



Hydropower Generation in the Age of Climate Change, Leveraging Causal AI

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We use AI to understand how infrastructure networks shape our lives and impact our environment.

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Acknowledgment





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Norway's Hydropower



https://www.mdpi.com/1996-1073/14/5/1425



- Hydropower's share of Norway's electricity production is about 95%.
- Hydropower is a clean and flexible source of energy for Norway and Europe.

Forecasting water behind dams is complex!

- More connection to Europe and the UK electric grids and their electricity markets.
- The recent energy crises in Europe.





Forecasting water behind dams is complex!

• Climate change (historical meteorological and hydrological data are not valid anymore!)





Forecasting water behind dams is complex!

 Integration of intermittent offshore wind energy (Norway plans 30GW by 2040).





Where and when do we have water?





1% improvement in inflow forecasting values billions of Euro!

Power Generation Market Size 2022

Scale	B Euro
Global	1660.3
Europe	682.8
Norway	30.6

Source: https://www.reportlinker.com/p06193685/

Classical hydropower Scheduling



Optimization of available hydropower generation resources to fulfill the electricity demand considering various constraints and uncertainties.



Solving this stochastic and dynamic optimization problem is complex, and time consuming.

Hydropower Scheduling & Al





Example of AI Application : Inflow Forecasting

Use Case

- Storåna river in Hjemland, Rogaland
- Lyseboten I and Lyseboten II Hydropower stations
- Data includes Meteorological and Hydrological parameters







Example of AI Application : Inflow Forecasting

Collected data





Table 1. Collected data

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Example of AI Application : Inflow Forecasting

Methodology

Module 1: Stepwise decomposition by VMD:

- It is a non-wavelet signal processing technique
- It is a self-adaptive technique and suitbale for nonlinear and non-stationary data

Benefits:

- Reduce the complexity by breaking down a timeseries into sub-elements
- Generate physically meaningful sub-elements



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Inflow Forecasting

Methodology

Module 2, Causal feature selection:

- It is a feature selection method based on causal inference.
- It finds features which have maximum contribution to the target value (inflow).

Benefits:

- Reducing the computational time by removing redundant features.
- Improving prediction performance.
- Improving understanding of the data (more explainability).



Example of AI Application : Inflow Forecasting Results

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Location 8 Precipitation Decomposition



Why not more than 5 Modes?





Selected Causal Variabels



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S:1)

Geo-spetial relationship between selected causal candidate



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Sil)



Sensitivity analysis on different training horizons for inflow forecasting at Location 8





Data splitting for training, validation and testing





Input data composition vs. CVD performance for inflow day ahead forecasting

Senarios	Data	Model	period	NRMSE	Computational time (s)
1	Historic inflow	LSTM	t+24	1.7	547
2 Weather	LSTM	t+2/	1.66	442	
	Weather	CVD-LSTM	1724	1.03	80
3	Weather+	LSTM	t+2/	1.06	629
3	hydrological data	CVD-LSTM	l+24	0.8	96
	Weather+	LSTM		0.68	900
4	hydrological+ HBV data	CVD-LSTM	t+24	0.51	76

70% improvement

25% improvement

Inflow Forecasting

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Results

Comparison of CVD performance with different forecasting horizones.

Madala	Metrics	Future forecast horizons					
wodels		t+1	t+2	t+6	t+12	t+18	t+24
CVD-RF	NRMSE	0.08	0.13	0.28	0.49	0.57	0.68
	NSE	0.98	0.98	0.93	0.8	0.73	0.61
	Std	0.9	1.27	2.71	4.71	5.53	6.63
CVD-LR	MSE	0.06	0.1	0.28	0.41	0.49	0.55
	NSE	0.99	0.99	0.93	0.85	0.79	0.75
	Std	0.7	1.02	2.65	4.02	4.8	5.27
CVD-MLP	MSE	0.12	0.17	0.32	0.41	0.51	0.53
	NSE	0.97	0.97	0.91	0.86	0.78	0.77
	Std	1.2	1.66	3	3.9	4,89	5.09
CVD-LSTM	MSE	0.1	0.16	0.31	0.38	0.46	0.51
	NSE	0.98	0.97	0.92	0.88	0.84	0.8
	Std	0.8	1.7	3.1	3.8	4.04	4.9

RF: RF: Random Forest ,R: Linear Regression, MLP: Multilayer perceptron, LSTM: Long Short-term memory.



Inflow Values at Location 8



Publications:

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journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Day-ahead inflow forecasting using causal empirical decomposition

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OPEN Short-term Cascade Inflow Forecasting using Causal Multivariate Variational Mode Decomposition

Mojtaba Yousefi^{1,*}, Jinghao Wang^{2,+}, Øivind Fandrem Høivik^{3,+}, Jayaprakash Rajasekharan^{2,+}, August Hubert Wierling^{1,+}, Hossein Farahmand^{2,+}, and Reza Arahandeh^{1,+}

Recent changes in climate affect patterns and uncertainties associated with river water regimes which have a huge impact on hydropower generation and reservoir storage operation. Hence, reliable and accurate short-term inflow forecasting is vital for better facing climate effects and improving hydropower performance. This paper proposes a Causal Variational Mode Decomposition (CVD) preprocessing framework for the multi-step ahead inflow forecasting problem. In other words, CVD is a preprocessing feature selection framework which is built upon multiresolution analysis and causal inference. The CVD can reduce the computation time while increasing the forecasting accuracy by down-selecting the most relevant feature to the farget value (inflow in a specific location). Moreover, the proposed CVD framework is a complementary step to any machine learning-based forecasting method as it is used four different forecasting algorithms in this paper. We validated the CVD using actual data from a river system downstream of a hydropower reservoir in the southwest of Norway provided by Lyse Produksjon AS company, one of the largest electricity producers in Norway. The experimental results prove that using CVD improves the day-ahead forecasting accuracy by almost 49%. We will investigate other possible variables and other causal inference

Takeaway



- Climate changes, the presence of renewable energy and the complexity of electricity price market have a huge impact on the hydropower scheduling problem.
- Causal AI can improve hydropower scheduling problems by reducing complexity, uncertainties and time consumption.
- An example of using Causal AI for forecasting water inflow for a damregulated reservoir is presented

Thank You



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