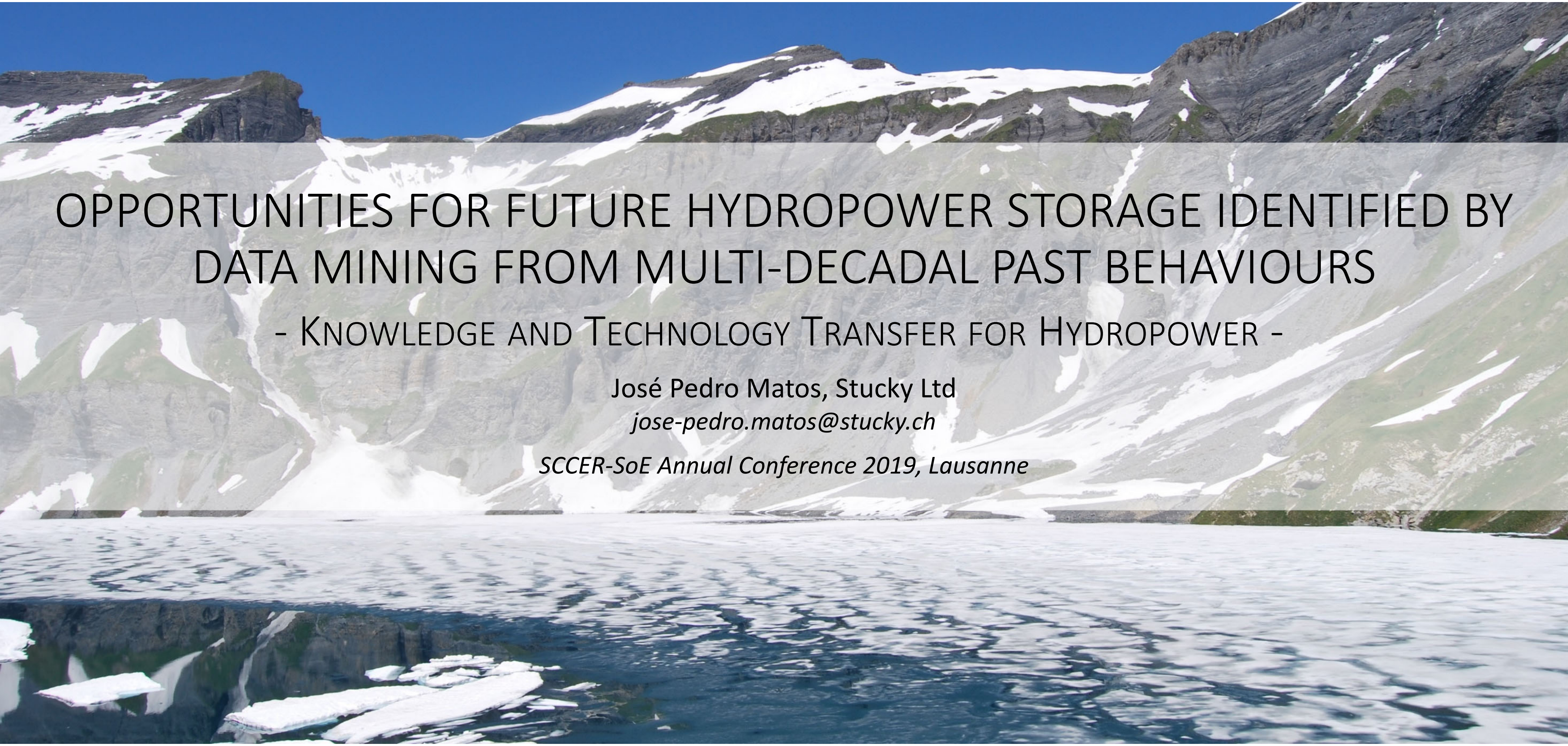

OPPORTUNITIES FOR FUTURE HYDROPOWER STORAGE IDENTIFIED BY DATA MINING FROM MULTI-DECADAL PAST BEHAVIOURS

- KNOWLEDGE AND TECHNOLOGY TRANSFER FOR HYDROPOWER -

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SCCER-SoE Annual Conference 2019, Lausanne

KWO GRIMSELSTROM

stucky a Gruner company

FlexSTOR

SCCER SoE
SWISS COMPETENCE CENTER for ENERGY RESEARCH
SUPPLY of ELECTRICITY

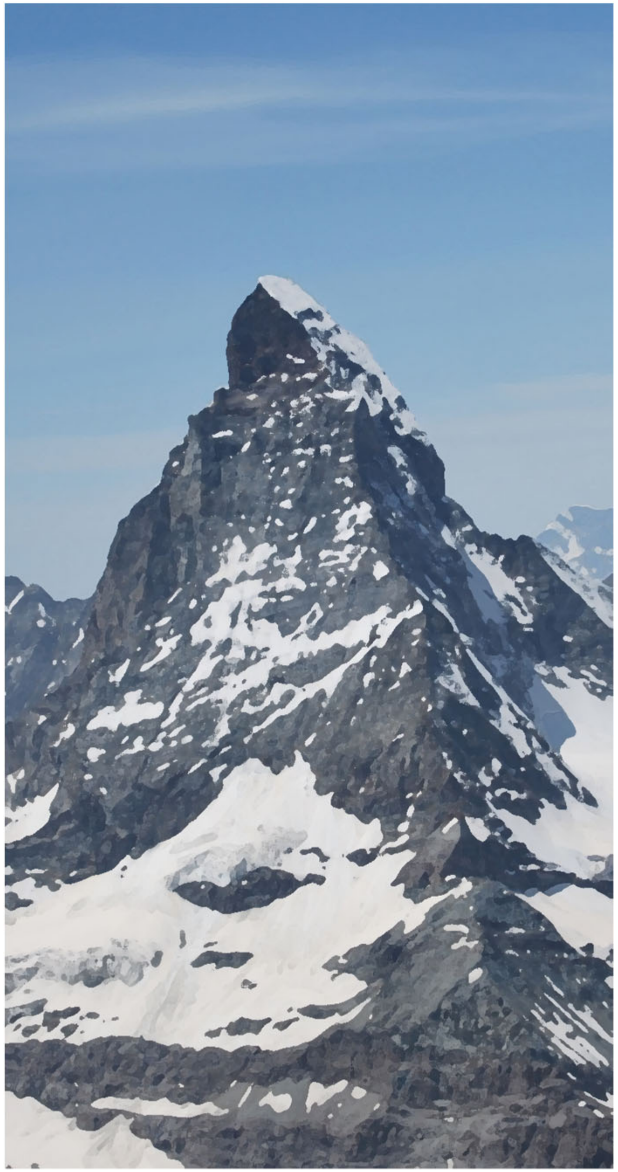
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

Motivation

- Understanding the past to predict the future.

- Planning and operation of hydropower schemes are often tackled with simple objectives.
  - Addressing environmental concerns.
  - Increasing efficiency.
  - Increasing potential.
  - Increasing flexibility.

- Reality can be more complex.
  - Divide between civil engineering and finance / economics.
  - What is the optimal use of the systems we design given real constraints?



Motivation

- The main questions to better design and adapt hydropower systems:
  - How do hydropower systems affect the environment around them?
  - What do hydropower systems respond to?

- Isolated, run-of-the-river HPPs are relatively easy to assess.
- If storage is considered, strategy begins to play an important role.
- Pumped-storage adds more complexity to operations.
- Interactions between multiple HPPs are hard to fully understand.

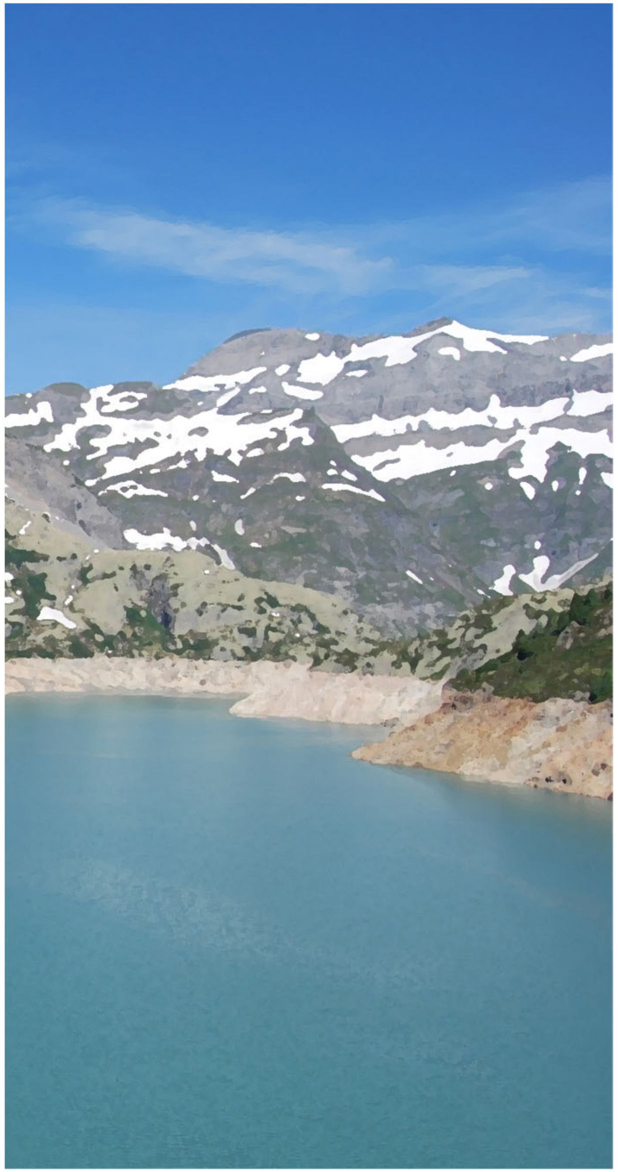
- Often design and adaptation strategy bets on general features:
  - More system capabilities.
  - Better system performances.
  - More flexibility.

Motivation

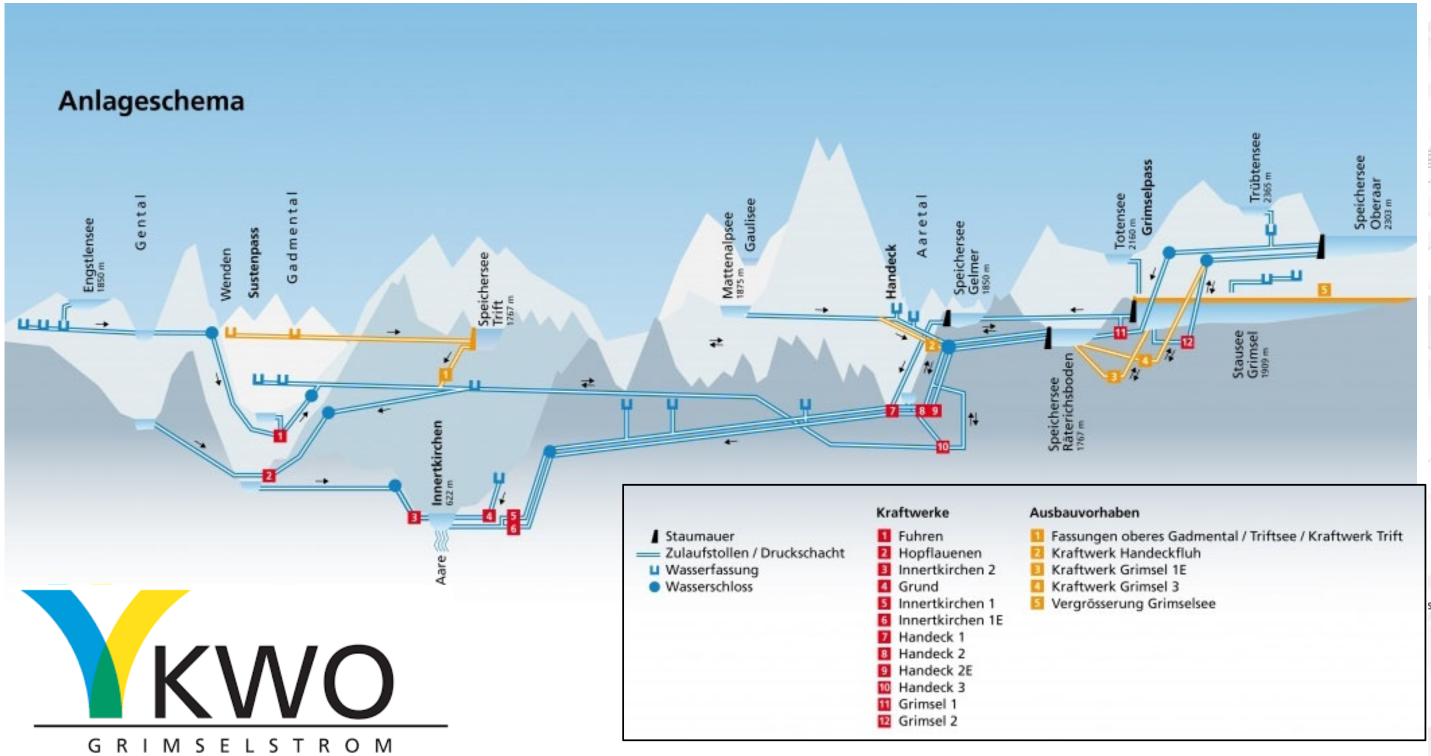
- We tried to understand how a complex system deploys its capabilities.
- What is at stake?
  - Operational limitations.
  - Hydrology.
  - Energy markets.
  - Business models.

- Two approaches:
  - A numerical model that captures all of this is extremely hard to achieve.
  - Mining 40 years of daily data and 1 year of sub-daily data of the KWO system.

- We tried to “explain” what drove operations and changes.
  - Understanding the past to predict the future.



The system (Further information at http://www.grimselstrom.ch)



Methods

Classical hydrologic/hydraulic modelling

- Full simulation of the system using an established model.

Data mining / machine learning

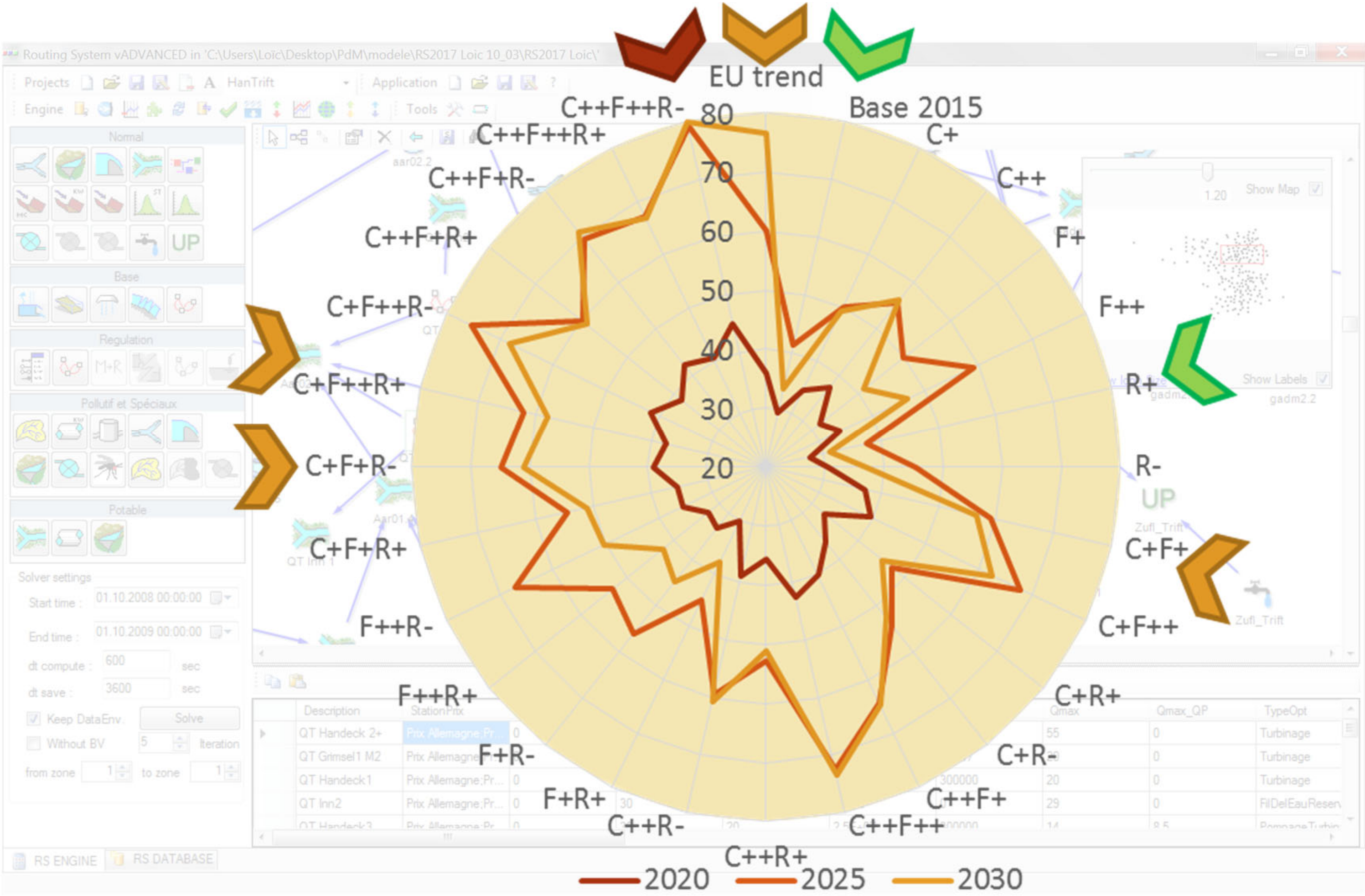
- Using machine learning to explain and understand extensive operational data.

Data analysis and visualization

- Explore new techniques for visualizing complex data.

Results

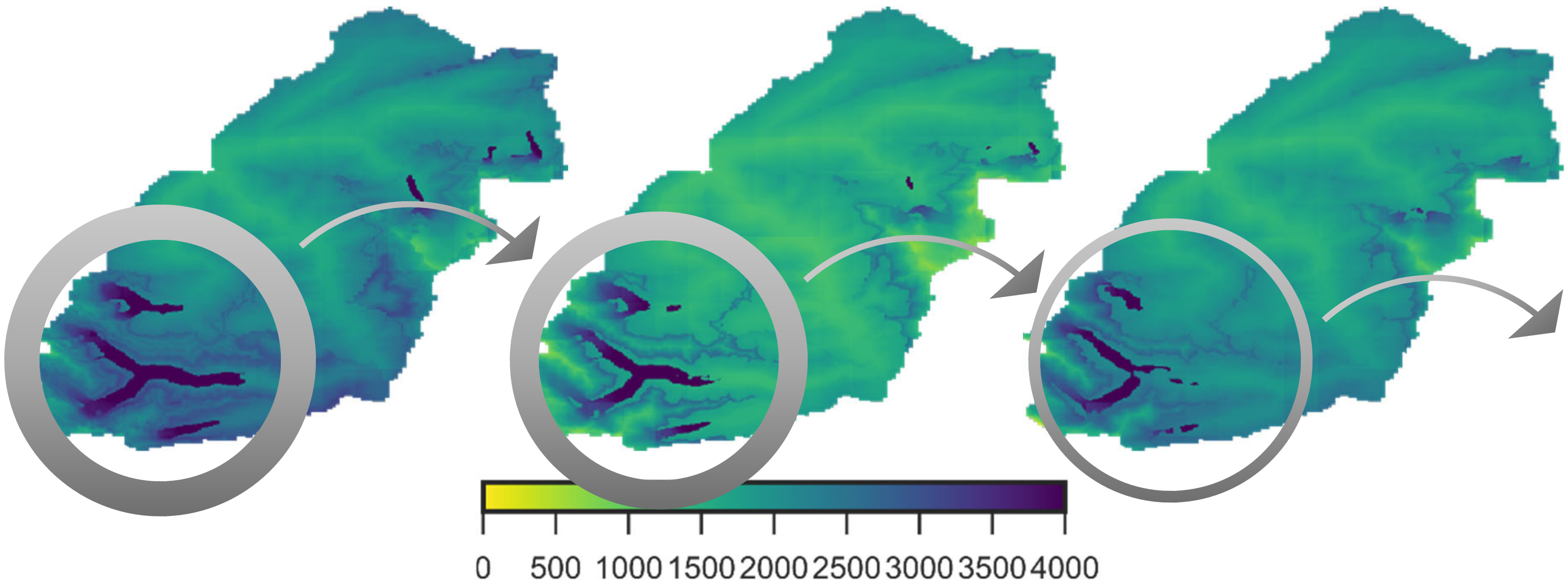
- Numerical modelling.
- Goes beyond heuristics.
- RS3+optiprod provide a powerful tool to simulate the future.
- Also limited in a number of ways…
- The business model of the system:
  - Long / medium term contracts.
  - SPOT market.
  - Load balancing.
- Fine operational limitations.



Results

- Characterizing hydrology

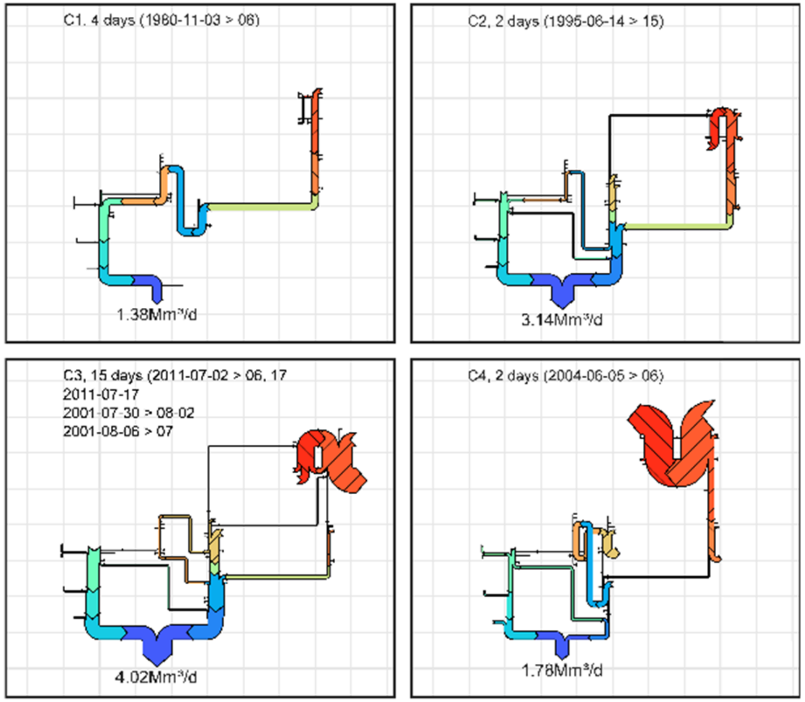
Degree-day factor model [runoff mm/yr]

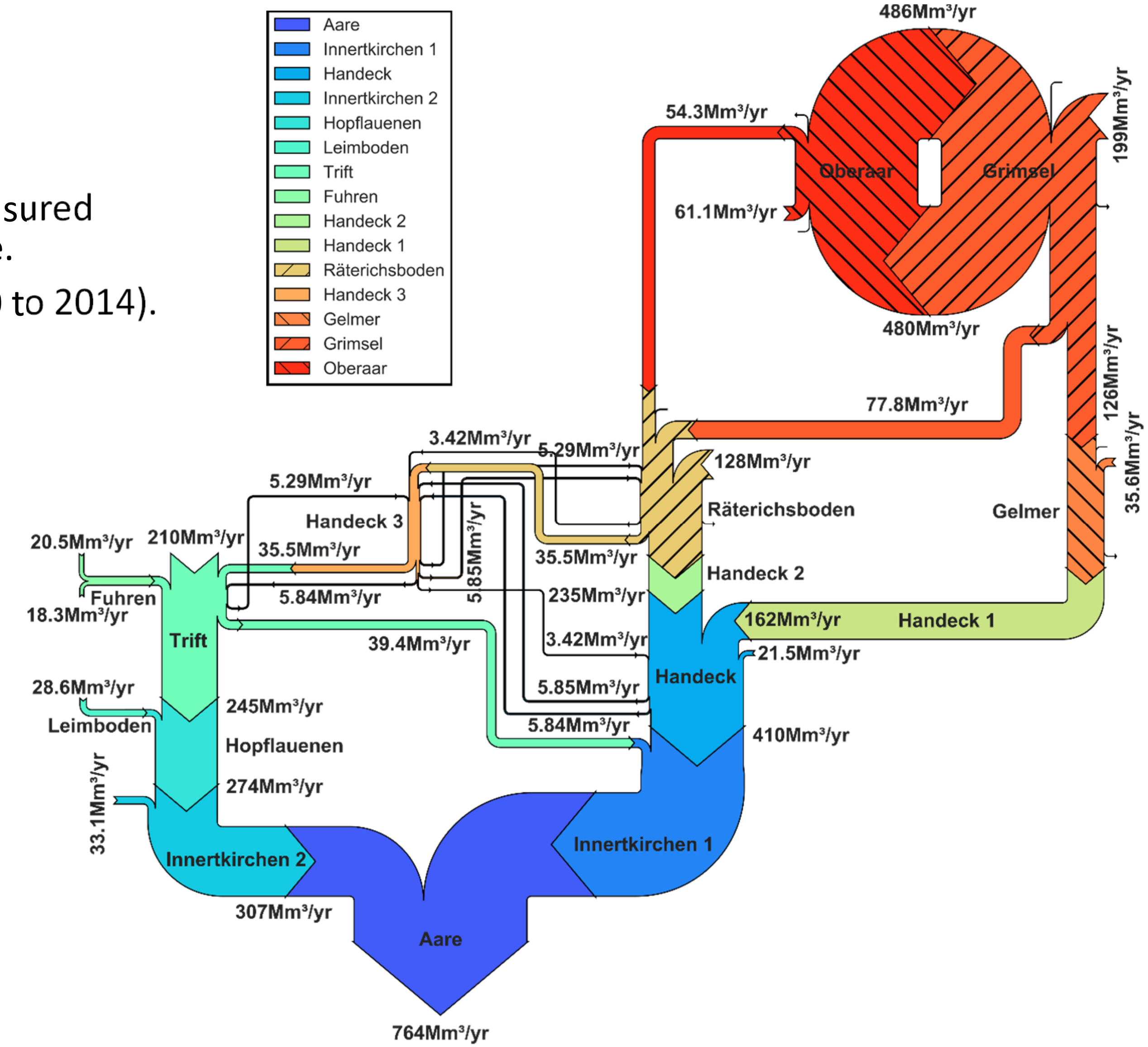


- Historical and future snow/ice coverage and runoff series from coarse gridded data.

Results

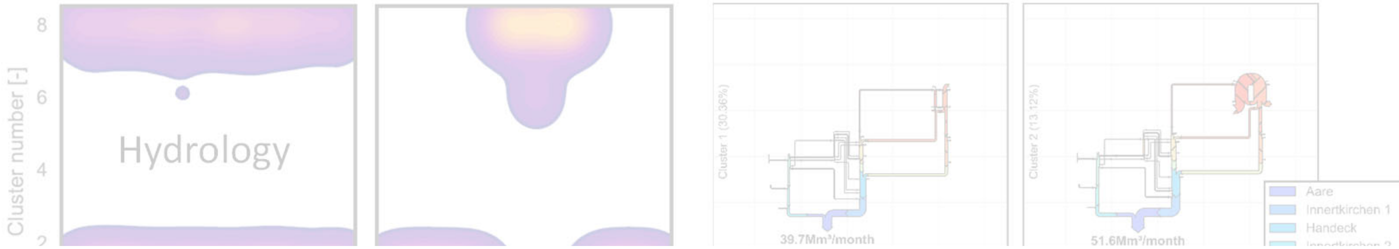
- Visualizing the system
  - Translating a 36 dimension problem (measured series plus time) into something tractable.
  - Sankey plot (ex. average fluxes from 1980 to 2014).
  - Outlier operation modes





Results

- Machine learning could help identifying what affects the system.



Inputs	LR	SVC_{lin}	SVC_{RBF}	RF	Mean	Best
Random	30.2%	30.2%	30.2%	30.3%	30.2%	30.3%
Storage	30.3%	30.2%	30.2%	30.7%	30.4%	30.7%
Day of week (DOW)	30.2%	30.2%	30.2%	31.5%	30.6%	31.5%
Long-term trend (LTT)	32.5%	34.3%	34.3%	37.7%	34.7%	37.7%
Yearly cycle (DOY)	30.2%	30.2%	30.2%	42.7%	33.3%	42.7%
LTT and DOY	31.6%	34.2%	35.2%	40.7%	35.4%	40.7%
LTT, DOY, and storage	31.8%	34.4%	38.4%	39.6%	36.0%	39.6%
All but hydrology	35.7%	38.7%	42.1%	41.0%	39.4%	42.1%
Hydrology	43.2%	43.3%	43.2%	43.7%	43.4%	43.7%
All	52.4%	53.4%	54.0%	52.3%	53.0%	54.0%
All but storage	53.6%	54.7%	55.0%	55.1%	54.6%	55.1%

- Hydrology is as important as the rest.
- Information on storage does not help predicting operations.

Results

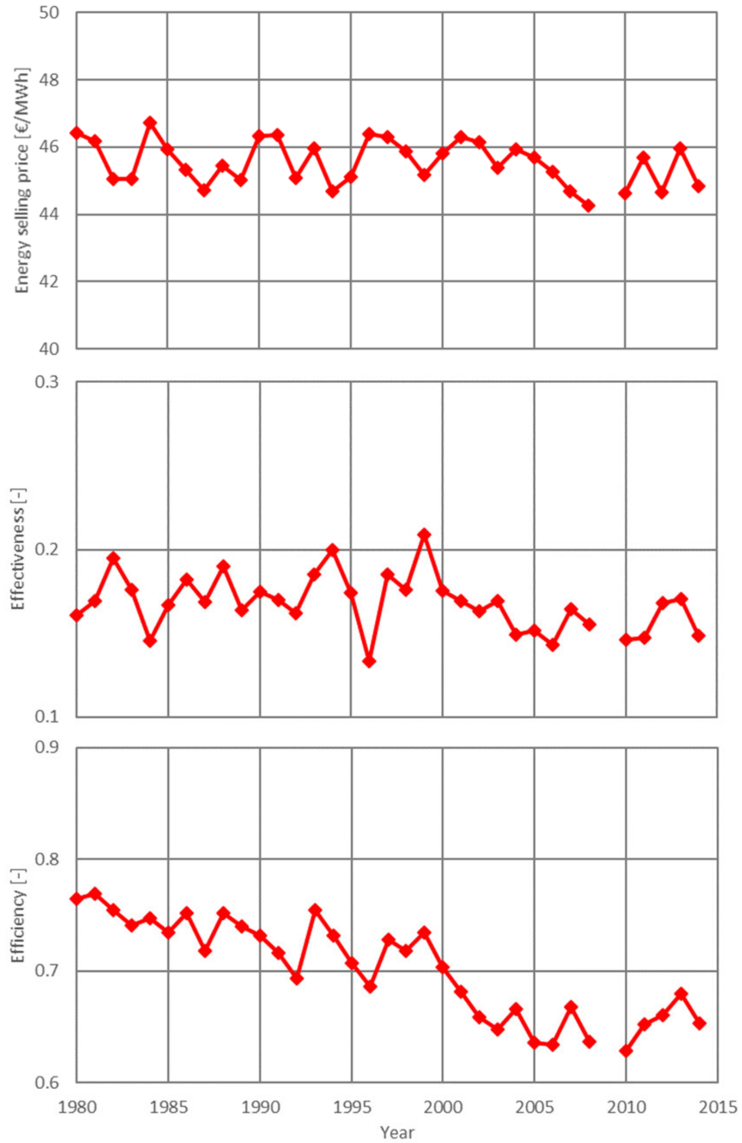
- The influence of the market.
- Synthetic series of prices from 1980 onwards.
  - How well would historical operations from 1980 to the present adapt to today's market?
- Three metrics analyzed the changes in the system.
  - Effectiveness: how much of the system potential is being used (no water and no storage limitations).
  - Efficiency: how "well" are the water resources being used (no storage limitations).
  - Energy selling price.

- The system seemed to perform increasingly worse.
  - This did not make sense!

Energy selling price

Effectiveness

Efficiency



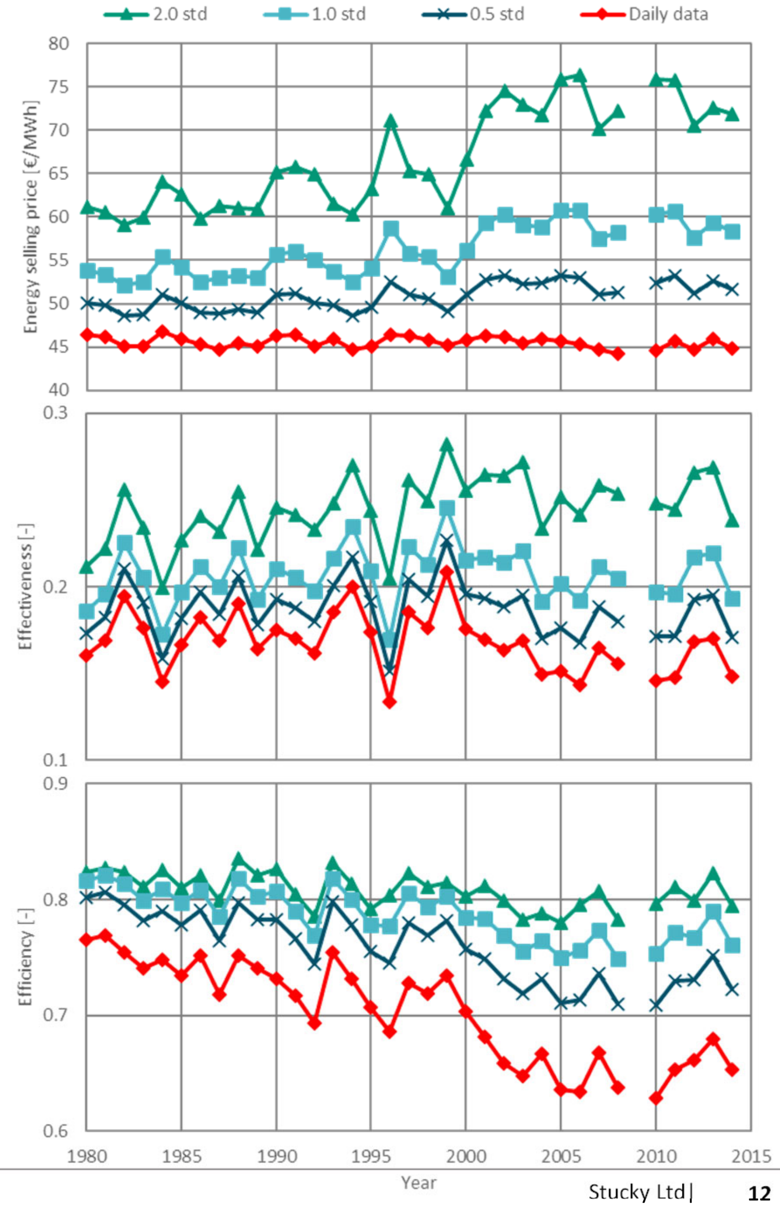
Results

- … unless intra-daily operations were considered.
- Increasing intra-daily price fluctuations reveal the sense of the systems' adaptations.
- Taking advantage of hydro's competitive advantages, intra-daily price variations are a major driving force behind operations.

Energy selling price

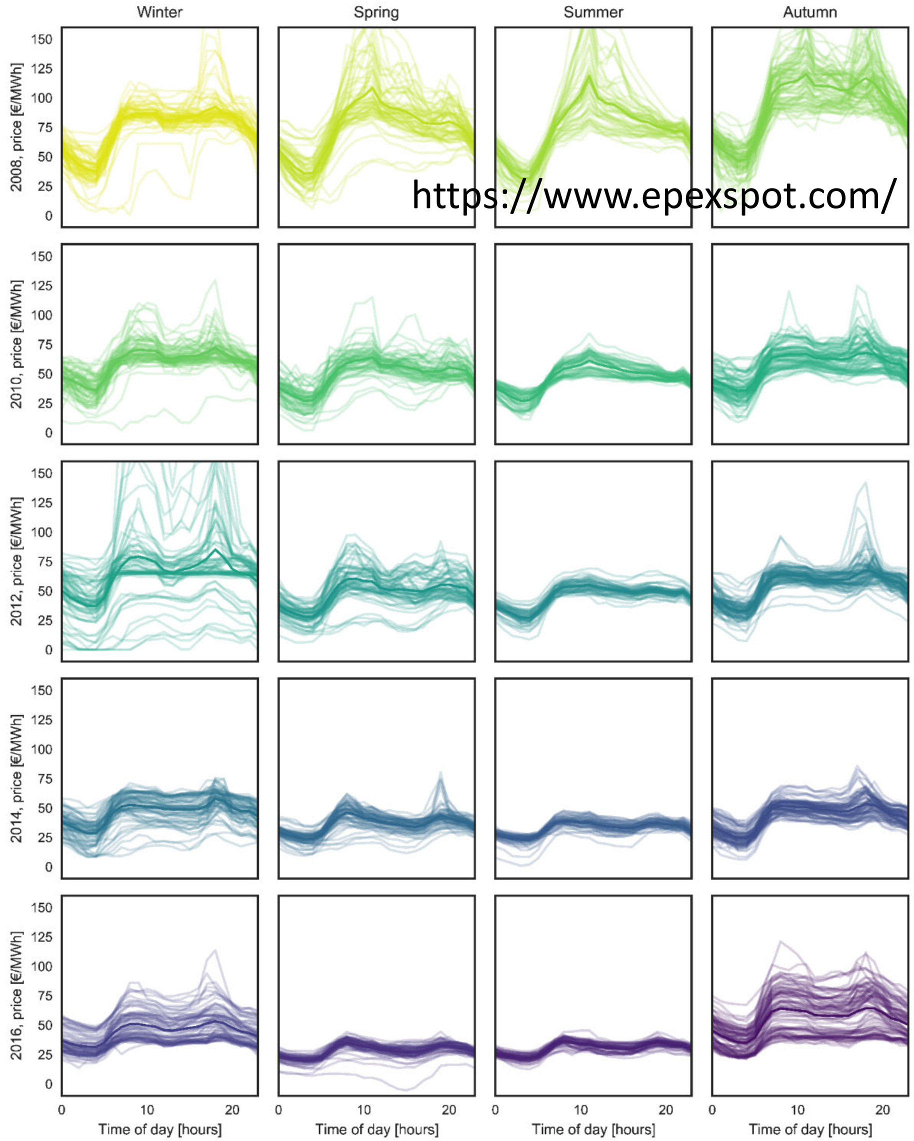
Effectiveness

Efficiency

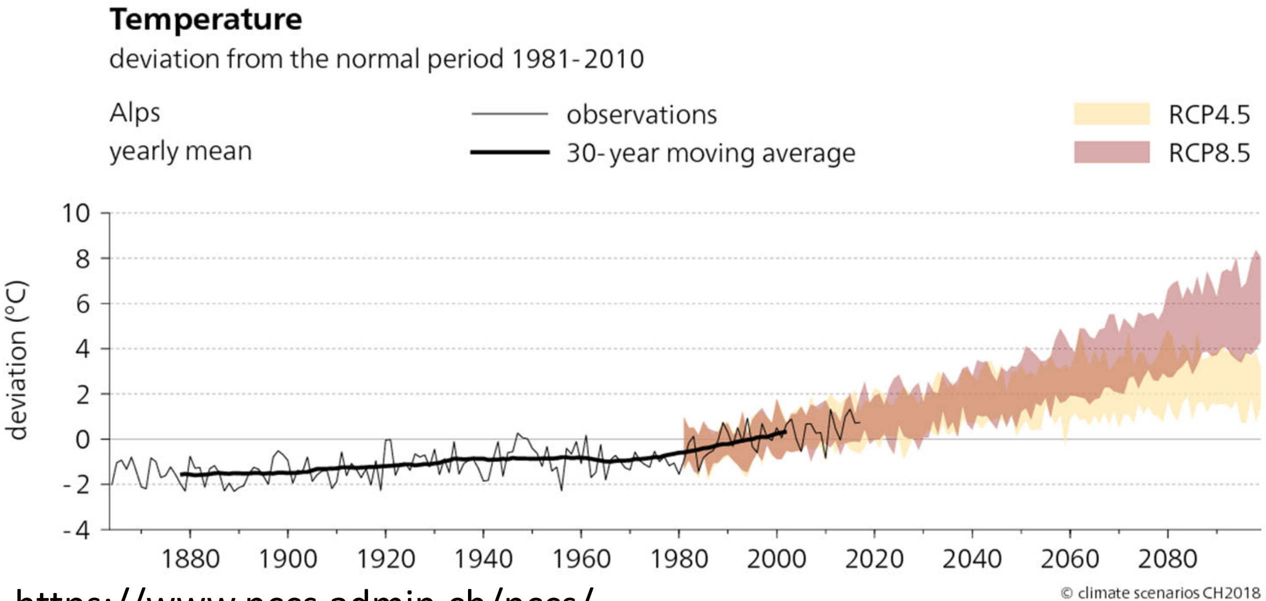


Results

- Not only climate change but also future energy markets will play a major role in the hydropower sector.
- For an informative assessment sub-daily analyses (and data) are extremely important.



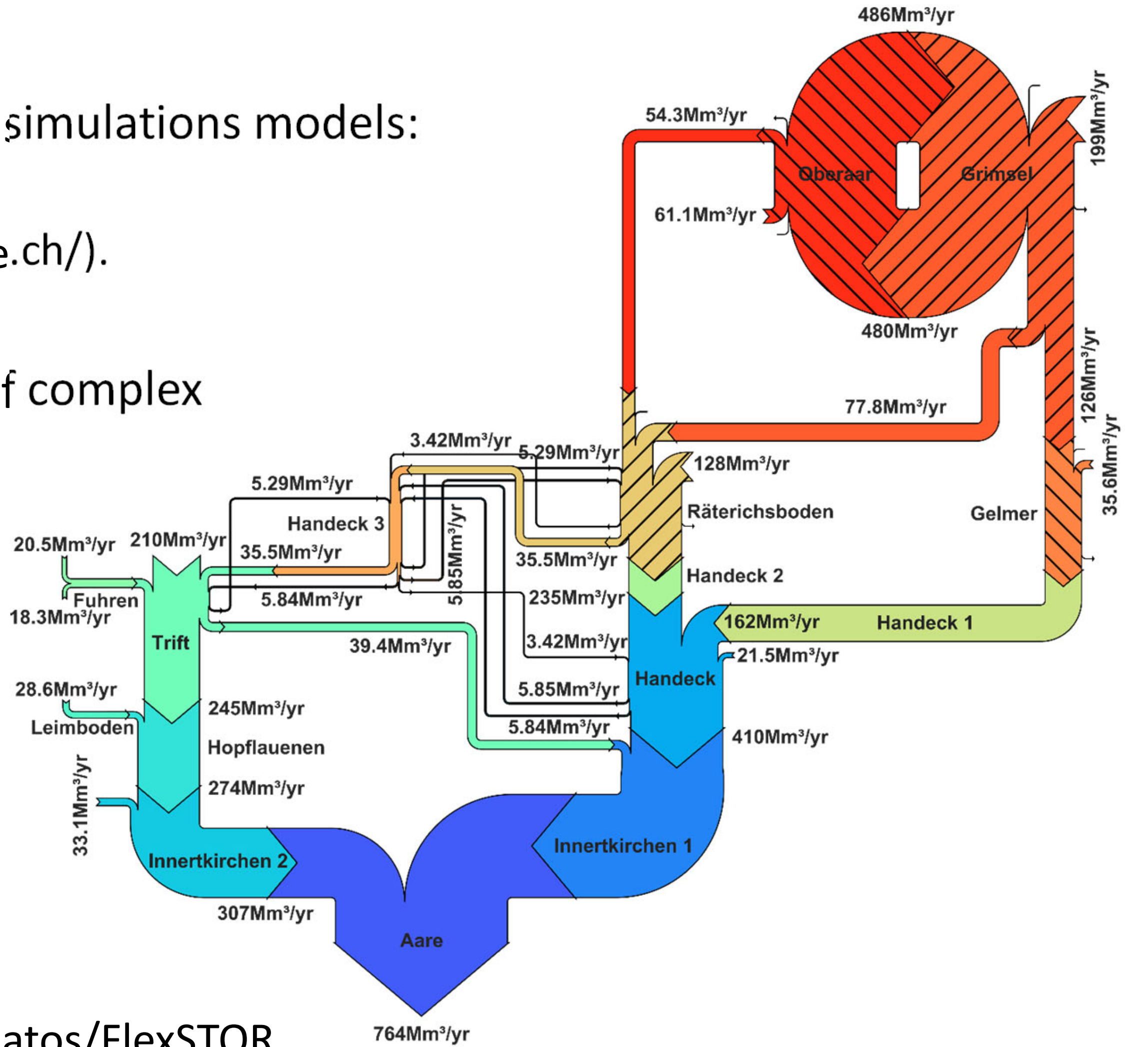
https://www.epexspot.com/

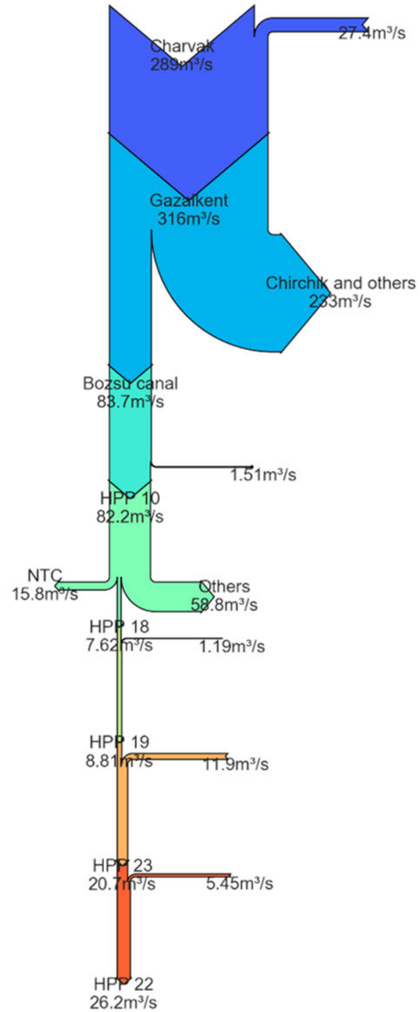


https://www.nccs.admin.ch/nccs/

Contributions

- Improvement of numerical simulations models:
  - Routing System 3 and
  - Optiprod (http://hydrique.ch/).
- Code for the visualization of complex hydropower systems.
- Code for the downscaling of meteorological data.





https://github.com/JosePedroMatos/FlexSTOR

Main outcome

- Insight into what drives complex hydropower systems.

- Sharing of tools to understand hydropower systems.
- Contribution to enlarge the traditional vision of dam engineers, which may at times downplay the role of energy markets.

Thank you