

CARTIF



Forecasting for system resilience: flow and power forecasting using Ensemble Machine Learning Models

Raquel López Fernández

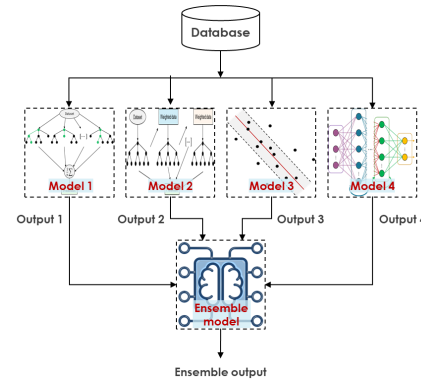
Energy Division. CARTIF Technology Centre

8 September 2026

1. Who we are and why now?



2. AI-based modelling approaches for flow/energy



3. Smart forecasting in La Vega HPP



4. Replication pathway



1

[TECHNOLOGY
CENTRE] **CARTIF**



WHO WE ARE?

 **247**
40 PhD Staff

Our goal

To generate cutting-edge scientific and technological knowledge, enabling innovation and technology transfer to address complex challenges in key factors

AGRI-FOOD AND PROCESSES



INDUSTRIAL AND DIGITAL SYSTEMS



ENERGY




iAMP-Hydro


D-HYDR FLEX


HYDR 4U



iAMP-Hydro Project overview



iAMP-Hydro **improves the digital operation** of existing Hydropower plants through **iAMP** – an **intelligent Asset Management Platform** with new digital sensors, services, and secure open data-sharing protocols.

Solutions:

1. Condition monitoring and predictive maintenance
2. Ecological status
3. Improved flow forecasting



Partners



Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

CARTIF

Cuerva*

EasyHydro

NORCE

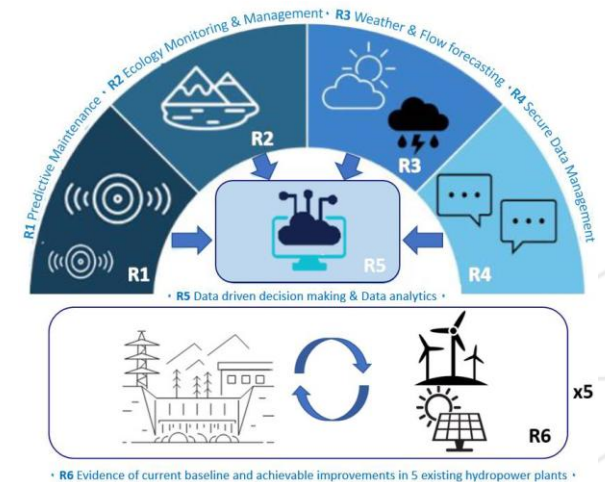


PPC
Renewables



Suite5
We Deliver Intelligence

WIP
RENEWABLE
ENERGIES



Horizon Europe Programme



1st Oct. 2023 → 30th Sept. 2026



iAMP-Hydro Project has received funding from EU's Horizon Europe research and innovation programme under grant agreement No 101122167.

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AI & digitalisation: a new strategic priority for the EU energy sector

NEW | European Commission

3 June 2026

Strategic Roadmap for Digitalisation and AI in the Energy Sector

COM(2026) 501 final

EU policy signal: accelerate AI deployment across the energy system while strengthening data, interoperability and secure digital services.

"Digital tools and AI can help grid operators, power plants, storage facilities and industrial sites run more efficiently and predictively."

European Commission, 2026

1

AI deployment

Digital & AI solutions across the energy system

2

Predictive operation

More efficient and predictive operation of energy assets

3

Data-driven energy system

Secure data sharing, interoperability and AI at scale



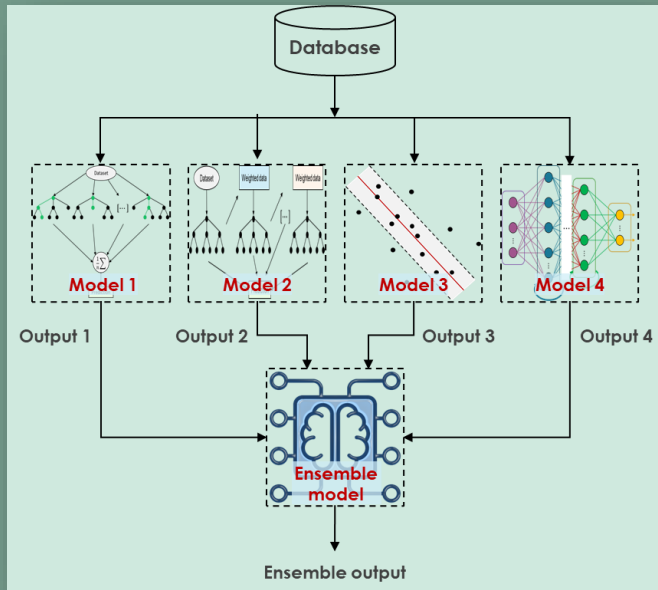
iAMP-Hydro is already putting this vision into practice for hydropower.

AI-based forecasting | Predictive O&M | Data integration | Digital services



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AI-based modelling approaches for flow/energy forecasting

What can AI forecast in hydropower?

- **CARTIF methodology**

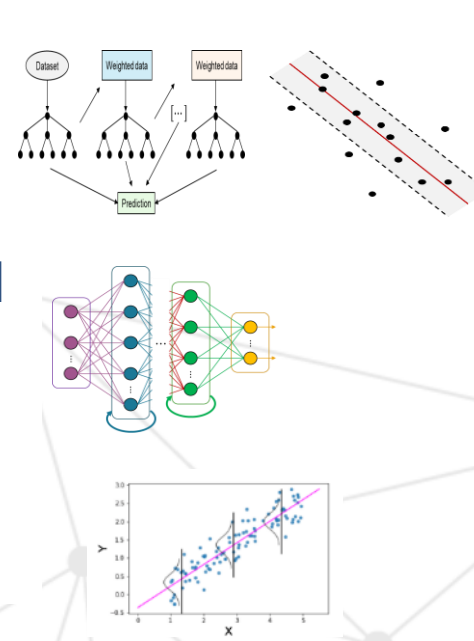
AI-based modelling approaches for flow/energy forecasting

- Increasing trend in AI applications HP forecasting over 20 years. Diverse countries and climates (China, Brazil, USA, Spain and Italy)
- Type of HP plants: reservoirs, RoR, cascade systems
- Key AI algorithms identified for forecasting: water level, inflow or extreme events (floods)

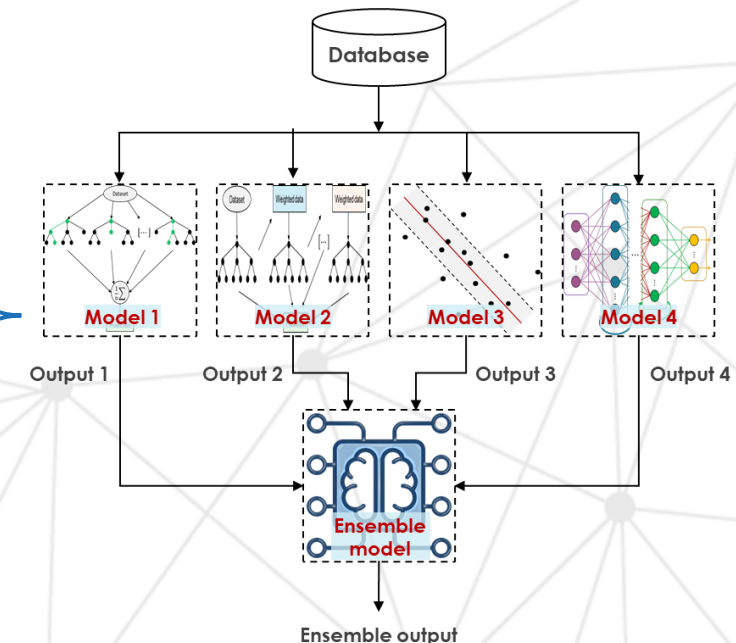
AI-based machine learning (ML) algorithms:

- Conventional ML:** Random Forest (RF) | eXtreme Gradient Boosting (XGBoost) | Support Vector Regression (SVR)
- Deep learning (DL):** Feedforward Neural Networks (FNNs) | Long Short-Term Memory (LSTM) Networks | 1D Convolutional Neural Networks (Conv1D CNNs)

Classical regression models: Linear regression | Polynomial regression



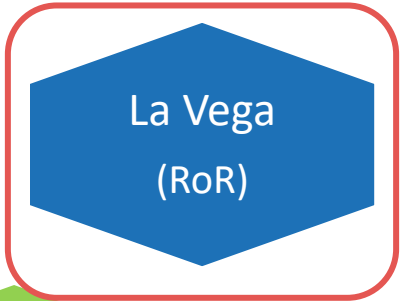
Ensemble modelling



iAMP-Hydro validation sites



CUERVA sites
Granada, Spain



PPC site
Western Macedonia, Greece



4th plant in a complex five-HPP cascade system (Aliakmon River)

Bermejales

Ensemble ML approach (RF–XGB–SVR) forecasting **daily storage changes** and **available power** under precipitation and irrigation-release scenarios



López, R. et al. (2026) — Journal of Hydrology: Regional Studies. "Scenario-based ensemble machine learning for reservoir storage forecasting under irrigation-driven operation". Revision in progress

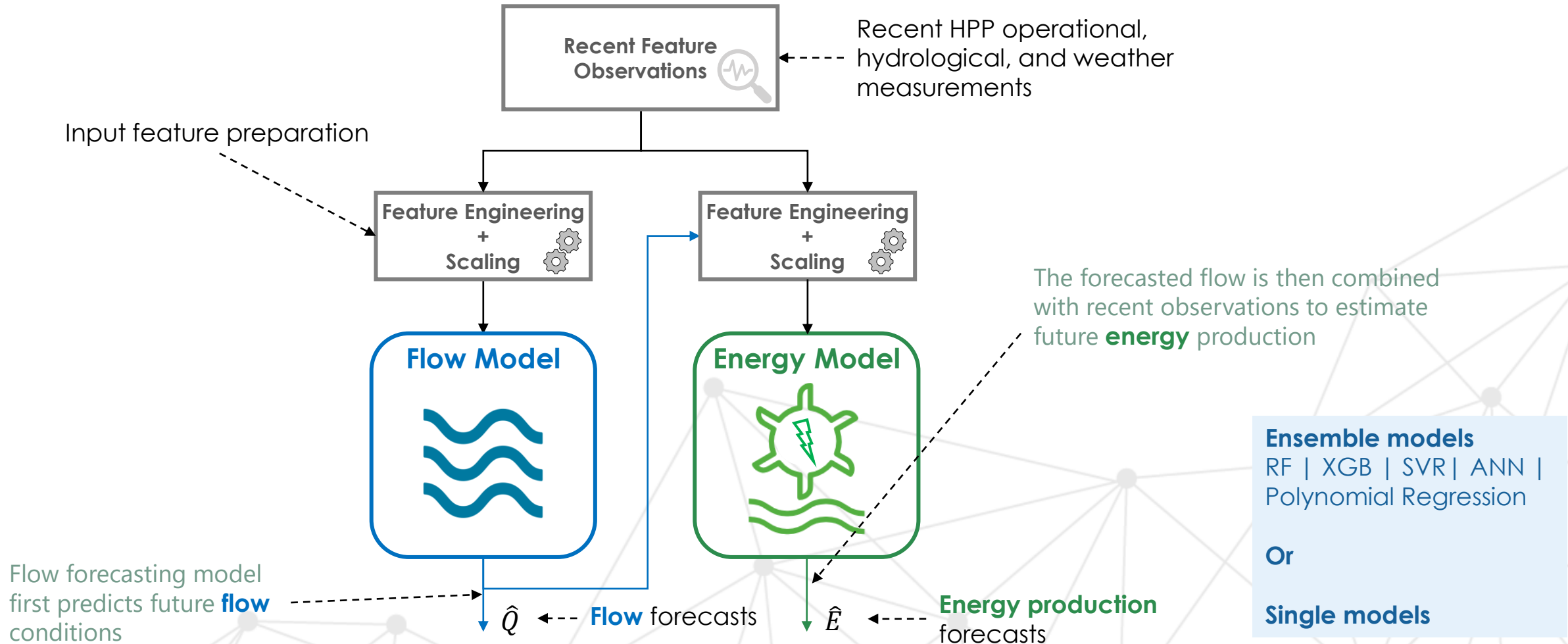
La Vega & Asomata

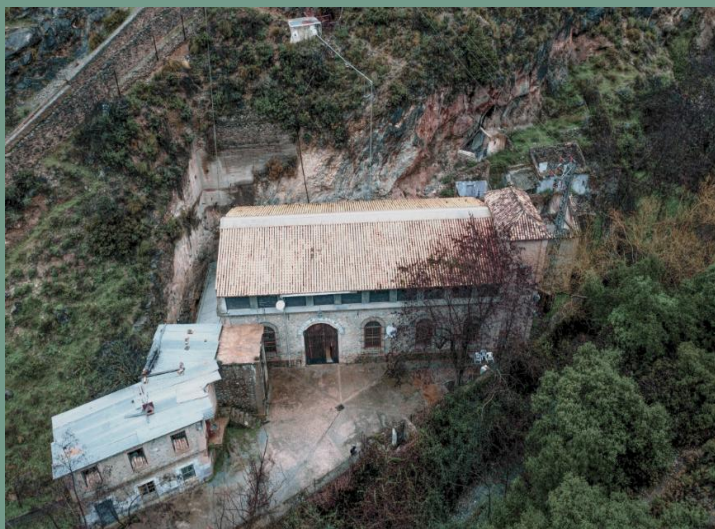
Standardized end-to-end ensemble ML approach (RF, SVR, XGB, ANN) for **process flow** and **available power**



Asomata HPP: Neagoe, A. et al. (2026). Available power forecasting for hydropower plants using artificial intelligence. Presented at SDEWES 2026, Gran Canaria, Spain.

Standardized end-to-end AI framework for process flow and energy forecasting





Smart forecasting in La Vega

HPP

Cuerva*



La Vega: System overview

- **Run-of-river** hydropower plant in the Sierra Nevada, Granada (Spain)
- Inflow mainly from **Monachil River** flows, fed by Sierra Nevada **snowmelt** and **mountain** catchments
- No significant storage reservoir. Generation **follows** natural river inflows
- Water channeled through a high-head diversion system to a **Pelton** turbine (2.407 MW)
- Net head: 183.5 m
- Tailwater discharged back to the river downstream

AI-based forecasting approach	Target variable	Forecast horizon	Status
Ensemble: RF, SVR, XGB, ANN	River flow Available power	7-day-ahead, daily resolution	Train/test: 8 years (2016-2024) Validation: 1 year (2025)

La Vega: available datasets & data splits

Period: 24 Jun 2016 – 31 Dec 2025

Frequency: Daily

24/06/2016

2023

2025

2026

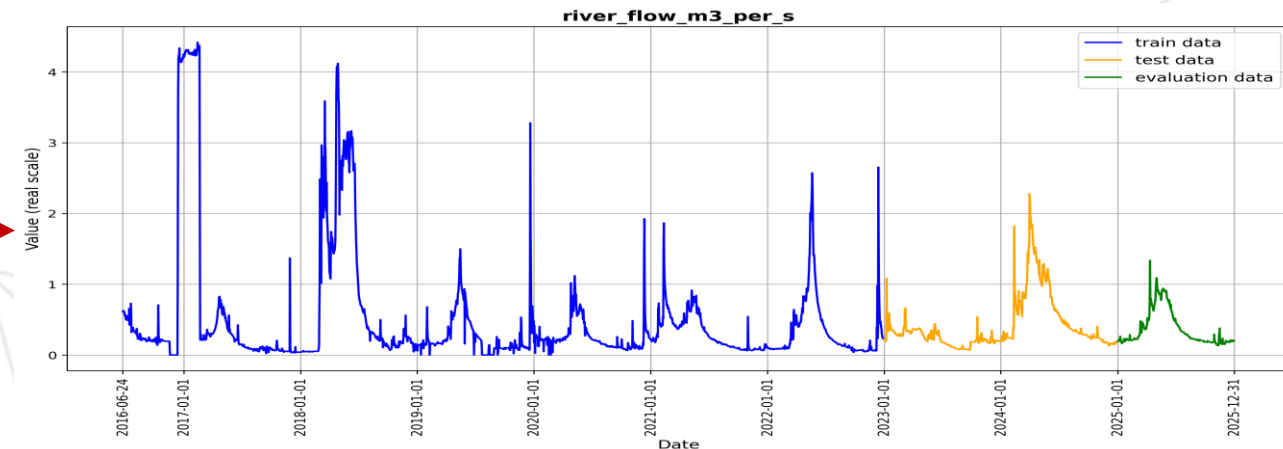
Train
(2381 days)

Test
(731 days)

Validation
(365 days)

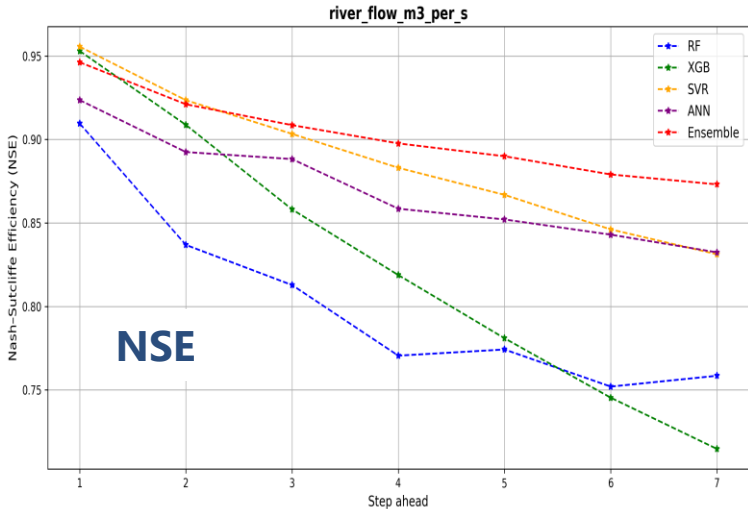
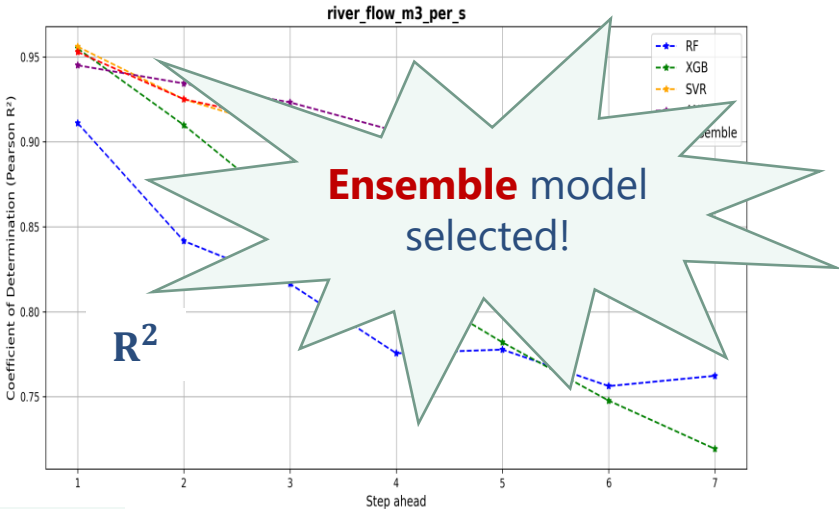
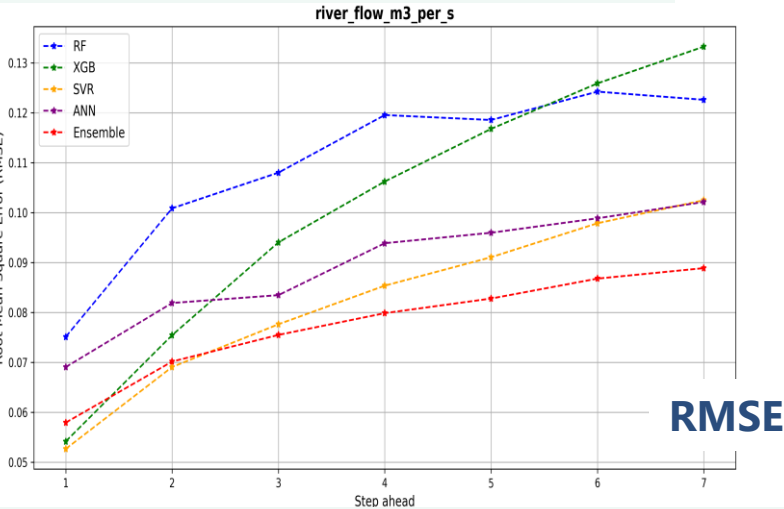
Horizon: 7 days ahead
Historical window: 24 days

Data	River Flow Forecasting	Energy Production Forecasting
River flow (m ³ /s)	✓	✓
River water level (m)	✓	
Monachil precipitation (mm)	✓	
Monachil temperature (°C)		
Veleta precipitation (mm)	✓	
Veleta temperature (°C)	✓	
Veleta snow depth (m)	✓	
Veleta wind speed (m/s)		
Energy production (MWh/day)		✓
Date	✓	✓

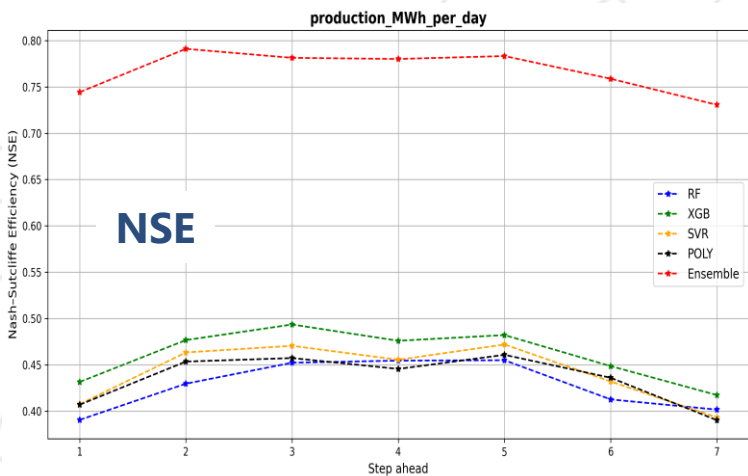
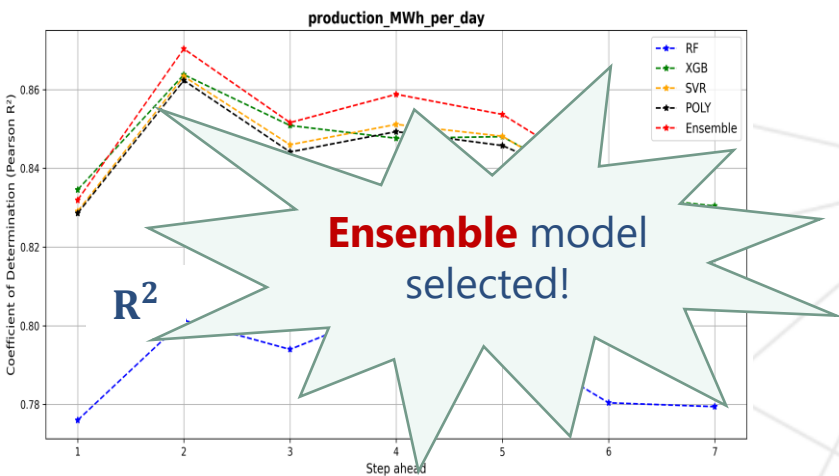
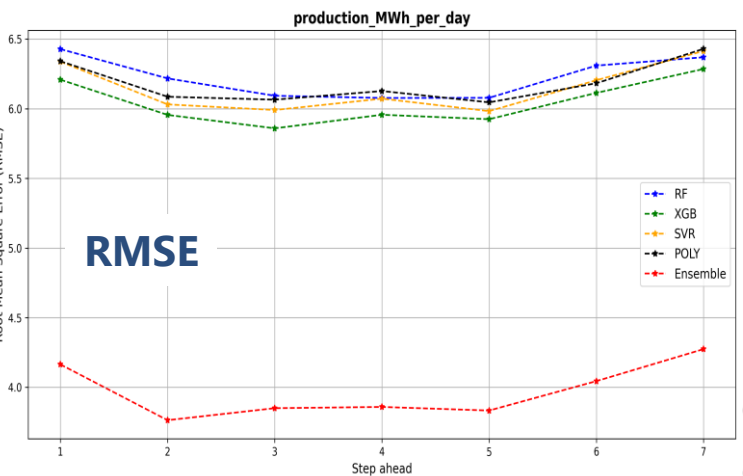


La Vega: model validation performance

River flow [m³/s] model metrics:



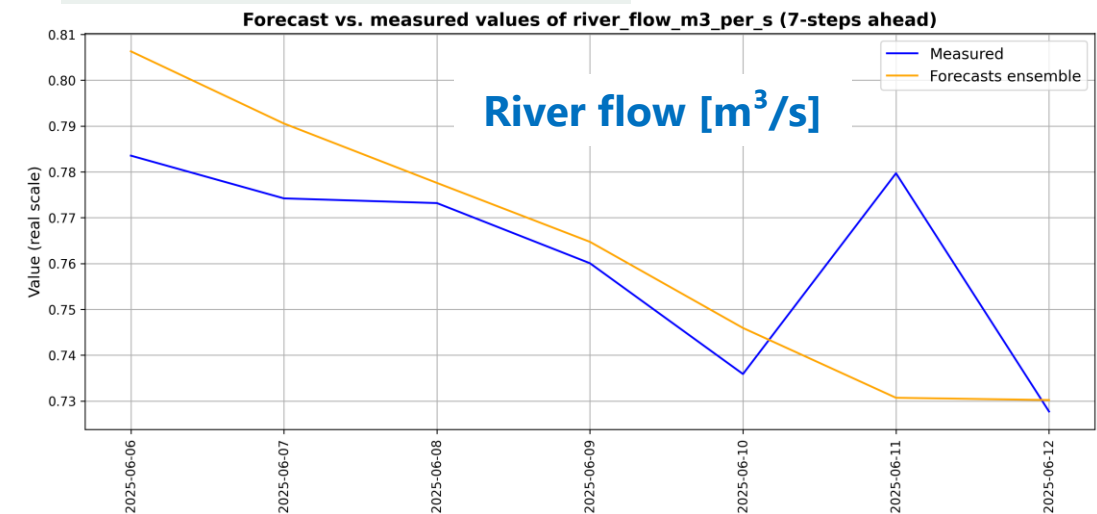
Energy production [MWh/day] model metrics:



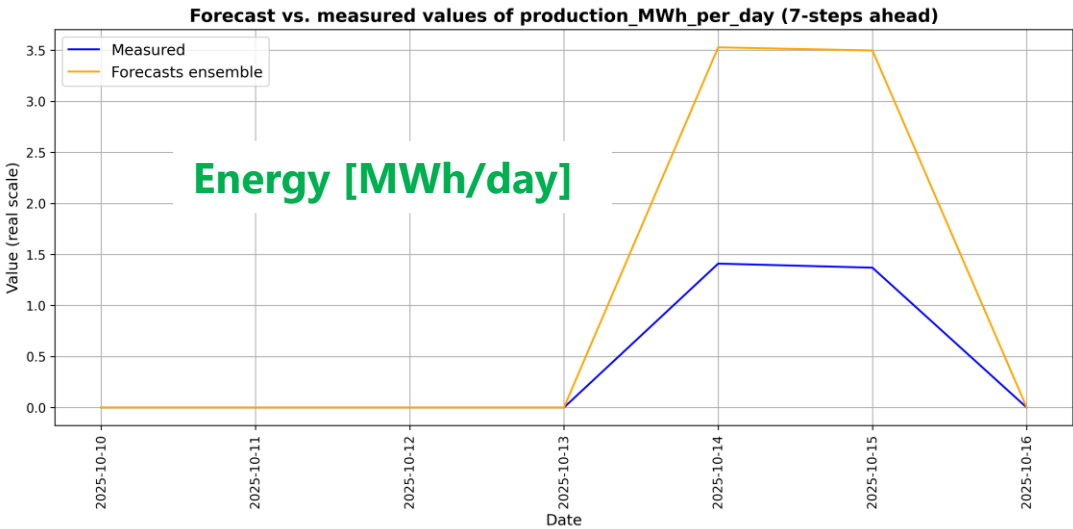
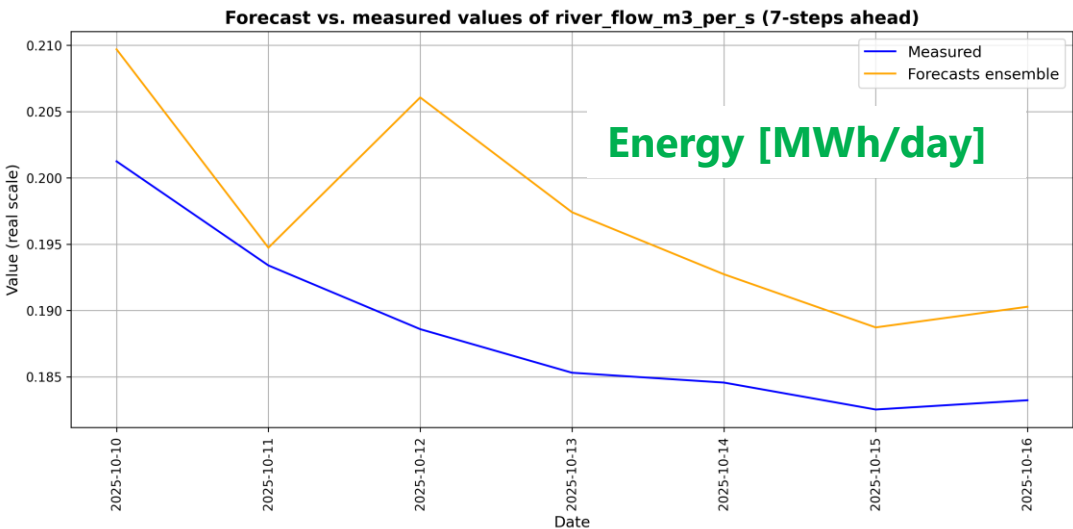
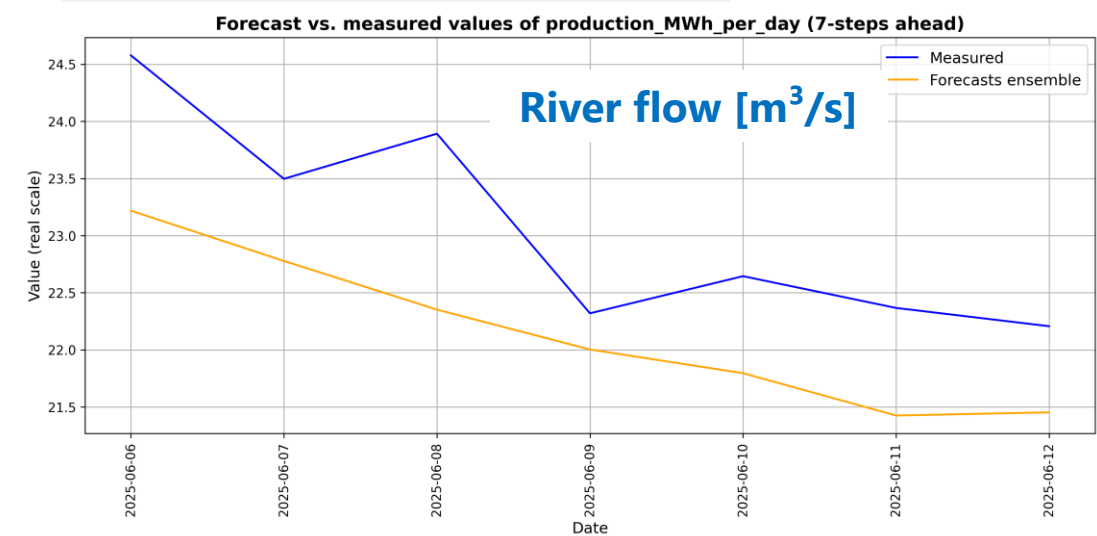


La Vega: performance across random forecast start dates

Forecast start: 6 June 2025



Forecast start: 10 October 2025





La Vega: Conclusions

- The ensemble models capture the **main dynamics** and **seasonal variability** of **river flow** and **energy production**.
- **Reliable forecasts are achieved up to 7 days ahead**, although accuracy decreases with lead time, especially for river flow, and abrupt variations may be smoothed or underestimated.
- **Energy production is not driven by water availability alone**: operational decisions not fully represented in the data introduce additional forecasting uncertainty.





Replication pathway



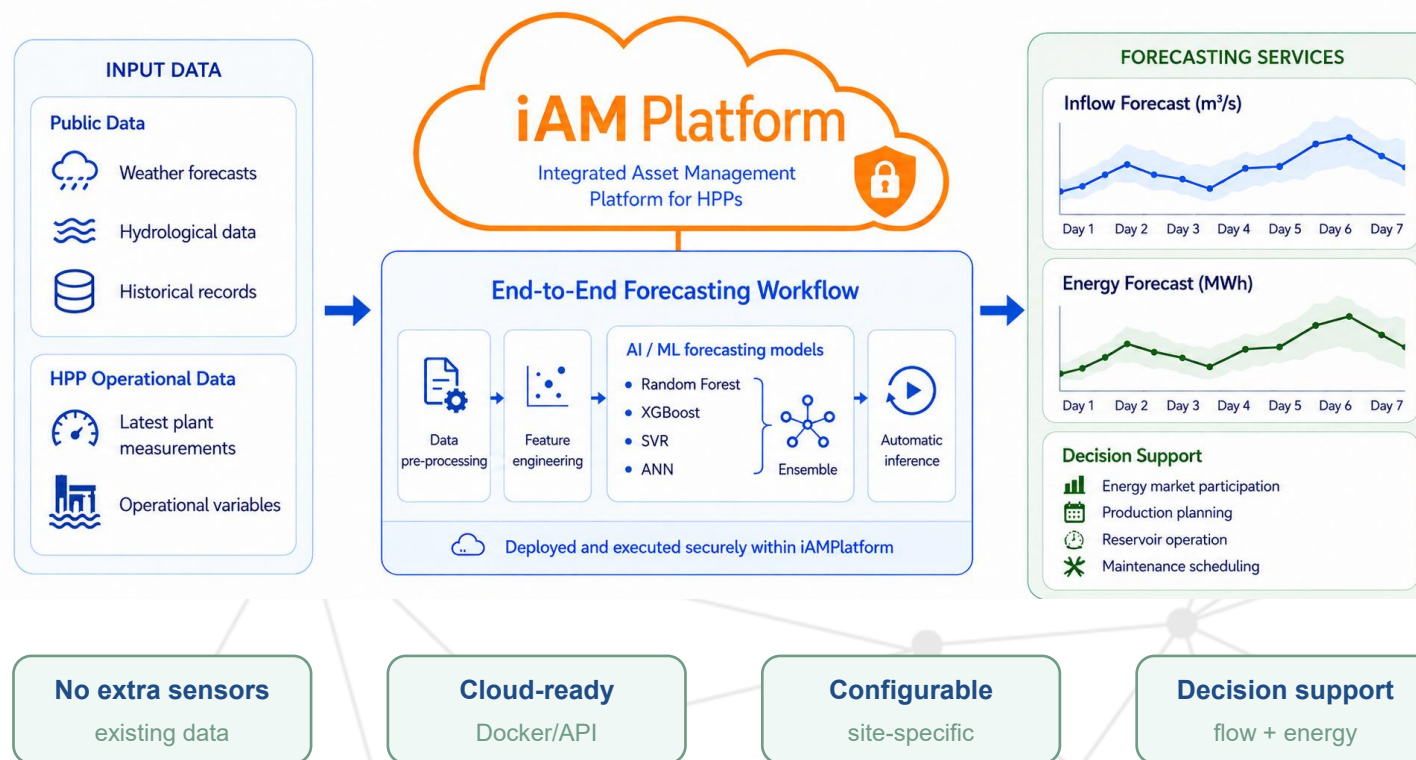
From validated pilots to a replicable forecasting service

Python-based AI forecasting workflow for European hydropower plants

What can be replicated?

- Uses existing public and plant operational data
- Configures AI models for each plant layout and data availability
- Forecasts flow / storage and available power
- Supports RoR, reservoir and cascade systems
- Can be deployed as a service within the iAM Platform

A forecasting workflow already validated in Spain and Greece can be adapted to other HPPs with limited site-specific tuning





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