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Di-Hydro

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Sustainable, secure and competitive energy supply

Di-Hydro

Digital maintenance for sustainable and flexible operation of HYDROpower plant

Grant Agreement No. 101122311

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Deliverable D6.3
Exploitation Plan

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0.3	18/07/2024	Debora Zanatto, Alessandro Tedeschi Gallo, DBL	SWOT analysis

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0.4	25 - 28/06, 8 - 12/07 & 22-23/07	Zisis Kyroudis, ATLANTIS	Market Landscape
0.5	15 - 18/07, 20 - 22/08 & 26-27/08	Jovana Milenkovic, ATLANTIS	Individual Exploitation
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SHORT ABSTRACT FOR DISSEMINATION PURPOSES

Abstract Deliverable D 6.3 describes the first iteration of the Di-Hydro project exploitation plan and details the exploitation objectives, the methodology during the different project stages as well as the initial plans for exploitation of the key exploitable results.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

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LIST OF PARTNERS

N.	Logo	Name	Short Name	Country
1		CENTRE FOR RESEARCH AND TECHNOLOGY HELLAS CERTH	CERTH	Greece
2		INSTITUT MINES-TELECOM	IMT	France
3		WATERJADE SRL	WATERJADE	Italy
4		ACCELIGENCE LTD	ACCELI	Cyprus
5		ATLANTIS ENGINEERING AE	ATLANTIS	Greece
6		MAS CONSULTING SRL	MAS	Italy
7		INOSENS DOO NOVI SAD	INO	Serbia
8		ACCENT PRO 2000 SRL	AP2K	Romania
9		DEEP BLUE SRL	DBL	Italy
10		PUBLIC POWER CORPORATION SA	PPC	Greece
11		A2A SPA - A2A	A2A	Italy
12		JOINT STOCK COMPANY ELEKTROPRIVREDA SRBIJE BELGRADE	EPS	Serbia
13		ASOCIACION DE INVESTIGACION METALURGICA DEL NOROESTE	AIMEN	Spain

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ABBREVIATIONS

Acronym	Description
AE	Acoustic Emission
AI	Artificial Intelligence
ASL	Average Signal Strength
CAGR	Compound Annual Growth Rate
CM	Condition Monitoring
D	Deliverable
DO	Dissolved Oxygen
DT	Digital Twin
EMC	Electromagnetic compatibility
GUI	graphical user interface
HP	Hydropower
HPP	Hydropower Plant
KER	Key exploitable result
MQTT	Message Queuing Telemetry Transport
O&M	Operation and Maintenance
PdM	Predictive Maintenance
ROV	Remote operated vehicle
SCADA	Supervisory Control and Data Acquisition
SHM	Structural Health Monitoring
TOC	Total organic carbon
UI	User interface
WP	Work Package

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EXECUTIVE SUMMARY

Deliverable D 6.3 Exploitation plan is the third deliverable of WP6- “Dissemination, communication and exploitation” of the Di-Hydro project. The deliverable describes the initial exploitation plan and details the exploitation objectives, the key exploitable results of the project, the methodology to be followed by the project consortium during the different project stages as well as the initial plans for exploitation activities.

The main aims of the deliverable are listed below:

- Presentation of the key exploitable results (KERs) and their exploitation potential.
- Mapping of the key actors for exploitation of the KERs.
- Identification of the target sector, end-users and audience.
- Identification of the exploitation strategy to be followed during the different project phases.
- Initial market analysis
- SWOT analysis

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1. INTRODUCTION

Europe possesses significant hydrodynamic potential due to its diverse altitude landscape and surrounding seas. However, only a small fraction (13.8%) of the EU's net electricity generation comes from hydropower plants (HPP). This low utilisation is primarily attributed to inadequate digital management, handling, and maintenance of HPPs compared to other energy generation methods. To fully harness this potential and bolster renewable energy production for a climate-neutral economy, Di-Hydro aims to digitise HPPs by developing smart devices and data acquisition techniques to predict and control operations and maintenance. Digital Twins (DTs) will facilitate real-time data exchange, alongside an intelligent decision-making tool for optimal coordination of power generation considering societal, weather, water flow, environmental, and biodiversity data.

1.1 Aims & objectives of the deliverable

The current deliverable is the first iteration of D 6.3 “Exploitation plan” of the Di-Hydro Project. This deliverable aims to describe the strategy, plan and activities in order to transform the key exploitable results of Di-Hydro project into commercial solutions/ products, during and beyond the project’s life. The project consortium will contribute by engaging into activities that will bring out the potential of the exploitable results and products delivered by the project. The main aims of the deliverable are listed below:

- Present the key exploitable results (KERs) and their exploitation potential.
- Map the key actors for exploitation of the KERs
- Identify the target sector, end-users and audience
- Identify the exploitation strategy
- Carry out an initial market analysis

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2. EXPLOITATION METHODOLOGY

This section explains the Di-Hydro exploitation methodology, thus presenting the steps that will be followed in order to successfully exploit the project results. A definition of the term Exploitation in the context of EU research is required and can be defined as "*the use of results in further R&I activities other than those covered by the action concerned, including among other things, commercial exploitation such as developing, creating, manufacturing and marketing a product or process, creating and providing a service, or in standardisation activities*" (European Commission, 2021). The term "results" may vary and can be defined as "*any tangible or intangible effect of a given action, such as data, knowhow or information, whatever its form or nature and whether or not it can be protected, as well as any rights attached to it, including intellectual property rights*" (European Commission, 2021).

According to the European Commission (2019), the measures for exploiting results may include the following:

- using them in further research activities (outside the action);
- developing, creating or marketing a product or process;
- creating and providing a service, or
- using them in standardisation activities.

The Di-Hydro exploitation methodology is structured in 3 phases aligning with the timeline of the project's implementation. Phase 1 activities will be presented in the first iteration of D 6.3 (version 1), while the final iteration of this deliverable will be submitted in September 2026 (M36).

Table 1. Activities during the different exploitation phases of the project

Phases	Description

Phase 1 (Year 1)	• Identification of:
	  ○ KERs and owners/collaborator (partners)
	  ○ exploitation potential
	  ○ exploitation strategy
	  ○ target stakeholders, end-users, clients and key market sectors
	  ○ Initial market research
	• Carry out first internal exploitation workshop.

Phase 2 (Year 2)	• Further elaboration of:
	  ○ individual exploitation plans per project partner or KER owner
	  ○ the exploitation potential of each KER
	  ○ each consortium partner's role in the exploitation of the KERs

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	○ the exploitation strategy i.e. an explanation of how the different owners of the KERs about how they are planning to exploit the results. Examples can be "internal adaption", "service offering" or "consultancy offering", "product sale", "publications". Project workshops will be used to exploit results and receive feedback for the market needs.
Phase 3 (Year 3)	During phase 3, individual business plans for the KERs will be constructed depending on the exploitation strategy outcome. Finalisation, of all the exploitation parameters and activities will also take place. Dissemination and communication activities will also aim to exploit KERs and project outcomes in general.

2.1 Phase 1 -Initial mapping

The first step of the exploitation methodology is to carry out the following actions:

- Identify the Di-Hydro KERs.
- Identify owners and contributors of the exploitation results as well as beneficiaries. Owners are partners who own the majority of the result, while contributors are partners that have contributed to the development of a specific part of the result. In addition, beneficiary partners will be those who are interested in exploiting results by another partner.
- Identify the exploitation potential of the KERs i.e. what potential they have to be exploited.
- Identify the target sector where the exploitation of the result is applicable to. Examples can be hydropower (HP) industry, hydropower plant (HPP) operators, transmission system operators (TSO), scientific community (research and academia), governing bodies, policy makers etc.
- Identify the target users/clients/audience of the exploitation activities and results.
- Organise an internal workshop with the consortium partners to perform a Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis for the Di-Hydro project. On the 18th of July a workshop was organised by DBL, where the consortium partners carried out the SWOT analysis that is presented at section xx.

Before identifying the exploitable results and the utilisation of intellectual property rights and research results of the project, the Di-Hydro consortium has defined both before and during the project, the background and foreground knowledge of the rights.

<u>Background</u>

Before the project started the Di-Hydro partners have been asked to define their Background i.e. pre-existing knowledge, know-how, expertise related to the thematic fields that they will be contributing to in the project. This included intellectual property,

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resources such as technologies, data, software that the partners will bring to the project. The rules for accessing the Background of each partner and any potential sharing of such information are explained in the Consortium Agreement. Background claims relevant to the key exploitable results were also registered during the project and are presented in section 3-INDIVIDUAL EXPLOITATION STRATEGIES

Foreground

During the Di-Hydro project, the partners have been asked to identify the Foreground, which is the intellectual property, results, know-how that have been generated as direct result of the project's activities. Such Foreground may include products, software tools, programming code, prototypes, methodologies, know-how that have been generated in the project's duration or even afterwards. The Technical Management Committee (defined in D 7.1 Project, data management and risk plan) will monitor and oversee any potential changes to claims and the foreground as the project develops as well as at its where the results will be finalised. Foreground claims are identified in this version of the deliverable under section 3-INDIVIDUAL EXPLOITATION STRATEGIES. However, these will be updated again in the last version of the D6.3 on September 2026 (M36).

2.2 Identification of exploitable results

The first and most important part of the exploitation methodology is identifying the exploitable results of the Di-Hydro project. It is important to note that since this deliverable is written at the end of Year 1 of the project some details could be matter of change while the significance of the exploitable results may change by the end of the project. A list of the KERs is provided below followed by details and definitions.

Table 2. Di-Hydro Key exploitable results list

	Di-Hydro Key exploitable results
KER1	Innovative sensors for HP machinery operation monitoring
KER 2	HP Structural Health monitoring and prediction AI based algorithms
KER 3	Underwater inspections assisted by AI image processing for defect detection
KER 4	Environmental monitoring sensor
KER 5	Biodiversity monitoring sensor
KER 6	Monitoring and predictive models for biodiversity and environmental effects of HP O&M
KER 7	Forecasting models for weather and water flow of HPPs
KER 8	HPP Digital twin
KER 9	HPP cluster modelling
KER 10	AI-based Decision support platform for HPPs and clusters
KER 11	Secure by design algorithms for HPP data collection, exchange and storage
KER12	HPP data modeling
KER 13	Visualization of HPP Data and Digital Twin Simulation Tool

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Table 3. KER1-Innovative sensors for HP machinery operation monitoring

Exploitable result 1- Innovative sensors for HP machinery operation monitoring	
Description	A sensor node developed for Structural Health Monitoring/ Condition Monitoring of HP machinery and infrastructure being capable of carrying out modal analysis and detect failures. The node will be constructed with low-cost, low-power consumption in mind. This node will consist of the following sensors: • Acoustic emission unit & piezoelectric sensors • Accelerometer for micro-vibration sensing • Magnetic flux sensor • Temperature sensor • Humidity sensor • Crack propagation sensor • Analog filters and amplifiers, analogue-to-digital converter, dedicated signal processor(s), memory for temporary storage of signals and features data, and single channel communication hardware
Type of result	Product
Users, clients, sector(s) of application	HP operator, Research & Academia
Timetable to commercial use	Not applicable
TRL	6
Type of IPR	Technology or consultancy service for the industry
Main owner	CERTH
Other partners involved in the development	No
Other partners involved by providing input	PPC by facilitating installation of the sensors
Key Exploitable result	Yes

Table 4. KER 2-HP Structural Health monitoring and prediction AI based algorithms

Exploitable result 2- HP Structural Health monitoring and prediction AI based algorithms	
Description	Development of predictive models to recognize patterns to assess the current state of assets, while achieving fault detection, identification, prediction for components and machinery health of hydro-power plants. Models will have greater accuracy and will be build based on advanced unsupervised, semi- and supervised techniques while fusion mechanisms for combining multiple models is also possible.

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Type of result	Software
Users, clients, sector(s) of application	HP operators; HP and Energy Sector; HP O&M; In general: Industrial manufacturing, Maintenance management, Manufacturing, Utilities, Maintenance consultants, Manufacturing companies, Consultants"
Timetable to commercial use	Possibly 5 -7 years after the project ends
TRL	5
Type of IPR	Trade Secret
Main owner	ATLANTIS
Other partners involved in the development	No
Other partners involved by providing input	PPC and CERTH with provision of historical and sensor data
Key Exploitable result	Yes

Table 5. KER 3-Underwater inspections assisted by AI image processing for defect detection

Exploitable result 3- Underwater inspections assisted by AI image processing for defect detection	
Description	Development and application of image processing and machine learning techniques for detection of damage in underwater inspection acquisitions taken by from a remote operated vehicle (ROV).
Type of result	Programming code
Users, clients, sector(s) of application	HP operators, Research & academia
Timetable to commercial use	N/A
TRL	5
Type of IPR	Technology or consultancy service for the industry
Main owner	CERTH
Other partners involved in the development	No
Other partners involved by providing input	PPC by providing their facilities for underwater inspections
Key Exploitable result	Yes

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Table 6. KER 4- Environmental monitoring sensor

Exploitable result 4-Environmental monitoring sensor	
Description	BioSensor for E.coli. Development, validation and installation of sensors for monitoring of water quality parameters. Development of a biosensor for e.coli bacteria detection, development of ammonia sensor based on ammonia-ion selective membrane, and algae sensor based on Chlorophyll A measurement. Installation of the commercially available sensor for monitoring of pH, turbidity, electrical conductivity and dissolved oxygen.
Type of result	Product
Users, clients, sector(s) of application	Environmental monitoring sector, food and safety security, healthcare
Timetable to commercial use	Not applicable
TRL	6
Type of IPR	Patents - confidential information
Main owner	INO
Other partners involved in the development	No
Other partners involved by providing input	EPS by providing their facilities for installation of the sensor
Key Exploitable result	Yes

Table 7. KER 5- Biodiversity monitoring sensor

Exploitable result 5-Biodiversity monitoring sensor	
Description	A cost affordable portable Digital Holographic Microscope with automated microorganism species recognition, that can identify key species relevant for the environmental health of the dammed water. Integrated in a multiparametric platform equipped with sensing technologies that allow to quickly assess the biodiversity landscape of the water body.
Type of result	Product
Users, clients, sector(s) of application	HP operator, water treatment sector, Research & Academia
Timetable to commercial use	At least 3 years after the end of the project
TRL	6
Type of IPR	Trade Secret
Main owner	AIMEN

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Other partners involved in the development	No
Other partners involved by providing input	EPS by providing their facilities for installation of the sensor
Key Exploitable result	Yes

Table 8. KER 6-Monitoring and predictive models for biodiversity and environmental effects of HP O&M

Exploitable result 6- Monitoring and predictive models for biodiversity and environmental effects of HP Operation & Maintenance	
Description	An automated classification software based on Machine Learning algorithms for key microorganism species identification on reconstructed images
Type of result	Software
Users, clients, sector(s) of application	HP operator, water treatment sector, Research & Academia
Timetable to commercial use	At least 3 years after the end of the project
TRL	6
Type of IPR	Software copyright
Main owner	AIMEN
Other partners involved in the development	No
Other partners involved by providing input	EPS by providing historical data
Key Exploitable result	Yes

Table 9. KER 7- Forecasting models for weather and water flow of HPPs

Exploitable result 7- Forecasting models for weather and water flow of HPPs	
Description	Configuration on the specific use case of the forecasting modelling chain (Digital Twin of the catchment, static version), including weather data collection, weather forecasts processing, calibration of the hydrological model and computation of water inflow forecasts in different points of interest. Development of the proprietary dashboard, which will allow users to interact with the geometry parameters of the system (Digital Twin of the catchment, dynamic version) after the initial set-up phase of configuration on the specific use case. During the project, the users involved will be able to access

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	and test the dashboard, after which access for users will be granted by license.
Type of result	Software
Users, clients, sector(s) of application	HP operator, water treatment sector, Research & Academia
Timetable to commercial use	At least 3 years after the end of the project
TRL	6
Type of IPR	Software copyright
Main owner	Waterjade
Other partners involved in the development	No
Other partners involved by providing input	A2A will provide historical and technical data of their facilities. However, they are not directly involved in the development
Key Exploitable result	Yes

Table 10. KER 8- HPP Digital twin

Exploitable result 8- HPP Digital twin	
Description	A highly advanced Digital Twin of a hydropower plant developed using Siemens' Amesim software. This Digital Twin is a virtual replica of the physical plant, capable of simulating, monitoring, and optimizing plant operations in real-time. By integrating data from various sensors and systems, it provides a comprehensive and dynamic model that reflects the current state and simulates performance of the hydro power plant.
Type of result	Design, Product
Users, clients, sector(s) of application	HP operators, OEMs
Timetable to commercial use	Not applicable
TRL	6
Type of IPR	Service
Main owner	ACCELI
Other partners involved in the development	PPC
Other partners involved by providing input	PPC will provide historical and technical data of their facilities.
Key Exploitable result	Yes

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Table 11. KER 9- HPP cluster modelling

Exploitable result 9- HPP cluster modelling	
Description	Development of a reduced-order model for the representation of the electrical interconnection of HPPs considered as a cluster. Developed models will be integrated into CERTH's in-house electrical grid simulator, named INTEMA.grid. Cluster system model will be available for the simulation of different operation strategies. Development of a new optimization model, facing the requirements provided by the HPP partners, in terms of production constraints and strategies, physical boundaries and energy market context.
Type of result	Software, Product
Users, clients, sector(s) of application	HP operators, TSOs, Research & academia, Hydropower Associations, OEMs, etc
Timetable to commercial use	Possibly 2-3 years after the project ends
TRL	5
Type of IPR	Software copyright
Main owner	CERTH
Other partners involved in the development	No
Other partners involved by providing input	PPC will provide technical data of their facilities.
Key Exploitable result	Yes

Table 12. KER 10- AI-based Decision support platform for HPPs and clusters

Exploitable result 10- AI-based Decision support platform for HPPs and clusters	
Description	Development of a new HPP Optimization platform able to consider the requirements of the Di-Hydro project, both in term of integration with digital twins and sensors, and in term of specificities of the power plants clusters considered. MAS will obtain new functionalities and integrations for the platform and a new optimization model.
Type of result	Software
Users, clients, sector(s) of application	HP operators, Asset management, traders
Timetable to commercial use	At the end of the project
TRL	7
Type of IPR	Software copyright
Main owner	MAS

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Other partners involved in the development	No
Other partners involved by providing input	PPC, A2A and EPS will provide input on the use of the platform
Key Exploitable result	Yes

Table 13. KER 11- Secure by design algorithms for HPP data collection, exchange and storage

Exploitable result 11- Secure by design algorithms for HPP data collection, exchange and storage	
Description	Development of new secure by design framework capable of mitigating vulnerabilities in HPPs by adapting data exchange protocols, ensuring Quality of Service (QoS), and reducing security exposure by dropping high-risk communication
Type of result	Framework
Users, clients, sector(s) of application	Hydropower plant operators, energy sector, smart infrastructure
Timetable to commercial use	Not applicable
TRL	5
Type of IPR	Open Source
Main owner	IMT
Other partners involved in the development	No
Other partners involved by providing input	PPC, A2A, EPS will provide technical data of their facilities
Key Exploitable result	Yes

Table 14. KER12 HPP data modeling

Exploitable result 12- HPP data modeling	
Description	Development of advanced data models for hydropower plant (HPP) operations, following European standards such as NGSI-LD. The aim is to establish unified data models for static and dynamic information, that can be applied across diverse HPPs and their various operations, in light of the requirements of the Di-Hydro project. This involves identifying the common elements inherent to each power plant whilst incorporating specific information relevant to distinct use cases.
Type of result	Data models

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Users, clients, sector(s) of application	Hydropower plant operators, energy sector, smart infrastructure
Timetable to commercial use	Not applicable
TRL	5
Type of IPR	Open Source
Main owner	IMT
Other partners involved in the development	No
Other partners involved by providing input	PPC, A2A and EPS will provide technical data of their facilities
Key Exploitable result	Yes

Table 15. KER 13- Visualization of HPP Data and Digital Twin Simulation Tool

Exploitable result 13- Visualization of HPP Data and Digital Twin Simulation Tool	
Description	Development of a visualization tool using PowerBI software for easy access. The tool is compatible with historical data, current data and future data. Real-time data works by connecting to SQL server or AWS cloud. The Visualization Tool works best on big screens for end-user operators and provides all the information needed for sensor data, environmental data, Digital Twin data and so on.
Type of result	Design, Product
Users, clients, sector(s) of application	HP operators
Timetable to commercial use	Not applicable
TRL	6
Type of IPR	Software copyright
Main owner	AP2K
Other partners involved in the development	No
Other partners involved by providing input	All
Key Exploitable result	Yes

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2.3 Market landscape

The Di-Hydro project's primary objective is to digitize operation and maintenance (O&M) and of HP plants and clusters by through innovative sensor technologies, interoperability, data transparency and safety, so as to create a highly efficient decision making tool based on HP Digital Twins (DTs), that incorporate novel Artificial Intelligent (AI) -based weather and/ water flow proactive modelling and take into consideration environmental, biodiversity and socioeconomic parameters, thus increasing EU's energy sector competitiveness, sustainability, cleanness and autonomy.

Digitisation of hydropower is a vast and extended topic that has been covered thoroughly in D1.1 "Digital transformation of the HP sector". In this section we provide a brief synopsis of the market landscape and the market segments related to the key exploitable results.

2.3.1 Market drivers and prospects

Hydropower is considered the backbone of low carbon energy production providing almost half of its production (IEA, 2021). According to IEA (2021), in 2020, hydropower supplied one sixth of the global energy production generation, taking the position after coal and natural gas. In the last 20 year the total global capacity of hydropower rose by 70% (IEA, 2021). Figures from the newly released International Hydropower Association "2024 World Hydropower Outlook" shows that conventional hydropower capacity grew in 2023 by 7.2 GW to 1,237GW, while pumped storage hydropower grew by 6.5GW to 179GW (IHA, 2024;7). However, a decrease in energy generation of 223TWh was observed from 2022's figures to 4,185TWh, as a result of droughts, which is projected to bounce back in 2024 (IHA, 2024;7). In Europe the installed hydropower capacity for 2023 was 259GW with 717 MW new installed capacity (IHA, 2024; 39) while the generation of the European region was 637GW (IHA, 2024; 39). With hydropower offering a great potential for a transition towards decarbonisation due to its ability to mitigate negative effects of intermittent power generation from renewable energy sources, as well as to mitigate climate change by offering water storage and supply (Corà and Mišech, 2021).

It is estimated that 50% of the hydropower plants (HPPs) worldwide were commissioned at least 40 years ago (Andritz Hydro GmbH, 2019b) with similar numbers reported for Europe, where 70% of the installed HPPs have an average age of 42 years (Leguizamon-Perilla et al., 2023), while Kougias (2019) suggests an average age of 46 years. This average age may vary with hydropower plants in North America being around 50 years of age, while the average age for Chinese HPPs being about 12 years (Leguizamon-Perilla et al., 2023).

The aging fleet of hydropower plants makes modernisation and digitisation of the global and European fleet imperative and strategically important if doubling the hydropower capacity is required until 2050 (IHA, 2024). Quantification of the impact of modernisation and digitisation for HPPs could potentially be difficult to put in numbers since its plant might vary in technology, age and overall characteristics. However, modernisation of the

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European hydropower facilities and specifically digitisation could increase efficiency of power generation for the European fleet by 1%, while inflow forecast could increase the generation by 11% (Quaranta et al., 2021). Other improvement strategies like new electromechanical equipment could improve efficiency by 4-6% (Quaranta et al., 2021). It is estimated that modernisation of all existing plants on global level, will account to almost 90% of the total hydropower investments by 2030, which is estimated to 276.5 billion EUR within this decade (IEA, 2021).

The following section provides a brief overview of the market related to the key exploitable results and digitisation of O&M of the hydropower sector. As explained in Deliverable 1.1, the term digitization of O&M is multifaceted and quite broad. Quaranta et al., (2021, 2023) suggest that digitisation covers the use of information, communication and control to improve operation and efficiency and performance of HPPs.

According to Arch et al. (2019), Figure 1 presents a list of digital technologies relevant to the hydropower sector. The list covers:

- Digital twins.
- Forecast modelling.
- Predictive maintenance.
- Real time KPI monitoring.
- Digital workforce management.
- Augmented and virtual reality.
- Unmanned vehicles and robots.

From the above list, the Di-Hydro key exploitable results cover almost all topics except digital workforce management as well as augmented and virtual reality technologies.

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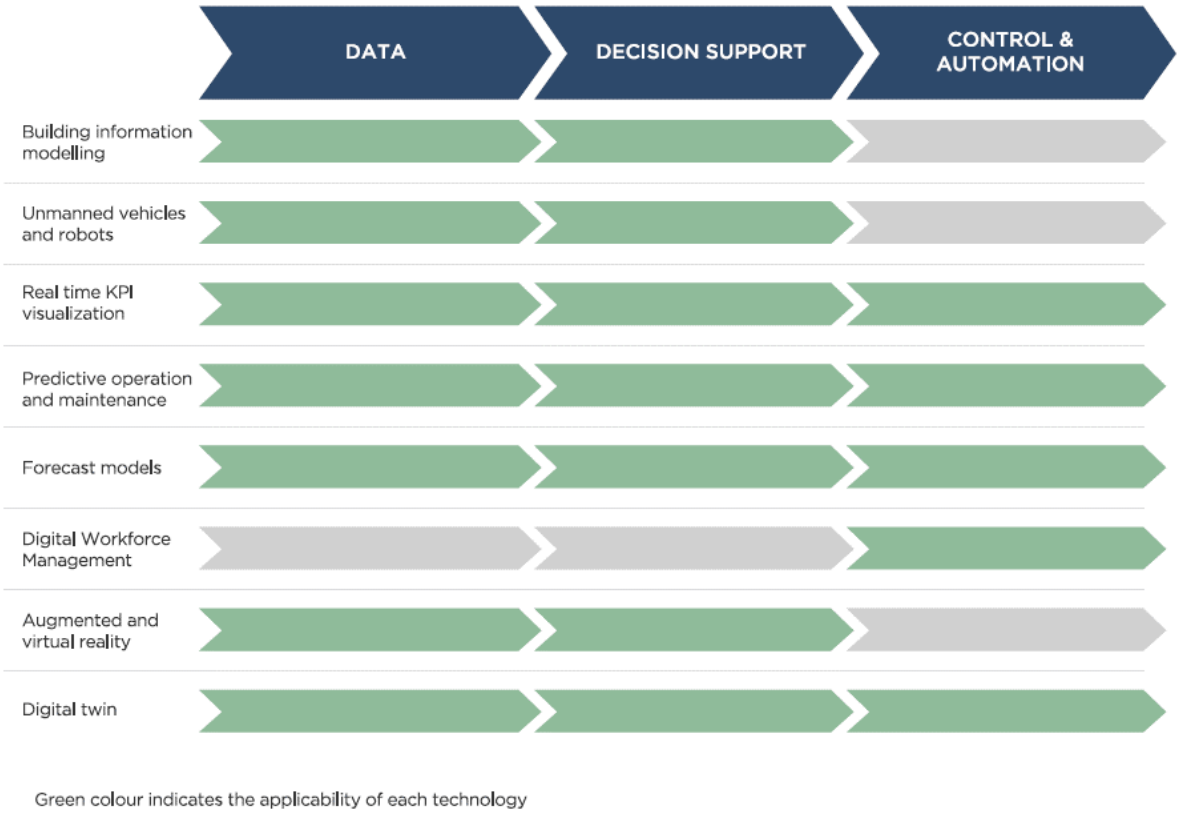

Figure 1. Digital technologies and their applicability in the main generic areas of digitisation

Source: Arch et al (2019; 32)

2.3.2 Digital Twins

A digital twin (DT) refers to the representation of a system in real life, with a digital replica environment using real time data and combining mathematical models, sensors and measurements (Arch et al., 2019; Wright and Davidson, 2020)

DTs do show trends of usage. However, the term is loosely used in many cases for digital representations of practically anything. The state-of-the-art research that was carried out in D 1.1 showed some documented cases either as a result of research-based implementations or the use of commercially available tools. Complete digitisation of HPPs are rare and such endeavors have been documented on a pilot level by Verbund (2019, 2020) and Axpo power companies. Most digital twins observed in D 1.1 were relevant to plant components and sections. CADFEM for example is a company that built a digital twin for Verbund's turbine runner (Gebhardt, 2019). Hydro-Clone (Power vision engineering, 2024) is an innovative Real-Time Simulation Monitoring System (RTSM) by Power Vision Engineering. Hydro-Clone, allows the development of a numerical copy of a hydropower plant, based on SIMSEN software, that is able to reproduce in real-time any dynamic behaviour of the installation based on boundary conditions measured in situ. This real time monitoring tool allows data processing and diagnostics of the HPP's health and data storage, while also allowing comparison and analysis of simulated and measured quantities

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from Supervisory Control and Data Acquisition (SCADA) data. Akselos a key player in asset management and building DTs has also build a DT for the Turlough Hill pumped storage station in Ireland (Global Infrastructure Hub, 2021).

General Electric (GE) has also developed DTs of generation units that have been installed in hydropower plants that are run by Energias de Portugal (EDP) and Enel Green Power (EGP) in Spain and other locations. The DT is combined with GE's Asset Performance Management (APM) software.

Simulink is a MATLAB-based graphical programming environment for modelling which provides a powerful toolset for creating digital twins. Simulink allows you to build models of physical systems using intuitive blocks that represent real-world components. MATLAB offers data analysis and machine learning techniques to incorporate real-world data into the model. The data can come from sensors on the physical system, allowing the digital twin to reflect its current condition and behaviour. Simulink combines physics-based modelling with data-driven approaches and facilitates the accurate representation of physical assets.

Dassault SolidWorks can be a powerful tool in the DT creation process. While itself isn't a complete digital twin solution, it excels at generating detailed 3D models and associated data of a variety of products. This serves as a strong foundation for the digital twin. By incorporating SolidWorks models into a digital twin platform, engineers can leverage its set of tools for simulations and analysis without needing physical prototypes. This streamlines the design process and allows for informed decisions before manufacturing begins.

Siemens' Amesim software excels in constructing digital twins by providing a powerful platform for simulating the behaviour of physical systems. This software allows engineers to create virtual models of real-world products, like an aircraft fuel system, or a Hydro-Electric power plant. These virtual models can then be integrated with real-time data from the physical system, creating a "hybrid model" that closely mimics the actual product. This digital twin can be used to predict performance, optimize design, and identify potential issues before they occur in the real world. Siemens Amesim is a powerful tool for developing and utilizing digital twins.

2.3.3 Structural health monitoring and condition monitoring of HPPs

Structural health monitoring (SHM) and condition monitoring (CM) is essentially the process of continuous monitoring of a structure or machinery, irrespective of application, allowing different physical variables to be monitored and evaluated. The variables that can be monitored can be mechanical, chemical, and electrical, thus allowing monitoring of changes in the structures as a result of environmental and operational conditions along their lifetime (Pozo et al., 2021). Such changes may lead to possible fails and/or damage of the structure or their components. Thus, the aim of SHM/CM is fault detection and

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potentially requires the use of sensors or sensor networks combined with the use of advanced signal processing. Such systems may carry out damage detection, localization prediction or raise alarms when certain thresholds parameters are exceeded. Applications of SHM/CM are many and may cover HPPs, wind turbines, civil structures, dams, bridges, hydropower plant equipment, naval, aerospace and many others (Betti et al., 2021; Pozo et al., 2021; Selak et al., 2014; Perez et al. 2010; Cusati et al., 2021).

Common types of sensors used for SHM/CM are the following:

- Strain gauges: measure deformations caused by strain and stress at different structural parts.
- Fibre optic sensors: use light to detect strain as well as temperature.
- Acoustic emission (AE) piezoelectric sensors: detect ultrasonic elastic waves propagating in materials caused by potential damage/failure. AE can detect crack initiation, growth and localisation.
- Fatigue damage sensors: that can be bonded to streel structures and are capable of showing the magnitude of fatigue damage under stress.
- Accelerometers: measure acceleration and vibration of components/structures, thus they can detect changes caused by failure or modal shift.
- Pressure sensors: monitor pressure inside structures and tanks and can detect pressure changes potentially induced by structural damage
- Temperature sensors: monitor temperature as the word implies, caused by thermal loads on structures that can cause potentially cause deformation or damage to a structure.
- Ultrasonic corrosion monitoring sensors: are used to monitor corrosion process in a structure making use of high frequency acoustic waves which are in turn used to measure thickness and properties of the material.
- Air gap sensors: detect the distance between the rotor and stator in hydropower turbines and could provide valuable information to the operator regarding the operating conditions before failure occurs.
- Partial discharge sensors: are used to detect partial discharge activity on high voltage equipment usually on the hydrogenator's stator windings

Geodetic monitoring solutions are additional technologies that can be used to measure structural movements of certain key points of the whole HPP infrastructure. Such technologies have millimetre accuracy and are used for monitoring dams. However, this topic is not covered by Di-Hydro project which focuses more on the HPP itself.

Going beyond the standard approach of applying sensors on structures new technologies like drones combined with orthophotography and assisted by artificial intelligence (AI) are capable of detecting damage on structures including dams or other vital structures of an

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HPP. Such companies are STRUCINSPECT[1] with a solution described in the table below. The application of drones and underwater drones for structural health monitoring of outdoor or even indoor areas of an HPP and its surrounding have been covered in D 1.1.

Table 16. Commercial solutions for SHM/CM

Commercial solutions	Description	Source
Delphin Technologies	Allows vibration monitoring for multiple locations on the turbine – peak-to-peak displacement and analysis of the signals through a software.	CAS Dataloggers (2023)
Bently Nevada 3500 Machinery Protection System	Bently Nevada 3500 provides protection and condition monitoring for continuous online monitoring for HPP machinery. The system provides connectivity for: tachometers, key phasor modules, relay modules, vibrometers, thrust position, sensors for position, air gap, temperature, pressure including seismic transducers. In addition, the system provides data analytics and machinery health audits, alarms and other features.	Baker Hughes (2024)
Bently Nevada System 1 Condition Monitoring and Diagnostic platform	Bentley Nevada offers a condition monitoring and diagnostic platform that requires the installation of various sensors on a turbine and generator capable of collecting data and displaying them to the user. In addition, the software is capable of collecting data from SCADA and control systems from different machinery and displays the condition of the latter through Human Machine Interfaces (HMIs)	Snyder (2021)
IMI Sensors	IMI offers a variety of vibration sensors for installation at the power generation units for locations like generator bearing, rotor, turbine bearing	IMI Sensors (2023)

[1] https://strucinspect.com/en/

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Voith OnCare.Health Hydro	Voith's system allows condition monitoring of the turbine and generator. A large variety of sensors are offered such as: keyphasor; vibrometers for bearings, shaft, stator and windings, wicket gate, turbine headcover, axial thrust; air gap sensors, magnetic flux, pressure, labyrinth gap and runner gap (depending on turbine type). The monitoring of the generation unit parameters allows the user to see the data through an interface, provides data analytics and predictions of failure modes.	Voith (2019)
Brüel & Kjær Vibro-Condition Monitoring Solution	Brüel & Kjær Vibro offers solutions for condition monitoring using a variety of sensors i.e. vibration, air gap, magnetic flux, oil analysis, temperature, pressure, flow distribution (cavitation and vortex) and partial discharge measurements. The system also allows integration with process control systems with SCADA or distributed control systems (DCS).	Brüel & Kjær Vibro (u.d.)
ABB condition monitoring	The ABB condition monitoring system consists of ABB's Ability™ Smart Sensors and ABB's Ability™ Condition Monitoring products which can be used for condition monitoring of rotating machinery like motors, pumps and fans. The sensors can monitor overall health condition of equipment through the measuring 3x vibrations, rpm speed, total running time, number of starts, supply frequency (Hz), Output power (hp/kW), skin temperature, bearing condition etc. The sensors come in a small eclosed unit that can be attached to the component that is monitored.	ABB (2022)
Kistler	Kistler offers sensors for structural health monitoring of HPP assets. Pressure sensors, accelerometers and sensors for acoustic signal generation are used for detecting implosion and cavitations in water brakes, pumps and turbines.	Kistler Group (2024)

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Qualitrol-Iris Power	The company offers a condition-based monitoring solution that uses a variety of sensors for monitoring partial discharge on stator windings, stator end winding vibrations, magnetic flux on rotors, air gap between rotor and stator, as well as overall mechanical vibrations.	Iris power (2017)
EMERSON	Emerson automation offers a system for condition monitoring of generation units that can carry out the detection of the following: imbalance, misalignment and coupling, cracks on turbine blade and shaft, lubrication of mechanical parts, cavitation erosion of the impellers, breakage of wicket gate linkage, partial discharge, vibrations from hydraulic system imbalance.	Cahil (2014)
GE predictive monitoring services	GE offers a variety of sensors and software that can be used for condition monitoring. Such sensors offered by GE are partial discharge analyser, temperature, pressure, flow, fan speed, motor current, vibrometers, air gap, shaft current, flux, brush wear measurement, oil contamination sensor,	GE Vernova (2023)
EtaPRO predictor	EtaPRO Predictor can detect faults on rotating machinery of HPPs using automatic changes in vibration signatures. The system combined with the installed sensors allows monitoring of the following faults: cavitation, eccentricity, instability, gear and bearing faults, pole position faults, winding shorts, pressure monitoring and other types of faults on machinery. Predictor is combined with other software from the company like EtaPRO APR for anomaly detection and the EtaPRO archive for data logging.	ETA PRO LLC (2021)
Leica GNSS monitoring system	This system is used for precise monitoring using GNSS receivers, GPS control points that measure displacement of a point of interest on X,Y,Z axis and geodetic station.	Leica-geosystems (u.d.)

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	Such systems also allow data processing and monitoring for the user.	
STRUCINPSECT	This company offers the construction of digital models using 3D models or orthophotos constructed with the application of aerial drones. The images are then processed by AI models that detect potential surface damage on the structures. An evaluation and report is then offered to the suer.	STRUCINPSECT (2024)

2.3.4 Inflow forecasting

HP operators are required to water optimize their power generation and balance economic, social and environmental targets. Several analytical tools have been developed to support operators in planning and optimizing the production and the operational decision making, allowing to compare planning alternatives by modelling hydrologic and hydraulic processes, hydropower production, water quality parameters and river hydrodynamics, estimating and forecasting variables such as water surface elevation, water velocity, water inflow, temperature and water quality parameters.

There are different types of companies which operate in the water sector, that may be described by differentiating between the type of product offered, namely hardware/sensors or software/data, and the product focus, namely industry or environment. Regarding the environmental focus and the software/data products, a possible non-exhaustive list of companies which operate in this sector is reported below.

Table 17. Commercial solutions for inflow forecasting

Company	Description of the company and proposed commercial solutions	Source
Waterjade	Provides the full reconstruction of the water cycle combining: a) hydrological modelling and machine learning algorithms b) an hydrological analysis of the state-of-the-art and c) water inflow forecasts/projections according to the meteorological evolution in the upstream catchment considering anthropic works	Waterjade (2024)
Wegaw	Company of the analysis and production of satellite-based products on snow and water, combined for the historical and near real-time monitoring	Wegaw (2024)

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Exolabs	Spin-off of the University of Zurich which provides snow maps based on satellite images and ground observations	ExoLabs (2024)
MMidro	Company which provides hydrological modelling and monitoring, alert services based on the installation of in-situ gauges	MMidro (2024)
ICS	Company that provides consulting services on climate change, through historical analysis and climate prediction services for decision-making	ICS (2024)
DHI	Company that deploys MIKE models, which are a group of software for hydraulic modelling. These tools can be combined to analyze also basins and integrated water resources management systems	DHI Group (2024)
AI Aqua	Company that provides a range of forecasting services for water management and planning in water supply systems	AIAqua (2024)
Meteologica	Company that offers forecasting services, mainly for energy sector, based on weather prediction models, in order to forecast the power or the production of the analyzed plant	Meteologica (2024)
Gecosistema	Company specialized in environmental engineering consulting and research, providing also water forecasts, mainly for the energy sector	GECOsistema (2024)

2.3.5 Predictive maintenance

Predictive maintenance (PdM) is a smart approach through which the equipment performance and duration are optimized. This technique is based on a condition monitoring that uses sensorial and historical data while it can also include machine learning and AI techniques to foreseen when a failure could occur and schedule a maintenance work before the failure happen (Mobley, 2002; Susto, 2015).

In 2023, the global Hydropower Market size was evaluated at 219.31€ bill. Also, the market is projected to grow from 229.37€ bill in 2024 to 329.28€ bill by 2031, exhibiting a Compound Annual Growth Rate (CAGR) of 5.30% during the forecast period. This information was reported by Kings Research (Antriksh, 2024) for various services offered by companies such as Alstom, Siemens, PowerChina, China Three Gorges Corporation, Tata Power, Voith GmbH & Co. KGaA, ABB, ALFA LAVAL, ANDRITZ AG, General Electric and others. As is known, the hydropower plants market is developing gradually, using and implementing various technologies, efficiency improvements as well as the integration of predictive maintenance (PdM) approaches. Thus, below in the following table are listed a few Key Players in Hydropower PdM and their solutions.

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Table 18. Predictive maintenance commercial solutions

Commercial solutions	Description	Source
GE smart signal	The GE solution provides early warnings of hydro assets irregularities i.e., anomalies, using machine learning algorithms and experts' rules to diagnose obtained data, define what is normal/abnormal and prioritize actions to be followed. These analytics provide insights on incipient failures, performance issues and the remaining useful life of the asset.	GE (2020)
ABB Ability™ Asset Health	This solution is an online condition monitoring system that collects diagnostics information, across all medium voltage and low voltage switch gear and circuit breakers. This reactive maintenance uses the data, that are locally stored into the cloud (cyber secured), analyses and optimises electrical systems, providing assistance to an operator in a view of real time alarms. and optimises electrical systems.	ABB (2019)
Senseye	Senseye Predictive Maintenance integrates with any asset, system, or data source (sensorial and/or historical) and enables application of smart technology and data analytics over a plant without the need for manual analysis. Since it combines AI with human insights, the platform assists the operator presenting the machine and maintainer behaviour models.	Siemens (2024)
OnCare.Health	The OnCare.Health is an online condition monitoring, analysis and diagnosis system, adapted to the requirements of hydropower machines able to efficiently support preventive maintenance strategies. Through a user interface (UI), the system presents clear and basic information on the machine's condition to the operator.	Voith (2019)
Metris DiOMera	Metris DiOMera Platform is a software tool suite that deals with optimization of operation and maintenance activities for hydropower assets. This system can be installed within the hydroelectric	ANDRITZ Hydro GmbH (2019a)

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	power premises (i.e. computer) and on a data concentrator (DC). Metris DiOMera stores the signals data and through a graphical user interface (GUI), it offers a vision of specific plant behaviour. It can run on any digital device using a web browser.	

2.3.6 Environmental monitoring & sensors

Environmental water monitoring is crucial for maintaining water quality and ensuring the safety of ecosystems and human health. On the other hand, some microorganisms such as phytoplankton and algae can have a negative effect to the hydro power operation. The advancement in sensor technology has significantly enhanced the capability to detect and monitor various contaminants, including heavy metals, pathogens, and organic pollutants. Different environmental water monitoring sensors are available on market today, and they can be classified according to their operation principle as:

- Electrochemical sensors measure the electrical properties (such as current, voltage, or impedance) that change due to the interaction between the sensor surface and the target analyte. They find application in detection of heavy metals and different ions in the water. Alto, have a high sensitivity and relatively low cost the main drawback is potential interference from other ions and the need for periodic calibration. Today they are widely used to monitoring different ions in waters such as ammonia, nitrate, nitrite, pH or electroconductivity.

- Optical sensors detect changes in optical properties (such as absorbance, fluorescence, or reflectance) when the target analyte interacts with the sensing element. They are used for monitoring of organic pollutants and pathogens. Their main advantages are high specificity, and ability to detect multiple analytes simultaneously. However, they are more complex and the measurement in water needs to be correlated with turbidity and ambient light intensity. Optical sensors are widely used to measure algae concentration, phytoplankton, and bacteria as well as a turbidity sensor.

- Biosensors utilize biological recognition elements (such as enzymes, antibodies, or nucleic acids) to detect specific analytes. They are used to detect pathogens, toxins, and heavy metals. They are highly specific and have the ability to detect low concentrations of targeted analytes. The main drawbacks are stability and limited shelf-life of biological components. Biosensors are used to measure different toxins in the water, specific pathogens, or spices.

- Acoustic sensors measure changes in acoustic wave properties (such as frequency or amplitude) caused by the interaction with the target analyte. They are widely

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used for detection of heavy metals, organic pollutants, and some biological contaminants. They are characterized by high sensitivity and good potential for real-time monitoring. However, they are sensitive to environmental changes such as temperature and pressure.

Recent trends and innovations in environmental sensor are really on the integration of sensor with be wireless and IoT-Enabled Sensors to enable real-time data transmission and remote monitoring, and deployment of sensor networks for comprehensive water quality monitoring over large areas. Moreover, different multisensory systems are available on the market integrating combination of different types of sensors in a single platform to provide comprehensive water quality assessments. Combining with machine learning and data fusion techniques to interpret complex sensor data.

The global market for water quality sensors is constantly growing due to increasing environmental regulations and awareness of water pollution, and adoption of smart water monitoring systems by municipal and industrial sectors.

Table 19 presents a comparison of different commercially available sensors for water monitoring, in terms of measurement ranges, and approximate prices of the listed water monitoring sensors.

Table 19. Environmental monitoring sensors

Sensor Model	Parameters Measured	Measurement Range	Price Range	Features
YSI ProDSS	Temperature, pH, DO, Conductivity, Turbidity, Chlorophyll, Blue-Green Algae, Ammonium, Nitrate, Chloride	- **Temperature:** -5 to 70°C - **pH:** 0 to 14 - **DO[2]:** 0 to 500% saturation - **Conductivity:** 0 to 200 mS/cm - **Turbidity:** 0 to 4000 NTU	$2,500 - $7,000	Multiparameter, interchangeable sensors, data logging, GPS functionality, rugged design
Hach HQ Series	pH, DO, Conductivity, ORP, TDS	- **pH:** 0 to 14 - **DO:** 0 to 20 mg/L - **Conductivity:** 0.01 to 200 mS/cm - **ORP:** -1500 to 1500 mV - **TDS:** 0 to 100,000 mg/L	$1,000 - $3,000	Laboratory and field applications, intuitive interface, reliable and accurate measurements
In-Situ Aqua	Temperature, pH, DO, Conductivity, Turbidity, Nitrate,	- **Temperature:** -5 to 50°C - **pH:** 0 to 14 - **DO:** 0 to 50 mg/L -	$2,000 -	Wireless data transmission, long-term

[2] Dissolved oxygen

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TROLL 600	Chloride, Ammonium, Blue-Green Algae, Chlorophyll	**Conductivity:** 0 to 100,000 µS/cm - **Turbidity:** 0 to 3,000 NTU	$6,000	deployment, antifouling features, high accuracy and stability
OTT Hydromet HYDROLAB HL7	Temperature, pH, DO, Conductivity, Turbidity, Nitrate, Chloride, Ammonium, Blue-Green Algae, Chlorophyll	- **Temperature:** -5 to 50°C - **pH:** 0 to 14 - **DO:** 0 to 50 mg/L - **Conductivity:** 0 to 100,000 µS/cm - **Turbidity:** 0 to 3,000 NTU	$4,000 - $10,000	Comprehensive multiparameter monitoring, robust design, long battery life, easy maintenance
Horiba U-50 Series	Temperature, pH, DO, Conductivity, Turbidity, ORP, Salinity, TDS	- **Temperature:** -5 to 55°C - **pH:** 0 to 14 - **DO:** 0 to 20 mg/L - **Conductivity:** 0 to 100 mS/cm - **Turbidity:** 0 to 800 NTU	$3,000 - $8,000	Portable and user-friendly design, high durability, real-time data display and logging
Campbell Scientific OBS-5+	Turbidity, Suspended Solids Concentration, Temperature	- **Turbidity:** 0 to 4000 NTU - **Suspended Solids:** Up to 50 g/L - **Temperature:** -5 to 50°C	$3,000 - $5,000	High accuracy, low maintenance, suitable for freshwater and marine environments, rugged design
Aqua TROLL 500	Temperature, pH, DO, Conductivity, Turbidity, Nitrate, Chloride, Ammonium, Blue-Green Algae, Chlorophyll	- **Temperature:** -5 to 50°C - **pH:** 0 to 14 - **DO:** 0 to 50 mg/L - **Conductivity:** 0 to 100,000 µS/cm - **Turbidity:** 0 to 3,000 NTU	$1,500 - $5,000	Compact and portable, wireless data transmission, high precision and stability
Eureka Manta+ 30	Temperature, pH, DO, Conductivity, Turbidity, Nitrate, Chloride, Ammonium, Blue-Green Algae, Chlorophyll, Oil in Water	- **Temperature:** -5 to 50°C - **pH:** 0 to 14 - **DO:** 0 to 50 mg/L - **Conductivity:** 0 to 100,000 µS/cm - **Turbidity:** 0 to 3,000 NTU - **Oil:** 0 to 500 ppm	$4,000 - $12,000	Customizable with a wide range of sensors, easy integration with telemetry systems, durable for long-term field deployment

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Selecting the appropriate water monitoring sensor depends on specific application needs, such as the parameters to be measured, environmental conditions, budget constraints, and desired features like wireless data transmission and long-term deployment capabilities.

2.3.7 Biodiversity monitoring & sensors

Market Positioning for Biodiversity Monitoring Sensors

To accurately position the sensors designed to measure biodiversity in wastewater, two overlapping markets must be considered. Firstly, the biological parameters sensor market, which is primarily driven by medical applications. Secondly, the water quality monitoring market, where biosensors are not widely mentioned but are highly relevant for measuring pollutants in wastewater. It is believed that the sensors developed under the Di-Hydro project could attract significant interest for this specific application.

Biological parameter sensors market: In 2023, the global optical biological parameter sensors market was valued at approximately USD 27.2 billion and is expected to reach USD 38.9 billion by 2030, at a Compound Annual Growth Rate (CAGR) of 7.8% (MMR, 2024a). In 2023, the medical segment dominated the industry and accounted for around 66.8% of the total revenue share (Grand View Research, 2024). Environmental monitoring, the main application of interest for Di-Hydro, remains underrepresented, and well-established data for sensors monitoring bacteria and algae in wastewater is lacking. Key players in this market are primarily focused on medical applications, including Bio-Rad Laboratories, Medtronic, and Abbott Laboratories.

However, it is possible to find very specific examples in this market for water monitoring, such as the fluorescent sensors provided by Moldaenke (2024):

Table 20. Biological parameter sensors

Company	Commercial Solutions	Source
Moldaenke	AlgaeTorch is a handy instrument for the measurement of microalgae and cyanobacteria in all types of water, both fresh and saline.	Moldaenke (2024)
Modern Water	AlgaeCheck Ultra provides is a portable fluorometer which provides a cost-effective solution for monitoring the effects of organic contamination, identifying potentially harmful cyanobacteria and turbidity.	Equipamento cientifico (2024)

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Water Quality Sensors Market would also encompass the biodiversity sensors to be developed at Di-Hydro. According to MMR (2024b), the size of this market was valued at US$ 5.87 Bn in 2023, and the total revenue is expected to grow at a CAGR of 7.8% from 2024 to 2030, reaching nearly US$ 9.93 Bn. According to the same source, the market is mainly segmented into Residual Chlorine, Total organic carbon (TOC), Turbidity, Conductivity, pH, ORP, and Others.

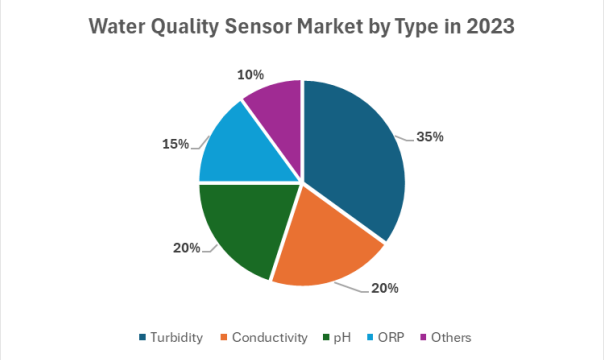

Figure 2. Water quality sensor market by type in 22023. Adapted from MMR(2024b)

These types of sensors cannot directly measure the presence of bacteria such as Escherichia Coli or algae. They can provide indirect indications of the possible presence of these organisms; for example, the TOC sensor could indicate organic matter including algae and bacteria, but without specifying which ones. We believe that this market would be of much greater interest for Di-Hydro sensors than the biosensor market. Currently, the use of biosensors in wastewater seems minimal, but for this very reason, it offers great growth potential. This is driven by the rising level of water pollution and the adoption of advanced monitoring and remote technologies for water facilities and wastewater treatment plants globally. Furthermore, the United Nations Sustainable Development Goal 6 aims to ensure access to water and sanitation for all people by 2030.

The global water and wastewater sensors market presents a highly fragmented competitive landscape, marked by the presence of numerous market vendors worldwide. The following major players are considered: These companies leverage optical sensor technologies to provide accurate, real-time monitoring of various water quality parameters, enhancing the ability to manage and protect water resources effectively.

Table 21. Water Quality Sensors

Company	Commercial Solutions	Source
ABB	ABB employs a variety of sensors for environmental and water quality monitoring, including optical sensors. ABB's optical sensors are commonly used for measuring parameters like turbidity, dissolved oxygen, and other critical water quality indicators.	ABB (2024)
Xylem	Xylem provides optical sensors for measuring parameters such as turbidity, chlorophyll, and dissolved organic matter. These sensors use optical technologies to provide real-time data on water quality.	Xylem (2024)

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Hach	Hach offers optical sensors for turbidity, colorimetric analysis (using light absorption), and other parameters like UV absorption for organic compound measurement.	Hach (2024)
OTT HydroMet	OTT HydroMet uses optical sensors for turbidity and other water quality measurements, employing light scattering and absorption techniques.	OTT HydroMet (2024)
YSI	YSI utilizes optical sensors for parameters like turbidity, chlorophyll, and blue-green algae. These sensors rely on fluorescence and absorbance principles to detect specific substances in water.	YSI (2024)
S::CAN	S::can specializes in using spectrometry sensors that employ UV-Vis optical technology to monitor water quality. These sensors measure absorbance across a range of wavelengths to detect organic and inorganic compounds.	S::can (2024)

Hydroelectric plants extensively use turbidity, pH, and other water quality optical sensors to maintain operational efficiency, prevent equipment damage, and minimize environmental impact. While the existing sensors do not measure Escherichia coli or algae, these specific applications could be of interest to hydroelectric plants if such products were available. Therefore, this market is identified as a priority for the exploitation of the biodiversity sensors developed by Di-Hydro.

2.3.8 Real time monitoring of hydropower plant Key Performance Indicators

Real time monitoring of Key Performance Indicators (KPIs) is a key aspect of digitisation of HPPs and the hydropower sector. This section refers to solutions that allow the monitoring of vital parameters of the HPP assets, depending on what the operator requires, in real time. Such solutions are closely connected to DTs and is part of the visualisation and information that DTs can provide as well as what sensorisation of an HPP allows, as described in previous sections. Examples of such KPIs can be power factor, health of assets, utilisation & availability of assets, etc. Systems that monitor HPP infrastructure and electromechanical equipment allow the collection of data that provide an overall picture to the operator about the plant's health, its performance and what corrective actions or scheduled maintenance is required.

KPIs can monitor poor performance of the assets and can be used to trigger corrective actions and maintenance (Oprea, 2017). Such information can be combined with Enterprise Resource Planning (ERP) systems and plant conditions specific metrics to calculate how these KPIs can be translated into business metrics i.e. operational costs (Arch et al. 2019).

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Table 22. Commercial real time KPI monitoring tools

Commercial solutions	Description	Source
Metris DiOMera	Metris DiOMera is a software platform developed by ANDRITZ. Metris is the technology brand of ANDRITZ for digital solutions for both new and existing plants. Together DiOMera and Metris as a software platform, offer a wide range of technology modules, sensor technology and augmented reality, forming a digital solution for cost efficient services for HPP Operation and Maintenance. The platform allows continuous monitoring of KPIs of multiple generations units or even power plants from an operator. It also allows monitoring of assets for operational efficiency and whether they work within their predefined boundary conditions, diagnosis and analytics of the KPIs. The aim of this platform is also to offer operation optimisation and predictive maintenance according to the data collected.	ANDRITZ (2024)
ABB Ability™ Asset Performance Management	ABB Ability is a software platform that allows the transition towards condition-based and predictive maintenance though monitoring of KPIs such as health status of equipment, critical diagnostic indicator, as well as health and fault indicators.	ABB (2019)
GE Hydro APM (Asset Performance Management)	Hydro APM is a software suite for asset performance management, reliability and strategy for O&M purposes. The software allows flexibility of operations by: 1) collecting data from sensors and all relevant systems, 2) using predictive analytics and methodologies and 3) providing recommendations for when to replace assets.	GE (2020)
Zenon Energy Edition from COPA DATA	Zenon Energy is a platform that allows HPP automation by offering monitoring, control and optimisation through their product. It is a scalable system that can be	COPA-DATA GmbH (2019)

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	used for HPPs or specific sub-sections. It offers visualisation, control, analysis and reporting of live or historical data. Finally, it offers warnings in the event of an alarm or maintenance.	
The Hydro Efficiency Analysis (HydEA) Platform	Enel Green Power has developed a platform driven by algorithms that analyse plant behaviour thus allowing real time detection of deviations from the optimum threshold values set by the manufacturer/user. This system allows engineers to intervene when equipment are operating outside expected norms.	Quaranta (2020)
Microsoft Power BI	Power BI allows the visualisation of key data from an HPP and provides analytics and graphs to showcase the data over time.	Microsoft (2024)
AVEVA PI System	AVEVA PI is a portfolio solution that enables companies to collect, process, store and visualise operational data.	AVEVA (2024)

2.3.9 Decision Support Tools

Managing hydroelectric power plants efficiently is crucial for maximizing their economic return and ensuring sustainable energy production. Decision support software plays a vital role in this process by providing advanced tools for optimizing operations, automate planning, and for a more effective participation in the energy market.

Several advanced decision support software options are available for these needs. IDRO is a commercial software designed to maximize the economic return of hydroelectric power plants. It models entire water cascade systems, including constraints like plant unavailability, minimum water release, and production ramps. By integrating a comprehensive database of historical data, real-time measurements and forecasts, IDRO supports long-term budgeting, short-term resource allocation, and what-if analysis. Its integration with the energy market enhances bidding effectiveness, making it a robust tool for production optimization and asset monitoring.

Hydrogrid offers modular support for managing both run-of-river plants and complex water cascade systems. It provides inflow predictions for run-of-river plants to minimize imbalance costs and optimizes production schedules for cascade systems to maximize economic returns based on forecasted energy prices. Hydrogrid considers environmental

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and operational constraints, turbine efficiency, and supports the bidding process by monitoring real-time energy prices, ensuring optimal bids and even direct market bidding.

Volue Smart Power focuses on the automation and optimization of large multi-asset portfolios, including hydroelectric power plants, thermal power plants, and renewable sources like solar and wind. It integrates asset models and data to compute optimal production schedules and supports participation in multiple European markets. The software's event-based framework allows for high customization and flexibility, while its intuitive graphical interface facilitates data management, simulation, and optimization tasks.

Table 23. Commercial decision support tools for HPPs

Software	Description	Source
IDRO	Maximizes economic return by modelling water cascade systems and integrating data for budgeting, resource allocation, and what-if analysis.	MAS Consulting (2024)
Hydrogrid	Supports hydro plant management by optimizing production schedules and bidding processes, suitable for both run-of-river and complex water cascade systems.	HYDROGRID (2024)
Volue Smart Power	Automates and optimizes multi-asset portfolios, integrating models and data for participation in European markets with customizable, event-based automation.	VOLUE (2024)

2.3.10 Data security and architecture of HPPs

Some tools exist in the market to model cyber-attacks and perform cyber risk analysis. Among them, Nessus detects and assesses vulnerabilities, misconfigurations, and policy violations across various devices and applications and generates detailed reports and prioritizes vulnerabilities based on severity. Qualys is a comprehensive vulnerability management, compliance monitoring, and web application scanning and provides continuous monitoring and detailed reporting. Splunk collects, analyses, and correlates data from various sources and offers real-time threat detection, incident response capabilities, and advanced analytics. BitSight evaluates the security posture of organizations through continuous monitoring and generates security ratings and provides actionable insights for third-party risk management. CyberGRX offers a dynamic cyber risk exchange platform for assessing and monitoring third-party risks and provides detailed risk reports and continuous monitoring.

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These tools offer a wide range of functionalities from vulnerability assessment and threat detection to compliance management and risk assessment. However, they do not use attack graphs and require a big effort from the network administrator to model cyber-attacks. Some tools that use attack graphs are MulVAL, which is an open-source framework that constructs attack graphs based on known vulnerabilities, network configurations, and attack patterns. It automates the analysis of multi-host, multi-stage attacks by modelling how attackers can combine different vulnerabilities to achieve their goals. Similarly, Cauldron is an advanced attack graph tool designed for comprehensive network vulnerability analysis. It uses a combination of network scanning, vulnerability assessment, and modelling to generate detailed attack graphs.

Table 24. Data security commercial solutions

Commercial solutions	Description	Source
Nessus	Detects and assesses vulnerabilities, misconfigurations, and policy violations across various devices and applications and generates detailed reports and prioritizes vulnerabilities based on severity.	Tenable Network Security (2022)
Qualys	Is a comprehensive vulnerability management, compliance monitoring, and web application scanning and provides continuous monitoring and detailed reporting.	Qualys, Inc. (2023)
Splunk	Collects, analyses, and correlates data from various sources and offers real-time threat detection, incident response capabilities, and advanced analytics.	Cisco (2024)
BitSight	evaluates the security posture of organizations through continuous monitoring and generates security ratings and provides actionable insights for third-party risk management.	BitSight Technologies, Inc. (2023)
CyberGRX	Offers a dynamic cyber risk exchange platform for assessing and monitoring third-party risks and provides detailed risk reports and continuous monitoring.	CyberGRX, Inc.
MulVAL	Is an open-source framework that constructs attack graphs based on known vulnerabilities, network configurations, and attack patterns. It automates the analysis of multi-host, multi-stage attacks by modelling how attackers can combine different vulnerabilities to achieve their goals.	ArgusLab (2012)
CyVision	Is an advanced attack graph tool designed for comprehensive network vulnerability analysis. It uses a combination of network scanning,	CyVision Technologies, Inc

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	vulnerability assessment, and modelling to generate detailed attack graphs.	

2.4 Identification of standards & regulations relevant to the exploitable results

D1.2 - *Requirements, tools and definitions* described the different use cases that will be carried out in the project. These are linked with the development of the key exploitable results, the application of different sensors, modelling and forecasting methods, development of the digital twins and in general with all the various activities that will be performed. The following tables presents relevant standards and regulations with the activities that will take place in the project.

Table 25 presents standards that are applicable to carrying out SHM/CM measurements of various types on hydropower plants and more specifically on generation units or other rotating machinery as like pumps and motors will be carried out in the Di-Hydro project. Thus, the aforementioned standards will be taken into account when carrying out the measurements with the SHM/CM sensor node that will be developed by CERTH.

Table 25. Standards related to SHM/CM monitoring of HPP

Standard	Description
ISO 20816-1:2016 Mechanical vibration — Measurement and evaluation of machine vibration Part 1: General guidelines	This standard is the basic document that specifies the general requirements for measuring and evaluating vibrations on housings and shafts of various machine types, installed at HPPs and pump-storage plants. The standard covers the vibration assessment that needs to be carried out.
ISO 20816-2:2017 Mechanical vibration — Measurement and evaluation of machine vibration Part 2: Land-based gas turbines, steam turbines and generators in excess of 40 MW, with fluid-film bearings and rated speeds of 1500 r/min, 1800 r/min, 3000 r/min and 3600 r/min	This standard covers land-based gas turbines, steam turbines and generators in excess of 40 MW with fluid-film bearings and rated speeds of 1500 r/min, 1800 r/min, 3000 r/min or 3600 r/min. In this case structural vibration sensors must be capable of measuring frequencies from 10 Hz to at least 500 Hz and shaft vibrations from form 1 Hz to at least 3 times greater of the normal operating frequency or 125 whichever is greater. It also covered the zone boundaries for vibrations on rotating shafts and non-rotating shafts. Finally, the standard covers alarm criteria for vibrations during run up, run down and overspeed.
ISO 20816-5:2018 Mechanical vibration — Measurement and evaluation of machine vibration	Part 5 of ISO 20816 sets the guidelines for vibration measurements made at bearings, bearing pedestals and bearing housings. It also sets the sets the guidelines for evaluating vibration measurements on hydraulic power generating and pump-storage plants when the machine is operating under normal operating range. The

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Part 5: Machine sets in hydraulic power generating and pump-storage plants	standard also covers sensor capabilities in terms of measurement range of vibrations. The standard is applicable to machines that have normal operating conditions of 60 RPM to 1000 RPM. ISO 20816-5:2018 also replaced ISO 7919-5 and ISO 10816-5.
IEC 62006:2010- Hydraulic machines - Acceptance tests of small hydroelectric installations	This standard refers to acceptance tests (i.e. safety approval tests, trial operation and reliability tests, including cavitation, noise and vibration measurements) required for small hydraulic turbines up to 15MW and reference diameter of about 3m.
ISO 13373-2 Condition monitoring and diagnostics of machines — Vibration condition monitoring Part 2: Processing, analysis and presentation of vibration data	Part 2 of ISO 13373 describes procedures for preprocessing/ processing, analysing and presenting vibration data from monitoring rotating machinery. The methods described are standard techniques (time domain and frequency domain analysis) that an expert working on vibration analysis should already know.
ISO 13374 Condition monitoring and diagnostics of machines — Data processing, communication and presentation	This standard has 2 main parts: • ISO 13374-1, Condition monitoring and diagnostics of machines — Data processing, communication and presentation — Part 1: General guidelines • ISO 13374-2, Condition monitoring and diagnostics of machines — Data processing, communication and presentation — Part 2: Data processing This family of standards provides a general overview of data processing, communication and presentation requirements for software systems for application such as condition monitoring and diagnostics of machines.
ISO 5348:2021 Mechanical vibration and shock — Mechanical mounting of accelerometers	This standard refers to contact type accelerometers, their technical properties and different recommended practices for mounting the sensors.
ASTM E2983 Standard Guide for Application of Acoustic Emission for Structural Health Monitoring	This standard describes the fundamental definitions of Acoustic Emission (AE) and its use as a method for SHM for detecting, assessment, and monitoring of flaws or faults in structures. Also, the standard describes the fundamental principles of the application of AE in SHM i.e. terminology, AE apparatus requires, data acquisition and processing, diagnosis monitoring and prediction.
ASTM E1106-12(2021) Standard Test Method for Primary Calibration of Acoustic Emission Sensors	This ASTM standard describes typical calibration procedures and requirements of the AE sensor before usage.

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ISO 10817 Rotating shaft vibration measuring systems	This standard consists of 2 parts • Part 1: Relative and absolute sensing of radial vibration • Part 2: Signal processing and covers the monitoring and evaluations of vibrations on shafts from large machines such as steam turbine generator sets, gas turbines, industrial turbosets, hydraulic machines. It covers the sensor requirements, signal processing methods, how to attach the sensor and its calibration procedures.
ISO 19283:2020 Condition monitoring and diagnostics of machines — Hydroelectric generating units	This standard suggests recommended condition monitoring techniques for detecting and diagnosing common failures on hydropower units. It suggests specific primary components, monitoring techniques and relevant standards.
IEC 60034-33:2022 Rotating electrical machines - Part 33: Synchronous hydrogenerators including motor-generators - Specific requirements	This standard applies to three-phase, salient-pole synchronous generators and synchronous motor-generators for hydraulic turbine and pump-turbine applications, that have rated frequency of 50 Hz or 60 Hz, rated output of 10 MVA and above, pole pair number 3 and above, and rated voltage of 6 kV and above
IEC 61000-6-5:2015 Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment	IEC 61000-6-5:2015 describes the EMC immunity requirements for electrical and electronic devices. Basically, the ability for a device of the aforementioned type to withstand electromagnetic phenomena within the range of 0 Hz to 400GHZ of different types.
IEC 61000-4-X Electromagnetic compatibility (EMC) – Basic immunity standards	IEC 61000-4-X is a series of basic EMC standards that cover recommended test levels and instruments, test setup and procedure as well as how to evaluate the results.
IEC 60034-27-2 Rotating electrical machines - Part 27-2: On-line partial discharge measurements on the stator winding insulation of electrical machines	IEC 60034-27-2:2023 describes procedures for online partial discharge measurements and provides measuring techniques and instruments to be used, as well as covering interpretation of results and reporting. This standard is relevant for machinery with rated voltage of 3kV and higher.
IEC 60034-27-3: 2015 Rotating electrical machines - Part 27-3: Dissipation factor	IEC 60034-27-3: 2015 describes the procedures for dissipation factor measurements on the stator winding

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measurements on the stator winding insulation of electrical machines	insulation of rotating machinery with rated voltage of 6kV and higher.

Table 26 presents standards related to predictive maintenance that will be considered in the project activities.

Table 26. Standards related to predictive maintenance activities

Standard	Description
Industry 4.0 - Interoperability	PdM tool uses a micro-services architecture with a message bus (Event Bus) for inter-service communication, allowing for interoperability and integration with various industrial systems, a key aspect of Industry 4.0.
Industry 4.0 - Data Exchange and Communication Protocols	The use of Message Queuing Telemetry Transport (MQTT) protocol and potentially Kafka for messaging aligns with common Industry 4.0 communication standards.
Industry 4.0 - Condition Monitoring and Predictive Maintenance	These functionalities are essential components of Industry 4.0, enabling real-time monitoring and maintenance of machinery to enhance productivity and reduce downtime.
Micro-services Architecture - Decoupled Services	The architecture follows a standard micro-services design pattern, where each service is independently deployable and scalable, which is a best practice in modern software development.
Micro-services Architecture - Asynchronous Communication	The use of message queues (e.g., MQTT, Kafka) for asynchronous communication between services is in line with micro-services standards, promoting scalability and fault tolerance.
Data Handling and Storage- InfluxDB and PostgresDB	The use of these databases suggests adherence to best practices for time-series data storage and relational data management, respectively.
Data Handling and Storage- Data Security and Integrity	The architecture follows data security standards such as access control, and authentication (e.g., token-based authentication in Data Consumer Post).
ISO 13374 - Condition monitoring and diagnostics of machine systems – Data processing, communication, and presentation	Already described in Table 25

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Table 27 and Table 28 describe standards and regulations related to data security and architecture that will be followed within the project.

Table 27. Standards related to data security and architecture

Standard	Description
NGSI-LD	It represents an advanced information model and API designed for the publishing, querying, and subscription of context information. Its primary purpose is to enable the open exchange and sharing of structured information among diverse stakeholders. This standard has been established by the European Telecommunications Standardization Institute (ETSI) through the Context Information Management Industry Specification Group, in response to a directive from the European Commission.
ISO 27001- Information security, cybersecurity and privacy protection — Information security management systems — Requirements	It is for information security management systems and defines requirements such systems must meet. It provides with guidance for establishing, implementing, maintaining and continually improving an information security management system.
ISO 27035- Information technology — Information security incident management Part 1: Principles and process	It presents basic concepts, principles and process with key activities of information security incident management, which provide a structured approach to preparing for, detecting, reporting, assessing, and responding to incidents, and applying lessons learned.
ISO 31000- Risk management	It is for Risk management Guidelines and provides principles, frameworks and processes for managing risk.
IEC 61850- Communication networks and systems for power utility automation - ALL PARTS	It defines communication protocols for intelligent electronic devices at electrical substations

Table 28. Applicable regulations relative to data privacy

Regulation	Description
General Data Protection Regulation-GDPR	It is a European Union (EU) regulation which governs the transfer of personal data outside the EU. Its goals are to enhance individuals' control and rights over their personal information and to simplify the regulations for international business.

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Table 29 and Table 30 present standards and regulations relevant to environmental and biodiversity monitoring. Serbian laws and regulations are also covered due to one of the pilot use cases taking place in Serbia.

Table 29 Standards related to environmental and biodiversity monitoring

Standard	Description
ISO 14001:2015 - Environmental management systems	Includes requirements for environmental management systems and can be applied to organizations that manufacture or use sensor equipment for water quality monitoring.
ISO/IEC 17025:2017 - General requirements for the competence of testing and calibration laboratories	This standard specifies requirements for competence, impartiality and consistent functioning of laboratories. Laboratories performing sensor calibration must be accredited according to this standard.

Table 30. Serbian Laws and regulations related to environmental and biodiversity monitoring

Regulation	Description
Law on technical requirements for products and conformity assessment „Службени гласник РС“, бр. 36/09, 98/12, 113/17 и 95/18)	This law regulates the technical requirements for products and the procedures for evaluating the conformity of products with technical requirements.
Rulebook on parameters of ecological quality of surface waters and quality standards ("Службени гласник РС ", no. 74/11, 50/12, 76/12, 1/16, 77/18)	Includes requirements for equipment used to monitor surface water quality.
Metrology Law ("Службени гласник РС ", no. 15/16	Rulebook on conformity assessment ("Official Gazette of RS", no. 98/12 and 98/16) • Describes procedures for evaluating product compliance with technical requirements.
Zakon o vodama (Službeni glasnik RS br.95/2018) **Law on water (Official Gazette of RS, No. 95/2018)**	This law regulates the legal status of water, integral water management, management of water facilities and water area, sources of funding and methods of financing water activities, monitoring of the implementation of this law, as well as other issues important for water management.
Uredba o graničnim vrednostima zagađujućih materija u površinskim i podzemnim	This regulation establishes the maximum values of polluting substances (polluting matter in

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vodama i sediment i rokovima za njihovo dostizanje (Službeni glasnik RS br.50/2012) **Regulation on maximum values of pollutants in surface and underground waters and sediment and deadlines for reaching them (Official Gazette of RS, No. 50/2012)**	surface and underground waters and sediment), as well as the deadlines for reaching them.
Uredba o graničnim vrednostima emisije zagađujućih materija u vodi I rokovima za njihovo dostizanje (Službeni glasnik RS br.01/2016) **Regulation on maximum values of polluting substances emission in water and deadlines for reaching them (Official Gazette of RS, No. 01/2016)**	This regulation establishes maximum emission values for the following groups or categories of polluting substances (polluting matter): industrial waste water before its discharge into the public sewage system; industrial and other waste water types that are directly discharged into the recipient; water that after purification is discharged from the public sewage system into the recipient and waste water that is discharged from the septic tank into the recipient, as well as the deadlines for reaching them.
Pravilnik o načinu merenja i uslovima za merenje količine i ispitivanje kvaliteta otpadnih voda i sadržini izveštaja o izvršenim merenjima (Službeni glasnik RS br.18/2024) **Rulebook on the method of measurement and conditions for measuring the quantity and testing the quality of wastewater, and the content of the report on the performed measurements (Official Gazette of RS, No. 18/2024)**	This rulebook describes in more detail the methods, conditions and place for installing devices for measuring quantities, taking samples and testing the quality of wastewater and its impact on the recipient, as well as the content of the report on the measurements of the quantity and quality of wastewater and its impact on the recipient and the method and deadlines for its delivery.
Pravilnik o parametrima ekološkog i hemiskog statusa površinskih voda i parametrima hemiskog i kvantitativng statusa podzemnih voda (Službeni glasnik RS br.74/2011) **Rulebook on the parameters of the ecological and chemical status of surface waters, and on the parameters of the chemical and**	This rulebook describes parameters of ecological and chemical status for rivers and lakes, parameters of ecological potential for artificial water bodies and significantly altered water bodies, and parameters of chemical and quantitative status of underground water. These parameters are used as the basis on which the status assessment of surface and underground water bodies is carried out.

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quantitative status of underground waters (Official Gazette of RS, No. 74/2011)	

Table 31. European regulations relating to biodiversity monitoring

Regulation	Description
EU Water Framework Directive (2000/60/EC)	Compliance with this directive is crucial for any technology used in water quality monitoring
Zero Pollution Action Plan	It includes specific goals for reducing pollution in water bodies, which directly aligns with the objectives of the Di-Hydro project.
Environmental Quality Standards Directive (2008/105/EC)	This directive sets specific EQS for a list of priority substances and certain other pollutants in surface waters, which include: • **Priority Substances:** Substances presenting a significant risk to or via the aquatic environment, such as heavy metals (cadmium, lead, mercury), polycyclic aromatic hydrocarbons (PAHs), and pesticides. • **Maximum Allowable Concentrations:** Specific thresholds that should not be exceeded to protect aquatic ecosystems and human health.

2.5 SWOT Analysis

An internal workshop was carried out with the aim of evaluating the different project elements and performing a SWOT Analysis. The workshop identified the internal and external factors which could make a difference in the success of the Di-Hydro project. The analysis of the project was categorized into four components: Strengths, Weaknesses, Opportunities, and Threats (SWOT) which are presented in Table 32.

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Table 32. SWOT analysis performed for Di-Hydro project

SWOT COMPONENT	CATEGORY	OUTCOME
Strengths	Expertise and Knowledge	• *Wide range of expertise and enhanced knowhow in the sector.* • *Value propositions based on state-of-the-art technologies.*
	Technological Advancements	• *Adoption and testing of cutting-edge technologies like digital twins, AI, and sensors.* • *Introduction of cost-effective monitoring systems for machinery and environmental conditions.*
	Environmental and Health Benefits	• *Added environmental and health-related values.*
	Support and Compliance	• *The project supports the compliance with environmental legislation and recognises the importance of supporting the end-users.*
	Operational Efficiency	• *Aiming to improve maintenance scheduling, reduce downtime, and enhance plant health monitoring.* • *Use of standardised data models to support decision-making processes.* • *Conducting diverse case studies to validate technologies.*
Weaknesses	Data and Information Management	• *Challenges in the exchange and confidentiality of data.*
	Technology and Market Position	• *Variation in the maturity of components and the absence of a demonstrable integrated product or digital twin* • *Competition from well-established players*
Opportunities	Technological Development and Transferability	• *Ensuring that the technologies and knowledge developed can be transferred to other sectors and partners enhances the project's value and impact.* • *Lack of existing standards presents an opportunity to create and implement technologies.*
	Innovation and Testing	• *Opportunity to pioneer and validate cutting-edge technologies.*

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	Market and Commercialisation	• *The project could cover a broad range of industrial applications, while EU laws can boost their commercialisations*
	Environmental and Global Awareness	• *There are growing awareness on environmental issues and the increased global interest in renewable energy resources.*
	Showcasing and Dissemination	• *Participating in prestigious international platforms like EU Horizon provides significant visibility. This can help attract more stakeholders, including investors, partners, and customers.*
	Modernisation Needs	• *Ageing hydropower plants (HPPs) need digitisation to enhance efficiency, performance, and data-driven decision-making.*
Threats	Market and Competition	• *The presence of new, untested products and costly monitoring systems in the market.*
	Financial Constraints	• *Companies may not allocate enough funds to address environmental concerns.*
	Cybersecurity Risks	• *Presence of constantly evolving cyber threats.*
	Infrastructure and Resources	• *Inadequate infrastructure for digitalization and insufficient data for modelling tools.*
	Regulatory Changes	• *Shifts in regulations can affect the implementation and compliance of the project's solutions.*

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3. INDIVIDUAL EXPLOITATION STRATEGIES

The Di-Hydro consortium consists of a variety of partners from different sectors. Consequently, the way that the partners will exploit their results and the overall project results, varies depending on their agenda and the sector they belong to. The following section presents the individual exploitation plans for each project partner. It needs to be noted that this is the initial identification of the exploitation strategies, which may be subject to change in the duration of the project and will be reported in the second iteration of the deliverable. In addition, end user partners such as PPC, A2A, EPS although they are focusing on specific pilot cases and exploitable results, their interest may change into results from other pilots.

The following table present the list of partners and their sectors

Table 33. Di-Hydro partners clustered according to sector

Power companies	• PPC • A2A • EPS
SMEs	• ACCELIGENCE • AP2K • ATLANTIS • DBL • MAS • Waterjade
Research centres and academia	• AIMEN • CERTH • IMT

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3.1 CERTH

Table 34. CERTH individual exploitation plan

CERTH individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Innovative sensors for HP machinery operation monitoring	Prior knowledge on Acoustic Emission and the different sensors of the node	Development of the sensor node that can be used for CM/SHM for HPP machinery or infrastructure, capable of carrying out modal analysis and detect failures. CERTH will gain experience in applying such nodes on larges HPPs. Plus, the development of the proprietary multisensory node.	Sensor applications is a field that CERTH already has expertise in. However, the creation of the sensor node itself which is a for multipurpose usage and its application on hydropower plants will add further expertise into this sector.	CERTH will offer the sensor node as a technology/ consultancy-based service to the HPP industry although the exploitation of this technology is not limited to the hydropower industry.
Underwater inspections assisted by AI image processing for defect detection	Prior knowledge on image processing techniques	Exploitation of the tool for automated data and image processing for underwater acquisitions. Exploitation of know-how	Underwater inspections using drones is a new growing field in the hydropower sector. CERTH would like to gain additional expertise in this field and pursue this result for further future exploitation.	CERTH would like to exploit this result as a technology-based service as well as build further expertise in the future to work towards autonomy of such underwater vehicles in carrying out inspections.

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HPP cluster modelling	Utilization of CERTH's in-house electrical grid simulator named INTEMA.grid. Already developed models that include standardised governor, exciter, machine and 3-phase system representation models.	To adjust to the Di-Hydro special needs, INTEMA.grid models will be enriched with all required specialised components to simulate reduced-order system models.	Novel HPP-related models will extend the modelling capabilities of CERTH's electrical grid simulator (INTEMA.grid) to cover specialised hydropower applications.	INTEMA.grid product upgrades for the Di-Hydro special objectives will expand the range of end-users and stakeholders who can capitalise on its services.

3.2 IMT

Table 35. IMT individual exploitation plan

IMT individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Secure by design algorithms for HPP data collection, exchange and storage	Prior knowledge of response to incidents in constrained environments, leveraging past activities, results and publications on the development and integration of a remediation ranking component supporting operators in responding to cyberattacks.	Created a computational framework for the security by design of HPPs by modelling the threats with Attack Graphs and establishing trust among HPP components for data sharing.	Enables the selective data sharing between HPPs to allow for maintaining data sovereignty across federated HPP operations.	Through the Di-Hydro proof of concept and associated publications, a future widespread adoption of this federated data exchange architecture can be achieved.

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HPP data modelling	Prior knowledge of modelling of static and dynamic data of smart spaces.	Created data models of HPPs by taking into consideration their physical spaces, sensor deployed and other assets digital or not.	Enables the adoption of a secure by design platform creation for federated HPP operations.	Through the Di-Hydro proof of concept and associated publications, a future widespread adoption of this secure by design approach for federated digital platforms can be achieved.

3.3 WATERJADE

Table 36. WATERJADE individual exploitation plans

WATERJADE individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Forecasting models for weather and water flow of HPPs	1) Weather data collection and weather forecasts processing (know-how, code/libraries, computational resources); 2) Configuration of the hydrological model (Digital Twin of the catchment - static version) (know-how,	1) Results (water inflow forecasts) provided through a proprietary licence dashboard with 2) access to involved partners; 3) Development of the flexibility of the dashboard: possibility to modify the hydraulic structures inside of the HPPs by an HP	The development during the Di-Hydro project will enhance the flexibility of the proprietary dashboard, allowing to modify the geometry of the system after an initial set-up phase (configuration on the specific use case).	After the project completion: the foreground will be exploited for commercialisation services; During the project: 1) free consultancy of the data for the partner involved, licence applied; 2) free access to the dashboard for the partner and companies in the

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	code/libraries, computational resources);	technician (Digital Twin of the catchment - dynamic version); 4) access to the proprietary dashboard via API (for involved companies in the consortium) in order to connect it to the Di-Hydro platform for decision-making		consortium, after that application of opportune licence and commercialisation of the service; 3) proprietary licence on the developed software/libraries, utilisation of the software/libraries in future works for commercialisation; 4) free access to the APIs provided to exchange the produced data with the other companies in the consortium and the partners, after that the APIs will be used in future works for commercialisation.

3.4 ACCELIGENCE

Table 37. ACCELIGENCE individual exploitation plan

ACCELIGENCE individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
HPP Digital Twin	ACCELIGENCE is an experienced technical partner with a proven track	ACCELIGENCE will enhance its capabilities in the development and validation	Cutting-Edge Technology Adoption.	Develop and validate the Digital Twin of our

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	record in European Union research initiatives, having contributed to multiple projects under both the Horizon 2020 and Horizon Europe frameworks. Our expertise encompasses software and hardware development, testing, and validation. Our engineering team is adept at digital modeling and testing, utilizing industry-standard tools such as Dassault Solidworks and AutoCAD.	of digital twin technologies. We will gain valuable experience in testing and validating cutting-edge sensor systems which will be developed by the project. This expertise will position us favorably for new business ventures within the relevant industries, contributing to the company's growth and value proposition.	Market Differentiation and Leadership. Revenue Generation through Licensing and Services: The expertise gained can be monetized through offering consulting services, licensing the Digital Twin technology to other plants, and providing continuous support and updates.	hydropower plant using Amesim software. Optimize plant operations using the Digital Twin and demonstrate tangible benefits. Commercialize the Digital Twin technology and expand into new markets.

3.5 ATLANTIS

Table 38. ATLANTIS individual exploitation plan

ATLANTIS individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
HP Structural Health monitoring and prediction AI based algorithms	Fault Detection, Fault Prediction, Fault Identification, Remaining Useful Life - Atlantis Engineering holds the	Atlantis Engineering holds the Intellectual Property Rights (IPR).	Novel ML/AI models will identify and predict trends in the HP function enabling maximum performance at the HP O&M. The models	Interaction with an end user is planned (participation will provide crucial feedback for ML/AI model development) while the model analysis,

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	Intellectual Property Rights (IPR). Any access, for implementation purposes, to the executables and technical details of the listed background will be subject to prior validation and/or negotiation between Atlantis Engineering and the interested Party(-ies). "		recognize patterns assessing the current state to achieve failure detection, failure identification and failure prediction of HP components and machinery health.	results outputs and failures will aid and support the maintenance and operational managers in their everyday tasks. Various stakeholders could benefit from such a solution as well.

3.6 MAS

Table 39. MAS individual exploitation plan

MAS individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
AI-based Decision support platform for HPPs and clusters	MAS owns a product that has being used for decision-making process by three companies operating the high majorities on the Eastern Italian Alps.	MAS will need to update its platform to take into account the new data streams that have become relevant in the Di-Hydro project according to the different use cases	The new platform pages and data streams developed in the context of the Di-Hydro project HPP will enhance MAS's decision-making platform, IDRO, by expanding its functionalities.	Additions to the functionality and integration requirements for Di-Hydro's specific objectives will broaden the spectrum of possible scenarios that may be relevant to new end-users and stakeholders.

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3.7 INOSENS

Table 40. INOSENS individual exploitation plan

INO individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Environmental monitoring sensor	Sensor technology know-how, optical and electrochemical sensor, ion selective membrane, biosensors. Sensor design and operation.	Development, testing and validation of sensor in laboratory and in-field condition.	The motivation to exploit environmental sensors stems from the growing need for real-time, accurate monitoring of pollutants and environmental changes. These sensors help in addressing pressing issues such as air and water quality, waste management, and climate change by providing critical data for regulatory compliance, public health, and environmental protection. Additionally, advancements in sensor technology have made them more accessible and cost-effective, encouraging widespread use to meet sustainability goals and mitigate environmental effects.	A long-term exploitation plan for environmental sensors focuses on integrating into sensor networks enhancing predictive analytics and ensuring sustainability through continuous monitoring. The plan includes scaling sensor deployment, developing more robust and cost-efficient technologies, and leveraging data for decision-making in environmental management, policy, and public health. It also aims to foster innovation and promote collaborations between industry, government, and academia to drive environmental impact and economic growth

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Monitoring and predictive models for biodiversity and environmental effects of HP O&M	Modelling of processes based on sensor data	Application of different machine learning algorithm based on vast sensors' data sets, historical data and water analysis results.	Monitoring and predictive models for biodiversity and environmental effects of hydropower plants are critical to the operation and maintenance of hydropower plant. Monitoring programs track real-time changes in water quality, vegetation and microorganisms that directly can have effect to the water flow and operation of impellers, and their cleaning. Predictive models help assess potential long-term impacts, including both impact on maintenance and operation of HPP, and ecological impacts on river ecosystems. Hydropower plants can alter water flow, temperature, and sediment transport, affecting aquatic habitats and biodiversity. Modelling can enable better decision-making strategy to mitigate negative effects, optimize plant operations, and ensure sustainable	A long-term exploitation plan for modelling in environmental monitoring focuses on refining predictive accuracy, expanding model applicability, and integrating real-time data from sensor networks. The plan includes continuously upgrading and improving models through machine learning, incorporating diverse environmental variables, different data sets and climate changes. Collaborative efforts between research, industry, and government agencies can drive model validation and scalability, ensuring long-term environmental protection.

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			energy production while preserving biodiversity.	

3.8 AP2K

Table 41. AP2K individual exploitation plan

AP2K individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Visualization of HPP Data and Digital Twin Simulation Tool	Prior knowledge on using data manipulation, visualization and Machine Learning Algorithms.	Successful Development of new techniques and new algorithms for industrial data visualization and better understanding of the needs of operators for real-time action.	The Visualization Tool will enhance data visualization for HPP operators by taking the proper decisions while operating the units in environmentally easy and friendly conditions.	The Visualization Tool will be further developed for HPP operators to maximize the functionality. In addition, The Visualization Tool will be extended to other areas needed.

3.9 PPC

Table 42. PPC individual exploitation plan

PPC individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
HP Structural Health monitoring and prediction AI based algorithms	PPC has prior knowledge on structural health monitoring of dams	Predict and monitor the structural health of the HP	The development of a predictive maintenance algorithms will potentially reduce plant downtime and	Through the Di-Hydro project, PPC will reduce downtime and maintenance costs and predict larger

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			improve efficiency while maintenance activities can be planned and manage more efficiently.	breakdowns. As a leader in the Greek energy market, PPC will also seek to further exploit this knowledge for further consultancy services to other providers.
Innovative sensors for HP machinery operation monitoring	PPC has prior knowledge on sensors for monitoring machinery operations from the different power plants (hydro and thermal)	Better understand and visualize the health status and conditions of the turbine.	Deployment of sensors for better monitoring of HP machinery	Through the Di-Hydro project, PPC will reduce downtime and maintenance costs and predict larger breakdowns. As a leader in the Greek energy market, PPC will also seek to further exploit this knowledge for further consultancy services to other providers.
AI-based Decision support platform for HPPs and clusters	None	To have decision support platform for the HPPs.	An integrated platform will support the optimal management of the HPPs. Also, the digitisation of PPC hydropower plants will enable operation control.	Through the Di-Hydro project, PPC will reduce downtime and maintenance costs and predict larger breakdowns. As a leader in the Greek energy market, PPC will also seek to further exploit this knowledge for further consultancy services to other providers. Plant digitisation through AI models and, possibly, DTs, will allow the optimal

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				scheduling of all PPC HP plants.

3.10 A2A

Table 43. A2A individual exploitation plan

A2A individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Forecasting models for weather and water flow of HPPs	Long term: models based on historical mean water flow values. Short term: weather and water flow observation, waterflow prediction based on expertise of plant workers	Long term: better models which take into account multiple variables Short term: water flow prediction based on algorithms	To better predict water flow rate entering the lakes	Improvement of business processes, both long- and short-term energy production planning
AI-based Decision support platform for HPPs and clusters	None	To have a platform which helps the users to make better decisions on energy market dispatch	To better dispatch the energy on the various energy markets	Improvement of business processes, both long- and short-term energy production planning

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3.11 EPS

Table 44. EPS exploitation plan

EPS individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Monitoring and predictive models for biodiversity and environmental effects of HP O&M	AI modelling know-how	Automated microorganism recognition through holographic image reconstruction	Internal use of this technology will enable better understanding and management of water quality, which is essential for ecosystem maintenance and safe operation of HPP.	This technology would become part of daily operations and provide us with the initial data for starting the lake cleaning project in the future.

3.12 AIMEN

Table 45 AIMEN individual exploitation plan

AIMEN individual exploitation plan				
Exploitation result	**Background**	**Foreground**	**Motivation to exploit**	**Long term exploitation plans**
Biodiversity monitoring sensor	Knowledge of optical spectroscopy sensors based on absorption and fluorescence.	Validation campaign including turbidity measurements. Sensor	The development of a field portable platform integrating several sensors, designed for monitoring organic parameters in water and microorganism detection, will help to evaluate the whole environmental	Firstly, the plan would consist of increasing the TRL in future R&D projects. Then the possibility of licensing the development to manufacturing third parties would be contemplated. A thorough market study should be performed in case this licensing is studied.

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		integration field design. Portable multi parametric platform for real-time assessment of the population of micro-organisms in water (pathogenic bacteria, cyanobacteria, green algae).	landscape of water bodies, regardless the application case (HP dammed water, natural lakes, rivers, etc.).	
Monitoring and Predictive models for biodiversity and environmental effects of HP Operations & Maintenance	Knowledge of optical monitoring based on microscopy combined with holographic techniques and image processing algorithms.	Monitoring and predictive models for biodiversity and environmental effects of HP operation.	Developing a software for DHM hologram automated reconstruction and image classification would enable developing cost affordable microscope solutions, that enable 3D visualization of label-free samples in several application fields such as biomedicine, biology, bioengineering, environmental science, micrometrology, etc.	In case any commercialization is contemplated, this would be linked to the multiparametric sensing platform. The algorithms would be under licensed proprietary form. All data collected and analyzed using this software would consist of open datasets.

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4. EXPLOITABLE DISSEMINATION ACTIVITIES

Dissemination activities within the project are critical not only for knowledge sharing and stakeholder engagement but also as valuable exploitable results. These activities, which include publications, presentations, workshops, and digital communications, serve to amplify the project's impact and visibility.

By effectively disseminating research findings and innovations, the Di-Hydro project can attract potential end-users, thereby facilitating the uptake and commercialization of project outcomes. Furthermore, the creation of high-quality dissemination materials, such as reports, guidelines, and multimedia content, can be repurposed as educational resources or marketing tools, adding further value. Thus, the strategic planning and execution of dissemination activities transform them into tangible assets that contribute to the project's overall exploitation strategy.

Table 46. Exploitable dissemination results

Exploitable Dissemination Results		
Exploitation result	**Motivation to exploit**	**Long term exploitation plans**
Scientific Publications	Establish credibility and contribute to the scientific community.	Foster new collaborations and secure additional funding opportunities.
Articles in Magazines	Reach a broader audience, including industry stakeholders and the general public.	Enhance project visibility and foster partnerships.
Best Practice Handbook	Provide valuable resources for practitioners and policymakers.	Promote adoption of project methodologies and solutions.
Videos	Demonstrate project impact and practical applications.	Attract new stakeholders and maintain public interest.
Project Conference	Facilitate networking and knowledge exchange.	Foster collaborations and further exploitation of project outcomes.
Cluster Activities with Sister Projects	Enhance collaborative efforts and leverage shared resources.	Create a network of interconnected projects to maximise impact, share best practices, and co-develop solutions. Ensure ongoing communication and joint events to sustain collaboration and extend the reach of all involved projects.

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