Integrated simulation of HP system operation

Presented by Paolo Burlando

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Task 2.5 Research Objective Phase 1

To develop:

an *advanced modelling framework* for the *integrated continuous simulation* of streamflow regimes and of *operation of HP systems* under future climate scenarios, operational constraints, and technical solutions.

*Tool for exploration of capacity of HP systems*

→ to achieve desired goals in production, reliability, flexibility of operation, etc. for given forcing and constraints

→ to analyse *trade-offs* among conflicting goals under *uncertainty*
Integrated modeling framework

**Socio-economic variables**
- Stochastic long-term price projections
- Price forecasts

**Optimal controller**
- Stochastic optimization
- Robust optimization

**Meteorological variables**
- Stochastic downscaling of Climate Change
- Meteo forecasts

**Topkapi-ETH**
- Reservoir release
  - Reservoir module
  - Hydrological module
  - Streamflow

**Output variables**
- Hydropower performance
- Hydrological response
- Environment response

1st phase SCCER

2nd phase SCCER
Performed numerical experiments

A. Stochastic Multi-Objective optimization of HP system operation.

B. Effect of different HP system operation strategies on the hydrology and river downstream.

C. Effect of climate change on glacier retreat and water availability.

D. Effect of climate change and price projection on HP performances.
Visp catchment, Mattmark reservoir

Legend
- Reservoir
- Pumping plant
- Production plant
- Channel
- River
- Basin

Visp
Stochastic Multi-Objective optimization of HP system operation (1/2)

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exploration of trade offs between production and revenues
A. Stochastic Multi-Objective optimization of HP system operation (2/2)

→ historical trajectories captured even in the absence of full system knowledge (e.g. pumping)
→ low margin for production increase, higher for revenue
B. Effect of HP system operation strategies on downstream streamflow regime (1/2)

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**Exploration of production strategies on downstream flow regime**
Comparison of different HP operations in terms of:
• HP reservoir dynamics
• Index of Hydrological Alteration (Richter, 1996).

→ optimised operation captures the variability
C. Effect of climate change on water availability (1/3)

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Exploration of how natural (stochastic) climate variability and climate change signal on P, T and glacier retreat reflects on reservoir inflows.
C. Effect of climate change on water availability (2/3)

- Initial glacier thickness map as in Huss and Farinotti (2012);
- Explicitly modelled glacier retreat (downwasting parameterisation by Huss et al. 2010)
- Stochastic downscaling of climate scenarios

⇒ ready for link to T2.1 (advanced glacier mapping)
C. Effect of climate change on water availability (3/3)

Stochastic projections of reservoir inflows (10\textsuperscript{th}-90\textsuperscript{th} percentiles) according to:
- middle emission scenario A1B (SRES, 2000),
- downscaled GCM ECHAM5 (Roeckner et al., 2003), and RCM REMO (Jacob et al., 2001) scenarios.

- **ready for link to T2.1 (new and refined downscaling)**

- **shift in seasonality and annual volume of inflow**
- **large uncertainties due to natural (stochastic) climate variability**
Advanced stochastic weather generator

Methodological development
new scenarios (stochastically downscaled CH-2018)
**Advanced stochastic weather generator**

T2.1 → **AWE-GEN-2d** (Advanced WEather GENerator for 2-D grid):

- combine *physical and stochastic* approaches to generate gridded climate variables
- high spatial and temporal resolutions (100s of m to km, min to hour)
- multivariable: P, T, SR, VP, RH, near surface wind fields)
- model re-parameterisation for CC impact studies in Phase II

→ see poster by Peleg et al. (area T2.1)

→ conceptualisation of reparameterisation completed

→ scenario generation on case studies on going
D. Effect of climate change and price projection on HP performances (1/2)

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Exploration of effects of co-variation of prices and CC signal/variability on HP trade-off production-revenue

See also poster by Anghileri et al. (area T2.4)
Effect of climate change and price projection on HP performances (2/2)

- Price projections according to SwissMod (University of Basel).
- Data driven stochastic variability of prices
- CC as in C.

- Revenue increase because of underlying increase of price projections (≈effect of CO$_2$ permit price)
- Decrease in production because of lower water availability
- Overlap at mid century due to stabilisation of glacier retreat
Summary of numerical experiments

*Integrated HP system model*

- capturing historical variability even without perfect knowledge of historical management
- conceptually ready for further applications (multiobjective, more complex systems)
- able to show the margin of trade-off operation of HP, jointly with effects of risks associated with changes of drivers and their co-variation
- ready for new climate scenarios

*Current limitations*

- incomplete information for calibration on current operation strategies
- speculative exercise vs sensitivity of HP systems in the absence of more information on HP companies objectives

*Dissemination*

- paper in review + paper ready for submission
- one more application on-going on complex pump-storage system (Maggia)
Key research directions (KDs) to be investigated with tools developed in Phase 1

**KD1:** Increase of flexibility in hydropower operation – structural and operation requirements

**KD2:** Update of climate change impacts on HP production and required adaptation strategies

**KD3:** Extreme natural events, hazards and risk of HP operation

**KD4:** Design of new projects under uncertainties

**KD5:** Reservoir sedimentation and sustainable use of storage HP
Case studies (exemplary) for KDs investigation by means of the integrated framework
Planned numerical experiments (selection)

1. **Effects of HP operation strategies on ecosystems** (KD5, effects of new release strategies, e.g. DEFs → NFP70 HydroEnv).

2. **Development of a robust planning and management approach** in planning new infrastructures or upgrading existing ones (KD4).

3. **Develop a real time operation framework** to integrate forecasts of price and flows on different time scales into the design of HP reservoir operation strategies (KD1).
1. Effects of HP operation strategies on ecosystem

Methodological development
- DEFs as drivers
- Assessment on ecosystems in HydroEnv
2. Robust HP planning and management

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Methodological development testing the limits of HP systems under (stochastic) co-variation of price and climate
3. Increase HP efficiency by use of forecasts

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**Methodological development**
- Co-operation with WSL
- See poster by Anghileri et al. (area T2.4)
Thank you for your attention

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