



Digital maintenance for sustainable and flexible
operation of HYDROpower plant

Decision Support System for Sustainable Hydropower Operations

Pietro Marzaroli



This project has received funding by the European Union's Horizon Europe research and innovation programme under Grant Agreement N° 101122311



Table of contents

01 DSS Presentation

02 Use Cases

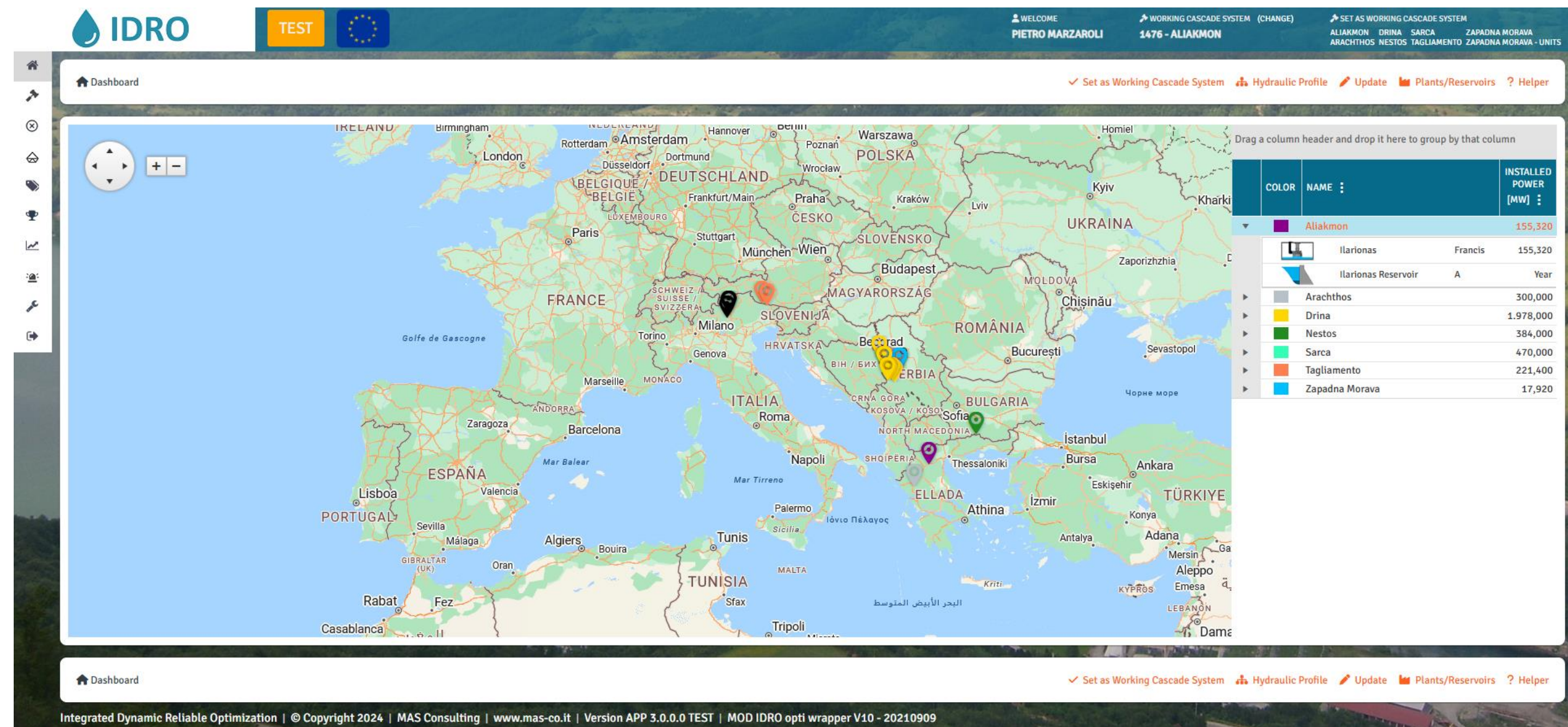
03 Tests Performed

04 Conclusions

05 Questions

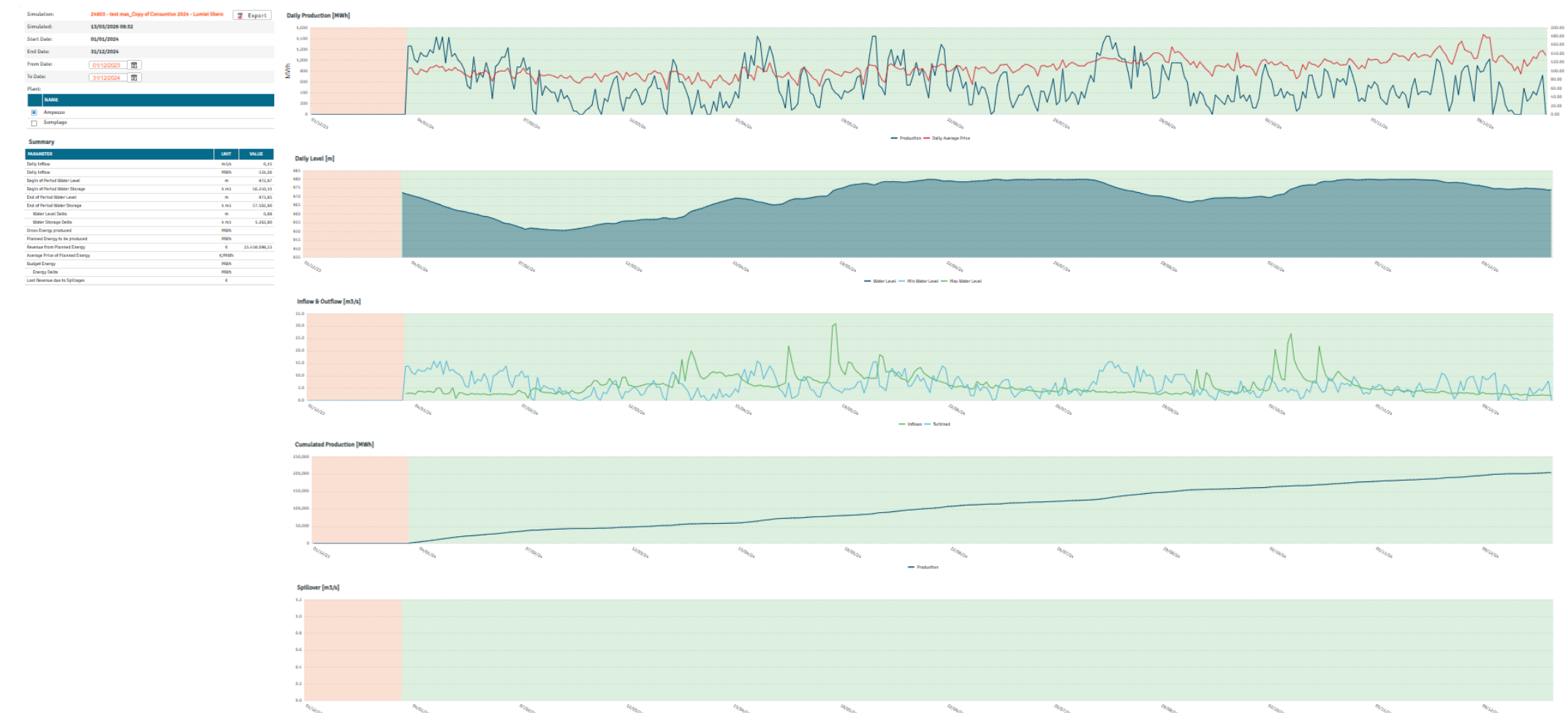
Platform structure: from assets to scenarios

- Unified workspace for hydropower asset and cascade management
- Geographic dashboard for selecting and exploring cascade systems
- Management of reservoir level constraints and plant unavailability
- Integration of simulation data: inflows, prices, technical and historical data
- Dedicated workflows for long-term and short-term optimization
- Results, monitoring and administration functions ensure traceability and controlled use



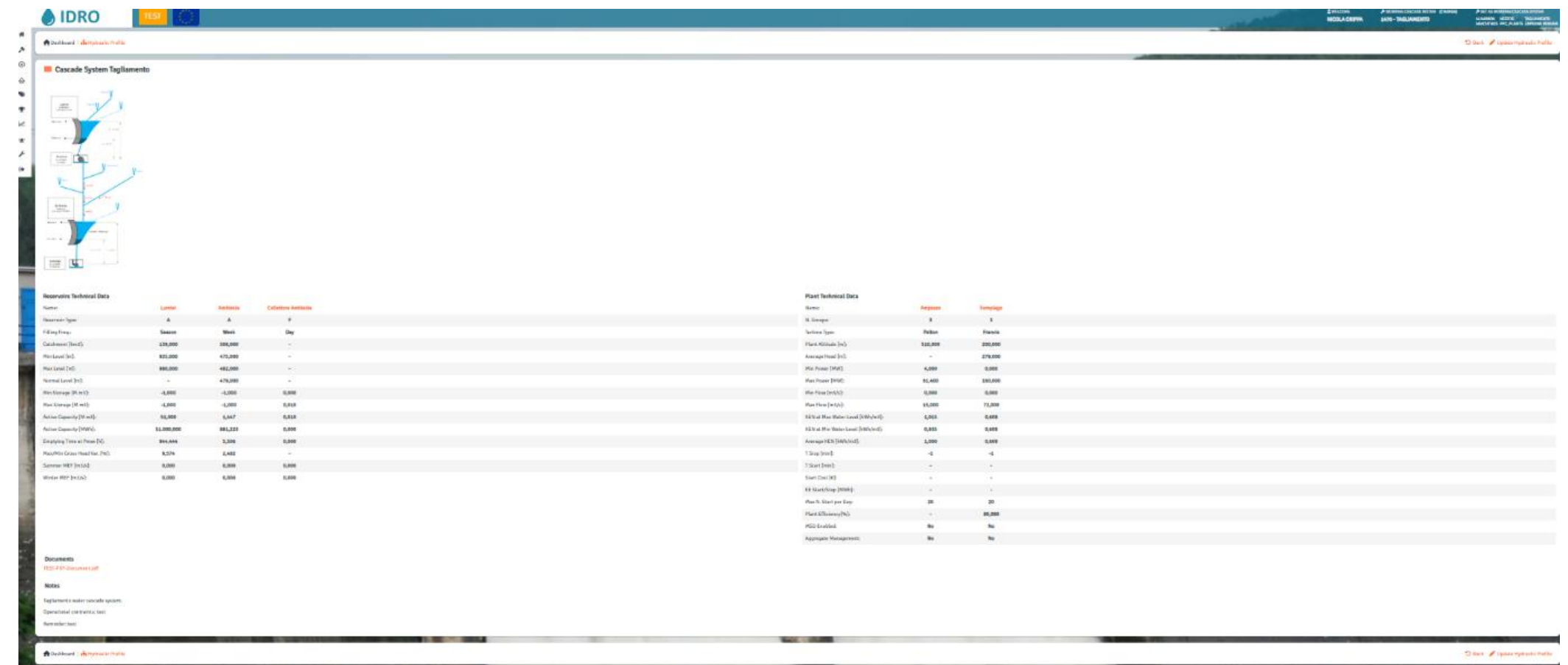
Optimization engine: feasible and value-driven schedules

- Modular optimization framework based on linear programming
- Water flows are the main decision variables across the hydraulic system
- Objective: maximise revenues over the selected planning horizon
- Reservoir balances, storage limits and technical constraints are embedded in the model
- Supports both long-term planning and short-term operational scheduling
- Produces feasible production schedules aligned with hydraulic and market conditions



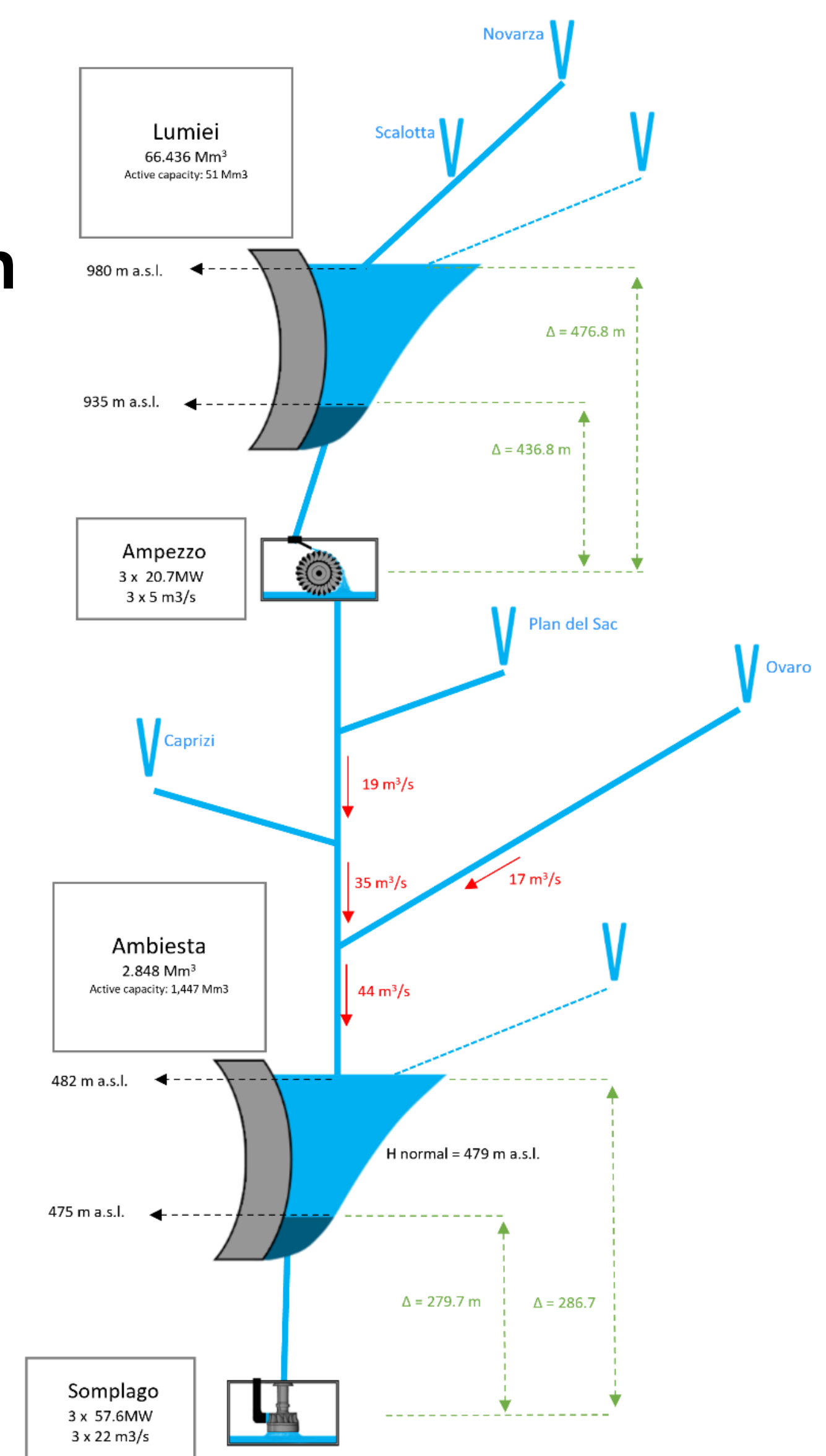
AI support: natural-language access to platform information

- An AI-based chatbot supports interaction with the Di-Hydro platform
- Provides access to project information and hydropower asset data
- Supports queries on plant limits, reservoir characteristics and capacities
- Facilitates access to optimization inputs and simulation results
- Enables users to retrieve operational information through natural-language questions
- Complements the DSS by making complex information easier and faster to access



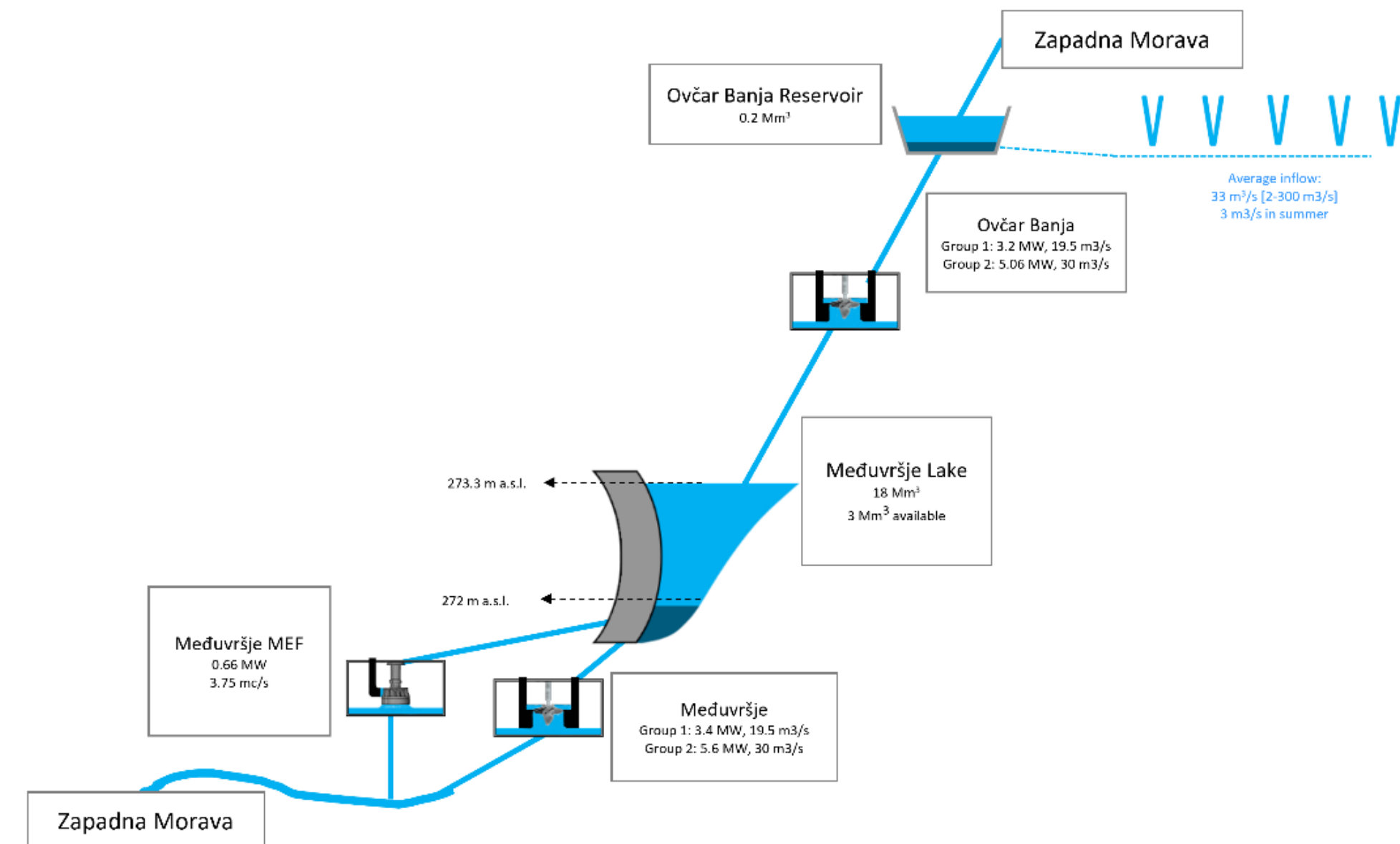
A2A Italian Pilot: Tagliamento Cascade System

- The cascade comprises two reservoirs and two hydropower plants (HPPs)
- Lumiei Reservoir is the upstream basin and provides seasonal storage capacity
- Lumiei feeds Ampezzo HPP, equipped with three Pelton units and 62.1 MW of installed capacity
- Water released from Ampezzo and several intakes reaches Ambiesta Reservoir, which provides weekly storage capacity
- Ambiesta supplies Somplago HPP, equipped with three Francis units and 172.8 MW of installed capacity



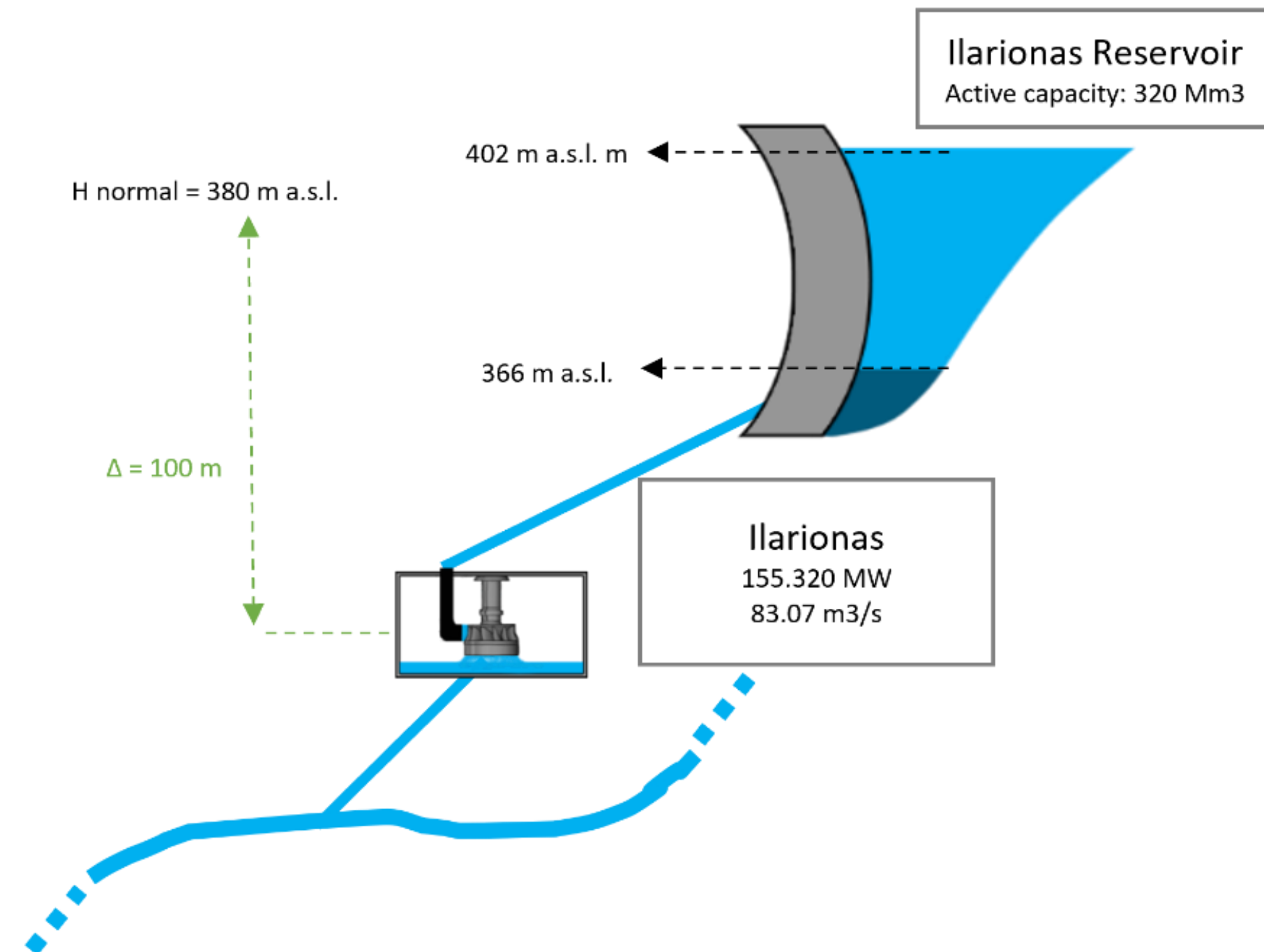
EPS Serbian Pilot: Zapadna Morava Cascade System

- The cascade comprises two reservoirs with daily storage capacity and requires coordinated short-term water management
- Ovčar Banja Reservoir supplies Ovčar Banja HPP, with two Kaplan units and 8.26 MW of installed capacity
- The outflow from Ovčar Banja HPP directly feeds downstream Međuvršje Lake
- Međuvršje HPP has two Kaplan units and 9 MW of total installed capacity
- A dedicated Francis unit uses the minimum environmental flow (MEF) for power generation



PPC Greek Pilot: Aliakmon Cascade System

- The Aliakmon use case is represented by the Ilarionas Reservoir–HPP system
- Ilarionas Reservoir provides annual storage capacity for long-term water management
- The reservoir supplies Ilarionas HPP, which has two generating units and 155 MW of installed capacity
- The reservoir–plant configuration supports long-term production and reservoir-management testing
- The PPC Greek pilot also includes HPPs in the Arachthos and Nestos cascade systems



A2A Long-Term Validation — 2023

- Validates the Di-Hydro DSS against A2A's internal annual optimization algorithm
- Full-year 2023 run using historical operating conditions
- Objective: compare Sauris/Lumiei reservoir management and hydropower production
- Historical Italian day-ahead prices and recorded inflows provide economic and hydraulic inputs
- Machine unavailability, official curves, operating limits and boundary levels ensure comparability

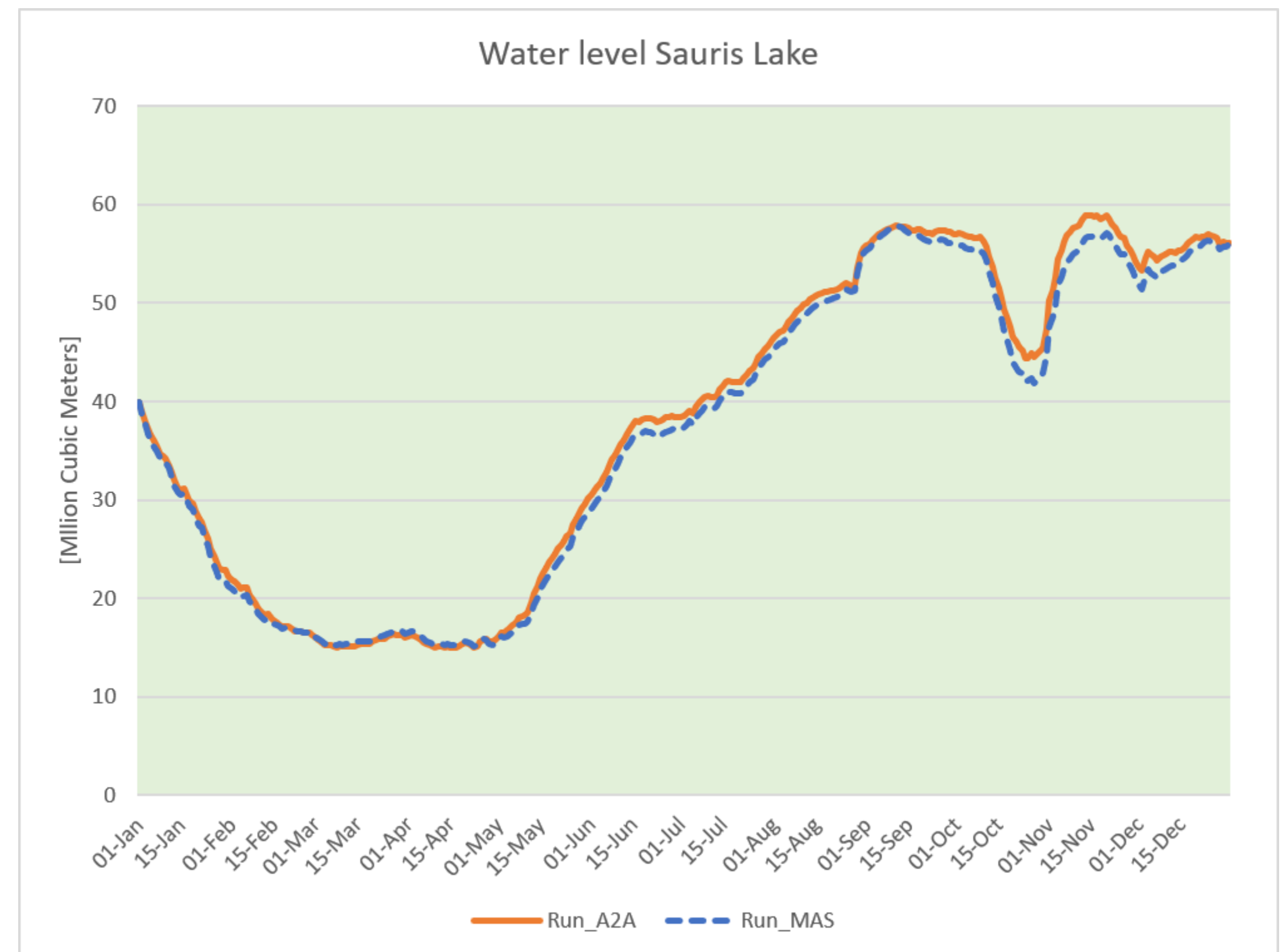
TEST CONFIGURATION

PLANNING HORIZON	Full year 2023
ECONOMIC SIGNAL	Italian day-ahead prices
HYDRAULIC INPUT	Recorded reservoir inflows
OPERATIONAL CONSTRAINTS	Unavailability + level limits
COMPARABILITY	Official curves and boundary levels

Historical conditions were reproduced before comparing optimized dispatch strategies.

A2A Long-Term Validation — DSS vs A2A

- DSS and A2A produce very similar annual Sauris Lake drainage trajectories
- The DSS generally maintains a slightly lower level, anticipating part of production
- Annual energy production is nearly equivalent: Ampezzo is approximately 0.3% lower and Somplago is unchanged
- Normalized revenue improves by approximately 0.3%
- Price capture improves by 0.5 €/MWh
- The DSS reproduces A2A's strategy while slightly improving economic optimization



A2A Short-Term Validation — February 2026

- Focuses on day-by-day management of Verzegnis/Ambiesta Lake
- The DSS is compared with A2A's dedicated short-term optimization algorithm
- Test period: 2–8 February 2026, including a rain event and strongly variable inflows
- Actual Italian day-ahead prices and observed inflows provide economic and hydraulic inputs
- Official curves, operating limits and equal boundary levels ensure comparability
- Ambiesta maximum level is constrained to 482 m a.s.l.

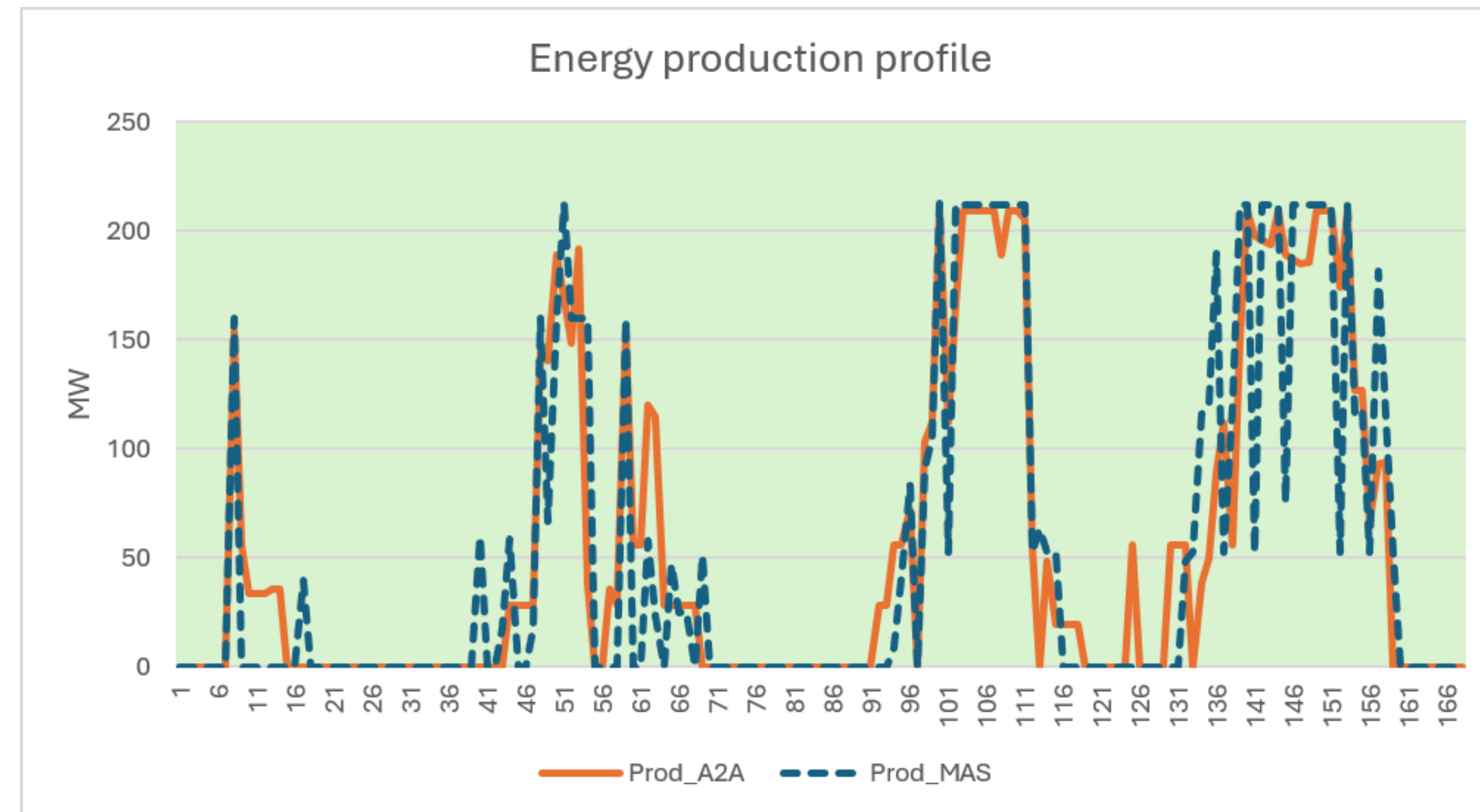
TEST CONFIGURATION

PLANNING HORIZON	7 days
STRESS CONDITION	Rain event + variable inflows
ECONOMIC SIGNAL	Actual day-ahead prices
RESERVOIR LIMIT	Ambiesta $\leq$ 482 m a.s.l.
COMPARISON BASIS	Same starting and ending levels

The test challenges short-term dispatch under rapidly changing hydrology.

A2A Short-Term Validation — DSS vs A2A

- Both algorithms generate similar short-term reservoir-management strategies
- The DSS follows the overall water-level evolution produced by A2A
- The DSS reaches the minimum reservoir level once more during the seven-day period
- A2A is therefore slightly better at avoiding operating limits
- The DSS achieves a 0.8% higher price-capture rate
- Hourly energy-production profiles remain very similar



EPS Short-Term Validation — Zapadna Morava System

EPS emphasized short-term optimization for the Ovčar Banja–Međuvršje system

Validation uses an August back-testing exercise and manual operation as reference

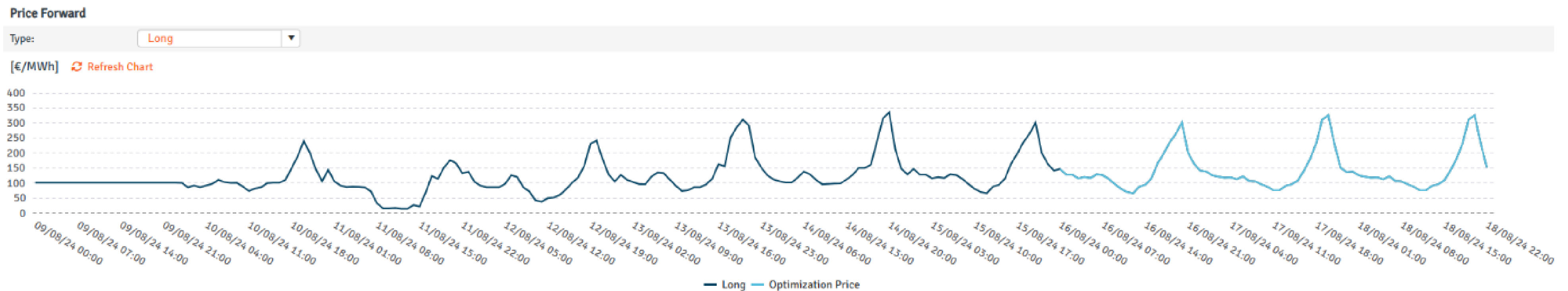
Hungarian day-ahead prices provide the economic signal

Estimated reservoir inflows provide the hydraulic input

Official technical data, level-storage relationships and boundary levels are included

Međuvršje Lake inflow is assumed to be zero for modelling purposes

Actual plant operating data under manual control support comparison



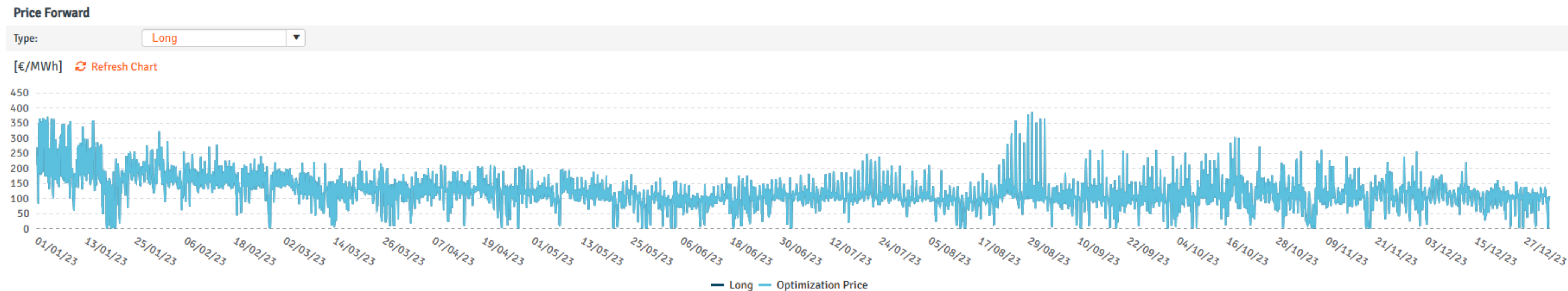
EPS Validation — Optimized vs Manual Operation

- Manual operation prioritizes low operational risk and nearly constant reservoir levels
- Fixed, conservative outputs limit dynamic storage use and can increase hydraulic losses
- The DSS evaluates inflows, reservoir constraints, turbine characteristics and prices together
- Digital turbine curves identify efficient operating points and allocate flow between units
- Water is stored during lower-price periods and dispatched during higher-price periods
- Validation remains constrained by hourly inflow-data quality and availability

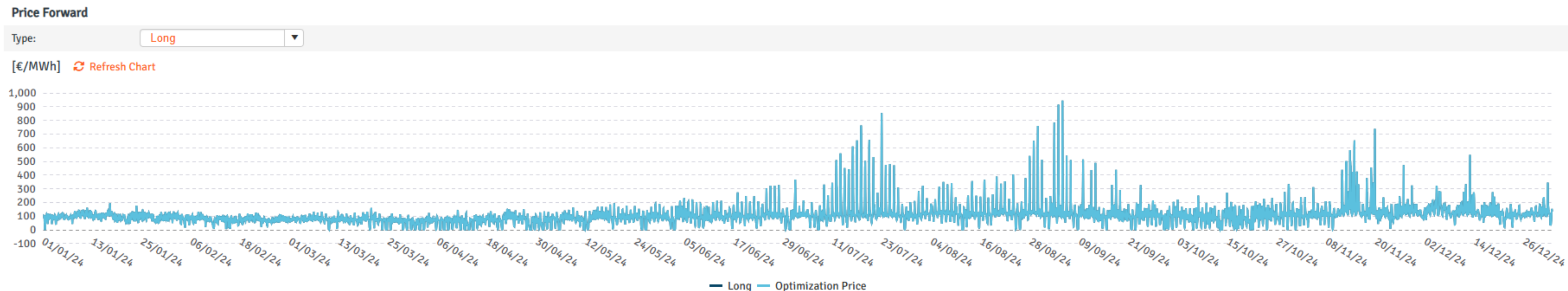


PPC Long-Term Validation — 2023

- DSS results are compared with actual 2023 production
- Historical Greek day-ahead prices provide the economic input
- Historical Aliakmon reservoir inflows provide the hydraulic input
- The official level-storage curve ensures comparable reservoir representation
- Starting and ending reservoir levels are defined for the optimization period
- The test assesses annual production scheduling under historical conditions



- The second PPC long-term validation uses historical operating conditions from 2024
- DSS results are compared with actual PPC production during 2024
- Historical Greek day-ahead prices and actual Aliakmon inflows provide the inputs
- The official level-storage curve ensures comparable reservoir representation
- Starting and ending reservoir levels are defined for the optimization period
- The 2023 methodology is repeated under a different market and hydrological year



Ilarionas Operation Diverges from DSS Results

- Actual dispatch must satisfy constraints beyond day-ahead price maximization
- Key divergence drivers include cascade coupling and commitments to the transmission system operator (TSO), including automatic and manual Frequency Restoration Reserve (aFRR and mFRR)
- Intraday and balancing-market participation creates additional dispatch opportunities
- Ecological, irrigation and municipal-water obligations can require releases regardless of electricity prices
- Start-stop costs, ramp limits and asset-protection practices further restrict feasible schedules

Divergence driver	Operational reality	Potential DSS gap
1 Water-use obligations	Seasonal irrigation and municipal-supply releases; continuous ecological minimum flows	Price-led dispatch may shift releases toward peak-price hours
2 Cascade coupling	Ilarionas releases affect Polyfytos, Sfikia and Asomata storage and head limits	Optimizing Ilarionas in isolation may over-dispatch the head reservoir
3 Ancillary services	Capacity is retained for TSO setpoints, spinning reserve and system flexibility	A day-ahead-only schedule may allocate too much volume to energy sales
4 Cycling and ramp limits	Operators limit starts, stops and rapid ramps to reduce wear, cavitation and water hammer	Low or missing transition costs can create excessive hourly switching
5 Intraday and balancing	Water is held for intraday adjustments and aFRR/mFRR opportunities driven by real-time imbalances	Perfect-foresight day-ahead optimization misses the option value of flexibility

1. FLEXIBLE ACROSS USE CASES

The DSS represents different plants, cascade configurations, planning horizons and operating conditions.

2. VALIDATED AGAINST OPERATING PRACTICE

Across the pilots, the DSS reproduced the main strategies of existing optimization approaches and delivered marginal economic improvements in selected tests.

3. DATA COMPLETENESS DRIVES RELIABILITY

Technical, environmental, water-use and market constraints must be modelled across the full water cascade system.

Follow Di-Hydro!

Visit the **Di-Hydro website**, where you'll find all the Di-Hydro Materials, such as flyers, reports, our newsletter issues, as well as what they say about Di-Hydro around!

Di-Hydro Website: <https://dihydro-project.eu/>

Follow us also on **LinkedIn**:

<https://www.linkedin.com/company/di-hydro-project/>

Check out the **Di-Hydro Podcast Series**:

https://youtube.com/playlist?list=PLna5U7-OPgOtFKTmZXYVby8mP_Daibnwh&si=5n1tL1Ikj0KBLZIZ

Subscribe to our LinkedIn Newsletter:

<https://www.linkedin.com/build-relation/newsletter-follow?entityUrn=7406647955916541952>



Check out the
Di-Hydro Innovation Handbook,
featuring the main results from
the project!



Digital maintenance for sustainable and flexible
operation of HYDROpower plant

Thank you.

Questions?



This project has received funding by the European Union's Horizon Europe research and innovation programme under Grant Agreement N° 101122311