Task 2.5

Task Title

Integrated simulation of hydropower systems operation

Research Partners

Chair of Hydrology and Water Resources Management (HWRM) at ETH Zurich, Swiss National Institute of Forest, Snow and Landscape Research (WSL), Kraftwerke Mattmark AG (KWM), Axpo, Officine Idroelettriche della Maggia SA (Ofima)

Current Project (presented on the following page)

Exploring productivity and profitability of Alpine hydropower plants under climate change and price variability

D. Anghileri, A. Castelletti, P. Burlando

Task Objectives

The purpose of Task 2.5 is to develop an advanced modelling framework for the integrated and continuous simulation of hydrological regimes and the operation of hydropower systems. The model allows accounting for climate change scenarios, the corresponding altered streamflow regimes, different energy market conditions (e.g., energy demand and price, increased production by solar and wind powerplants), as well as new boundary conditions for operation (e.g., aquatic ecosystem conservation) and technical solutions (e.g., dam crest heightening or installation of more flexible machines). The modelling framework allows a quantitative assessment of current and future hydropower reservoir operation strategies in terms of energy production and revenue, integration with other power sources, and effects on natural water bodies and ecosystems. The specific objectives are:

- assess impacts of climate change on available water resources at existing and planned HP systems, on their extremes (low and high flows), on floods and sediment transport and, more in general, on any element of change that can affect the hydropower production potential;
- assess the energy production increase achievable by current reservoir operating strategies or ad hoc designed to account for technical improvements and/or adaptations of the hydropower systems to future hydro-climatic and socio-economic forcing;
- analyse the effects of increasingly volatile demand and market conditions (as induced, for instance, by production from other renewable energies) on the production potential and to design more flexible and robust hydropower system operation strategies.

Interaction Between the Partners – Synthesis

- Several collaboration has been established with other research partners within the context of the SCCER and other related projects. This represents the first steps towards the integration of the results achieved by different WP2 tasks and activities into a common modelling framework. A strong connection has been built with some industrial partners thanks to periodical meetings, which have the scope of updating the stakeholders of the work results and to include their feedbacks into the research activities, thus collaborating together to shared solutions in view of the energy strategy 2050.
- In particular, we are working in collaboration with Task 2.1 to extend our research spatially distributed hydrological model to include a more detailed representation of the glacierised areas. Moreover, we are going to use the high-resolution climate change scenarios developed in Task 2.1 to simulate the effect on hydrological regimes and hydropower system operation across the investigated river basins. The main partners of these activities are: ETH Zurich (Hydrology and Water Resources Management), ETH Zurich (Laboratory of Hydraulics, Hydrology and Glaciology), Center for Climate Systems Modeling (C2SM), and Kraftwerke Mattmark AG / Axpo Power AG.
- Further, we are working in collaboration with Task 2.2 to assess the impact of different market scenarios on future hydropower operation. We are combining multi-objective optimization techniques and a Swiss electricity market model to design different reservoir operating policies to assess which reservoir operating strategies can lead to maximisation of production to support the 2050 energy strategy. The main partners of these activities are: ETH Zurich (Hydrology and Water Resources Management), Uni Basel (Research Center for Sustainable Energy and Water Management), and Kraftwerke Mattmark AG / Axpo Power AG.
- We have established a collaboration with OFIMA to assess future operating strategies also including the effect of different reservoir operating policies on the ecology of downstream river corridors. This activity links to Task 2.4 and to the NRP 70 funded project “HydroEnv”, the purpose of which is to identify key environmental indicators and environmental flow policies to be included in the integrated model as performance metrics to evaluate future hydropower system operation from the ecological point of view.

Highlights 2016

- The progresses on Task 2.5 were presented in two international conferences thanks to two oral contributions:
    - Exploring current and projected tradeoffs between hydropower profitability and reliability of supply in the Alps. American Geophysical Union - Fall meeting 2015 - San Francisco - USA
    - Alpine hydropower in a low carbon economy: assessing the local implication of global policies. European Geosciences Union General Assembly 2016- Vienna – Austria
- The aims and tasks of SCCER-SoE were presented during the ETH Water Week (September 11–16 2016) organized for students from all ETH departments thanks to a poster presentation.
- Several master theses have been conducted to test and develop the modelling framework and analyse two study sites. The students involved come from ETH Zurich as well as from other European universities.

SCCER-SoE Annual Conference 2016

SCCER SoE
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Exploring productivity and profitability of Alpine hydropower plants under climate change and price variability

Daniela Anghileri, Andrea Castelletti, and Paolo Burlando

Motivation

Fast dynamical and uncertain processes will probably characterize the Swiss hydropower (HP) sector in the future because of:

- climate change (CC), which is affecting the timing and amount of water availability,
- energy market liberalization and increasing share of new renewable energy sources, which are resulting in lower energy prices and increased price volatility,
- nuclear phase out by 2035, whose energy production would be partially replaced by HP and other new renewable energy sources.

As a consequence, HP systems' operators will likely need to change the current operating strategies to be more flexible and robust.

Objectives and relevance of the work

We develop a decision analytic framework to:

- design several HP reservoir operating strategies to explore different tradeoffs between productivity and profitability of HP systems,
- investigate how these tradeoffs may evolve in time under current and future climate change and energy price projections.

Results inform about:

- the impacts of changes in water availability and energy price on Alpine HP systems,
- the adaptive capacity of HP reservoir operation to water availability and price changes,
- to which extent HP companies could cope in the future with both secure energy supply and profitable operation (without infrastructural investments).

Methods

The decision analytic framework consists of 4 phases:

1. Generating water availability and price scenarios,
2. Modeling HP systems (reservoirs and plants) and their interaction with the natural environment,
3. Designing the HP operating policy using multi-objective (MO) optimization techniques,
4. Simulating and analysing the HP system performances.

1.A - CLIMATE SCENARIOS
- Emission Scenarios: A1B
- Climate models: ECHAM5, RegCM3
- Stochastic Downscaling

(Bordoy Molina, 2013)

1.B - PRICE SCENARIOS
SWISSMOD model of the Swiss electricity market using the DC load flow approach *(Schlecht and Weigt, 2014a,b)*

Temperature and precipitation →

Electricity price →

1.C - MODEL OF THE CATCHMENT
TOPKAPI-ETH hydrological model

Streamflow →

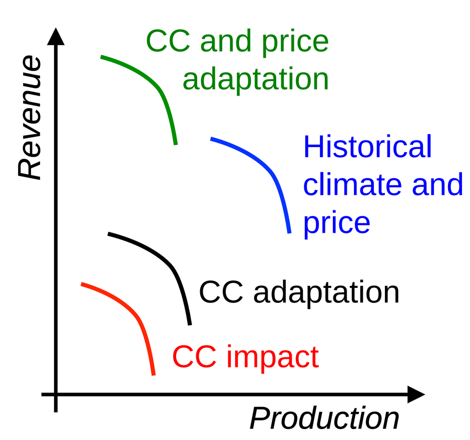
2.A - MODEL OF HP SYSTEM
- Physically based model of HP system
- Model of the HP company decision making process

2.B - HP SYSTEM PERFORMANCE
- HP production
- HP revenue

3. RESERVOIR OPERATION DESIGN
MO optimization of the reservoir operating policy

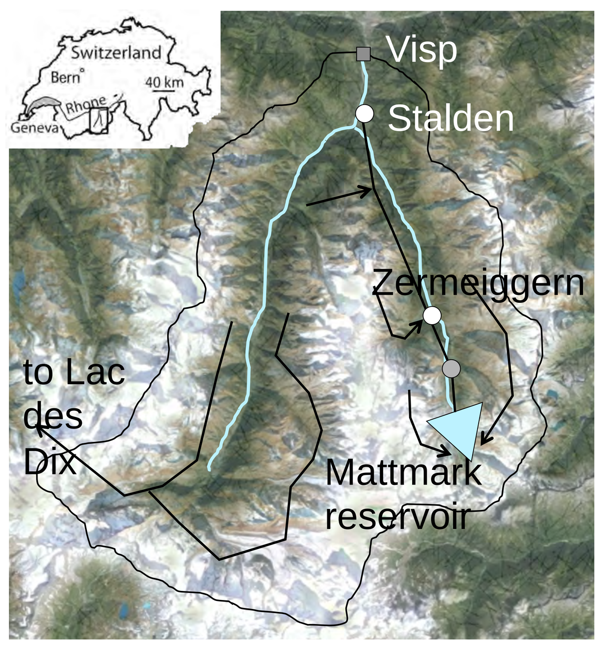
Operating policy →

4. TRADEOFF ANALYSIS
Assessment of impacts and operational adaptive capacity



- Bordoy Molina (2013). Spatiotemporal downscaling of climate scenarios in regions of complex geography. PhD. Thesis – ETH Zurich.
- Schlecht and Weigt (2014a). Swissmod: A model of the Swiss electricity market. *Social Science Research Network.*
- Schlecht and Weigt (2014b). Linking Europe: The role of the Swiss electricity transmission grid until 2050. *Social Science Research Network.*

Study site



Mattmark hydropower system

Hydropower company: Kraftwerke Mattmark AG c/o Axpo Power AG

Mattmark storage: 100,101,000 m^3

Zermeiggern power plant: 38.8 MW

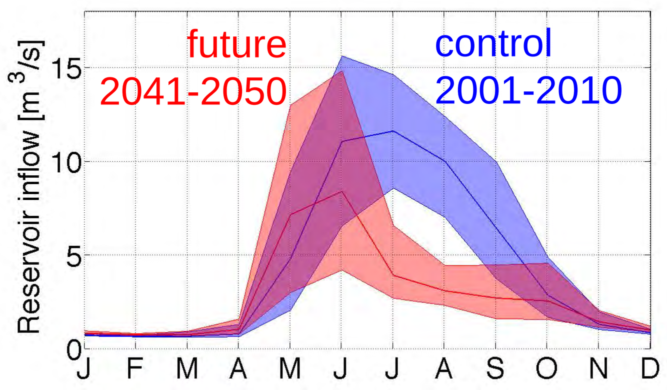
Stalden power plant: 187 MW

Catchment area: 778 km^2

Glacier extention: 29% of the catchment

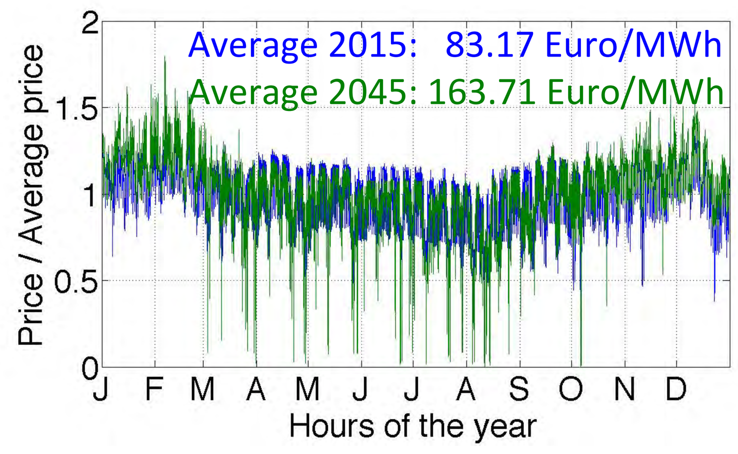
Results

Reservoir inflow and energy price scenarios



Future reservoir inflow shows a reduction of the annual volume due to changed snow-melt dynamics and glacier retreat.

Future energy price shows increasing mean and variance due to higher share of renewables (*Schlecht and Weigt, 2014b*).



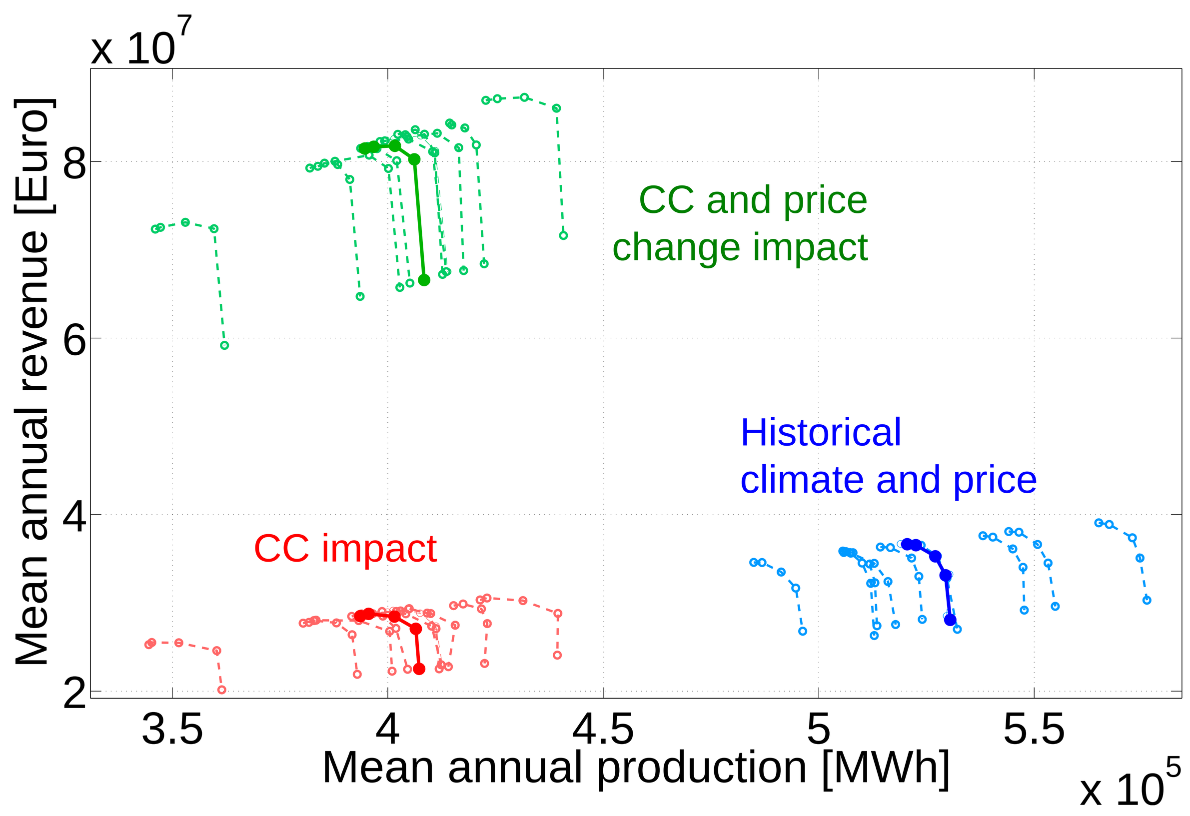
Impacts of changes in water availability and energy price

Each Pareto Frontier (PF) represents different reservoir operating strategies, balancing maximization of energy production and revenue.

The blue PFs represent the current climate (dashed PFs are 10 different stochastic realizations; solid PF is their average) and current energy price: natural climate variability can produce a variation in production and revenue of ±6%.

The red PFs represent the impact of CC: the reduction of water availability causes a reduction of about -20% in production and revenue.

The green PFs represent the impact of CC and energy price change: the increased price average induces a big increase in the revenue and the increased price variability induces a slightly more pronounced conflict between production and profitability.



Adaptive capacity of HP system operation to climate change

The operation of the HP system can be optimized to account for the future changed water availability (black PFs).

The performances w.r.t. both production and revenue are only slightly improved, meaning that a change in the HP system operation alone could not cope with the decrease in the annual water volume flowing into the reservoir.