S1: Details on possible extensions of exogenous parameters the hydro-economic model

Our hydro-economic hydropower model was designed to combine approaches of economic hydropower optimization with hydrological parameters. The main goal was the assessment of water level fluctuations in a hydropower reservoir. The basic premise of our approach is to provide a flexible modular setup that can easily be adjusted to available model capacities. The presented generic model represents the linkage between economic dispatch and WLF. This in turn can be linked to more detailed economic models providing price inputs and market dynamics on the economic side and more detailed hydrological, and climate models on the water inflow side. We would like to emphasize that more detailed programming inevitable makes the model more case-specific because more exact boundaries and exogenous parameters have to be assumed. To pertain to a more general approach in the main manuscript we therefore provide possible model adjustments here in the supplementary materials.

Adjustments to generic model formulation to extend economic aspects

From an ecological perspective the seasonality of WLF is crucial because it affects aquatic organisms' life-cycles (see main manuscript for examples). Based on published literature on hydropower operations, we therefore chose mid-term optimization that shows monthly or weekly resolutions of storage level values for our model (Birger et al. 2001). As a more detailed production optimization, an alternative short-term optimization can be adopted with a time horizon consisting of incremental steps such as hours or quarter-hours. Such a model extension merely requires more detailed price data and potentially higher computation capacities as the model size increases, but the generic formulation remains unchanged (Borghetti et al. 2008; Chang et al. 2001). In the generic model energy prices were assumed as exogenously given. A possible model extension is to approximate real and future prices by stochastic dynamic programming (Eichhorn 2010); i.e., by using time series of historic information to generate price distributions, by forward simulation (a model tries to find possible value developments based on current data sets (Longstaff and Wang 2004)), or by a rolling planning model approach (Troy et al. 2010). Further details how stochastic dynamic programming is used to determine energy prices and inflows could be taken from: Siqueira et (al. 2006) who employed stochastic programming; from Blanco et al. (2001) who modeled prices with geometric Brownian motion; from Birger et al. (2001) who used Stochastic Dynamic programming based on a Markov chain principle; and from Zambelli et al. (2009) who modeled prices and inflows in concert using an open-loop feedback control framework.

Adjustments to exogenous hydrological parameters

The second adjustable aspect of the generic model is its linkage to detailed hydrological inflow and climate models. In the generic formulation this linkage is represented by the external input parameter *natural inflows* i_t. For the climate change scenario S2 we adjusted the base case values according to forecasts specifically modelled for the reservoir which we investigated.

Consequently, the same can be carried out for a large variety of other influences like evaporation depending on the available model capacities. Further details of how climate change in the form of all possible effects on the water-balance of a reservoir catchment can result in different exogenous parameters can e.g. be found in Wang et al. (2014) who used Grey Forecasting Models to forecast precipitation. An overall review of methodologies developed to capture and forecast the effects of climate change on hydropower reservoirs in alpine regions can be found in Gaudard et al. (2014)

Finally, also the included technical parameters can easily be tailored to the specificities of the investigated hydro plant (Lu et al. 2004). Turbine capacities, minimum and maximum storage levels and further regulatory restrictions can be adjusted and added/omitted following the logic presented in the generic model framework (Schlecht and Weigt 2014).

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