SHORT TERM OPTIMIZATION OF HYDROPOWER PRODUCTION: TOWARD AN INNOVATIVE HYDRO-ECONOMETRIC MODELLING FRAMEWORK

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KEY POINTS

- *Water resources management.*
- *Optimization.*
- *Econometric forecasting.*

1 INTRODUCTION

Optimal management of artificial reservoirs is of paramount importance especially in the view of an altered climate that could affect severely water-related sectors such as hydropower generation (*De Ladurantaye et al.*, 2007), or floods and droughts (*Xu et al.*, 2015). In this context, the optimization of hydropower production represents a key factor aiming at maximizing revenues as well as to comply with hydraulic and environmental flows constraints (*Reed et al.*, 2013). This, nevertheless, is a challenging problem which involves both hydrological and economic forecasting under multiple spatial-temporal scales and is characterized by different source of uncertainty (*Raya et al.*, 2017).

Consequently, the resulting complexity forces to face the optimization problems isolating one factor from the others in order to understand its role the entire problem. The main object of this work is thus to analyze coupled econometric and hydrological modeling as proper tool in order to enhance short term hydropower optimization and to establish the first step in the full comprehension of the problem. In particular, this contribution is an investigation on the advantages that innovative econometric models could have on reservoir management (*Avesani et al.*, 2022).

2 METHODOLOGY

Optimization of short-term hydropower production scheduling is achieved in the present work by combining forecasts of day-ahead energy prices and synthetic observations of incoming flow to the reservoir (*Avesani et al.*, 2022). Economical revenue (R) is maximized by means of the following equation:

$$\mathrm{R}=\sum_{t=1}^{24} \gamma \cdot Q(t) \cdot \Delta t \cdot \Delta H(Q) \cdot \eta \cdot P(t) \tag{1}$$

where γ is the specific weight of water, Q is the turbined flow, ΔH is the net hydraulic head, taking into account the hydraulic losses, in turn dependent on Q, Δt is the time interval, η is the energy coefficient of the system, and finally P is the energy price, at the current time t. Equation (1) is maximized by means of an inverse problem in which the hourly scheduling of turbined flow represents the unknown.

Forecasting of short-term energy price P is performed with two families of models: a linear autoregressive model, selected as benchmarks because of its widespread use in the literature and its relatively good performance, and an Autoregressive Integrated Moving Average (Autoarimax) approach based on an iterative lag selection and dummy variables (i.e. variables determined outside the econometric model. This last case could be considered as the state of the art in econometric modeling (*Gianfreda et al.,* 2020). For sake of clarity, the following variables are considered as exogenous: local electricity demand, commodity prices and RES (Renewable Energy Systems) production.

Since the objective of the present work is to evaluate solely the possible revenues increase due to use of an innovative econometric forecasting model, we assumed that inflow to storage reservoirs is known as provided by the ICHYMOD model (*Norbiato et al.,* 2009). Finally, the objective function defined in equation (1) is maximized by using Speed-constrained Multi-objective Particle Swarm Optimization. This algorithm was selected due its capability to handle complex and non-linear optimization problems.

3 CASE STUDY

The optimization is applied to the management of the Vernago's reservoir which is placed along one of the tributaries of the upper Adige river. The reservoir has a storage capacity of about 40 Mm^3 with a maximum outflow rate of 13.7 m^3s^{-1} and an annual regulation with a maximum reservoir level in late summer and a minimum reservoir level at the end of the winter season. It is worth to mention that, due to the fact that this work does not consider weekly or seasonal reservoirs optimization and in order to avoid early emptying of the reservoir, we limited the maximum daily volume available for the energy production on the basis of simulated production data, by means of HYPERstreamHS (*Avesani et al.*, 2021 & *Galletti et al.*, 2021), during an historical period mimicking the long-term pattern of the daily releases from the reservoir. In addition, it is worth to mention that, due to the location of the reservoir and optimization window, this work focuses coherently on the Northern Italy market zone using day-ahead electricity price forecasting estimated over such market zone (*Bille et al.,* 2020).

Regarding outflow water scheduling forecasting, the optimization process is performed for the year 2018, where actual energy prices are available as well as short term price forecasts with both benchmark and Autoarimax models. In particular, the optimization driven by actual prices establish the reference solutions. These are afterwards used in order to assess the economical revenues computed with foretasted prices.

4 RESULTS AND CONCLUSIONS

The aim of this section is to compare the revenue obtained with the optimization driven by the benchmark model and the revenue obtained with the optimization driven by the Autoarimax model. This is accomplished by introducing the percentage ratio metric $\Phi_M{}^d$ which can be expressed as follows:

$$\phi_M^d = \frac{R_d^M}{R_d^R}$$

where $R_d{}^M$ is the actual revenure obtained by the bidding as driven by the Benchmark (M = B) and the Autoarimax (M = A) econometric models while $R_d{}^R$ is the revenue given by the optimization driven by the perfect 1 day- ahead foresight.

Figure (1) shows $\Phi_B{}^d$ and $\Phi_A{}^d$ obtained in the reservoirs of Vernago and Monguelfo at monthly scale, respectively. It can be noticed that: $\Phi_M{}^d$ is always larger than 82%; the use of Autoarimax forecasts leads to a revenue increase at Vernago up to 2.31% with respect to the case in which Benchmark forecasts; the maximum gain decreases to 1.31% at Monguelfo; the maximum gain given by the adoption of the Autoarimax model respect to the Benchmark is registered in April for both hydropower systems; and the Vernago cases shows an attenuated seasonal variability, though associated to dissimilarities between monthly values of $\Phi_B{}^d$ and $\Phi_A{}^d$.

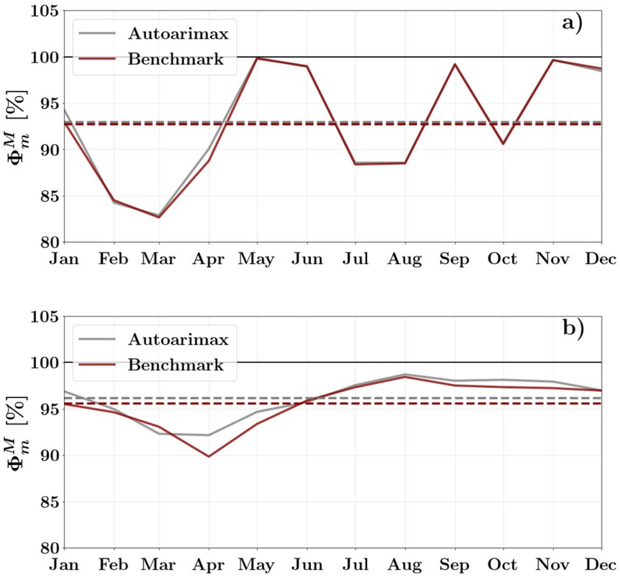

Figure 1*: Revenue percentage ratios for optimizations driven by Autoarimax (grey) and Benchmark (red) econometric forecasts for the Monguelfo (a) and the Vernago (b) reservoirs. Annual average percentage ratios are also presented as dashed lines.*

These results show that selection of the econometric model directly influence hydropower optimization. Though the monthly revenue differences seem limited in its magnitude for the reported case study, this difference is not negligible it term of net income for an energy company.

It is also worth pointing out that reservoir size is undoubtedly a key factor in short term optimization of hydropower production and it will be explored in future works.

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