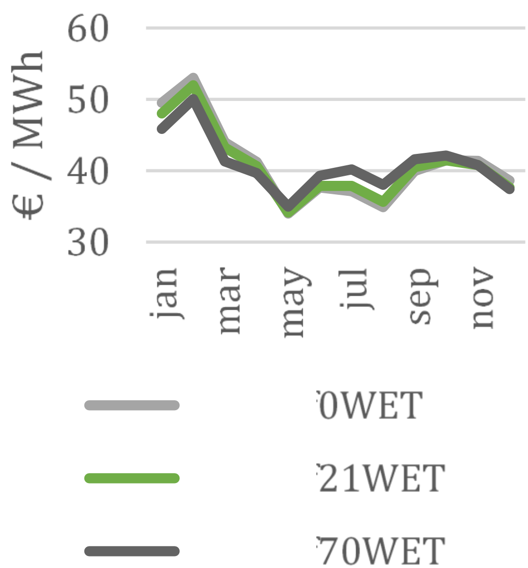
Average



Compared to avg weather:

’21: -1.2% (yearly)
’70: -0.9% (yearly)

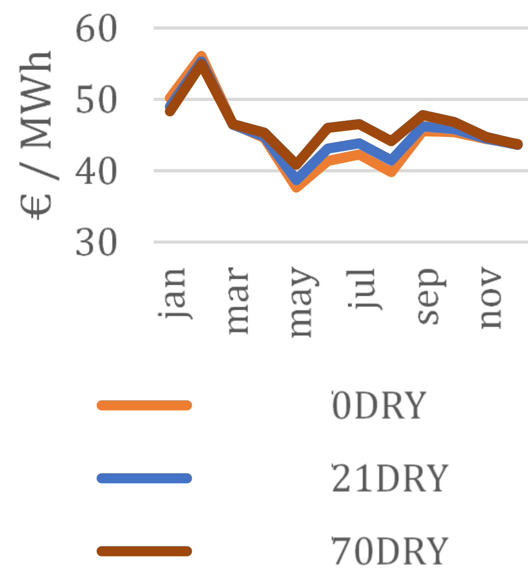
Wet



Compared to avg weather:

’0: -4.7% (yearly)
’21: -5.3% (yearly)
’70: -4.9% (yearly)

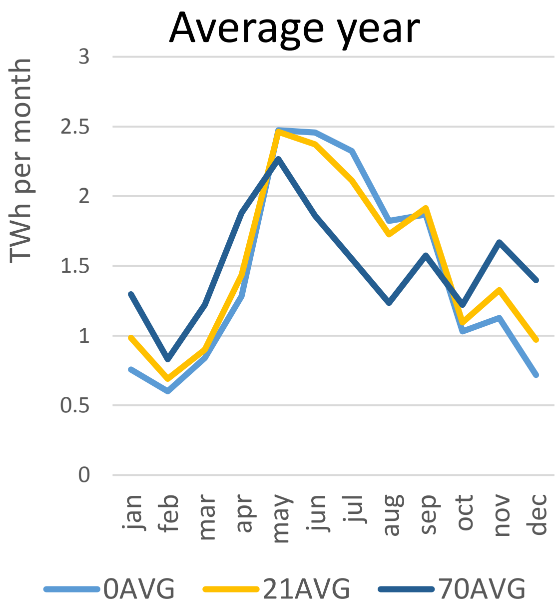
Dry

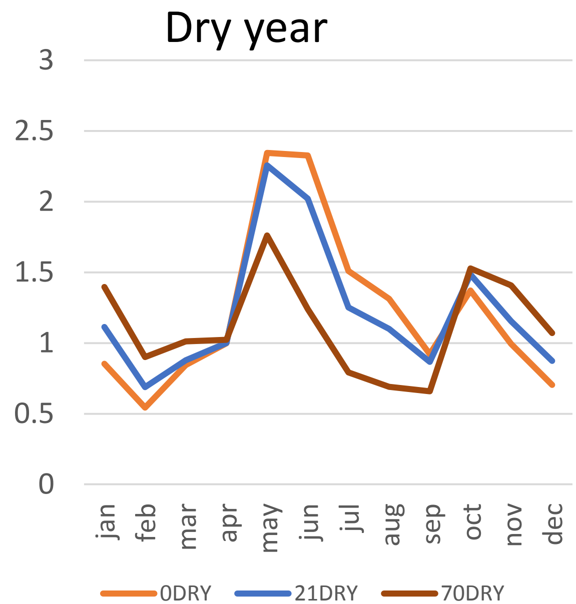


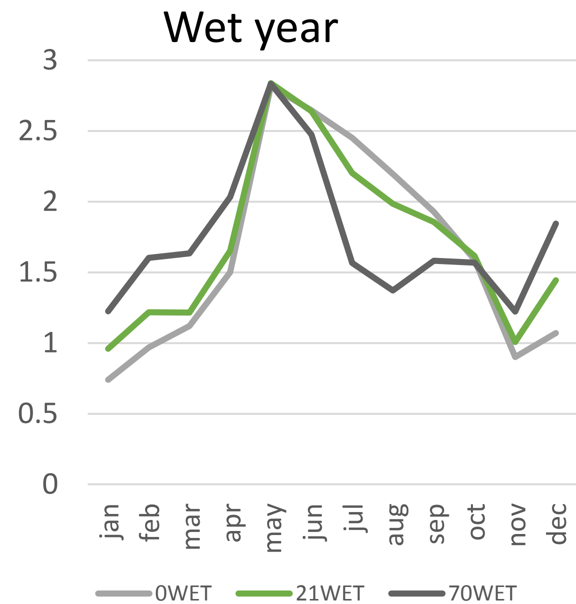
Compared to avg weather:

’0: +4.0% (yearly)
’21: +5.1% (yearly)
’70: +7.5% (yearly)

Results: RoR-hydro generation







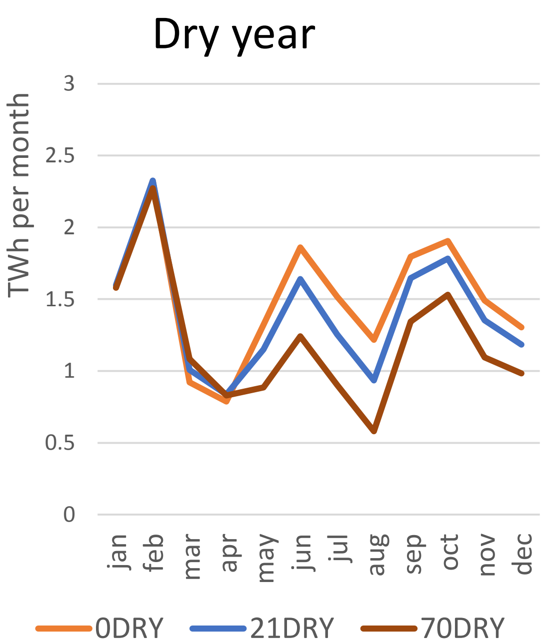
Changes:

’21: +4.0%
’70: : +4.1%

’0: -14.9%
’21: -15.1%
’70: : -22.1%

’0: +15.2%
’21: +19.3%
’70: : +21.2%

Results: Dam-hydro generation



Changes:

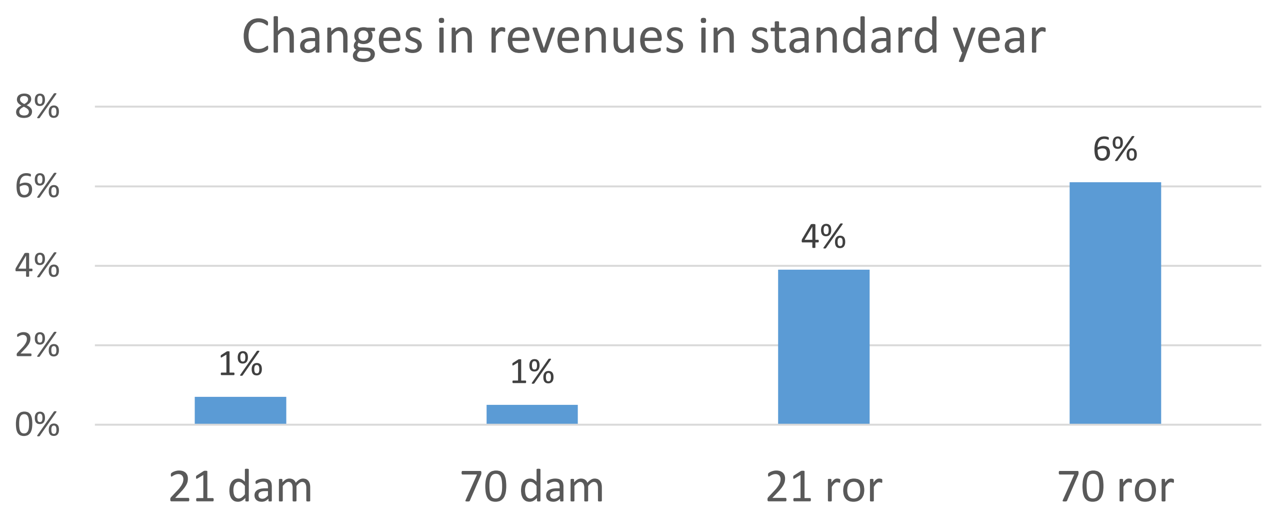
’21: +1.4%
’70: : +0.0%

’0: -8.8%
’21: -12.6%
’70: : -25.1%

’0: +10.7%
’21: +11.1%
’70: : +10.7%

Results: Revenues

- Revenue increases for all climate scenarios for both dam and RoR
- RoR benefits significantly more from better seasonality than dam



- For other weather conditions:
  - Dry years get worse
  - Wet years get better

Limitations

- Climate change only considered for Swiss hydropower, not for:
  - Demand
  - Hydropower abroad
  - Solar
  - Wind
- Selection of base-weather years drive results to some degree

Conclusions

- Runoff data already shows
  - Clear shift of seasonality
  - Weather dominates climate
  - Extremes become more extreme
- Model shows economic impacts
  - Slightly flatter price curve over the year
  - RoR plants more impacted by shift in seasonality than dam plants
  - Revenues increase across plant types
- Challenge: Capturing extremes (i.e. select extreme years) without losing generality (model results driven by chosen year)

Backup

Model: Swissmod

$$\min_{e_t^{cpp}, e\uparrow_t^{hpp}, e\downarrow_t^{hpp}} \left\{ C \quad = \quad \sum_t \sum_{cpp} vc^{cpp} E_t^{cpp} \right\}$$

Node Balance

$$E_t^n = \sum_{cpp} \mathbf{cpi}_{cpp}^n E_t^{cpp} + \sum_{hpp} \mathbf{hpi}_{hpp}^n E\downarrow_t^{hpp} - \sum_{hpp} \mathbf{hpi}_{hpp}^n E\uparrow_t^{hpp} - d_t^n$$

Line Flow

$$E_t^l \quad = \quad b^l \sum_n \mathbf{i}_{l,n} X_t^n$$

Classical dispatch model:

- Cost minimization (QP due to linear increasing generation costs)
- DC-Load flow, node balance, capacity restrictions
- Detailed hydro representation with endogenous determination of water value

Model: Swissmod

Capacity Restrictions

$$E{\downarrow}_t^{hpp} = \alpha^{hpp} W{\downarrow}_t^{hpp}$$

$$E{\uparrow}_t^{hpp} = \frac{\alpha^{hpp} W{\uparrow}_t^{hpp}}{\beta^{hpp}}$$

$$E{\downarrow}_t^{hpp} < \overline{e\downarrow}^{hpp}$$

$$E{\uparrow}_t^{hpp} < \overline{e\uparrow}^{hpp}$$

$$WS_t^{wn} < \overline{ws}^{wn}$$

Water Storage Balance

$$WO_t^{wn} = WI_t^{wn} - \Delta WS_t^{wn}$$

$$\Delta WS_t^{wn} = WS_t^{wn} - WS_{t-1}^{wn}$$

Inflow/Outflow Definitions

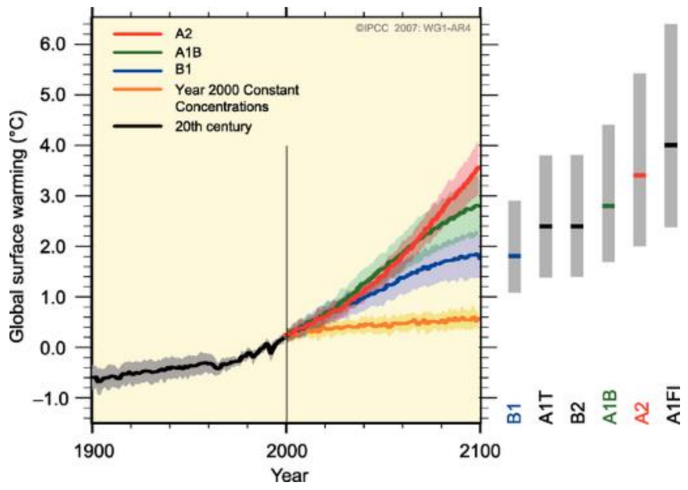
$$WI_t^{wn} = \mathring{w}_t^{wn} + \sum_{hpp} \mathbf{lwr}_{hpp}^{wn} W{\downarrow}_t^{hpp} + \sum_{hpp} \mathbf{upr}_{hpp}^{wn} W{\uparrow}_t^{hpp} + \sum_{uwn} \theta_{wn}^{uwn} \overrightarrow{W}_{t-\mathbf{lag}_{wn}^{uwn}}^{uwn} \quad \forall \;\; wn, t$$

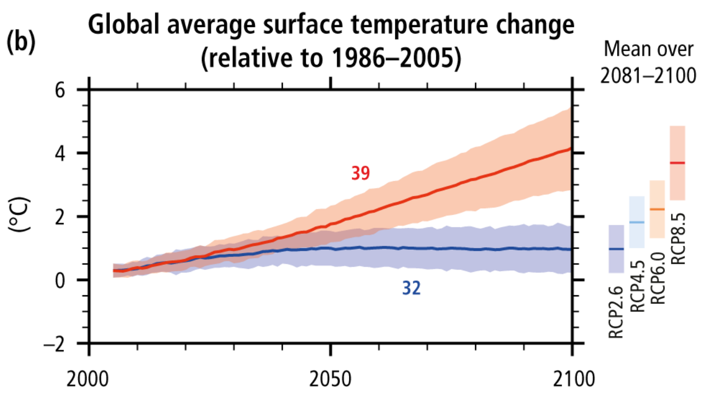
$$WO_t^{wn} = \sum_{hpp} \mathbf{upr}_{hpp}^{wn} W{\downarrow}_t^{hpp} + \sum_{hpp} \mathbf{lwr}_{hpp}^{wn} W{\uparrow}_t^{hpp} + \sum_{lwn} \theta_{lwn}^{wn} \overrightarrow{W}_t^{wn} \quad \forall \;\; wn, t$$

Climate data: Climate data

- Delta change method (Bossard et al., 2011)
  - Historical values scaled according to a climate change signal
  - Climate change signal derived from climate model data as the change between a scenario period (SCE) and a control period (CTL)
  - Spatio-temporal patterns as well as the correlations between the variables closely follow observed records
- We use discharge data by Speich et al. (2015)
  - Reference period 1980–2009
  - Predictions for the periods 2021–2050 and 2070–2099
  - Based on ten different climate model chains from ENSEMBLES using IPCC SRES scenario A1B
- A1B scenario [disclaimer: not a climate scientist]
  - Already overtaken by reality
  - Emissions already above the emission pathway of A1B scenario

Climate data: A1B scenario in context





https://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-5.html

http://ar5-syr.ipcc.ch/topic_futurechanges.php