HYDROPOWER EUROPE

POWERING EUROPE IN A SUSTAINABLE WAY

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# 1 Overview of results and their exploitation and dissemination

## 1.1 Introduction and context

Hydropower has a long tradition in Europe and contributed significantly to industrial development and welfare in most of the countries in Europe. The ambitious plan for energy transition in Europe seeks to achieve a low-carbon climate-resilient future in a safe and cost-effective way, serving as an example worldwide. The key role of electricity will be strongly reinforced in this energy transition. In many European countries, the phase out of nuclear and coal generation has now started, with a transition to new renewable sources comprising mainly solar and wind for electricity generation. However, solar and wind are variable energy sources and difficult to align with demand. Hydropower already supports integration of solar and wind energy into the supply grid through its flexibility in generation as well as its potential for storage capacity. These services will be in much greater demand in order to achieve the energy transition in Europe, and worldwide. Hydropower has all the characteristics to serve as an excellent catalyst for a successful energy transition.

Furthermore, there is still significant untapped hydropower potential in Europe which can contribute, together with other renewables, to the transition from fossil energies towards more electricity-based energy markets in the sector of transportation (electrical cars) and heating (heat pumps). The recent catastrophic war situation in Ukraine at the borders of Europe has highlighted again the importance of a safe and independent electricity supply in Europe as the basis for a successful energy transition in the green deal. Moreover, since hydropower is situated at the crossroads of two major issues for development – water and energy – hydropower reservoirs can often deliver services beyond electricity supply, such as the mitigation of freshwater scarcity by providing security during low flow and drought and for drinking water supply, irrigation, flood control, fish farming and navigation services among others. Hydropower generation corresponds to about 12% of the European (EU-28) net electricity generation and 36% of electricity generated from renewable resources. In an average hydrological year hydropower generation reaches almost 650 TWh and that arises from using only 65% of the economically feasible hydropower potential within the European continent, including Turkey. Since 2013 the annual production has stagnated near 650 TWh and the total installed capacity near 250 TW. Nevertheless, many countries still have considerable potential for hydropower development (Figure 1). Sixteen countries out of a total of 41 countries (see Figure 1) have developed less than 50% of their economically feasible potential (assuming market conditions demand for it). For 14 countries the share of hydro in their overall electricity generation is between 25 and 50%, for three countries between 50 and 90% and for another two countries even higher than 90%. This reveals that in more than half of the countries on the European continent, hydropower has an important share in the electricity generation, which is important for the success of the energy transition.

The potential for additional deployment of hydropower in the mid-term can be estimated rather conservatively in the European Continent by some 20% increase of the total yearly generation comprising about 10% due to uprating and modernization of existing powerplants and 10% due to new storage powerplants designed as multipurpose projects creating a win-win situation between all involved stakeholders.

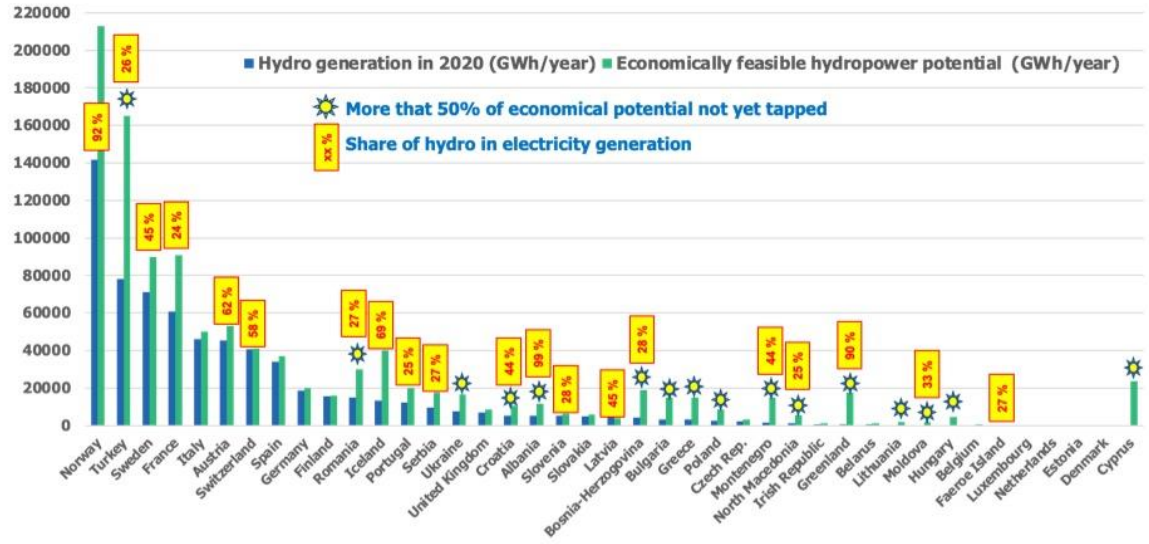


*Figure 1 Generation and extension potential of hydropower in countries in the European region (according to Hydropower & Dams World Atlas 2021).*

HYDROPOWER EUROPE, supported by funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 826010, has been preparing from November 2019 until February 2022 a Research and Innovation Agenda (RIA) and a Strategic Industry Roadmap (SIR) for the hydropower sector. A forum was created that gathers all relevant stakeholders of the hydropower sector in Europe and in February reached some 630 participants. This allowed discussion of the contents of the RIA and SIR in several technical fora and transparent public debates. Based upon a first enhanced draft, a second wider online consultation process started in August 2020 accompanied by an online event called “Hydropower seeking its role in the clean energy transition” in October 2020. Some 185 stakeholders participated actively in this second wider online consultation process and feedback was received regarding the priorities of the research themes covering numerous topics and the strategic actions. In March and June 2021, the consultation results were discussed in workshops with the HYDROPOWER EUROPE Consultation Expert Panel (CEP) with the purpose of establishing final priorities and to define suggested programme timelines, the indicative magnitude of funding required as well as the expected TRL of the research themes. Furthermore, the strategic actions were discussed in detail and ranked according to their priorities. The prioritisation process was finally validated by including the results of a complex system analysis carried out for hydropower in Europe as well as European initiatives regarding the energy transition and the European Green Deal. The final versions of the RIA and SIR

comprise recommendations under eighteen research themes including some 80 identified topics (RIA) as well as eleven strategic directions including some 40 detailed actions (SIR) ranging from regulation framework to social acceptance and innovative environmental strategies.

Starting from 2021 the project results have been presented and discussed in several dissemination events such as conferences and workshops held online and in hybrid format (in person combined with online). Furthermore, the results have been published, besides the official reports available on the HYDROPOWER EUROPE website, in several scientific and professional journals as well as newsletters, interviews and communications through other organizations active in the wide hydropower sector and civil society.

## 1.2 Overview of results

### 1.2.1 Creation of the forum HYDROPOWER EUROPE

The HYDROPOWER EUROPE Forum was built on the ambition to achieve a Research and Innovation Agenda (RIA) and a Strategic Industry Roadmap (SIR) for the hydropower sector, based upon the synthesis of technical fora and transparent public debates through a forum that gathers all relevant stakeholders of the hydropower sector. Through an extensive program of review and consultation addressing the whole hydropower sector and stakeholders (including construction, production, environmental and social issues), the Hydropower Europe Forum provides a focal point for reviewing and developing hydropower in Europe, and subsequently European hydropower in the wider world. Building from this extensive programme of consultation, the Hydropower Europe Forum has developed a strategic Research and Innovation Agenda (RIA) as well as a Strategic Industry Roadmap (SIR), towards implementation of the vision “Hydropower as a catalyst for the successful energy transition in Europe”.

A Consultation Platform was created to help manage the HYDROPOWER EUROPE consultation process (https://hydropower-europe.eu) where more than 630 stakeholders and experts have registered (until February 2022) and have been involved in the consultation process, which may be considered a success. Besides organization of several consultation events and Brussels-based as well as regional workshops (Nordic, Alpine and Mediterranean region), a successful workshop on environmental and social aspects was held in October 2020 and a round table with NGOs in January 2021, a Partner Event at the EU Green Week in June 2021 under the theme of Zero Pollution and an EU Sustainable Energy Day event on the sustainability and acceptability of hydropower as part of the clean energy transition in September 2021; these are more recent examples of increased consultation with civil society. A first dissemination event of the results was held during the HydroES Conference in Lyon on September 22, 2021. Finally, during a closing online event on 23rd February, 2022, the results of HYDROPOWER EUROPE and the conclusions drawn from the consultations to sector

stakeholders were presented by focussing on needs for research and innovation, challenges of hydropower development in Europe as well as the future of the hydropower sector.

## 1.2.2 Research and Innovation Agenda (RIA)

### *1.2.2.1 Overview*

The Research and Innovation Agenda (RIA) provides recommendations on the R&I priorities for hydropower, for the EU institutions and national authorities to contribute towards shaping public spending for R&I. The RIA identifies the main challenges for further hydro development, optimised maintenance, environmental and economic performance of existing assets and the related R&I gaps. As a result, R&I needs for hydropower development are listed and clarified, specifying the type of challenge, expected results, R&I activities needed, the relevant stakeholders, and indicative timeframe along with an assessment of the likely funding needed. The RIA is not only limited to technological issues, such as equipment and infrastructure improvement and extension or advanced operation managing systems. It also includes environmental, social and economic issues with a view for sustainable development and to understand how community and the wider public react to hydropower projects and how social acceptance can be enhanced. However, the RIA looks at these issues exclusively through a research and development perspective. The R&I needs have been prioritised according to criteria defined with the support of the Consultation Expert Panel (e.g. consistency with EU policy objectives, the maturity of the technology, expected benefits, etc.). The research themes identified are grouped according to the challenges which hydropower in Europe must address, namely:

- Increasing flexibility
- Optimisation of operations and maintenance
- Resilience of electromechanical equipment
- Resilience of infrastructures and operations
- Developing new emerging concepts
- Environmental-compatible solutions
- Mitigation of the impact of global warming

In total 18 research themes, including a total of 80 detailed research topics spread across these themes, have been formulated based upon the wide consultation feedback. After several workshops with the Consultation Expert Panel the priorities, the suggested time horizon when the call should be initiated as well as the recommended funding scheme for all research themes, were defined as summarized in the Figure 2. Under each research theme more detailed research topics were listed for which the TRL was also defined.

| Hydropower Europe recommended R&I themes | Challenges | Research Themes | Consultation Feedback: Priorities | Recommended Call | Recommended Funding Scheme |
|---|---|---|---|---|---|
| | Increasing fexibility | 3.1.1. Innovation in flexibility, storage design and operation | Very High | before 2025 | € 26-35 million |
| | | 3.1.2. Innovative design of turbines including reversible pump-turbines and generators | High | before 2030 | € 16-25 million |
| | | 3.1.3. New models and simulation tools for harsher operation conditions | High | before 2030 | € 8-15 million |
| | | 3.1.4 Development and application of a business model for flexibility | Very High | before 2025 | € 8-15 million |
| | Optimisation of operations and maintenance | 3.2.1. Digitalisation and artificial Intelligence to advance instrumentation and controls | High | before 2030 | € 16-25 million |
| | | 3.2.2. Monitoring systems for predictive maintenance and optimised maintenance intervals | High to Very High | before 2030 | € 2-7 million |
| | Resilience of electro-mechanical equipment and infrastructures | 3.3.1. New materials for increased resistance and increased efficiency of equipment | Medium High to High | before 2030 | € 8-15 million |
| | | 3.4.1. New materials and structures for increased performance and resilience of infrastructure | Medium High to High | before 2030 | € 8-15 million |
| | | 3.4.2. Databases of incidents and extreme events, integrated structural risk-analysis models and innovative solutions for multi-hazard risk analysis | High | before 2030 | € 8-15 million |
| | | 3.4.3. Innovative sediment management technologies for sustainable reservoir capacity and river morphology restoration | High to Very High | before 2025 | € 8-15 million |
| | | 3.4.4. Innovative techniques for enhancement of working life of concrete structures | Medium High to High | before 2030 | € 8-15 million |
| | | 3.4.5. Innovative techniques for enhancement of overtopping safety of embankment and rockfill structures | High | before 2035 | € 2-7 million |
| | Developing of new emerging concepts | 3.5.1. Development of innovative storage and pumped-storage power plants (e.g. multipurpose PSH, sea water PSH, etc.) | Very High | before 2030 | € 16-25 million |
| | | 3.5.2. Marine energy | Medium High to High | before 2030 | € 8-15 million |
| | | 3.5.3. Hybrid & virtual power plants | High to Very High | before 2030 | € 8-15 million |
| | Environmental-compatible solutions and mitigation of the impact of global warming | 3.6.1. Flow regime management, assessment of environmental flow release, innovative connectivity solution for fish and biodiversity protection and improvement of stored water quality in reservoir | Very High | before 2025 | € 16-25 million |
| | | 3.6.2. Assessment of the general impact and contribution of hydro-power to biodiversity and the identification of innovative approaches and guidelines to support more sustainable hydropower | Very High | before 2025 | € 8-15 million |
| | | 3.7.1. Innovative concepts of hydropower infrastructure adaptation and tapping hidden hydro | Very High | before 2030 | € 16-25 million |

Figure 2 HYDROPOWER EUROPE research themes

The Research Themes shown in Figure 2 were obtained through a wide stakeholder consultation process and indicate priority levels, time perspective, budget requirement and desired TRL level. The numbering of the research themes corresponds to the chapters of the full RIA report available from www.hydropower-europe.eu.

In the following sections, grouped by the challenges listed above, the research themes which were allocated a “high to very high” and “very high priority” by the Consultation Expert Panel, are briefly described and more detailed research topics also having “high to very high” and “very high” priority are listed.

### *1.2.2.2 Increasing flexibility*

Flexibility is a requirement inherent to all power systems and in recent years there has been an increasing focus on how to manage it. It is widely accepted that hydropower, due to its quick response and good ramping capabilities, represents an important asset for the system operator. Improving the ability of hydropower installations to provide system services will increase their value and permit increased integration of variable renewable energy into the power system. Despite already being one of the most flexible and versatile renewable power sources, several organisations have pointed out that further increasing the flexibility of equipment and hydropower infrastructures will increase the value of hydropower in a future energy system. Hydropower in combination with modern converter technology may not only provide better balancing in the grid, but also a set of other ancillary services such as frequency control, reactive power compensation, power oscillation damping and increased transient stability of other units in the power system.

#### 1.2.2.2.1 Research theme: Innovation in flexibility, storage design and operations

Priority: Very High; Recommended call: initiate research before 2025; recommended funding scheme: € 26-35 million

*Background and challenges*

Today, pumped-storage hydro (PSH) and reservoir hydro are currently the cheapest and most mature large-scale technologies for energy storage and balancing the electricity network. In addition, they have long lifetime, offer attractive grid services (e.g. black start availability, synchronous inertia response, and island grid build up) and are not dependent on rare materials. However, there can be significant environmental and social barriers to PSH deployment and projects also have high CAPEX. Nevertheless, they are a key enabler for reliable electricity supply in the context of increasing variable RES generation. European reservoirs are large and can be used for flexible operation. Today's storage capacity in European hydropower reservoirs exceeds 185 TWh, thus, being the largest battery available, and an energy storage system for other renewables. Storage capacity is huge and available from a technical point of view and there is still considerable untapped potential in Europe. Only relatively few of the existing reservoirs are equipped with pumps or pump-turbines, and therefore active electrical energy storage (i.e. storing electricity flowing through the network) is not possible in most hydropower reservoirs. 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. The massive and fast penetration of solar PV and wind generation will undoubtedly place enormous pressure on grid stability and balancing requirement. By consequence, this means that creation of market and/or regulatory mechanisms to stimulate entry of storage and flexibility providers is a high priority. In this context, hydropower advantages as a well understood technology with low lifecycle costs will enable it to compete with other technologies in the power market. By connecting existing large seasonal reservoirs with PSH, they can, under certain conditions, also enhance the seasonal transfer of energy storage requirements.

*Suggested research topics with "very high" priority*

- Developing and optimising hydraulic design and control strategies for pump turbines and waterway system in existing PSH (Expected TRL: 6-7; Budget range: €7-10M)
- Enhancing flexibility of run-of-river power plants and using existing run-of-river cascades for energy storage (Expected TRL: 6-7; Budget range: €4-6M)

*Suggested research topics with "high to very high" priority*

- Developing design algorithm and innovative construction technologies for new PSH parallel to existing storage powerplants by using existing upper and lower reservoirs (Expected TRL: 6-7; Budget range: €4-6M)
- Overall assessment models of run-of-river, storage and pumped storage power plants regarding market and socio-economic issues (Expected TRL: 6-7; Budget range: €1-3M)
- Improving the feasibility and cost-efficiency of seawater PSH (Expected TRL: 6-7; Budget range: €4-6M)

#### 1.2.2.2.2 Research theme: Development and application of a business model for flexibility

Priority: Very High; Recommended call: initiate research before 2030; Recommended funding scheme: €8-15 million

*Background and challenges*

The hydropower business case is representative of some of the issues facing the development of an adequate market model for a new energy system. The energy market has traditionally been based upon competition driven by fuel costs. In the past hydro was in competition with fossil fired thermal plants. Since the decarbonisation policy has led to decommissioning of fossil fired plants, a new energy system, in which only renewable (solar, wind, water) and other low carbon sources will be developed, needs a new appropriate market model. The revised Renewable Energy Directive (RED III) increases the overall Union target for renewable energy in 2030 to 40%. The RED III proposals, however, fall short in terms of supporting energy storage deployment to facilitate renewable energy sources (RES) integration. More precisely, the main challenge for Hydropower is the limited payoff in today's markets of flexibility, although hydropower is unique in its ability for providing system flexibility across all timescales. To demonstrate the solution and to give an accurate price to the flexibility, a market design must be built on an economic model taking account the wide portfolio of renewable energy sources, the interconnection and the liquid power markets.

*Suggested research topics with "very high" priority*

- Development and application of a business model for flexibility to decarbonise the energy sector (Expected TRL: 6-7; Budget range: €8-15M)

### *1.2.2.3 Resilience of hydropower infrastructure and operation*

The resilience of hydropower structures means the capacity and adaptability to operate in adverse situations, which may range from extreme events to slightly different changes in hydrological patterns from those for which the power plant and related infrastructure have been primarily designed (including civil, hydromechanical and electrical systems). Extreme

adverse situations for hydropower plants and infrastructure resilience derive mainly from extreme flood events that can cause landslides, slope instabilities, GLOF (Glacial Lake Outburst Flood) or other natural hazards such as earthquakes. The priority is, therefore, to maintain or even increase the resilience of infrastructure against these threats. Another source of risk is the ageing of infrastructure, which causes a decrease or variation in structural material strength properties. In the coming decades, more and more infrastructures are going to reach the end of thetheir expected life span (100 years) and most of them will need retrofitting. Through regular monitoring and risk assessment, infrastructure owners can manage risks from natural events. Moreover, it is important to consider that climate change will increase the risk of natural hazards (such as floods, droughts, wood fires, windstorms, sediment yield into reservoirs, landslides, rock falls etc.), multiplying threats for hydropower infrastructure in the future. Finally, even if dams and hydropower plants are critical infrastructures in view of operation and safety, the associated risks are small compared to other energy technologies. However, since the consequences may be significant in the case of failure, continuous efforts for managing and reducing the risks are required. That is why dam safety has been one of ICOLD's highest commitments for almost a century and IHA has launched the Climate Resilience Guide for the hydropower sector to identify, assess and manage climate change risks associated not only with the infrastructure but also with the operations.

#### 1.2.2.3.1 Research Theme: Innovative sediment management technologies for sustainable reservoir capacity and river morphology restoration

Priority: High to very high; Recommended call: initiate research before 2025; Recommended funding scheme: € 8-15 million

*Background and challenges*

Reservoir sedimentation is known as the process of gradual accumulation of the incoming sediment load from a river in natural lakes and manmade reservoirs. The sediment load transported by rivers as suspended fine material or bed load settles in the reservoirs when flow velocities drop as the river flow enters into large open areas of reservoir water. Anthropogenic activities such as deforestation and overgrazing, combined with climate change effects exacerbate soil erosion and deposition. Reservoir sedimentation is one of the most serious problems endangering the sustainable use of worldwide reservoir capacity. The worldwide loss in reservoir storage capacity is reported to be 1 % per year, and based on filling rates observed in Asia, on average the existing hydropower reservoirs will be 85 % filled by 2035. The situation is even more severe for other reservoirs used mainly for irrigation and water supply. Nevertheless, due to the effects of climate change, especially glacier retreat and droughts in Europe, will increase the future sediment yield entering reservoirs during floods. Over the last decades, many technical and operational mitigation measures against reservoir sedimentation have been developed. Unfortunately, there is not a single solution which is successful for all reservoirs. Nevertheless, the wide and rich portfolio of confirmed measures supports finding tailor-made solutions for each reservoir. Still, finding the best solution requires highly innovative engineering competence with a scientific understanding

of the processes involved and the impact in the cost of maintenance and the loss of energy production and other valuable services. Solution-oriented research and development are still urgently needed.

#### *1.2.2.4 Optimisation of operations and maintenance*

Next to efficiency, the availability of a power plant determines productivity. Minimising outage time including by optimising the operations and maintenance intervals is a considerable challenge for hydropower projects delivering balancing power. Reducing the maintenance cost and effort by keeping high safety standards of hydropower schemes is one of the main challenges of the next ten years. One of the methods that may contribute to the reduction of the maintenance cost is predictive maintenance (condition monitoring). To carry out predictive maintenance of hydraulic installations, better knowledge of the past and future behaviour of the monitored structure is essential. This knowledge involves defining, measuring and analysing behaviour and health indicators. To date, predictive maintenance has been discussed by many companies, while practised by only a few. Industrial Internet of Things (IIOT) sensor solutions seem to be one of the best ways to collect this information to achieve predictive maintenance. The sensors, based on wireless technologies, are often low cost and easy to install, sometimes even revolutionising the way a structure is monitored. This implies a change of approach that involves placing dozens of non-intrusive sensors at low cost (but with degraded measurement accuracy), rather than placing one or two precise and intrusive sensors.

In view of climate change and the increased risk of flooding, hydropower dams and reservoirs can contribute to the attenuation of the flood peak through proactive management. This needs sophisticated real-time meteorological and hydrological simulation models which can predict the probability of inflowing floods to the reservoir. Loss of energy production due to preventive lowering of the reservoir or changing turbine operation because of the downstream flooding risk, if not foreseen in the concession agreement, and has to be negotiated with the authorities taking advantage of that protection. Artificial intelligence, combined with proved methods and long-standing expert systems will help convince the Authorities to reduce production losses whilst improving hydrological warning alerts to pass floods and hence improving resilience.

##### 1.2.2.4.1 Research Theme: Monitoring systems for predictive maintenance and optimised maintenance intervals

Priority: High to Very High; Recommended call: initiate research before 2030; Recommended funding scheme: € 2-7 million

*Background and challenges*

Higher availability of hydropower plants, as with any machinery and equipment, actually translates into minimisation of the outage times of these plants. Such plants need to be available when required. For this reason, more effort must be focused on the deployment of intelligent sensor-based condition monitoring systems within the hydropower plants, to detect early failure mechanisms or postpone unnecessary maintenance actions, i.e. avoid unplanned outages (failures), limit planned outages, thereby providing higher overall plant

availability. Moreover, additional investigations are required to develop a strategic asset management approach in powerplants based upon the exploitation of predictive maintenance software, facilitating the design of optimal predictive maintenance strategies for optimising HPP machinery maintenance management in combination with sediment management. Today's monitoring systems are used mainly to avoid equipment failure rather than to optimise maintenance intervals. Knowing when to maintain the plant will become more important as plants are operated in ways that will tend to wear out components faster, such as operating at low-load or as a spinning reserve.

Obtaining data from existing systems is of high value, allowing deeper knowledge of the system and its functioning condition. It serves as input data for the design of future systems and knowledge of system behaviour improves our understanding of its yield under different operational strategies. Older infrastructures are often poorly equipped with monitoring systems, and very often only geodetic survey and traditional piezometers are the only available data for systems including dams and reservoirs. To be more efficient, e-Monitoring systems need improved wear and tear models, data process management and qualification. This is of great importance to secure efficient operation and maintenance practice for European hydropower resources.

*Suggested research topics with "high to very high" priority*

- Developing monitoring techniques that isolate the effect of materials on lifetime needs and modelling the cost of service (wear and tear) in relation to expected gains (Expected TRL: 6-7; Budget range: €4-6M)

#### *1.2.2.5 Developing new emerging concepts*

While hydropower is a highly mature technology, there remain avenues for novel approaches such as innovation in planning, design and operation of HPPs and PSHs. In Europe, around 60% of the available and economically viable hydropower potential has already been utilised. Accordingly, when investigating break-through technologies, it is sensible to also discover innovative ways to improve the yield from existing infrastructure. Moreover, as "easier" sites for hydropower projects are already tapped, the hydropower equipment industry increasingly needs to provide innovative equipment capable of adapting and performing well under more challenging design constraints. For greenfield development multi-purpose schemes have become a must since they allow to achieve a win-win situation for all stakeholders involved and the best synergy between all purposes. This is a difficult task and confirmed methodologies including evaluation of non-monetary goals and cost-sharing approaches are still missing.

##### 1.2.2.5.1 Research theme: Development of innovative storage and pumped-storage power plants

Priority: Very High; Recommended call: initiate research before 2030; Recommended funding scheme: €16-25 million

*Background and challenges*

Multipurpose schemes refer to the use of reservoirs to provide other services beyond electricity generation. Hydropower projects present multiple opportunities to create

environmental and socio-economic value for their host communities and regions. Through multipurpose schemes, hydropower reservoirs can contribute to appropriate water management, including water supply, flood and drought management, irrigation, navigation, fisheries, environmental services and recreational activities. Dams have most often been built to serve only one of the above-mentioned purposes. However, due to the increasing demand for these various provided services, their spatial and temporal overlaps, the increasing threat posed by climate change and national and international sustainability goals, construction and/or retrofitting multipurpose uses of dams has been favoured in recent years as they can then fulfil several purposes through a single facility. Multi-purpose water infrastructure encompasses all constructed water systems, including dams, dykes, reservoirs and associated irrigation canals and water supply networks. Through these uses, the profitability of storage and pumped storage plants can be improved, while at the same time making HPPs amenable for the wider public. However, clarification of the legal framework is needed to put in place some of these uses. Even if not yet widely used, seawater pumped storage plants and tidal range plants are already mature technologies and these technologies have a potentially large market. They are highly predictable and there is no competition with freshwater resources.

*Suggested research topic with "very high" priority*

- Integrating storage and pumped storage in hybrid and virtual power plants (Expected TRL: 6-7; Budget range: €4-6M)

*Suggested research topic with "high to very high" priority*

- Transforming a storage power plant into a pumped storage plant (Expected TRL: 6-7; Budget range: €4-6M)

#### *1.2.2.6 Environmentally compatible solutions*

Hydropower is an excellent way of producing electricity from renewable energy. It is therefore very important to find environmentally compatible solutions to minimise the impact on flora and fauna. It is necessary to improve innovative freshwater connectivity solutions for biodiversity protection and to better understand the potential and effects of improvement in regulated rivers on a "case by case" basis, to better adapt a solution to the specific locations/hydropower site. Finding solutions to reduce negative impacts of hydropower plants on the environment are high on the priority list for the hydropower community. Important actions are to ensure sustainable hydropower development and operation, and to preserve public perception and social acceptance of hydropower as a clean, renewable and environmentally compatible energy source.

##### 1.2.2.6.1 Research theme: Flow regime management, assessment of environmental flow release, innovative connectivity solutions for fish and biodiversity protection and improvement of stored water quality in reservoirs

Priority: Very High; Recommended call: initiate research before 2025; recommended funding scheme: €16-25 million

*Background and challenges*

To reduce the negative impact of hydropower plants on the environment, R&I activities are needed to address the impacts of hydropower on upstream and downstream ecosystems to

improve the ecological conditions and re-establish connectivity. One of the key issues is to determine and re-stablish the environmental flows that mimic the natural water flow whilst maintaining the necessary climate protection (e.g. one of the tools to determine the necessary environmental flow is the use of airborne laser bathymetry data with high resolution). Another issue is to also ensure sustainable ecosystems and population consistent with human needs for land-use and water-use, sometimes in heavily modified water bodies (e.g. appropriate measures and approaches need to be developed to balance different needs in a fair way). Nevertheless, environmental measures such as environmental flows need to be site-specific – there is no one size that fits all (e.g. concerning the Water Framework Directive). More research should also be undertaken on ecological flows within Mediterranean contexts as well as for high altitude alpine contexts and on the assessment of the impacts of hydropeaking on the dynamics and resilience of biological community populations based on the typology of rivers and the multiple pressures they experience. Other important issues are bearing the costs invested in hydro morphology (e.g. private companies, public organisations, etc.); and the fact that public services provided by operators (cleaning waste from rivers, flood protection, grid stabilisation, climate change mitigation etc.) are not taken into account. The protection of fish populations by reducing mortality at power plants is another key issue and there is still a need for development and finding solutions for downstream fish migration devices and guiding fish to such downstream bypass systems.

*Suggested research topic with "very high" priority*

- Measures and approaches to protect biodiversity (Expected TRL: 6-7; Budget range: €4-6M)

*Suggested research topic with "high to very high" priority*

- Development and testing of solutions for improved biodiversity and fish protection (Expected TRL: 6-7; Budget range: €4-6M)
- Investigating linked effects on biological community resilience population dynamics and diversity through analysing different ecological flows in various geographical contexts (Expected TRL: 4-5; Budget range: €4-6M)

#### 1.2.2.6.2 Research theme: Assessment of general impact and contribution of hydropower to biodiversity and identification of innovative approaches and guidelines to support more sustainable hydropower development

Priority: Very High; Recommended call: initiate research before 2025; recommended funding scheme: €8-15 million

*Background and challenges*

The Global Assessment Report on Biodiversity and Ecosystem Services points out that there is an urgent need for action to better conserve and sustainably use biodiversity. This challenge can be addressed with various actions or measures, both technical and non-technical, through cross-sectoral and multidisciplinary collaboration among decision-makers and other stakeholders at all levels. Such technical measure can include, for example side channel reconnection, removal of bank protection and riverbed protection / structures, restoration of floodplain habitats, reduction of land use intensity, restoration of sediment continuity,

hydrological aspects, etc. Before launching these actions, greater knowledge on ecosystems is needed for the development of the best and most effective solutions. Technical and environmental innovations have to guarantee that residual impacts would be acceptable. The question arises as to how to develop new green field hydropower projects in such an environmentally friendly and sustainable way that they can contribute to the achievement of the European Green Deal?

*Suggested research topic with "very high" priority*

- Innovative and comprehensive approaches for successful hydropower projects and win-win situations (Expected TRL: NA; Budget range: €4-6M)

*Suggested research topic with "high to very high" priority*

- Assessment of the general impact and contribution of hydropower to biodiversity (Expected TRL: NA; Budget range: €7-10M)

#### *1.2.2.7 Mitigating impact of global warming*

Exploring the theme of 'Water and Climate Change', UN Water's annual report on World Water Day highlighted that hydropower forms an essential part of the solution to climate change. Hydropower is indeed a climate-friendly technology preventing (lowest release of CO2) and mitigating (water storage) the impact of global warming and climate change. It plays a valuable role in the framework of the European decarbonisation strategy: HPPs produce clean energy and their flexibility in generation strongly contributes to balancing the frequency of the power network and ensuring grid resilience, thus fostering the deployment of intermittent renewable energy sources. Climate change results in an increased frequency and intensity of flood and drought events, so discharge capacities need to be upgraded in many cases. For this, cost-efficient solutions must be developed. On the other hand, the need for additional storage due to climate change could also be seen as a chance to improve water-management alongside hydropower.

##### 1.2.2.7.1 Research Theme: Innovative concepts of hydropower infrastructure adaptation and tapping hidden hydro

Priority: Very High; Recommended call: initiate research before 2030; recommended funding scheme: €16-25 million

*Background and challenges*

Europe has a lot of sites with low head potential, where hydraulic structures like small barriers are already present, and for example, used for irrigation purposes or old mill sites. These structures are sometimes abandoned. The rehabilitation and optimisation of waterwheels for hydropower production and water services can be a valuable source of renewable energy.

*Suggested research topics with "very high" priority*

- Regional potential of reservoirs mitigating the consequences of floods and long dry periods and their combination with hydropower to mitigate the consequences of volatile renewable energy production (Expected TRL: 6-7; Budget range: €4-6M)
- Pilot projects validating and exploiting innovative solutions for hidden hydro at existing water infrastructures (Expected TRL: 6-7; Budget range: €7-10M)

*Suggested research topics with "high to very high" priority*

- Research on allocation methodologies and future GHG emissions savings for multipurpose use reservoirs (Expected TRL: 4-5; Budget range: €1-3M)

## 1.2.3 Strategic Industry Roadmap (SIR)

### *1.2.3.1 Overview*

The goal of the Strategic Industry Roadmap is to provide recommendations for European regulators, policymakers, civil society, NGOs, technology developers, planners, utilities and system operators to discuss together and to take balanced decisions on further hydropower development to enable the new energy system to benefit fully from the storage and flexibility potential of this valuable resource.

*There is a gap between hydropower services to society and policy support*

In contrast to the huge contribution to society, and although hydropower has all the features which the European Union needs for a sustainable, secure and competitive energy supply, there is little emphasis on the role that hydropower could play in the future European energy system.

*The Strategic Industry Roadmap has the ambition to fill the gap*

An innovative roadmap built from lessons learnt from unsuccessful projects recommends strategic steps for bridging the gap between parties and convincing society that hydropower delivers the reliable and secure provision of affordable electricity whilst also meeting environmental goals.

According to the global system analysis (see next Chapter 1.2.3), two critical factors which are influencing the success of hydropower development in Europe in a dominant way, are the "Volatility of the Electricity Generation" and the "Public Awareness Hydro". The first one is not controllable. However, the "Public Awareness Hydro" can be influenced directly by each of the high priority strategic actions increasing public acceptance. These may be considered according to the following approach:

1. Increase public awareness with communication and dissemination
2. Develop best practices for sustainability for successful projects and win-win situations
3. Increase security, decentralization and independence of the European energy system with PSH
4. Give a collaborative platform to the hydro sector.

Amongst the most controllable active factors, there are "Environmental Mitigation Measures" and "European Green Deal". All of the strategic actions on "Environmental Mitigation Measures" can be considered under the following strategic actions:

1. Collect best practice for sustainability and biodiversity protection
2. Increase the knowledge on environmental impacts
3. Develop innovative compensation measures for the protection of biodiversity
4. Develop comprehensive approaches allowing compromises.

Amongst the first highest level, controllable active factors, there are also "Electricity Generation Hydro" and "Reservoir Volume" which actively influence the future of hydropower deployment. They can be increased in the short term by upgrading power plants,

dam heightening and by effective sediment management of current facilities and in the mid-term by new hydropower installed capacity, new multipurpose projects and last but not least new pumped-storage powerplants.
The implementation of new capacity should be boosted by the high priority strategic actions supporting better hydropower deployment, adapting regulations to the energy transition, investing more thanks to new business models, and simplifying approval procedures and legislation. Reservoir capacity and water uses also need a future resilience to climate change. Finally, reservoir volume is mainly depending upon the most reactive factors: "Flexibility" and "Markets opportunity". Consequently, it will be more difficult and uncertain to be successful with all of these actions. It means that hydropower needs a strong collective strategic framework to be adopted, for instance comprising:

1. Improvement of flexibility markets
2. Best practice for investing under uncertainties
3. Development of a more pertinent regulation framework.

#### *1.2.3.2 Suggested strategic actions with very high priority*

Having received a very high priority from the wider stakeholder consultation and the Consultation Expert Panel (CEP), the following detailed strategic actions are grouped and listed according to the challenges mentioned above.

*Strategic actions to increase social acceptance*

- Collect a catalogue of examples of best practice of successful multi-purpose projects creating a win-win situation between all stakeholders
- Develop innovative approaches to address environmental issues and biodiversity protection with comprehensive approaches allowing compromises
- Increase awareness of European citizens to the importance of hydropower development

*Strategic actions to develop environmental mitigation measures*

- Develop sustainability best practices with the help of international associations (IHA, ICOLD, World Bank, etc.) including taxonomy for sustainable finance and biodiversity strategies
- Develop sustainable sediment management strategies for ensuring sustainable reservoir capacity and sediment dynamics in rivers
- Protection of biodiversity in hydropower projects by innovative compensation measures
- Collect experience with the water framework directive and lessons learnt solutions to maintain or improve water quality in rivers and reservoirs

*Strategic actions for better hydropower deployment*

- Solve the "missing money" issue with adequate remunerations in future flexibility markets
- Contribute to supply security, decentralisation and independence of the European energy system with PSH
- Increase resilience by mitigating the impact of ageing and maintaining the high safety level of power plants

*Strategic actions to adapt regulation to energy transition*

- Research and development for regulation improvements (increase CO2 cost, abolishment of the double taxation of pumped storage hydropower, concessions, safety, taxes, etc)
- Development of a more stable regulation framework which promotes green renewable power with a fair price, tax policy and subsidy model designed for a level playing field amongst different technologies, based on a comprehensive analysis of the carbon footprint and life cycle

*Strategic action to simplified approval procedures and legislation*

- Enhanced dialogue between civil society and the European Commission to define appropriate ways and tools to deploy more hydropower and to balance environmental protection legislation and climate friendly energy legislation.

### 1.2.4 Comparison and validation of the research theme and strategic action priorities with the results of a complex system analysis

Based on the feedback received from the wider stakeholder consultation of the first draft of the Strategic Industrial Roadmap (SIR) and the Research and Innovation Agenda (RIA), a list of 103 factors were identified which were considered relevant for a system analysis. With these factors a network of the hydropower market in Europe was built (Figure 3). Through the circular visualisation shown in Figure 4, the activity of the factors (those that are influencing) on the whole hydropower system are shown.

Through a matrix analysis of the interconnection of all factors within the network, their activity and reactivity could be determined (Figure 5). Two important categories for the active or critical factors have to be distinguished: those that can be controlled directly by an action and those that are not controllable. The controllable factors can be used as a lever and are therefore important for the prioritisation of any actions.

The priority categories of the research themes and the strategic actions obtained from the consultation process and feedback of the Consultation Expert Panel could be validated by the results of the complex system analysis, when comparing them with the controllable, active factors having a high impact level on the network describing the hydropower system in Europe.

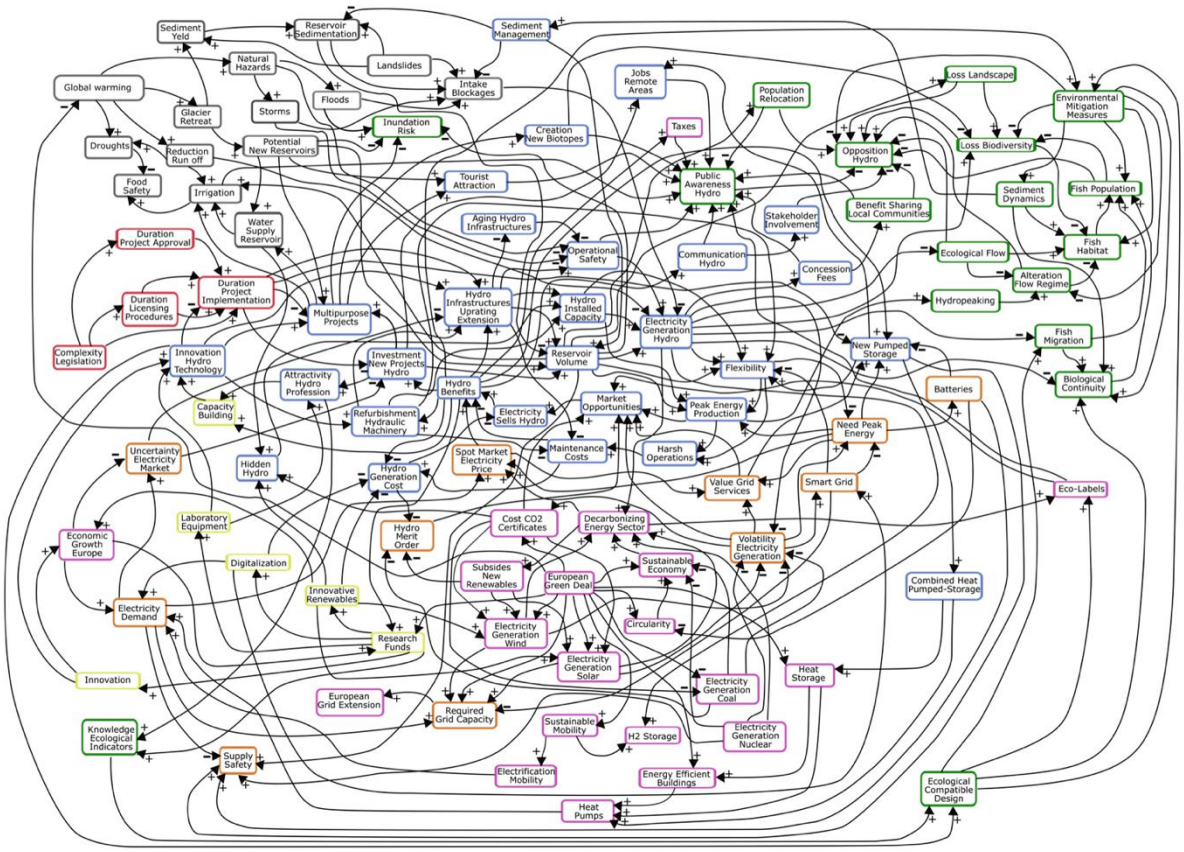


Figure 3 Hydropower in Europe in a complex environment: Network of factors representing the different sectors

Figure 3 shows the system analysis for hydropower in Europe. The different sectors include Hydropower (blue), Energy and Economic Policy (pink), Electricity Market (orange), Environment and Public Society (green), Research and Development (yellow), Legal Framework (red) and Climate Change (black).

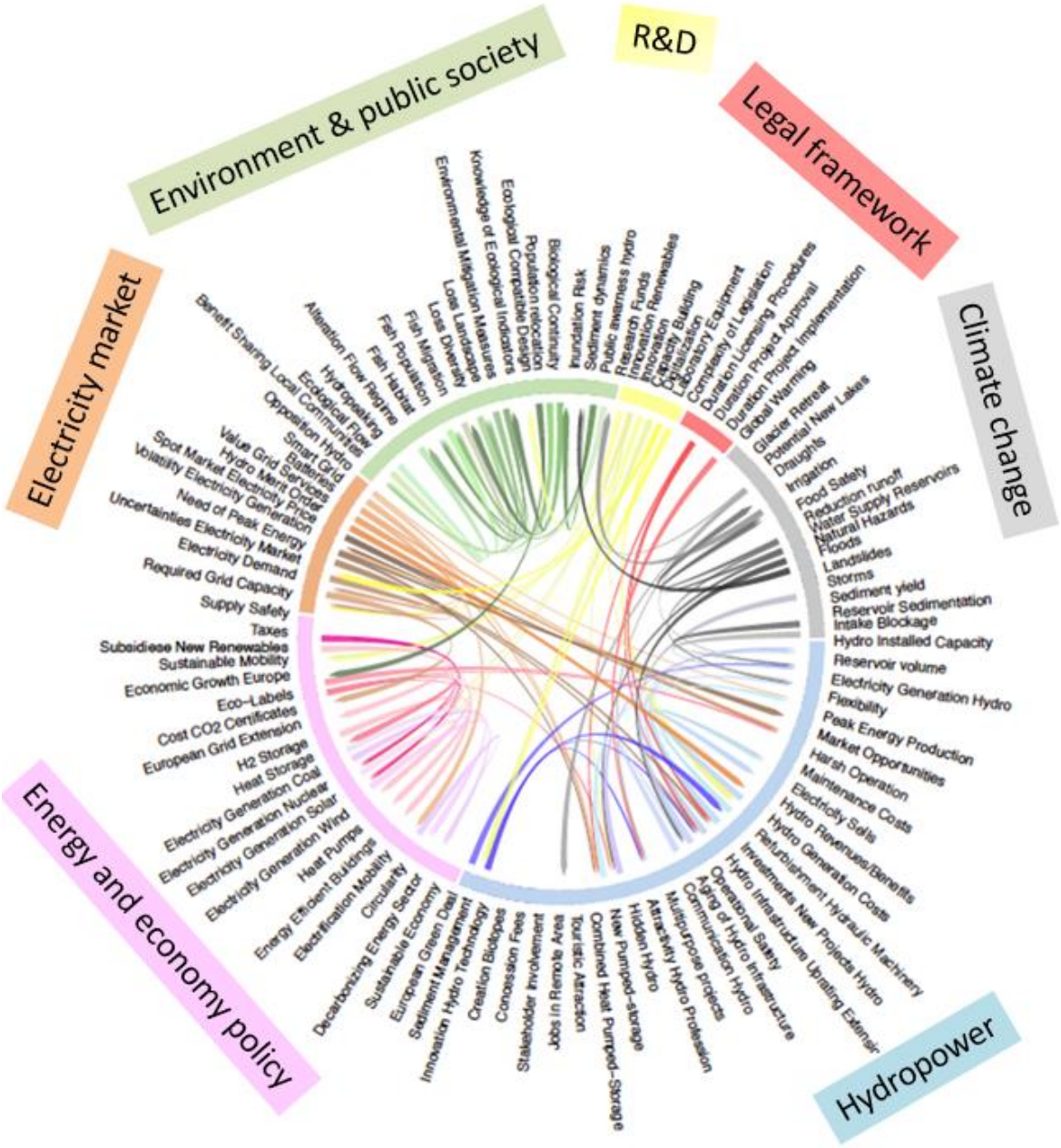


Figure 4 Circular visualisation of network factors

Figure 4 shows a circular visualisation of network factors showing their activity (influencing intensity) for the sectors Hydropower (blue), Energy and economy policy (pink), Electricity market (orange), Environment and public society (green), Research and development (yellow), Legal framework (red) and Climate change (black).

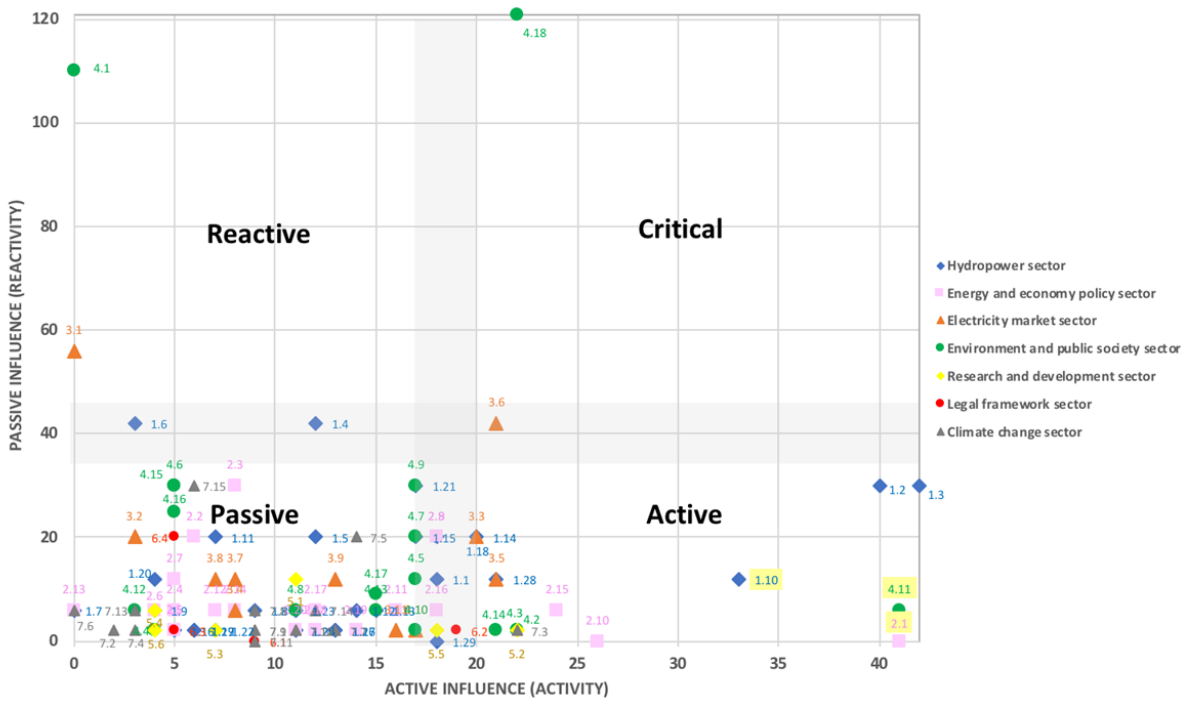


Figure 5 Matrix analysis of the network representing the complex situation of hydropower in Europe

In Figure 5 the matrix analysis of the network representing the complex situation of hydropower in Europe is shown. Key critical factors are: Public Awareness Hydro (4.18) and Volatility of the Electricity Generation (3.6). Key active factors are: Electricity Generation Hydro (1.3), Environmental Mitigation Measures (4.11), European Green Deal (2.1), Reservoir Volume (1.2) and Hydropower Benefits (1.10).

## 1.3 Exploitation and dissemination

### 1.3.1 Implementation and exploitation

Through this substantial programme of consultation, the HYDROPOWER EUROPE Forum has defined three key strategic directions needed to support the role and development of hydropower:

A. Providing economic and legal support for an effective hydropower contribution to flexibility and storage within the new electricity system in the Net Zero Economy.
B. Increasing societal resilience and local employment.
C. Preserving biodiversity and improving river ecosystems

#### *1.3.1.1 Market, political and legal pathways to the 2050 net zero energy system*

There is a large consensus concerning the necessity to re-design the electricity market. A new energy system, where renewable energies sources will only be used, needs a new market model. Fundamentally, storage and flexibility are externalities of variable renewable

energy supplies. Externalities are not addressed by the market; they are only controlled by regulation. The lack of compensation for many 'flexibility services' is called: "the missing money problem". Consequently, public regulation is crucial to properly remunerate storage and flexibility services. To implement a Zero Net Economy, investors need a more stable regulation framework. Policy measures that recognize the value of storage in the European power system, like abolishment of any kind of double taxation, will provide future revenues for flexibility and storage projects and can reduce investment risks and thus help ensure the economic viability of the European Green Deal. An economic model giving a value to flexibility in the European power system is therefore needed. A comprehensive modelling exercise, simulating a 100% renewable resources-based European energy system, would build quantitative evidence to support policymaking in pricing flexibility. All services provided to the grid should be fully compensated according to their value. A well-functioning single European energy market and an effective EU Emissions Trading System, which promote green renewable energy with a fair price, tax policy and a subsidy model designed to provide a level playing field amongst different technologies, based on a comprehensive analysis of their carbon footprint and life cycle, are the best way of ensuring fulfilment of the European energy policy objectives. Multi-criteria analyses should be considered in the tenders, giving value to indicators of energy consumption, carbon footprint and costs of the production, exploitation, recycling, and decommissioning. European policy could bring back a long-term vision and set long-term revenue streams securing future long-term investments.

#### *1.3.1.2 Sustainability is the social pathway to the European Green Deal*

Communication and dissemination are needed to increase public awareness regarding the benefits and further support of new sustainable hydropower plants. Actions towards increasing social acceptance of hydropower are to make information more readily available, to develop specific strategies to quantify the benefits of hydropower and to share these messages with society. Regional workshops, gathering all stakeholders, under an appropriate administrative framework, are good opportunities to explore specific barriers and to promote best practice and uptake of hydropower. Large hydropower development may only occur if it is included within a coherent national energy policy, ensuring public water and energy services and security. In addition, robust sustainability standards and enforcement measures by national authorities are needed to increase investor confidence and gain public acceptance. The hydropower sector needs to adopt a holistic position considering the new social context, climate change, grid requirements and more generally the use of water for increasing social welfare. Development of comprehensive, innovative approaches, methods and tools using social sciences and humanities are needed to help balance the European energy market rules and European environmental goals. Large reservoirs provide very important electric system security services such as prevention of network crashes, black-start, and regulation capabilities, that decision-makers and regulators must quickly protect and secure the independence and flexible operation of the European Electric System by launching new pumped-storage power plant solutions in

Europe. Long-term support for European hydropower 'know-how' is required to maintain and enhance hydropower in the future and to support continued employment in the sector.

#### *1.3.1.3 Environmental commitment in the European Green Deal*

A key collaborative action between hydropower stakeholders is to collect, share, disseminate and apply knowledge on best practice for protecting freshwater ecosystems. Collecting best practice with the help of international associations, best examples of biotope creation and restoration and lessons learnt from experiences with the water framework directive, drawbacks and limitations will help prevent, minimize, or support compensating for environmental impacts at the European level and support the discussion of approaches with up-to-date information. Increased monitoring and processing big data will help develop and share enhanced knowledge on ecosystems and how hydropower affects and can mitigate these whilst supporting the Green Deal. A scientific program investigating, monitoring and benchmarking the application of best practice for protecting biodiversity and addressing climate change impact to improve knowledge and minimize impacts of industry and climate change on aquatic ecosystems is needed. Improvement of biodiversity protection and river continuity in hydropower projects thanks to innovative design and compensation measures is a key strategic action that would show the environmental commitment of the hydropower sector. The development of innovative and comprehensive approaches to address environmental issues and biodiversity protection undertaking a synthesis of lessons that can be drawn from best practice and the latest research outputs and allowing sound and transparent discussion between all parties is a top priority.

### 1.3.2 Dissemination

#### *1.3.2.1 Overview on main events and actions*

A Consultation Platform was created to help manage the HYDROPOWER EUROPE consultation process (https://hydropower-europe.eu) and to disseminate directly the outcomes, where more than 635 stakeholders and experts have registered and have been involved in the consultation process, which may be considered a success. Besides organization of numerous consultation events and Brussels-based as well as regional workshops (Nordic, Alpine and Mediterranean regions) in the summer of 2019, a successful workshop on environmental and social aspects was held in October 2020 and a round table with NGOs in January 2021. A Partner Event (with EERA) at the EU Green Week in June 2021 under the theme of Zero Pollution and an EU Sustainable Energy Day event on the sustainability and acceptability of hydropower as part of the clean energy transition in September 2021 were also held. These are more recent examples of increased consultation with civil society. A first dissemination event of the results was held during the HydroES Conference in Lyon on 22$^{nd}$ September, 2021. Finally, during the above-mentioned closing event on 23$^{rd}$ February 2022, the results of HYDROPOWER EUROPE and the conclusions drawn from the consultation events with different sector stakeholders were presented by focusing on needs for research and innovation, challenges and opportunities of hydropower development in Europe as well as the future of the hydropower sector. Finally, a workshop

on 28th February, 2022 on the question "What research and innovation are needed to tap more hidden hydro opportunities in the future?" successfully concluded the project mission.

During the HYDROPOWER EUROPE project consideration was given to sustainability of the HYDROPOWER EUROPE Forum and different business models were assessed. As part of this process feedback was sought from the more than 600 Forum members, as well as specific industry organisations. The conclusion was that two approaches may be supported through the HYDROPOWER EUROPE Forum comprising:

1) A research and innovation focussed association aiming to identify and facilitate industry priority R&I actions including tracking of existing programmes in more detail and facilitating cooperation and co-funding of R&I actions directly by Industry members (meeting those priorities not being addressed elsewhere)
2) A classical trade association in the model of existing EU-focused renewable energy trade associations, attending to regulation around hydropower

In view of refinement of the proposed business model through further consultation with industry, including clarifying the scope and balance between the two options, as a first step, HYDROPOWER EUROPE has organised a special session with a roundtable discussion on « Promoting Future Hydro in Europe » at HYDRO 2022 in Strasbourg on 25th April, 2022, which will gather some 500-1000 stakeholders from the hydropower sector (https://www.hydropower-dams.com/hydro-2022/wp-content/uploads/Hydro2022.pdf?x25592).

#### *1.3.2.2 Extended Executive Summary Brochures and Dissemination Video*

Extended Executive Summary Brochures on the main outcomes of the Research and Innovation Agenda (RIA) as well as Strategic Industry Roadmap (SIR) have been published. A video entitled "Hydropower as a key partner for the energy transition" summarized the outcomes of the HYDROPOWER EUROPE Forum and has been disseminated via the HYDROPOWER EUROPE website and YouTube.

#### *1.3.2.3 Selected publications*

HYDROPOWER EUROPE (2021). Hydropower as a catalyst for a successful energy transition. Communication in Europe in European Energy Innovation Magazine Autumn 2021, page 21. https://www.europeanenergyinnovation.eu/OnlinePublication/Autumn2021/index.html#p=21 Emanuele Quaranta, George Aggidis, Robert M. Boes, Claudio Comoglio, Carlo De Michele, Epari Ritesh Patro, Evgeniia Georgievskaia, Atle Harby, Ioannis Kougias, Sebastian Muntean, Juan Pérez-Díaz, Pedro Romero-Gomez, Marco Rosa-Clot, Anton J. Schleiss, Elena Vagnoni, Markus Wirth, Alberto Pistocchi. (2021). Assessing the energy potential of modernizing the European hydropower fleet. Energy Conversion and Management, Volume 246,114655, ISSN 0196-8904, https://doi.org/10.1016/j.enconman.2021.114655

Anton J. Schleiss (2021). Hydropower as a catalyst for the energy transition. VGB Hydropower Industry Guide 2021/2022 (2nd issue), p.10-15.

Jean-Jacques Fry, Anton J. Schleiss and Mark Morris (2022). Hydropower as a catalyst for the energy transition within the European Green Deal: Part I: Urgency of Green Deal and role of Hydropower. Part II: The complex environment of hydropower, biodiversity challenges and main innovation and research directions. Proc. of the Symposium “Sharing water: Multi-purpose of Reservoirs and Innovations”, 27th ICOLD Congress, Marseille, May 30 - June 4, 2022, France (accepted for publication).

J.-J. Fry, A. Misech, M. Morris, A. J. Schleiss (2022). Suggested research themes and strategic actions to promote hydropower as a catalyst for the energy transition in Europe. Journal on Hydropower & Dams. 29: Issue 2: 37-27.

Jean-Jacques Fry (2021) HYDROPOWER EUROPE – A roadmap for European hydropower sector development. The future of hydropower – IEA special market report. Energetyka Wodna 3/2021 (39) Free copy ISSN 2299-0674

Jean-Jacques Fry, Mark Morris, Anton Schleiss. (2022) Hydropower, a catalyst for energy transition in Europe. Journal La Houille Blanche (accepted for publication).

Jean-Jacques Fry, Mark Morris, Anton Schleiss. (2022) Voies de recherche et actions stratégiques pour promouvoir l’hydroélectricité comme un catalyseur de la transition énergétique. Journal La Houille Blanche (accepted for publication).

# 2 Conclusions from the project

Hydropower in Europe is facing a great number of challenges. To tackle these environmental, societal, technological and market challenges, the hydropower sector needs to find novel approaches to future development in accordance with environmental and social demand. So where is hydropower, the world's largest renewable energy source heading in the foreseeable future? Predictions show that hydropower will hold the lead among other renewable energy sources as the world's largest source of renewable electricity generation. Climate change will play a decisive role in the development of hydropower energy due to its threat to the entire hydrological cycle. Moreover, the hydropower sector will have to show its worth, in dealing with continuous opposition from critics voicing concerns about the environmental and social damage caused by hydropower projects, as is also the case for other renewable energy sources (onshore and partly offshore wind, distribution/transmission grid projects).

One of the avenues for the future sustainable growth for this sector lies in the development of run-of-the-river plants (as a less controversial type of hydropower plant) or in pumped storage plants that benefit from a closed cycle, hence not interfering with natural water bodies. Furthermore, multi-purpose storage power plants and reservoirs will become vital for mitigation of climate effects such as droughts and floods. There is significant potential for increasing the volume of existing reservoirs through the heightening of dams. New large multi-purpose reservoirs may be limited by environmental and socio-economic constraints, but by taking advantage of synergies, compromises may be found. Another avenue for development lies in the increasing digitalisation of hydropower, with several hydropower plant operators utilising various Industrial Internet of Things (IIoT) technologies to make hydropower more efficient, cheaper and environmentally compatible. Hydropower delivers many services beyond just electricity supply, as an important player in both water resources management and water storage. This will be key in the near future due to climate change. However, regulation and remuneration play an important role in this future scenario because of their impact on hydropower revenues. Frequent alteration of regulations is indeed a factor that impacts negatively on the decision-making process for new hydropower projects, since it increases the risk of uncertainty in a sector that is already capital intensive and has a large market risk.

The Research and Innovation Agenda (RIA) and the Strategic Industry Roadmap (SIR) are key contributions to the growing debate on the net zero economy and the European Green Deal under the challenge of a safe and independent energy supply. They will be highly relevant for discussions on finding the best solutions to provide the new energy system with flexibility. They will help European regulators, policymakers, civil society, NGOs, technology developers, planners, utilities and system operators to discuss together and to take balanced decisions on further hydropower development to enable the new energy system to benefit fully from the storage and flexibility potential of this valuable resource. Hydropower technology is established, widely deployed and highly efficient. Hydropower provides ancillary and important back-up services which help stabilise the grid for intermittent and non-

dispatchable renewable resources such as wind or solar power. Hydropower is born to be a catalyst for the energy transition.

# 3 Socio economic impacts

As already mentioned under Chapter 2 the outcomes of the HYDROPOWER EUROPE Forum are key contributions to the growing debate on the net zero economy and the European Green Deal under the challenge of a safe and independent energy supply. They will be highly relevant for discussions on finding the best solutions to provide the new energy system with flexibility. They will help European regulators, policymakers, civil society, NGOs, technology developers, planners, utilities and system operators to discuss together and to take balanced decisions on further hydropower development to enable the new energy system to benefit fully from the storage and flexibility potential of this valuable resource. Hydropower technology is established, widely deployed and highly efficient. Hydropower provides ancillary and important back-up services which help stabilise the grid for intermittent and non-dispatchable renewable resources such as wind or solar power.

Hydropower has all the characteristics to be a catalyst for the energy transition with the challenge of safe and independent supply in Europe. The outcomes of the HYDROPOWER EUROPE Forum show the pathway to the vision for hydropower in Europe defined in a wide consultation with following four directions:

- Increasing hydropower production through the implementation of new environmental friendly, multipurpose hydropower schemes and by using hidden potential in existing infrastructures
- Increasing the flexibility of generation from existing hydropower plants by adaptation and optimization of infrastructure and equipment combined with innovative solutions for the mitigation of environmental impacts
- Increasing storage by the heightening of existing dams and the construction of new reservoirs, which have to ensure not only flexible energy supply, but which also support food and water supply and thus contribute to the WEF NEXUS and achievement of the SDGs of the United Nations
- Strengthening the contribution of flexibility from pumped-storage power plants by developing and building innovative arrangements in combination with existing water infrastructure.

This vision underlined by the Research and Innovation Agenda (RIA) and the Strategic Industry Roadmap (SIR), can be also an inspiring example for hydropower development worldwide which is of high importance to the hydropower sector in Europe which is already playing a major role in the worldwide market today.

# 4 The Project Website

The project website may be found at: https://hydropower-europe.eu/

The HYDROPOWER EUROPE Consultation Platform may be accessed via the project website or directly at: https://consultation.hydropower-europe.eu/

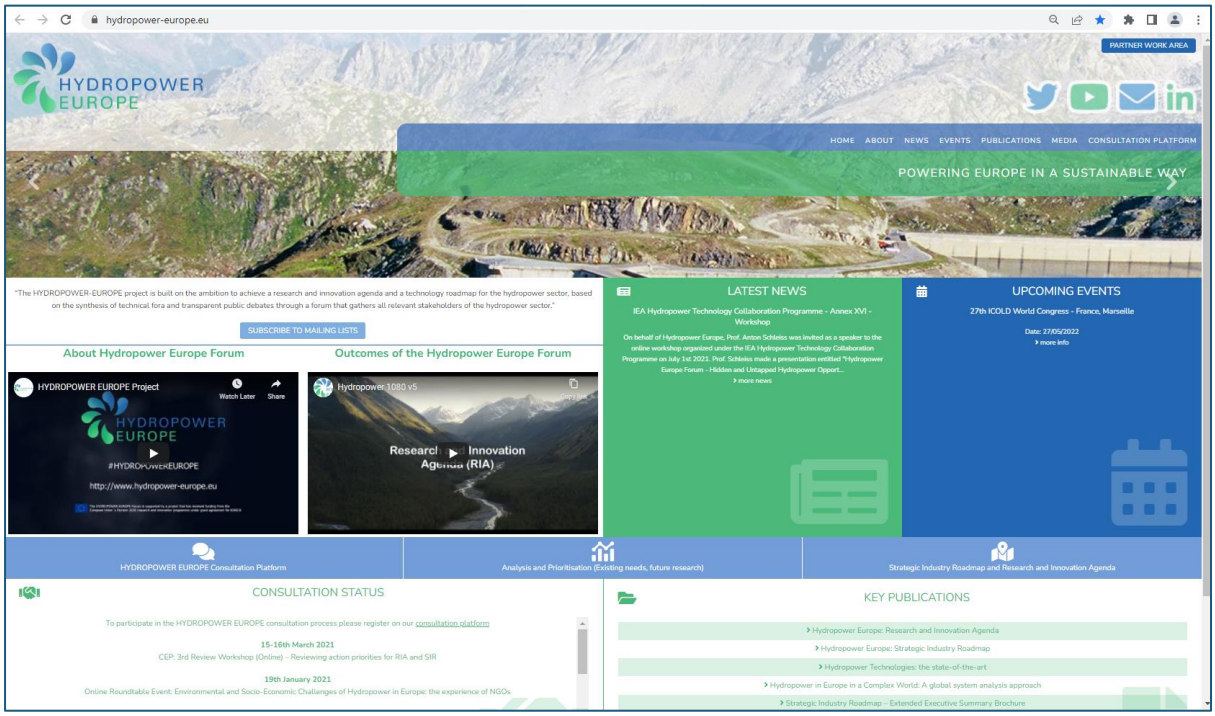


Figure 6 Project website homepage (April 2022)

# 5 Project branding, diagrams, photographs and videos illustrating the work

The following images reflect a range of events and media used during the project, all of which utilise the project branding.


Figure 7 A video introduction to HYDROPOWER EUROPE


Figure 8 Regional consultation workshop (Scandinavia) – August 2019


Figure 9 Regional consultation workshop (Alpine) – September 2019

Figure 10 Regional consultation workshop (Mediterranean) – September 2019


Figure 11 Online dissemination event – June 2021

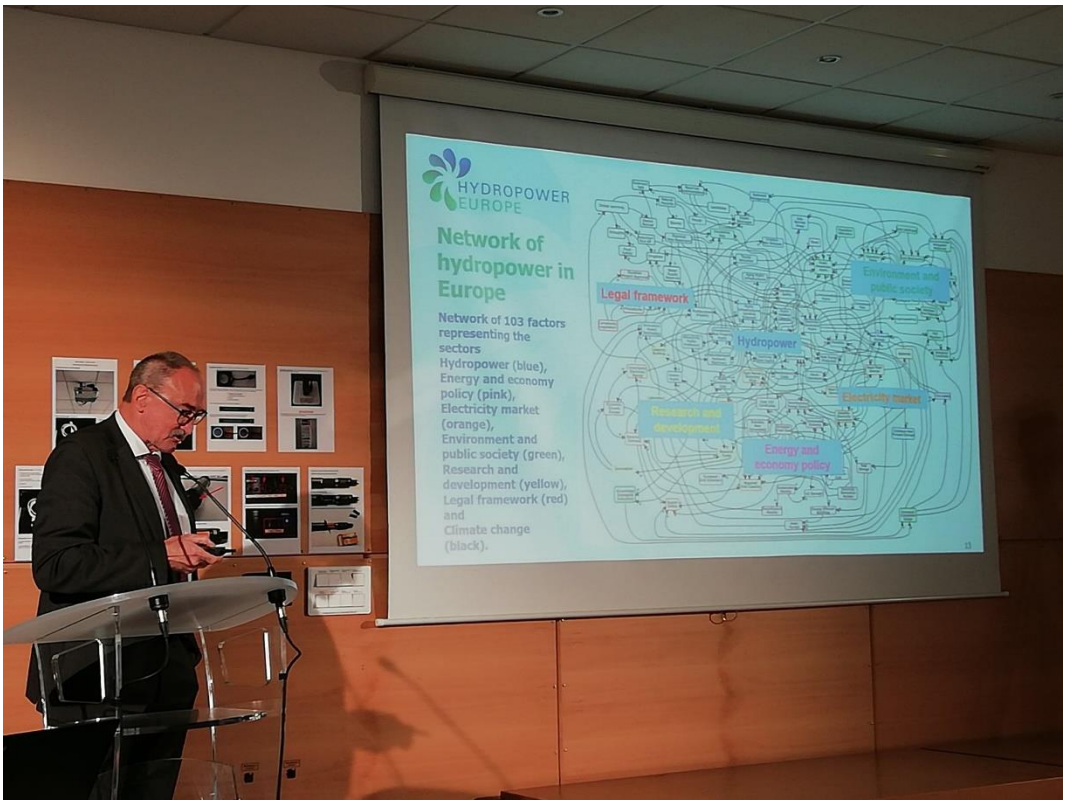


Figure 12 HydroES hybrid dissemination event – September 2021


Figure 13 A video presenting the HYDROPOWER EUROPE results

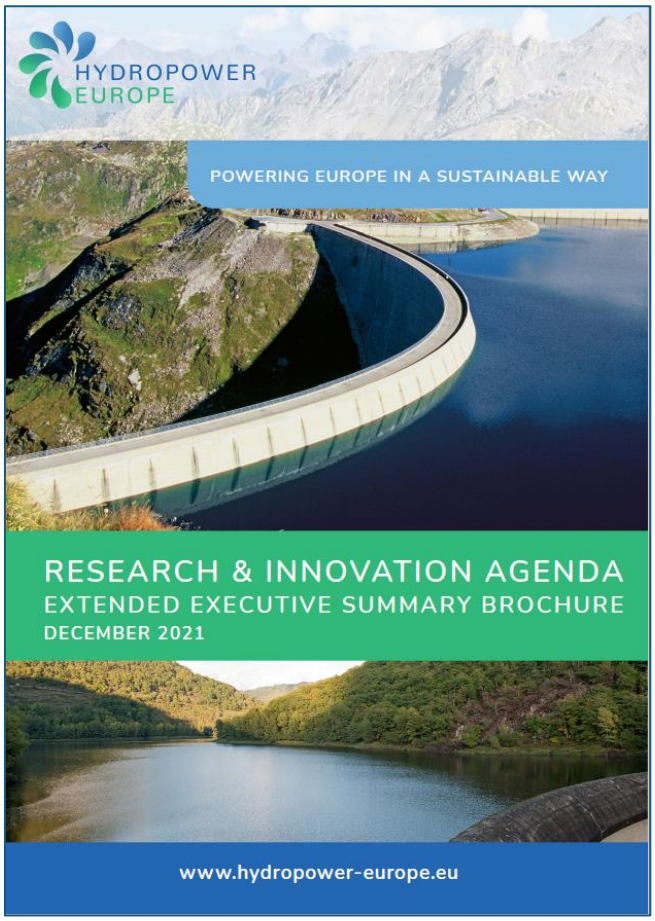


Figure 14 The Research and Innovation Agenda Executive Summary Brochure

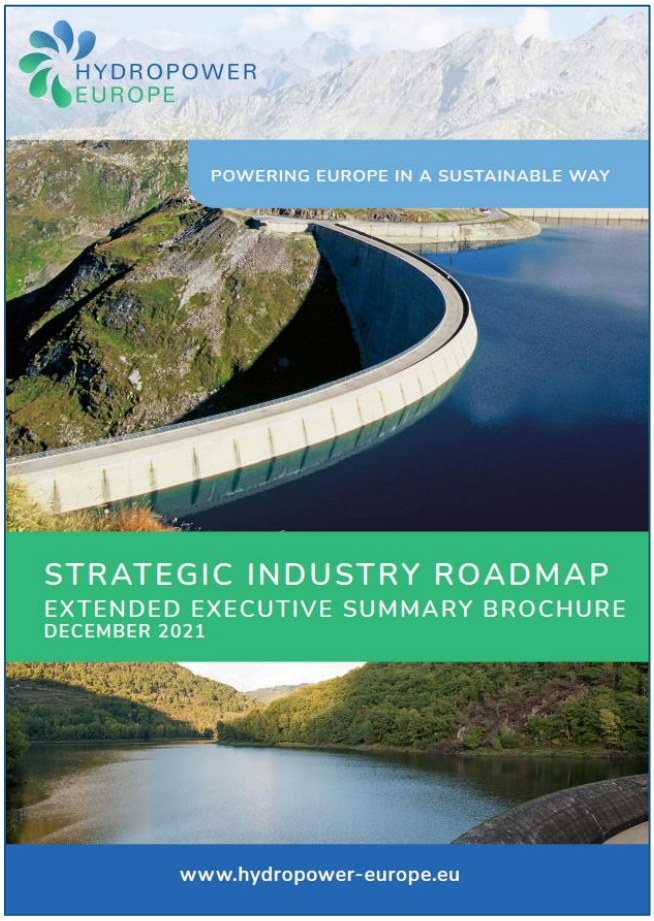


Figure 15 The Strategic Industry Roadmap Executive Summary Brochure

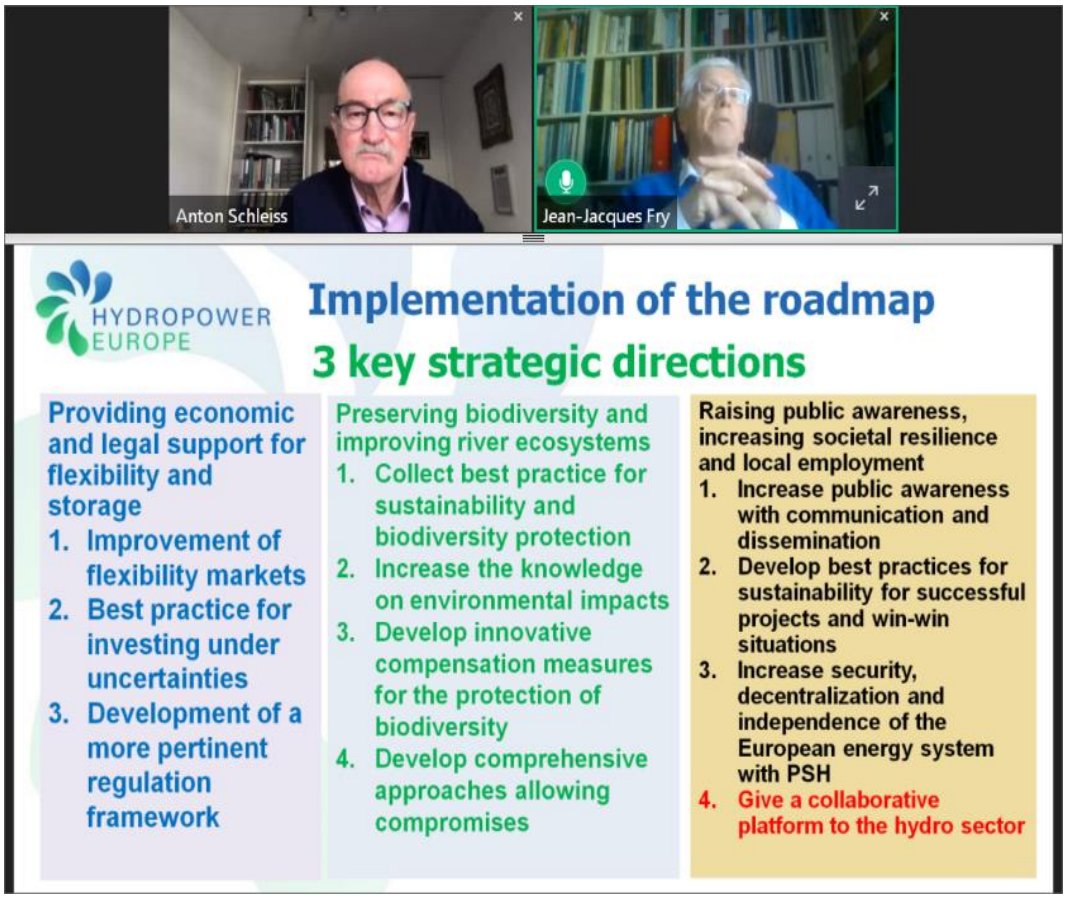


Figure 16 Online dissemination event – February 2022