Position Paper

HYDROPOWER FOR A RESILIENT, SECURE, AND COMPETITIVE EUROPE

Maximizing Impact through FP10 and a Dedicated SET Plan Implementation Working Group

To meet the goals of **industrial competitiveness, sovereignty** and **security** of supply, Europe urgently requires more **dispatchable, domestically anchored clean electric power capacity.** Hydropower —Europe's largest source of stored energy[i] and second-largest renewable electricity source[ii] —uniquely combines **flexible low-carbon generation, long-duration storage multi-purpose water management and environmental resilience**[v] that supports these goals. In doing so, hydropower directly contributes to at least **four of the SET-Plan's key actions:** it enables the system integration of renewables through flexibility and balancing services; supports cost reduction by optimising and upgrading existing assets; delivers innovative technologies and services to consumers via digitalisation, hybridisation and storage solutions; and strengthens the resilience and security of energy systems by providing reliable, dispatchable and climate-adaptive capacity. In addition, hydropower underpins water resilience — an increasingly critical pillar of EU policy — and should be explicitly acknowledged within the European Water Resilience agenda.

Despite this **multipurpose** unique system value, the attention in regulation and the effort in funding dedicated to hydropower has remained modest compared to other renewables. To secure Europe's energy sovereignty and industrial competitiveness, **we call for a targeted boost in FP10 funding and the establishment of a dedicated SET Plan Implementation Working Group on Hydropower.**

Unlocking Hydropower's full potential for value creation in Europe: Why now?

The **rapid growth of intermittent renewable technologies** like wind and solar, together with the electrification of energy use, puts Europe on the road to decarbonisation. However, intermittent generation increases system variability, and the subsequent need for flexibility ; this can be provided by hydropower: the key pillar for industrial competitiveness, sovereignty and security of supply.

Hydropower: Integrating Six Key Strategic Benefits for Europe

Flexibility and Energy Transition

Hydropower, representing run-of-river, reservoir and pumped-storage, is the **only proven, large-scale power technology that can provide balancing and flexibility critical services from milliseconds to months**[i].
Today, European Hydropower reservoirs hold **hundreds of TWh** of stored energy – hydropower provides 16% of total EU electricity consumption[ii], and pumped storage totalizes **~46 GW** of flexible power capacity. Multiple prospective analyses indicate the need to **at least double to quadruple this storage capacity by 2050**[iii], aligned with the **2025 PSH Paris Pledge**[iv]. Moreover, the **Net-Zero Industry Act (NZIA)**, formally recognises hydropower as a key, strategic technology for accelerating the EU's clean energy transition.

- **Dispatchable Storage:** Current Pumped-Storage Hydropower (PSH) capacity (approx. 46 GW in EU) provides the backbone for long-duration energy storage[i].
- **Expanding Capacity:** Expanding PSH Capacity: As explained in the PSH Paris Pledge, the industry stands ready to deliver over 35GW of new pumped storage projects. Europe has the natural resources to potentially double its PSH fleet by 2050.[iv].
- **Accelerated Deployment:** The Renewable Energy Directive (RED III) recognizes hydropower as a technology of "overriding public interest" (IROPI), prioritizing its system integration role[vi].
- **Hybridization development:** the close integration of Hydropower units with other energy & storage technologies (floating PV, batteries, wind farm, virtual power plants, ...) will be essential to enrich the catalogue of win-win efficient options to provide innovative and cost-effective flexibility services.

Strategic Autonomy, Sovereignty and Industrial Competitiveness

Hydropower is intrinsically 'Made in Europe', bolstering the EU's strategic independence and industrial base.

- **Domestic Resource:** Relies solely on domestic water resources and established European technology supply chains, providing autonomy from imported fuels associated to uncertain and unstable availability and affordability.
- **Low Risk to Critical Raw Materials:** Has low exposure to CRMs, serving as a natural hedge against supply chain risks faced by other storage options.
- **Regional Anchor:** Sustains high-qualified jobs across manufacturing, construction, operation and maintenance (O&M) , anchoring activity in European regions[i,v]
- **Industrial value-chain:** Sustains engineering, manufacturing and research skills at one of highest international standards, though highly challenged by other continents, especially Asia, through the world competition.

Affordability and Market Stability

Hydropower provides long-term, competitively priced electricity, essential for industrial competitiveness and social affordability.

- **Minimal LCOE:** Assets operate for over 80 years (at minimum), resulting in one of the lowest Levelized Cost of Energy (LCOE) profiles across all energy technologies[vii].
- **Price Insulation:** Insulates industrial users and households from fossil fuel price volatility, strengthening social affordability.

Climate Neutrality and Low-Carbon Footprint

Hydropower delivers reliable, near zero-carbon generation, actively contributing to the EU's 2050 climate neutrality commitment.

- **Ultra-low GHG Emissions:** Median world lifecycle Greenhouse Gas (GHG) emission rates stand at only 23 gCO_2-eq/kWh[viii] and are even much lower in most European countries.
- EU Taxonomy Compliant: This performance is well below the stringent technical screening criteria of the EU Taxonomy (<100 gCO_2-eq/kWh)[ix]
- **Efficiency Gains:** Modernisation and digitalisation deliver more output and higher efficiency from existing assets without additional land use[i].

Water Resilience and Socio-Economic Value of Hydropower

In a rapidly evolving geopolitical landscape, strengthening Europe's resilience and preparedness has become a strategic priority.
Hydropower is more than just electricity generation and storage: multi-purpose hydropower reservoirs are core assets for **climate adaptation and integrated water management**, directly supporting the European **Water Resilience agenda.**

- **Droughts & Floods:** Reservoirs store water to buffer droughts and regulate river flows to limit floods.
- **Water Security:** Secure irrigation, industrial, and urban supply, enhancing transport resilience by maintaining navigable inland waterway levels.
- **Water-Energy Nexus Improved Appraisal:** Explicit recognition of these co-benefits in funding frameworks will accelerate projects delivering combined energy and water security[i,iii].
- **Local communities:** Hydropower supports local economies in rural and mountainous areas, delivering clear added value and contributing to EU Cohesion Policy goals.

Environmental and Biodiversity Protection

Modern hydropower is evolving to be nature-positive, demonstrating that sustainable solutions can comply with the EU Biodiversity Strategy for 2030, the Nature Restoration Regulation and and the Water Framework Directive (WFD).

- **Nature-Positive Measures:** Modernization may include installing fish-friendly diversion / passage system (e.g. turbines, screens,fish guidance, fish ladders and lock lifts, by-pass rivers), restoring ecological minimum flows, and implementing innovative sediment management solutions to maintain dynamic river morphologies.
- **"Win-Win" R&I:** Targeted R&I funding is required to rapidly develop and scale these technical "win-win" solutions that balance technical performance with ecological needs and biodiversity protection as well as societal needs[i,v].

Enhanced FP10 Funding to Boost Hydropower R&I

The hydropower sector needs EU support to accelerate technology and innovation so it can **deliver the clean, competitive, sovereign, dispatchable and sustainable energy and long-duration storage service that a European Net-Zero electric system requires whilst also maintaining Europe's industrial position amid fast-rising global competition.**

Hydropower is the electric system's **balancing and storage backbone** that enables large shares of wind and solar PV to connect while keeping the grid stable. Meeting this role now requires **enhanced targeted R&I** to adapt and modernise existing assets, deploy new capacity where appropriate, and modernise operation & maintenance especially with digitised innovative solutions.

Funding needs

During the 1995-2015 period, EU funding for Hydropower R&I through successive FP's represented only 1% of total funding for renewable energy technologies[x]. Even though this rate increased progressively in the most recent H2020 and Horizon Europe programs (an average annual support of €10 to 17 million/year, e.g. remaining 10 to 20 times less than funding for solar PV and wind), hydropower R&I support appears modest relative to its critical added value to the European electricity supply transition.

A targeted uplift of EU funding for hydropower would align support with electricity supply needs while efficiently complementing current priorities for less mature emerging technologies.

This funding gap also coincides with **rising competition with Asia** and a **tightening skills pipeline** in Europe's OEM/EPC/SME value chains. R&I support at the European level will thus become critical as a **powerful vehicle to attract and maintain future generations of talented European professionals in all segments (engineering, manufacturing, research, O&M)** that Europe will need in the long term in this industrial competition.

To ensure that research and innovation efforts are targeted, coordinated and aligned with EU energy and climate objectives, the required actions have been clustered into a set of clearly defined priority themes.

This thematic approach enables a comprehensive coverage of the hydropower sector, spanning the full range of technology readiness levels. An annex to this document outlines proposed hydropower R&I priorities, structured around ten thematic areas and covering the full TRL spectrum.

Annex: Recommendations for future calls of Research and Innovation projects for hydropower technologies

Background: Developed together by EERA JP Hydropower and ETIP HYDROPOWER with contributions from IEA-TCP Hydropower, Cost Action Pen@Hydropower and IHA, these recommendations reflect broad industry input. They build on the HYDROPOWER EUROPE RIA and SIR, plus subsequent workshops and prioritisation, and have been endorsed by the involved organizations' boards. The recommended R&I focus will help sustain and grow hydropower's role. Each of the ten actions is tied to key EU priorities—competitiveness, security, simplification, diversification, strategic autonomy, affordability, digitalization (AI) and resilience.

Setting the scene

Hydropower has a long tradition in Europe, historically contributing to welfare and industrial development. Today, it is a key enabler of the clean energy transition, delivering dispatchable zero-carbon power, long-term storage, grid resilience, water-security co-benefits, and industrial competitiveness. Its dispatchable nature is crucial for integrating variable renewables, while modern technologies allow nature-positive operation.

Europe generates over 650 TWh annually, utilizing around 65% of economically feasible hydropower potential, with installed capacity reaching nearly 230 GW in 2024. In the EU, hydropower accounts for 152 GW, generating approximately 300 TWh, the second-largest renewable source after wind. Many countries still have significant untapped potential, in nearly half of the European region, hydropower provides 20–50% or more of electricity generation, while others have developed less than 50% of their feasible potential.

Pumped storage hydropower (PSH) complements reservoirs by providing long-duration flexibility. The EU currently hosts 46 GW of PSH, about a quarter of global capacity, with 43 GW under planning or permitting. In 2024, nearly 1.9 GW of new PSH were under construction across several countries, highlighting its central role in ensuring grid stability, flexibility, and resilience during critical events like the Dunkelflaute in November 2024.

Background & Impact

The energy crisis in 2022 revealed the importance of an independent electricity supply with high availability in Europe. Here the existing hydropower reservoirs already played an important role in helping to overcome the critical situations of Dunkelflaute in former, as well as in upcoming winter half-years without the risk of blackout. New multi-purpose storage schemes and pumped-storage powerplants will be vital in future for a safe, independent and renewable electricity supply besides other services such as flood and drought protection to mitigate climate change effects.

Nevertheless, to tackle environmental, societal, technological and market challenges, the hydropower sector needs to find novel approaches to future development in accordance with environmental and social demand by the help of research and innovation projects in future calls.

As outlined above, hydropower advances core EU goals: it boosts strategic autonomy and a competitive industry; adds grid flexibility for the transition; cuts emissions with a low footprint; supports fair prices and market stability; strengthens water resilience and climate adaptation; and protects ecosystems and biodiversity. **These priorities guide the selected research topics.**

Adaption of hydropower operation to climate change

RECOMMENDATION R&I 1

Priority: Water resilience and Socio-Economic value of hydropower

Empowering hydropower to thrive under shifting climate realities through smarter, resilient operations

Expected EU contribution per project: The estimated contribution of around EUR 5.0 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 20.0 million.

Type of Action: Research and Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 4-5 by the end of the project. Activities may start at any TRL.

Scope

Why, what, and how should we anticipate and model compound events? What are the impacts on hydropower and water resources management, including reservoir operations?

This research program focuses on anticipating, modelling, and managing compound hydrological extremes—specifically droughts and floods—to enhance the resilience and performance of hydropower and water resources management systems under climate variability and change.

Proposals are expected to address the following aspects:

- Investigate the drivers and interactions of compound events, examining how multiple climatic and hydrological extremes co-occur or cascade across spatial and temporal scales.
- Develop and evaluate modelling frameworks capable of anticipating these complex events, integrating climate projections, hydrological models, and probabilistic forecasting techniques.
- Assess the impacts of compound extremes on hydropower generation, reservoir operation, and water resource allocation across competing uses (e.g., energy, irrigation, flood control, ecosystems).
- Advance digitalization in hydropower operations, incorporating real-time monitoring, data assimilation, and decision-support tools to improve forecasting accuracy, operational flexibility, and risk mitigation.
- Propose strategies for adaptive and resilient management, aligning technical innovations with policy and governance approaches to support sustainable water-energy management under future climate uncertainty.

Expected Outcome

The research program is expected to generate scientific and technological outcomes that strengthen the resilience of hydropower and water resource systems under climate variability.

Scientifically, it will improve understanding of compound hydrological extremes—such as concurrent droughts and floods—by developing integrated modelling and forecasting approaches that combine climate projections, hydrological simulations, and probabilistic analysis. These advances will enhance the ability to anticipate and manage complex water-related risks.

Technologically, the project will deliver digital decision-support tools for hydropower and reservoir management, using real-time data, predictive analytics, and optimisation algorithms to improve operational flexibility and risk-informed decision-making. The results will include guidelines and metrics for incorporating compound-event risk assessments into water and energy management frameworks.

At the policy and societal level, the research also will enable more responsive engagement with local communities through transparent information sharing and timely adaptation to community needs and feedback.

Conversion of existing infrastructures to pumped storage

RECOMMENDATION R&I 2

Priority: Grid Flexibility and Energy Transition

Transforming today's hydropower assets into tomorrow's clean energy batteries

Expected EU contribution per project: The estimated contribution of around EUR 15.0 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 30.0 million.

Type of Action: Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 6-7 by the end of the project. Activities may start at TRL 4-5

Scope

This research program aims to explore and enable the transformation of conventional storage hydropower plants into pumped storage hydropower (PSH) systems, thereby significantly expanding the grid's active energy storage capacity and flexibility. The program focuses on the technical, mechanical, hydraulic, and operational challenges associated with such retrofits and on identifying innovative solutions that enhance system performance, efficiency, and reliability.

Proposals are expected to address one of the following aspects:

- Assess the mechanical and electrical modifications required for conventional turbines and generators to operate in both generating and pumping modes, including the design and integration of reversible pump-turbines and variable-speed generator technologies.
- Analyse and redesign waterway systems—such as intake, tunnels, shafts, and penstocks—to accommodate bidirectional flow and pumping operations while mitigating cavitation and hydraulic transients. Investigate solutions to accommodate requirements for both upstream and downstream water storage capacities
- Investigate the optimal placement and depth of pump-turbines, addressing cavitation risks and structural constraints without requiring costly powerhouse enlargements
- Develop and test innovative design concepts aimed at reducing frictional and hydraulic losses in waterways, thereby improving overall energy efficiency and operational stability.
- Evaluate the system-level benefits of variable-speed and low-loss technologies for grid services, such as fast frequency response, peak shaving, and renewable energy integration.

Expected Outcome

Transforming conventional storage power plants into pumped storage power plants would contribute to increasing the current active electrical energy storage capacity by several orders of magnitude. How will the mechanical and electrical equipment need to be changed or modified, and which changes are needed for the waterway system to operate in pumping mode.

Pump-turbines normally need to be set deeper than conventional turbines to avoid cavitation issues. To prevent the excessive costs of modifying and enlarging the powerhouse, new turbines or variable speed generators must be developed. Variable speed technology can provide sub-second and faster frequency response, which is an attribute not very well known. Furthermore, operational stability of the hydraulic system should be maintained during operation and transition modes. At the policy and societal level, the research will inform regulatory frameworks and investment strategies that support the modernisation of storage hydropower, ensuring that permitting, market incentives, and grid-integration rules recognise the added value of flexible, fast-responding pumped storage. It will also promote transparent engagement with local communities by providing evidence-based assessments of environmental impacts, water use, and social benefits, thereby fostering public acceptance and enabling more inclusive decision-making during project planning and deployment.

Regional Grid Flexibility and Resilience through Hydropower

RECOMMENDATION R&I 3

Priority: Grid Flexibility and Energy Transition
Strengthening regional power systems with hydropower-driven stability and flexibility.

Expected EU contribution per project: The estimated contribution of around EUR 15.0 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 30.0 million.

Type of Action: Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 6-7 by the end of the project. Activities may start at TRL 3-4

Scope

The role of Distribution Grids has changed significantly through the continuous integration of decentralised renewable intermitted energy sources like wind and solar-PV as well as the growing flexible load portfolio caused, for example, by heat pumps and EVs. Due to the increasing complexity and variability of their network operation, DSOs need sustainable flexibility services to balance the supply and demand side on a regional level. Furthermore, the regional grids are increasingly in the spotlight to build up their resilience to address "low-probability, high-impact" disaster events, and by doing so, decentralising national centralised grid system to become less vulnerable.
This research program aims to support the integration of hydropower solutions in distribution grids to significantly enhance their operation and supply security. The program will focus on two emerging hydropower systems:

- Small Pump Storage
- Kinetic hydropower

Proposals are expected to address the following aspects:

- **Regional flexibility services and resilience requirements:** The needs of DSOs must be specified in more detail and valued in respect to the added value offered by the two emerging hydropower systems.
- **Grid integration and synchronization:** What technical requirements need to be considered by the two emerging hydropower systems for an effective regional grid integration including the digital coordination with smart grid infrastructure (smart control systems etc.)? What specifics need to be considered in case of direct hybridization with intermitting renewable energy technologies on regional level?
- **Technology optimization and cost reduction:**

1. **SPSP:** Projects a still addressed with more or less customised technology. However, due to their smaller capacity requirement, the development of standardised pump turbines with variable speed based on existing systems technology for a certain capacity range should be viable. Based on the identified regional market and grid requirements it should be the aim to offer such pump turbine as an off-the-shelf product. Such an approach will reduce the price, raise the profitability and speed up the implementation.
2. **KHS:** Continued R&D based on the identified regional grid requirements to improve turbine efficiency, reliability, and durability in varying flow conditions, while reducing installation and maintenance cost.

- **Demonstration and Scaling;** Support for pilot and demonstration projects in diverse environments to validate performance, prove bankability, and de-risk private investment.

Expected Outcome

The project will contribute significantly to the supply security and resilience of regional distribution grids. The specific knowledge of technical and market requirements, the related technology improvement and proof of concept will enable the fast deployment of standardised hydropower solutions to enhance the operation of regional grids. Resilient regional grids will support the decentralisation of vulnerable centralised national grids and the independence of the European energy system.
The project results will furthermore strengthen the excellence of the European Hydropower Industry by finalising the development of innovative standardised solutions for market entry. Once their high value in European regional grids is proven they can be easily deployed on a global scale.

Water Quality under Climate Change – Hydropower Reservoir Management

RECOMMENDATION R&I 4

Priority: Water resilience and Socio-Economic value of hydropower
Safeguarding water quality in a changing climate through innovative reservoir stewardship.

Expected EU contribution per project: The estimated contribution of around EUR 7,5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 30.0 million.

Type of Action: Research and Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 4-5 by the end of the project. Activities may start at TRL 3.

Scope

This project aims to address critical challenges at the intersection of sediment management, reservoir sustainability, and climate resilience. Proposals are expected to address minimum two key focus areas, combining scientific innovation with applied solutions

Proposals are expected to address one of the following aspects:

- Development of integrated modelling frameworks that bring together hydrology, sediment dynamics, and water quality, particularly under climate extremes such as floods and droughts.
- Introduce artificial intelligence to support the creation of decision-making tools to optimize the timing and efficiency of sediment bypassing, venting, and flushing operations.
- Development of digital twins that integrate ensemble forecasts, sediment connectivity models, and eco-flow optimization strategies to enable flexible and adaptive reservoir operations.
- Development of innovative sediment management technologies, including the pilot testing of solutions such as density venting, siphon flushing, and hybrid nature-based restoration approaches.
- New turbine design, surveillance, and maintenance to improve resilience in sediment laden water.
- Enhance the operational reliability of reservoir cascades under variable hydrological conditions
- Restoration of downstream river morphology and the continuity of sediment transport, thereby enhancing overall ecosystem resilience. In doing so, it will strengthen climate resilience and water security by balancing the competing needs of energy generation, environmental protection, and ecological integrity. Outputs will include open-access models, datasets, and guidelines to ensure replicability across European river basins and support global knowledge sharing.

Expected Outcome

The project will generate new scientific knowledge, digital tools, and operational practices to sustain reservoir capacity, improve water quality, and strengthen ecosystem resilience under increasing hydroclimatic variability. It will implement a basin-scale "sediment-smart" approach to reservoir management that balances renewable energy production, environmental protection, and water security in a changing climate.

An integrated modelling framework will couple hydrology, sediment dynamics, and water quality with artificial intelligence for adaptive reservoir operation. A basin-scale digital twin will provide real-time decision support, optimizing sediment bypassing, venting, and flushing based on seasonal forecasts. Pilot-tested technologies—such as density venting, siphon flushing, high sediment concentration through turbines, and hybrid nature-based solutions—will demonstrate effective sediment continuity and restoration of downstream morphology.

The project will enhance the sustainability of reservoir systems by reducing sediment accumulation, restoring effective storage, and mitigating hypoxia and algal blooms. These outcomes will extend asset lifetimes, maintain hydropower flexibility, and advance the EU's renewable energy, Water Framework, and Biodiversity objectives.

Open dashboards, APIs, and datasets will improve operational decision-making, support compliance, and facilitate replication across Europe and beyond. Evidence-based insights will inform future water and energy policies, promoting integrated basin management and climate resilience.

Ultimately, the project will pave the way for a Sediment-Smart Europe where reservoirs function as adaptive, climate-resilient systems that sustain water quality, renewable energy, and ecological integrity

Adaptive E-Flow Management for Biodiversity and Sustainable Hydropower

RECOMMENDATION R&I 5

Priority: Environment and Biodiversity protection

Balancing clean energy and vibrant ecosystems with intelligent, adaptive environmental flows

Expected EU contribution per project: The estimated contribution of around EUR 15 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 15 million.

Type of Action: Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 6-7 by the end of the project. Activities may start at TRL 3.

Scope

The project addresses the challenge of defining and implementing environmental flow (E-flow) regulations to mitigate the ecological impacts of hydropower operations and other human interventions on river systems. It aims to determine how much water must flow in riverbeds, when and where, to sustain healthy aquatic ecosystems and ensure biodiversity protection under changing climatic and hydrological conditions.
The research will take a holistic, catchment-scale approach that can integrate hydrological, ecological, hydraulic, geomorphological, socio-economic, and legal factors.
Proposals are expected to address the following aspects:

- Analyse hydropower impacts on river ecosystems across different European regions (Alpine, Mediterranean, Northern).
- Develop guidelines and decision frameworks for selecting the most suitable E-flow methodologies for specific contexts, from small run-of-river plants to large hydropower systems.
- Establish state-of-the-art biological and hydraulic performance criteria, clarifying relationships between "fish and flow" under modern turbine operations and altered flow regimes
- Incorporate climate change sensitivity and adaptive management principles to ensure resilience under future hydrological variability.
- Integrate technical, ecological, and governance aspects, considering cumulative effects of multiple water uses within a basin.

Expected Outcome

The project will produce a harmonised European guideline for assessing and implementing environmental flow (E-flow) regulations, providing an adaptive framework for selecting the most appropriate methodologies across diverse hydropower contexts and geographic regions. By integrating ecological, hydraulic, and sediment dynamics, it will enhance understanding of how aquatic ecosystems respond to flow regulation and enable more accurate quantification of hydropower impacts on fish populations, habitats, and ecosystem services.

Validated case studies will demonstrate effective restoration and mitigation strategies, including habitat rehabilitation, improved fish migration pathways, and adaptive management of flow releases. These efforts will be supported by integrated decision-support tools that combine hydrological modelling, ecological indicators, and socio-economic data to guide operators and regulators in practical E-flow management.

The project will also strengthen policy alignment and governance by providing evidence-based recommendations supporting the EU Biodiversity Strategy for 2030, the Water Framework Directive, and the European Green Deal. Open-access datasets, best-practice guidelines, and training resources will foster capacity building and knowledge transfer among hydropower operators, researchers, policymakers, and local stakeholders. Collectively, the project will advance ecosystem restoration, biodiversity recovery, and climate-resilient water management, delivering scalable solutions applicable across Europe and contributing to sustainable, adaptive river basin governance.

Development of innovative manufacturing, construction methods, and design tools

RECOMMENDATION R&I 6

Priority: Strategic Autonomy, Sovereignty and Industrial Competitiveness

Accelerating next-generation hydropower with cutting-edge design, construction, and manufacturing solutions

Expected EU contribution per project: The estimated contribution of around EUR 10 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 30 million.

Type of Action: Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 5-6 by the end of the project. Activities may start at TRL 3.

Scope

The project addresses the need to modernize the hydropower industry by developing innovative, efficient, and sustainable manufacturing and construction methods for hydropower structures and components. Current practices, while reliable, rely heavily on long-established techniques that limit opportunities for digitalization, cost reduction, and environmental performance.

The research will combine advanced materials science, digital engineering, automation, and sustainability assessment to design next-generation methods and tools for hydropower infrastructure. This includes the use of high-performance and low-carbon materials, modular and prefabricated construction systems, robotics and additive manufacturing, and digital twins for predictive design, construction, maintenance, and methods for on-site tooling will enable cost- and time-effective refurbishment.

Collaborative demonstration projects will integrate laboratory research, pilot-scale testing, and field implementation to validate new technologies across diverse hydropower settings—new builds, refurbishments, and retrofits. The project will also establish a knowledge base and open-access toolkit to support industry adoption, standardization, and training.

Expected Outcome

The project will deliver a new generation of innovative, resource-efficient, and low-carbon construction and manufacturing solutions for the hydropower sector. These will enhance design flexibility, reduce construction time, and lower costs while improving structural integrity and environmental performance.

Validated digital twin and BIM-based tools will enable real-time optimization of construction processes and predictive maintenance, improving safety and operational efficiency. Additive manufacturing and modular construction techniques will demonstrate measurable reductions in material waste and carbon footprint.

The project will also strengthen the competitiveness and sustainability of the European hydropower industry by fostering collaboration between research institutions, technology developers, and industry stakeholders. The results will contribute to the EU Green Deal, Circular Economy Action Plan, and climate-neutral energy system goals, positioning hydropower as a modern, adaptive, and resilient cornerstone of renewable energy infrastructure.

Valuing Hydropower's Flexibility: Development and Application of a Business Model for Flexibility in a Decarbonized Energy System

RECOMMENDATION R&I 7

Priority: Affordability and Market Stability

Unlocking the true market value of hydropower flexibility for a fully decarbonized energy future

Expected EU contribution per project: The estimated contribution of around EUR 5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 20 million.

Type of Action: Research and Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 4-5 by the end of the project. Activities may start at any TRL.

Scope

This project aims to develop and apply a comprehensive business and economic model that accurately values the flexibility services provided by hydropower within a fully decarbonized European energy system. It will assess hydropower's role alongside alternative flexibility technologies under different scenarios of digitalization, demand response, interconnection development, and policy evolution.

Proposals are expected to address the following aspects:

- Characterization of all hydropower flexibility types (pumped storage, hydro peaking, reservoir, pondage, run-of-river).
- System modelling of a 100% renewable-based European energy grid, considering the full mix of renewable sources and integration challenges.
- Evaluation of flexibility needs in 2030–2050 scenarios and identification of gaps.
- Comparative analysis of competing flexibility technologies (batteries, power-to-gas, etc.) based on performance and cost.
- Investigation of climate change impacts on hydropower operation and reliability.
- Analysis of market mechanisms including pricing models, ancillary service compensation, and long-term investment incentives.
- Design of tailored business models for hydropower assets, aligning with future energy markets and regulatory frameworks.

Expected Outcome

This project will result in the development of a comprehensive valuation framework that quantifies the full range of flexibility services provided by hydropower across all relevant timescales and grid needs. It will deliver a robust business model tailored for hydropower operators, enabling them to participate effectively and profitably in future electricity markets by capturing revenues not only from energy production but also from capacity and ancillary services.

The research will generate detailed system modelling results under a variety of future scenarios—accounting for different levels of digitalization, interconnection, sector coupling, and market design—which will demonstrate the role and value of hydropower within a 100% renewable-based European energy system. These modelling results will also identify the required mix of flexibility technologies and assess the techno-economic performance of hydropower in comparison with alternatives such as batteries and power-to-gas systems.

The outcome will also provide a set of policy and market design recommendations aimed at correcting the "missing money" problem, ensuring that flexibility services are fully recognized and fairly compensated. This includes proposing reforms to current balancing, intraday, and ancillary service markets to reflect the true value of fast-response and long-duration storage capabilities offered by hydropower.

In addition, the research will outline investment guidelines and incentive structures to attract long-term funding into hydropower and storage technologies, considering future uncertainties such as climate change impacts on water availability. Finally, the outcomes will support European policymaking by contributing strategic input to the implementation and revision of directives such as Renewable Energy Directive, helping to remove barriers to hybrid renewable energy and storage projects, and ensuring hydropower's central role in achieving a decarbonized and flexible power system.

Innovative Solutions for Fish Protection and Monitoring in Hydropower Systems

RECOMMENDATION R&I 8

Priority: Environment and Biodiversity protection

Advancing eco-friendly hydropower with smart technologies for fish safety and real-time monitoring.

Expected EU contribution per project: The estimated contribution of around EUR 7,5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 30 million.

Type of Action: Research and Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 4-5 by the end of the project. Activities may start at any TRL.

Scope

This research and innovation project focuses on developing and implementing advanced, cost-effective, and low-maintenance solutions for fish protection in hydropower systems, particularly targeting both physical and behavioral guidance methods. The scope includes that, based on fish behavior, improving existing physical barriers and developing new innovative behavioral deterrents that may be based on light, sound, detailed flow fields or electrical fields to enhance fish passage efficiency and reduce mortality during both upstream and downstream migration.

In parallel, the project will advance automated AI-driven fish monitoring systems that extend and improve upon conventional methods such as electrofishing, sonar, and underwater cameras. These innovations aim to enable persistent, long-term biodiversity monitoring, particularly for run-of-river and impoundment hydropower plants, and in certain cases, pumped storage hydropower systems.

The project also encompasses ecological modelling and fish behavior forecasting, as well as site-specific solutions adapted to the river typology, hydropower plant scale, and local biodiversity. This includes a better understanding of turbine-related mortality risks, optimal fish passage designs, and the cumulative impacts of hydropeaking, climate change, and other stressors on fish populations.

The research will further explore the development of standardized monitoring protocols and predictive tools, along with evaluating the effectiveness of emerging technologies. Ultimately, the project aligns with environmental objectives such as the Water Framework Directive and supports biodiversity preservation within the context of a transitioning, carbon-neutral energy system.

Expected Outcome

This project is expected to produce a suite of innovative and practical solutions for fish protection and monitoring that can be implemented across a wide range of hydropower sites. These will include advanced physical and behavioral fish guidance systems designed to be more effective, cost-efficient, and easier to maintain than existing options. The project aims to significantly improve the efficiency of fish passage systems and reduce fish mortality rates, with particular attention to species currently at risk due to hydropower operations.

In addition, the development of automated, AI-driven fish monitoring technologies will reduce the cost of conventional monitoring methods by 50% or more, while improving data quality, observation longevity, and standardization. These technologies will facilitate the installation of automated monitoring systems at an estimated 100 small hydropower sites annually across Europe.

The research will also deliver a better understanding of species-specific migration behavior, ecological flow needs, and turbine-related risks, enabling more effective site-specific design of fish protection measures. Outcomes will include improved ecological status and connectivity of water bodies, enhanced biodiversity through more effective migratory support, and strengthened guidance for policymaking and hydropower regulation.

By integrating innovative fish protection technologies with robust ecological monitoring and forecasting tools, the project will contribute to safeguarding freshwater ecosystems, supporting the fishing industry, protecting the environmental well-being of surrounding communities, and ensuring hydropower development is compatible with biodiversity conservation goals in a carbon-neutral future.

High Dynamics Flexibility for Hydropower: Advanced Control, Simulation, and Operational Optimization

RECOMMENDATION R&I 9

Priority: Grid Flexibility and Energy Transition

Maximizing hydropower responsiveness through precision control, dynamic simulation, and optimized operations

Expected EU contribution per project: The estimated contribution of around EUR 10 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 50 million.

Type of Action: Research and Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 6-7 by the end of the project. Activities may start at any TRL.

Scope

With the increasing need for rapid response to grid balancing requirements, hydropower plants face more frequent and extreme operating conditions, such as higher start/stop cycles, cavitation, and increased fatigue on turbines and generators. These operations are often conducted outside traditional design conditions, leading to uncertainties regarding performance and reliability.

The scope of the project includes the development of advanced control strategies for pump-turbine systems, focusing on mitigating flow instabilities, optimizing mode change times, and improving the ramping capabilities required by power systems.

Proposals are expected to address the following aspects:

- Advanced modeling tools to simulate plant behavior under extreme conditions, such as floods and droughts, including hydromechanical equipment and civil infrastructure.
- Development of AI-based models to predict real-time performance and integrate past system data with new operational regimes.
- Application of simulation and optimization models to enhance predictive maintenance strategies and improve operational planning.
- Exploration of how retrofitting existing hydropower plants can address emerging flexibility requirements, such as improved inertia response, frequent power modulation, and black start capabilities.
- Collaboration with stakeholders (operators, insurance companies, authorities) to create integrated tools for managing extreme weather events in a safe, sustainable, and optimized manner.
- Handling larger fluctuations in river flows due to increased flexibility requests add burden to Hydropower systems and operations. For example: in river cascades spill gates are used for power balance planning to spill water past bottlenecks; this puts strain on infrastructure and forces non-conventional use of existing equipment.

Expected Outcome

One key outcome will be the creation of AI-based modeling and optimization tools that will allow hydropower plants to better manage their operational responses, including predictive maintenance measures and improved system reliability. These tools will provide planners and designers with guidelines to assess the impact of various operational changes and retrofitting measures on plant performance, helping to ensure plants can meet future power system flexibility needs.

The research will also contribute to a better understanding of how hydropower plants can support grid stability through high-dynamics capabilities, such as fast ramping, inertia support, and back-up power, including during black start scenarios. This knowledge will inform retrofitting strategies for existing plants, allowing them to meet the increasing demand for flexibility in decarbonized energy systems.

By developing simplified, accessible simulation tools and guidelines, the project will empower hydropower plant operators to optimize their systems in real-time, improving the longevity and safety of equipment, reducing risks associated with extreme weather and operational extremes, and minimizing potential damages to hydropower infrastructure and surrounding ecosystems.

In collaboration with key stakeholders such as insurers, authorities, and equipment suppliers, the project will also develop an integrated approach to managing extreme weather events and natural hazards, enhancing the resilience of hydropower plants and contributing to broader environmental sustainability goals.

Ultimately, the expected outcome is a more flexible, reliable, and resilient hydropower sector, equipped to handle the dynamic demands of modern electricity grids and contribute effectively to a decarbonized energy future.

Bridging the GHG Knowledge Gap in Hydropower – Emissions Accounting & Mitigation

RECOMMENDATION R&I 10

Priority: Climate Neutrality and Low-Carbon Footprint

Delivering credible, transparent GHG insights to drive low-carbon hydropower development

Expected EU contribution per project: The estimated contribution of around EUR 5 million would allow these outcomes to be addressed appropriately. Nonetheless, this does not preclude submission and selection of a proposal requesting different amounts.

Indicative budget: The total indicative budget for the topic is EUR 20 million.

Type of Action: Research and Innovation Action

Technology Readiness Level: Activities are expected to achieve TRL 4-5 by the end of the project. Activities may start at any TRL.

Scope

This research project seeks to address the urgent need for a more accurate, consistent, and transparent methodology for assessing greenhouse gas (GHG) emissions from hydropower systems.

It will focus on the differentiation of emissions based on asset types—such as conventional, run-of-river, and pumped storage hydropower—as well as on the operational characteristics that influence emissions, including reservoir dynamics. A key area of investigation is the carbon footprint of pumped storage hydropower, for which no established assessment methodology currently exists.

In addition to improving the technical accuracy of emissions accounting, the research will explore how hydropower fits into the broader context of electricity system decarbonization. While hydropower can be a source of GHG emissions, it also plays a critical role in enabling the integration of variable renewable energy sources and enhancing grid stability.

The scope further includes the identification of effective, scalable mitigation strategies and the promotion of more transparent, standardized reporting practices to reduce the confusion caused by conflicting data currently in circulation.

Expected Outcome

The expected outcomes of this research include the development of a comprehensive review of existing emissions accounting methods for hydropower, with an emphasis on identifying key methodological limitations and inconsistencies.

The project aims to produce a robust and unified framework for emissions assessment that integrates asset-specific characteristics, accounts for direct and indirect emissions—including those from reservoirs—and provides a basis for evaluating pumped storage systems. Through analytical modeling or case study applications, the research will demonstrate how this methodology can be applied across diverse hydropower contexts.

Furthermore, the project will offer a nuanced understanding of hydropower's role in supporting decarbonized electricity systems by quantifying the avoided emissions associated with increased renewable energy integration. A set of practical mitigation strategies tailored to different hydropower configurations will be proposed, alongside recommendations for improving emissions reporting practices and supporting the development of policy-relevant standards.

Overall, the research will contribute to closing the GHG knowledge gap in hydropower and support the global shift toward more sustainable and transparent energy infrastructure planning.

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