A Decision Support System to test new hydropower operation strategies to adapt to the changing climate and socio-economic context

Hydropower operations has been challenged by the changing climate and socio-economic context
Hydropower is a strategic source of electricity in many parts of the world, not only because it provides clean energy, but also due to the flexibility of newest hydropower plants, which guarantees very fast response to sudden fluctuations in demand. Hydropower systems have been challenged by major changes in their operating context in the last decades. On the one hand, climate change has influenced the hydrological regime, altering water availability, seasonality, and the frequency of the extreme events. On the other hand, electricity markets all over the world are experiencing a phase of change, due to their partial or total liberalization (i.e., the opening of electricity market to private companies) and the increasing share of new renewable sources in the electricity portfolios of many countries. Consequently, the annual water availability and the electricity price, driving the amount and timing of hydropower production, have experienced considerable changes. In this continuously evolving context, the traditional operating rules of the hydropower reservoirs might be challenged in ensuring adequate electricity production.

A Decision Support System to assess potential alternative hydropower adaptation strategies and guarantee adequate hydropower production and revenue
We propose a modelling framework which is capable of anticipating the effects of different combinations of water availability and electricity prices (scenarios), and assessing the effectiveness of different hydropower system operation strategies as tools to adapt to these scenarios. This framework represents a Decision Support System (DSS) for the hydropower companies, i.e., a virtual laboratory which can aid hydropower operators during the decision-making process for strategic and operational planning. the framework is capable of translating complex, large-scale processes (such as climate change or energy policies) into specific effects at a local scale which is of interest for hydropower companies. A notable feature of the framework is the capability of accounting for the uncertainty which characterises the operating context, so that, multiple different scenarios can be considered at the same time and robust adaptation strategies can be identified. Another salient feature is the flexibility of the approach which allows for assessing the effectiveness of the adaptation strategies from multiple points of view, thus accounting for the complex business development strategy typical of power companies.

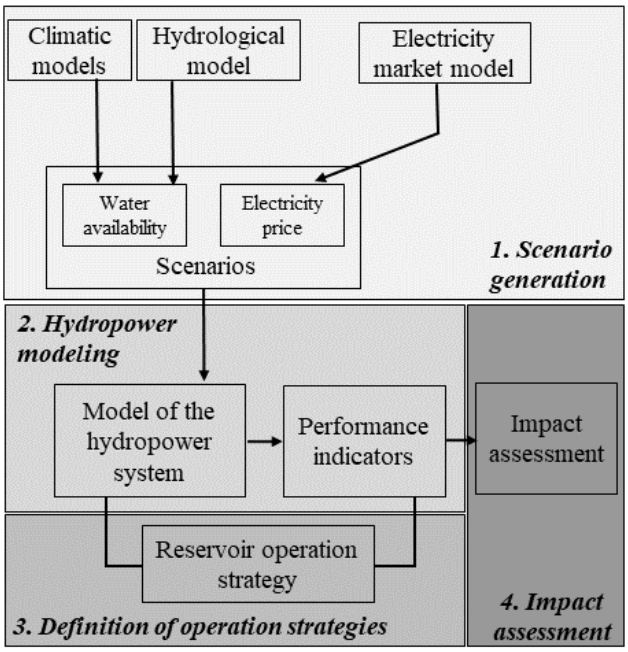

Figure 1: The framework adopted in this study. Modified from: Anghileri at al., 2017.

Our DSS is made of an ensemble of interconnected numerical models to accomplish four main steps (Figure 1). First, we use climate models, a hydrological model, and an electricity market model to generate different alternative scenarios for water availability and electricity price. These models are able to reproduce complex processes, such as the change in water availability as a consequence of global warming and the change in electricity price and fluctuations as a consequence of different energy mix portfolios, CO2 emission permit prices, or changes in the electricity transmission infrastructure. Second, we use a model of the hydropower system, including reservoirs, turbines, etc. to assess the impacts of the scenarios on the hydropower operations. We define a series of performance indicators to quantify these effects, such as annual production or revenue. Third, we use stochastic multi-objective optimization techniques to define reservoir operations strategies that can cope with the scenarios. Finally, we assess the efficacy of these strategies by comparing the performances of business-as-usual (or traditional) operations to the performances of different adaptation strategies.

The impact of climate and price change on hydropower operation and the role of adaptation strategies

We test the DSS on a real-world case study, the Mattmarksee in Southern Switzerland, as it is representative of many other hydropower systems in the mountainous regions around the world. The hydropower system includes a major reservoir located in the upper part of the catchment collecting water from high elevation areas where snow and glacier melt are the dominant hydrological processes and a cascade of power plants exploiting the height differences characteristic of the alpine landscape.

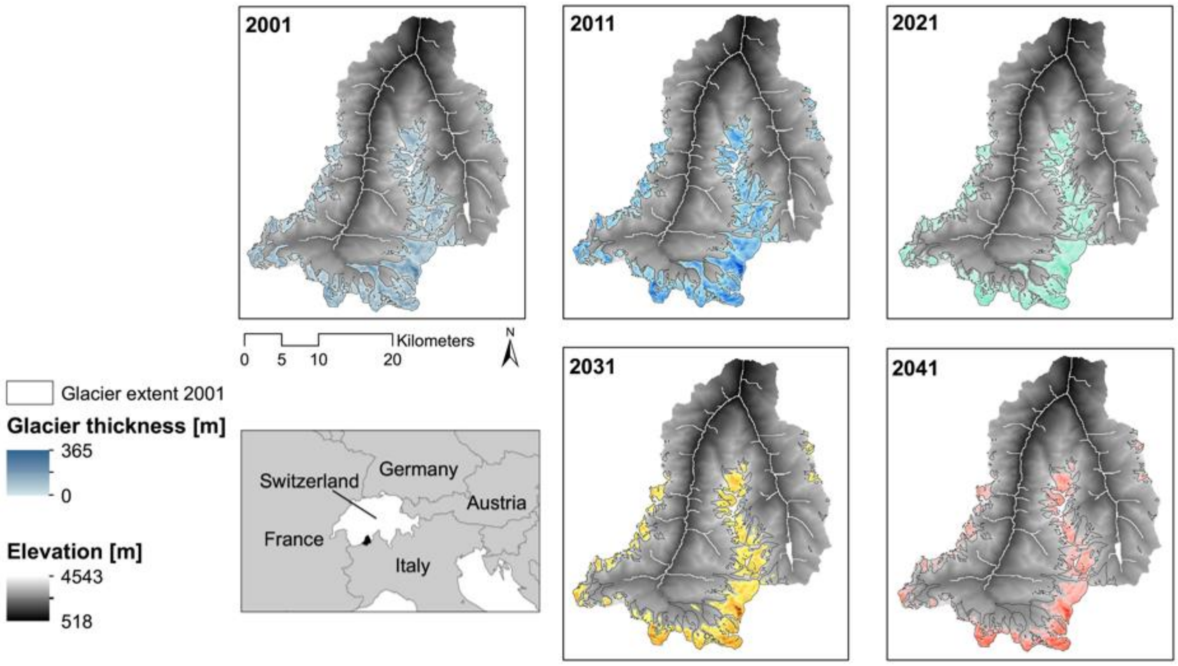

Figure 2: Future evolution of ice distribution at the beginning of each decade of the future scenarios. Modified from: Anghileri at al., 2017.

The climate scenarios up to 2050 consistently show a temperature raise which induces an increase in the winter flow, as liquid precipitation increases in face of a reduction in snow fall, and an overall reduction of annual water availability because of glacier retreat. The hydrological model of our modelling framework is capable of accurately reproducing the complex orography and the hydro-meteorological processes typical of the mountainous regions, thus allowing for an accurate representation of the glacier melt processes (Figure 2). We account for the official energy strategies of the European Union and Switzerland to generate the scenarios of future electricity price. These energy strategies are characterized by nuclear phase out in many European countries, increase in the share of solar and wind power sources, and increasing CO_2 emission permit prices. The corresponding electricity price scenario shows a significant increase in price in comparison to historical records and an enhanced volatility due to the intermittency of solar and wind generation.

We assess the impacts of the water availability and price scenarios accounting for two performance metrics which represent the two main interests of hydropower companies, i.e., the electricity production and the corresponding revenue. These two metrics are used to define possible different adaptation strategies which aim at maximizing the production and/or the revenue when considering the scenarios of water availability and electricity price. The difference between the seasonal patterns of water availability (usually abundant in spring) and electricity prices (usually higher in winter) causes the maximization of electricity production not to coincide with the maximization of revenue.

The performances of each different hydropower reservoir operating strategy are, thus, graphically represented with Pareto fronts (solid lines in Figure 3), where each point represents a different trade-off between the two performance metrics. Since we aim at maximising both the metrics, an operating strategy is better than another if it is located upper-right. The Pareto fronts are surrounded by a coloured area which represents the uncertainty associated with the climate variability.

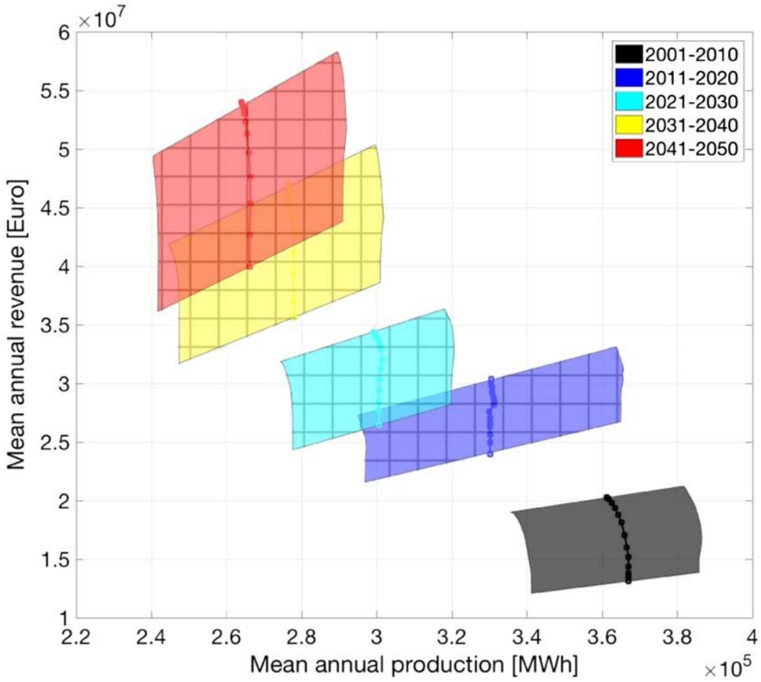

Figure 3: Results of the DSS application. Solid dotted lines represent the Pareto fronts corresponding to each scenario. Since the numerical models generate more than one plausible water availability series to represent the uncertainty of the future, we compute the Pareto front of each of these series, but, instead of plotting all of them, we colour the area which they span and highlight the intermediate Pareto front. The grey area represents the traditional operation strategy, while the coloured shaded areas with square pattern represent the performance of the adaptation strategies computed considering both water availability and electricity price change.
Source: Anghileri et al., 2017.

Figure 3 represents the results of the DDS application. The performances between the traditional operation strategy (grey area) and the strategies adaptating to the water availability and electricity price change (colored areas) show an increase of the mean annual revenue (moving upwards) and a decrease of mean annual production (moving to the left). Indeed, the percentage of future production loss with respect to the traditional operation strategy is consistent with the percentage of reduced water availability across decades with respect to the current water availability. The same consistency is observable also when considering the increase of revenue and the price evolution in the next decades. Although the electricity production is projected to decrease, the revenue is expected to increase considerably with respect to the current price scenario. Figure 3 shows that the size of the colored areas is variable from the decade 2011-2020 to the decade 2041-2050, meaning that the uncertainty of each scenario varies across decades. For example, in the farthest decade in time, the 2040-2050, the uncertainty is much bigger than in the others due to a higher share of new renewable sources in the mix of sources for electricity generation.
These results show that energy policies, for example, CO2 emission permit price, which are usually not considered in impact studies, may have significantly more impactful effects on hydropower systems than climate change, which is instead a standard practice in scientific literature impact studies.

Acknowledgments
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For a more detailed description of our work, please refer to the following publication:

Anghileri, D., Botter, M., Castelletti, A., Weigt, H., & Burlando, P. (2018). A comparative assessment of the impact of climate change and energy policies on Alpine hydropower. *Water Resources Research*, 54, 9144-9161. https://doi.org/10.1029/2017WR022289