Joint White Paper

DIGITALISING HYDROPOWER FOR EUROPE

iAMP-Hydro

D-HYDROFLEX

Di-Hydro

The iAMP-Hydro project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101122167.

Digitalising Hydropower for Europe's Future Flexibility Needs

Unlocking Reliable, Predictable, Sustainable and Intelligent Hydropower Services through European Innovation

Intended Purpose

This white paper follows on from previously published white papers and aims to share the experiences of three EU-funded projects on the topic of digitalisation in hydropower. It shall support informed decision-making on hydropower in the context of the EU's energy, climate, and environmental objectives, and is addressed to European and national policymakers, particularly those involved in research, energy, digitalisation, and environmental policy. Its aim is to provide an informed overview of the opportunities and potential benefits of digitalisation in the hydropower sector, while highlighting the need for continued and coordinated EU-wide research to support its future development and implementation.

Executive Summary

Europe's energy transition is creating an unprecedented need for flexibility. As wind and solar generation continue to expand, the electricity system increasingly depends on resources capable of balancing variability, maintaining grid stability and providing reserve capacity. Hydropower is uniquely positioned to fulfil this role thanks to its ability to store energy, respond rapidly to system needs and provide a broad range of flexibility services.

However, the role expected from hydropower today differs fundamentally from the role for which much of Europe's hydropower fleet was originally designed. Many plants are ageing, environmental requirements are becoming more stringent, climate variability is increasing, and operators are expected to provide greater flexibility while maintaining reliability, safety and sustainability.

Recent European research and innovation projects demonstrate that digitalisation can address these challenges. Advanced condition monitoring, predictive maintenance, weather and inflow forecasting, ecological monitoring, secure data platforms, digital twins and decision-support systems have already been validated in operational environments across Europe. These solutions improve asset availability, increase operational efficiency, support biodiversity objectives and strengthen hydropower's contribution to flexibility services [1].

The evidence is clear:

Digitalisation is no longer a future concept. It is becoming a prerequisite for operating hydropower as a strategic flexibility asset within Europe's future energy system.

1. Why Europe Needs Digital Hydropower

Europe's decarbonisation pathway relies on rapidly increasing shares of variable renewable generation. While wind and solar technologies are essential pillars of the energy transition, their variability creates growing requirements for flexibility across all timescales, from seconds to seasons. ETIP Hydropower's White Paper "Hydropower's key role in flexibility and storage for a safe, clean and secure European power system – today and tomorrow" identifies hydropower as *Europe's most important renewable flexibility resource*, providing dispatchable generation, storage capability, ancillary services and system resilience [2].

At the same time, ETIP SNET's White Paper highlights the emergence of "Flexibility as a Service", where flexibility must become measurable, predictable, verifiable and secure. Future *flexibility providers will need digital capabilities* that enable participation in increasingly sophisticated energy markets and grid-support schemes [3].

Hydropower can fulfil this strategic role, but only if operators are equipped with the tools required to understand asset condition, anticipate changing hydrological conditions, manage environmental impacts and optimise operations across multiple objectives simultaneously.

Digitalisation therefore should not be viewed as an objective in itself. It is the **key enabler** that allows hydropower to deliver flexibility safely, efficiently and sustainably.

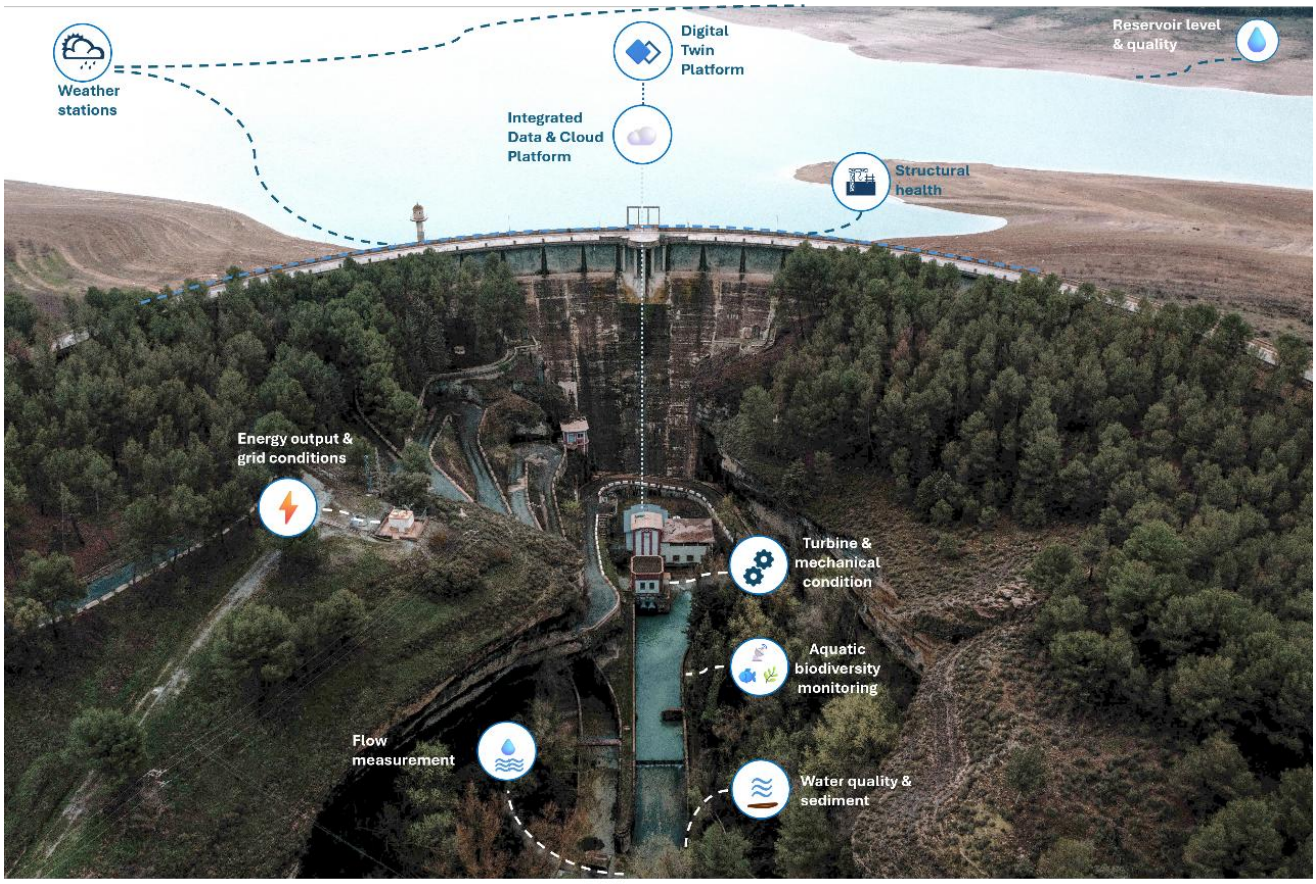

Figure 1: Digitalisation Enabling Hydropower Flexibility – described at iAMP-Hydro demonstration site Bermejales (Spain)

2. Digitalisation as an Enabler of Hydropower Flexibility

Reliable Flexibility

Hydropower can only provide flexibility if assets remain reliable and available.

EU-funded research projects such as Di-Hydro and iAMP-Hydro have demonstrated advanced **digital condition-monitoring** and **predictive-maintenance solutions** capable of identifying degradation processes **before failures occur**. AI-supported techniques can detect bearing faults, cavitation, turbine degradation and abnormal operating conditions using continuously collected operational data.

By reducing unplanned outages and supporting risk-based maintenance, these systems increase confidence in more dynamic plant operation and help operators provide **flexibility services without compromising long-term asset health**.

Predictable Flexibility

Providing flexibility requires more than reliable assets. It also requires reliable knowledge about future water availability and generation potential.

Within iAMP-Hydro, advanced forecasting systems combining machine learning, hydrological models, meteorological data and operational information were developed and validated across multiple European hydropower sites. These solutions support predictions of inflows, reservoir behaviour and energy production.

Complementary work within the Di-Hydro project demonstrated that physically based hydrological models combined with forecasting services can **reduce** inflow prediction **errors by approximately 70%** compared with traditional approaches based purely on historical averages [4].

Forecasting transforms hydropower flexibility from a reactive capability into a predictable and schedulable service.

Sustainable Flexibility

Hydropower flexibility must also remain **environmentally sustainable**.

Within iAMP-Hydro, **novel digital environmental monitoring solutions** were developed and validated to continuously measure ecological conditions such as water temperature, water levels and dissolved gas concentrations. These systems enable operators to move beyond periodic compliance monitoring towards continuous environmental awareness.

The collected information can support decisions related to hydropeaking mitigation, environmental flows, biodiversity protection and water-quality management. Digital ecological monitoring therefore helps reconcile flexibility services with environmental objectives rather than treating them as competing priorities.

Intelligent and Connected Flexibility

The value of digitalisation ultimately depends on the ability to transform information into decisions.

The iAMP-Hydro **Intelligent Asset Management Platform** demonstrates how hydropower data, environmental information, forecasting outputs and market signals can be integrated within a secure and interoperable environment. The platform supports data harmonisation, secure sharing, common information models and decision-support processes across diverse hydropower applications [1] [5].

Together with **digital twins** and **decision-support solutions** developed within the projects Di-Hydro [6] and D-HYDROFLEX [7], these platforms provide operators with the ability to evaluate scenarios, optimise operational strategies and maximise the value of flexibility services [1].

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3. Best Practices and Real-World Experiences

Digitalisation is already delivering practical results in operational environments.

Asset Health and Predictive Maintenance

Di-Hydro [8] and iAMP-Hydro successfully demonstrated AI-based diagnostics and predictive-maintenance solutions capable of detecting equipment degradation and supporting proactive maintenance decisions.

Forecasting and Operational Optimisation

iAMP-Hydro and Di-Hydro demonstrated advanced weather, inflow and production forecasting across sites in Greece, Italy, Serbia and Spain, allowing operators to improve planning, water management and flexibility provision.

Environmental Intelligence

Novel ecological monitoring systems were validated across multiple European sites, demonstrating the feasibility of continuous environmental observation and enabling stronger integration of ecological considerations into plant operations [9].

Secure Digital Platforms

The iAMP-Hydro platform demonstrated interoperability, data sovereignty, secure information exchange and digital decision-support capabilities across five European validation sites [1] [5].

New Business Models

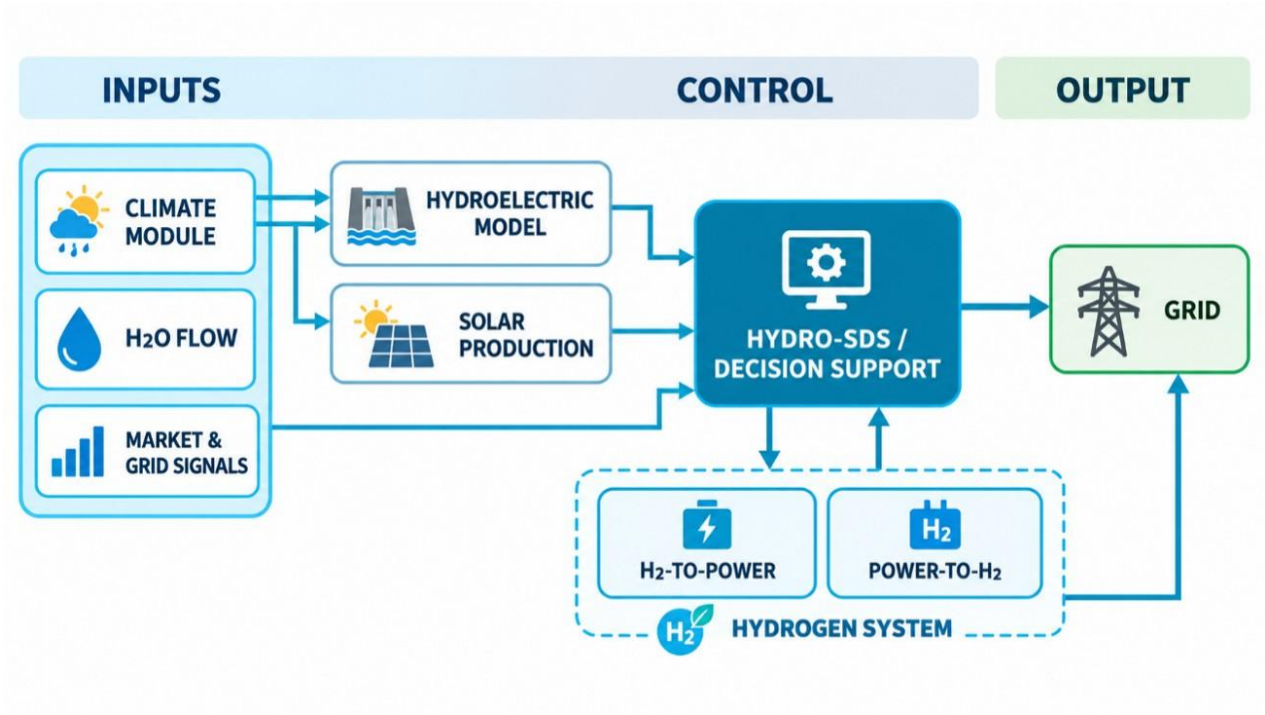

Figure 2: Scheme of the D-HYDROFLEX SDS concept

D-HYDROFLEX introduced the HYDRO-SDS (Smart Decision Support) concept, demonstrating how hydropower, photovoltaic generation, hydrogen systems, storage technologies and electricity markets can be coordinated within a common digital framework. This illustrates how digitalisation can create entirely new value streams and business opportunities beyond traditional electricity generation [10].

Broader European Experience

Additional initiatives such as ReHydro, including the Røldal-Suldal pilot in Norway, further demonstrate how innovation and digitalisation can support flexibility-oriented operation and modernisation of Europe's hydropower fleet [11].

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4. What Is Possible Today and Where the Journey Should End

What Is Possible Today

Hydropower digitalisation is already well established in parts of the sector.

Major OEMs (Original Equipment Manufacturers) such as ANDRITZ and Voith offer sophisticated monitoring, diagnostics, predictive-maintenance and lifecycle-management services. Platforms such as Metris DiOMera [12] and HyService [13] demonstrate the significant value that digital technologies can provide in improving reliability, reducing downtime and supporting maintenance planning.

The **projects** presented in this White Paper **build upon this progress rather than replacing it**.

Current Limitations

At the same time, European demonstration projects reveal several important limitations.

Many existing solutions remain focused on individual components, technologies or vendor ecosystems. Data frequently remains *locked within proprietary silos* and cannot easily be combined with hydrological, environmental or market information. Interoperability remains limited, and large quantities of high-quality data are required to successfully deploy advanced AI solutions.

Project experience also confirms that *no single solution fits every hydropower plant*. **Future digitalisation** efforts must therefore remain **modular, adaptable and scalable** [4].

Where the Journey Should End

The future is not simply a hydropower plant equipped with more sensors.

The future is a **Digital Hydropower Infrastructure** where:

- asset health information,
- environmental intelligence,
- forecasting tools,
- market signals,
- secure data exchange,
- digital twins,
- and decision-support systems

operate together within **a common ecosystem**.

Such an infrastructure would continuously optimise flexibility provision while simultaneously supporting biodiversity protection, climate adaptation, resilience and efficient water management.

5. European Innovation as a Catalyst for Digital Hydropower

The advances described in this White Paper are the result of sustained European support for research, innovation and demonstration activities.

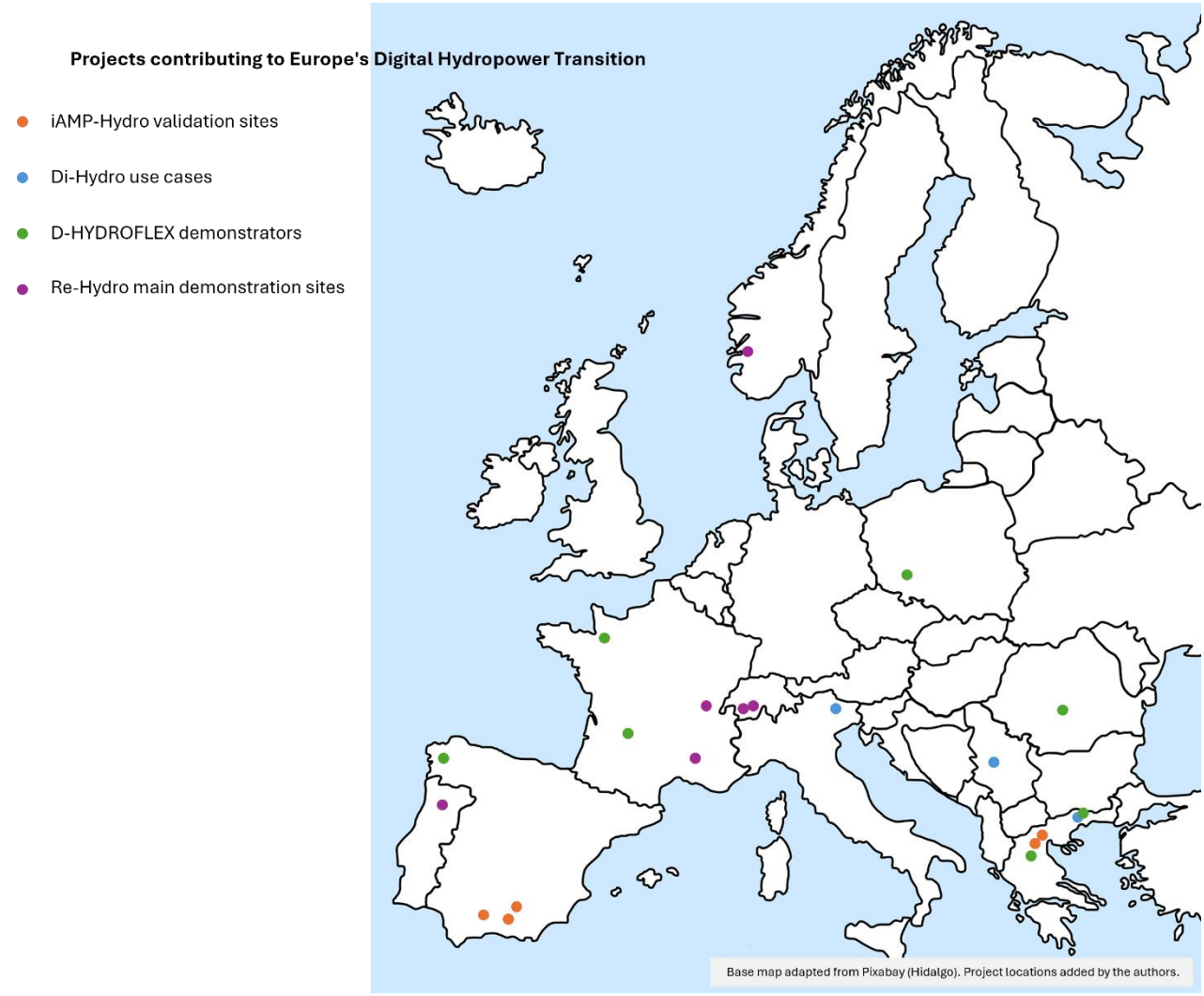

Figure 3: Map showing European Digital Hydropower Innovation Portfolio

The Digitalisation Sister Projects, iAMP-Hydro, Di-Hydro and D-HYDROFLEX, have collectively demonstrated key elements of future digital hydropower operation, including monitoring, forecasting, environmental intelligence, interoperability, decision support and new business models.

These projects have been complemented by broader initiatives, including ReHydro, SE-Hydro [14], TIES [15] and HydroPulse [16], which contribute to innovation, refurbishment strategies, stakeholder engagement and societal readiness.

This portfolio of projects demonstrates that **European funding** is producing tangible results and helping prepare hydropower for its evolving role within **Europe's future energy system**.

6. Outlook

The technologies described in this White Paper have progressed from research concepts towards operational validation.

The **next** challenge is **deployment at scale**.

Future European initiatives will play a crucial role in accelerating this transition. In particular:

HORIZON-CL5-2027-02-D3-24

Large-scale operational validation and upscaling of state-of-the-art generative AI tools and models powering a next-generation digital energy system

This topic directly aligns with emerging opportunities in forecasting, optimisation, digital twins and AI-supported decision-making.

HORIZON-CL5-2027-07-D3-11

Demonstration of hydropower technologies for efficient and forward-looking refurbishment of existing hydropower plants

This topic aligns closely with the need to modernise Europe's ageing hydropower fleet while integrating advanced digital capabilities.

Looking ahead, Europe should focus on:

- interoperability and common standards,
- Digital Twin deployment,
- AI-enabled decision support,
- environmentally adaptive operations,
- hydropower refurbishment,
- large-scale replication of demonstrated solutions.

The **objective** should no longer be the validation of isolated technologies, but the **creation of a secure, interoperable and scalable Digital Hydropower Infrastructure across Europe**.

Conclusion

Europe's energy transition requires flexibility, resilience, sustainability and security at unprecedented levels. Hydropower is uniquely positioned to contribute to all these objectives. Yet fulfilling this role increasingly depends on digital solutions capable of supporting advanced operations, environmental awareness and intelligent decision-making.

The projects and initiatives presented in this White Paper demonstrate that the necessary building blocks already exist. Advanced condition monitoring, predictive maintenance, forecasting, ecological monitoring, secure data platforms, digital twins and decision-support systems have all been successfully demonstrated under real operational conditions.

The challenge ahead is not proving the technologies.

The challenge is enabling their widespread deployment across Europe's hydropower fleet.

Key Message

Europe needs a Digital Hydropower Infrastructure capable of simultaneously delivering energy security, flexibility, biodiversity protection, climate adaptation and efficient water management**.**

Continued support for innovation, interoperability, digitalisation, hydropower modernisation and large-scale deployment will help transform Europe's hydropower assets into a cornerstone of a resilient, competitive and climate-neutral energy system

For more details about the benefits described in this Joint White Paper, you are invited to visit our websites and get on touch with us if you have further questions about our experiences.

D-HYDROFLEX

Website: D-HYDROFLEX - Digital solutions for hydroelectric plants

Di-Hydro

Website: Di-Hydro - Homepage

iAMP-Hydro

Website: Home - www.iamp-hydro.eu

To follow current running digitalisation in the European hydropower sector, visit also the **ReHydro** project.

Website: ReHydro

References

[1] iAMP-Hydro (2026): "Digital Monitoring and Environmental Intelligence for Hydropower - From Data to Decisions: Digital Platforms for Hydropower", https://www.iamp-hydro.eu/news/news/news-session-1-digital-monitoring-and-environmental-intelligence-for-hydropower/05_iAMP-Hydro_Spiros_Kousouris_The-iAMP-Platform-and-Integrated-Solutions-_ETIP_Hydropower_final.pdf (last visited 30.09.2026).

[2] ETIP Hydropower (2025): "Hydropower's key role in flexibility and storage for a safe , clean and secure European power system – today and tomorrow", https://etip-hydropower.eu/assets/White-Papers/WG1_WHITEPAPER_FINAL.pdf (last visited: 14.10.2026).

[3] ETIP SNET (2026), „Flexibility as a Service", https://smart-networks-energy-transition.ec.europa.eu/sites/default/files/2026-08/flexibility%20as%20a%20service-HZ0126111ENN.pdf (last visited 30.09.2026).

[4] iAMP-Hydro (2026): "iAMP-Hydro White Paper and Di-Hydro lessons-learnt", https://www.iamp-hydro.eu/news/news/news-session-2-digital-twins-and-forecasting-for-flexible-hydropower/12_iAMP-Hydro_White_Paper_and_Di-Hydro_lessons-learnt.pdf (last visited 30.09.2026).

[5] iAMP-Hydro (2026): "Introducing iAMP-Hydro: Towards Intelligent Hydropower Systems", https://www.iamp-hydro.eu/news/news/news-final-event-of-the-iamp-hydro-project-exchanging-insights-with-experts-at-the-4th-etip-hydropower-day/01_iAMP-Hydro-Aonghus-McNabola_ETIP_Presentation_8th_Sept.pdf (last visited 30.09.2026).

[6] Di-Hydro (2026): "About _ Concept and Challenges", https://dihydro-project.eu/about/ (last visited 30.09.2026).

[7] D-HYDROFLEX (2026): "Digital solutions for improving the sustainability performance and FLEXibility potential of HYDROpower assets", https://d-hydroflex.eu/wp-content/uploads/2026/03/D-HYDROFLEX_ReHydro_webinar_presentation.pdf (last visited 30.09.2026).

[8] Zikopis, V. (2026), "AI-Based Predictive Maintenance for Hydropower Plants: From the Laboratory to the Operating Asset", https://dihydro-project.eu/wp-content/uploads/2026/10/Atlantis-White-Paper-Contribution-1.pdf (last visited 14.10.2026).

[9] Enqvist, M. (2026), "iAMP-Hydro: Ecological monitoring system, digital sensor and data logger", https://www.iamp-hydro.eu/news/news/news-joint-white-paper-what-three-eu-funded-projects-have-learnt/ (last visited 14 October 2026).

[10] Rodríguez Carro, S. (2026): “D-HYDROFLEX: digital hybridisation for more flexible hydropower”, https://www.iamp-hydro.eu/news/news/news-joint-white-paper-what-three-eu-funded-projects-have-learnt/ (last visited 14 October 2026).

[11] ReHydro (2026): “Røldal-Suldal Kraftverkene (Lyse, Norway)”, https://www.rehydro.eu/demonstration/roldal-suldal-kraftverkene-lyse-norway/ (last visited 14.10.2026).

[12] Andritz (2026): “Maximize the availability of your hydropower plant with Metris DiOMera”, https://www.andritz.com/products-en/hydro/products/diomera (last visited 07.09.2026).

[13] Voith (2026): “Let’s turn complexity into > confidence“, HyService, Keep your energy flowing | Voith (last visited 14.10.2026).

[14] SE-Hydro (2026): “Socially and Environmentally harmonized HYDRopower Operations”, https://www.se-hydro.eu/ (last visited 14.10.2026).

[15] Cordis (2026): “Transforming Hydropower: Integrating Flexibility, Ecosystem Health, and Societal Needs (last visited 14.10.2026).

[16] HydroPulse (2026): “Hydropower, rebuilt around living rivers.”, https://www.hydro-pulse.org/#/ (last visited 14.10.2026).