The energy crisis in Europa reveals the importance of reliable hydropower as a catalyst and enabler for the clean and safe energy transition

By Anton J. Schleiss, Jean-Jacques Fry and Mark Morris

Situation of hydropower in Europe

Hydropower has a long tradition in Europe, contributing significantly during the first half of the last century to the welfare and industrial development of most countries across the continent. Today, reaching nearly 650 TWh of annual generation in an average hydrological year, the economically feasible hydropower potential within Europe (including Turkey) is approximately 65% utilized thus far (Figure 1). The installed capacity in Europe including Turkey reaches almost 230 GW today. Since 2013 annual hydropower and the total installed capacity has stagnated close to today's values. It should be noted that in principle the yearly hydropower production is influenced by the hydrological situation each year.

Figure 2 illustrates a snapshot of the current situation for hydropower usage and untapped potential in countries within the European region. It can be noted that many countries still have considerable potential for development. The countries highlighted with a "sun star" in Figure 2 have developed less than 50% of the economically feasible potential, should the market conditions demand for it. For 14 countries the share of hydro in the overall electricity generation is between 25% and 50%, for three countries between 50% and 90% and for another two counties higher than 90%. This demonstrates that in more than half of the countries in Europe, hydropower represents a significant share of electricity generation, which is important for the success of a safe energy transition to renewable sources.

Nevertheless, relatively little investment has been undertaken over the last 15 years, as can be seen in Figure 3 which shows the installed capacity under construction. After 2011, a quite significant increase in the construction of new power plants reaching almost 10,000 MW can be seen. This may be attributed to the Fukushima catastrophe of 2011, leading many countries to redefine their energy strategy towards renewable sources, such as hydropower, alongside the planned phasing out of nuclear energy. Since 2015, however, construction activity has decreased to some 3000 MW in 2021.

The low investment level can be attributed to low electricity prices on the European spot market, due to the following reasons:

- Production capacity in Europe was too high
- Cost of CO_2 certificates were very low, doing little to dissuade conventional thermal methods
- Market distortion (change of merit order for hydropower) due to the high subsidies provided for other renewable energy sources such as solar and wind.

Thus, under such market conditions hydropower generation was strongly penalized, until the start of the energy crisis in 2022 triggered by the war in Ukraine. However, the energy crisis reveals the vital role of reliable hydropower to help ensure a safe supply of electricity in the coming winters across Europe. Storage and pumped-storage hydropower will be the most vital source of electricity supply to avoid blackouts under critical situations.

Due to the energy crisis, the attractiveness of the extension and upgrading of existing hydropower plants, with the purpose of making them more flexible through the refurbishment of equipment and increasing storage where possible, together with the construction of new pumped-storage power plants has increased again strongly in countries with high storage potential. Furthermore, in many countries a significant amount of untapped hydropower potential still exists. However, in view of environmental and socio-economical constraints, the partial use of this remaining potential is extremely challenging and can be reached only through innovative and sustainable solutions for new hydropower plants.

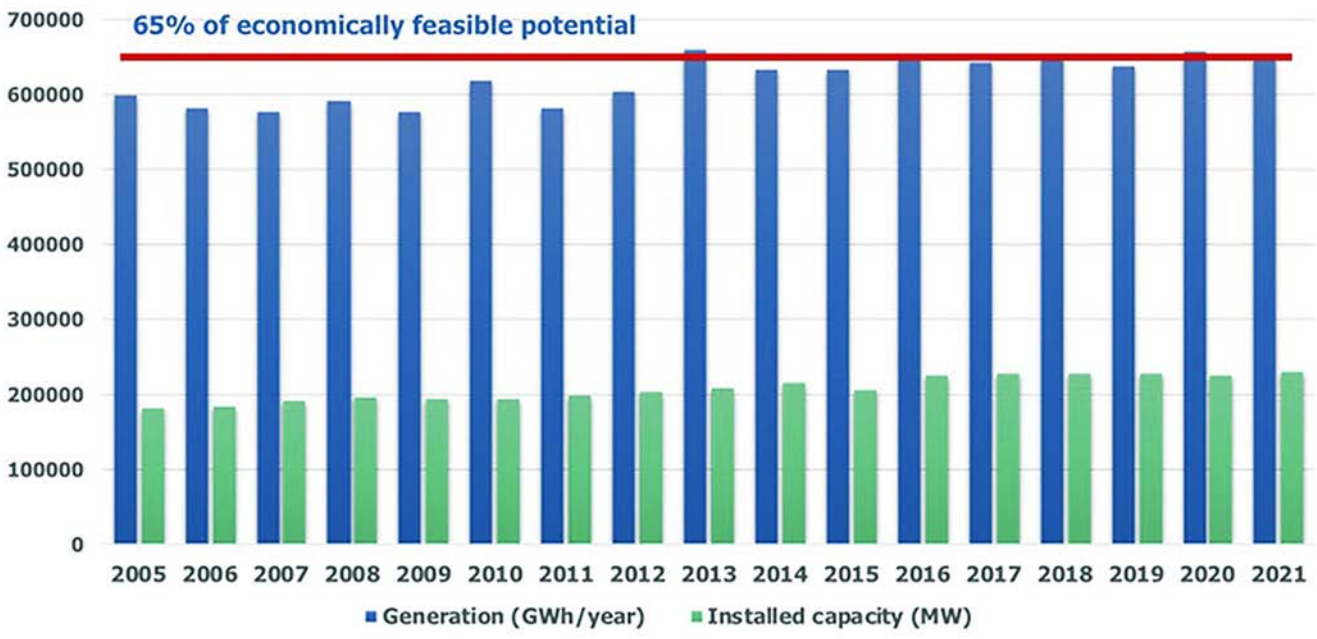

Figure 1 | Evolution of yearly production and installed capacity of hydropower in Europe including Turkey since 2005 (according to Hydropower & Dams World Atlas 2022).

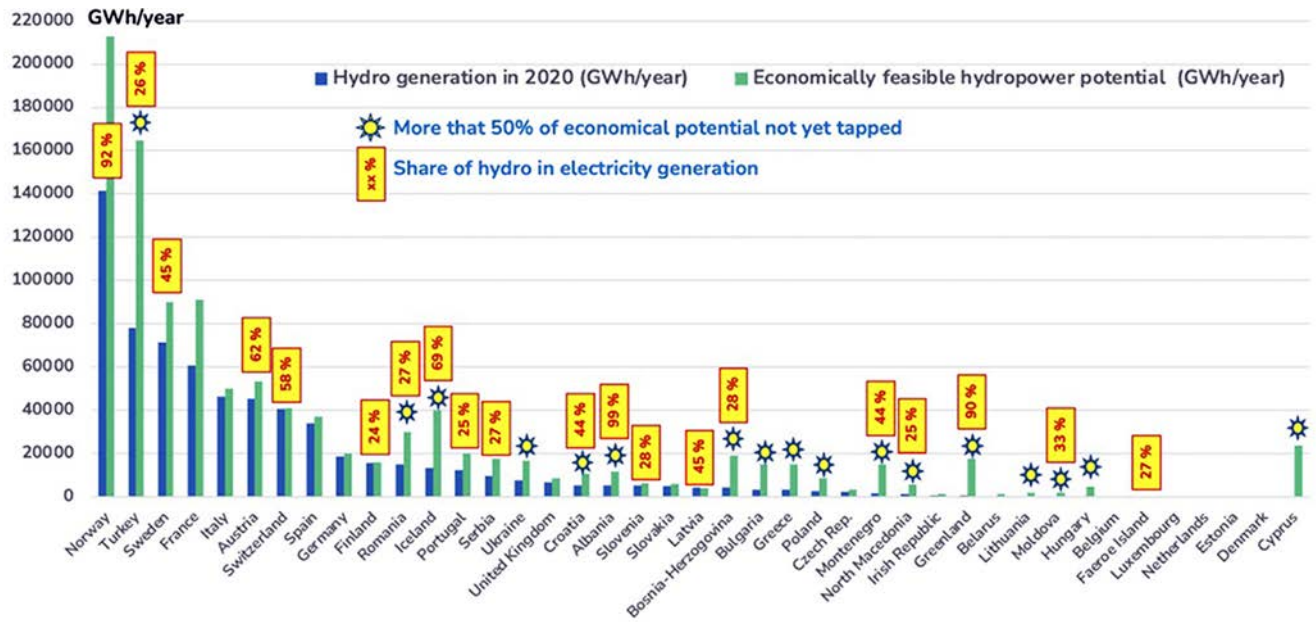

Figure 2 | Generation and extension potential of hydropower in countries in the European region (according to Hydropower & Dams World Atlas 2021). The countries having developed less than 50% of their economical feasible potential (assuming market conditions have demand for it) are highlighted with a "sun star". The share of hydro in the electricity generation is indicated for the countries with a share of more than 25%.

Advantages of hydropower

Hydropower in Europe and worldwide has many advantages including:

- Renewable energy without direct emission of CO_2
- Unbeatable energy gain or pay-back during a long project life
- Excellent efficiency, with reliable production easily adapted to the demand (very flexible and timely peak energy)
- In-country, independent energy-sector, job creation and financial resources in remote areas (taxes and concession fees)
- Improvement of infrastructure and attractiveness for tourism
- Contribution to flood and drought protection (drinking water, irrigation, flood routing), as many hydropower dams are multi-purpose
- Facilitation of navigation for the large rivers in Europe

Looking in more detail at the life cycle analysis, hydropower is by far the best option in view of sustainability. Regarding the so-called recovery factor or energy pay back ratio of primary energy, which is obtained by the total expense of non-renewable energy (direct and indirect) during a lifetime to operate an installation, hydropower is unbeatable[1]. For hydropower plants with reservoirs created by dams the energy pay back ratio is between 205 and 280, and for run-of-river power plants between 170 and 270 considering a technical life of 80 years. In fact, these numbers exceed very clearly those attained by other renewable energies such as, for example, solar photovoltaic (3 to 6) and wind (18 to 34), whose technical life may be expected so far to be only 20 years. Their recovery or gain factors are rather small today, but important technical progress can be expected in the future. On the other hand, thermal power plants producing electricity with non-renewable fuels have, as expected, a much lower energy pay back ratio which is close to 1 or even below (for example a coal fired closed cycle powerplant is 0.97).

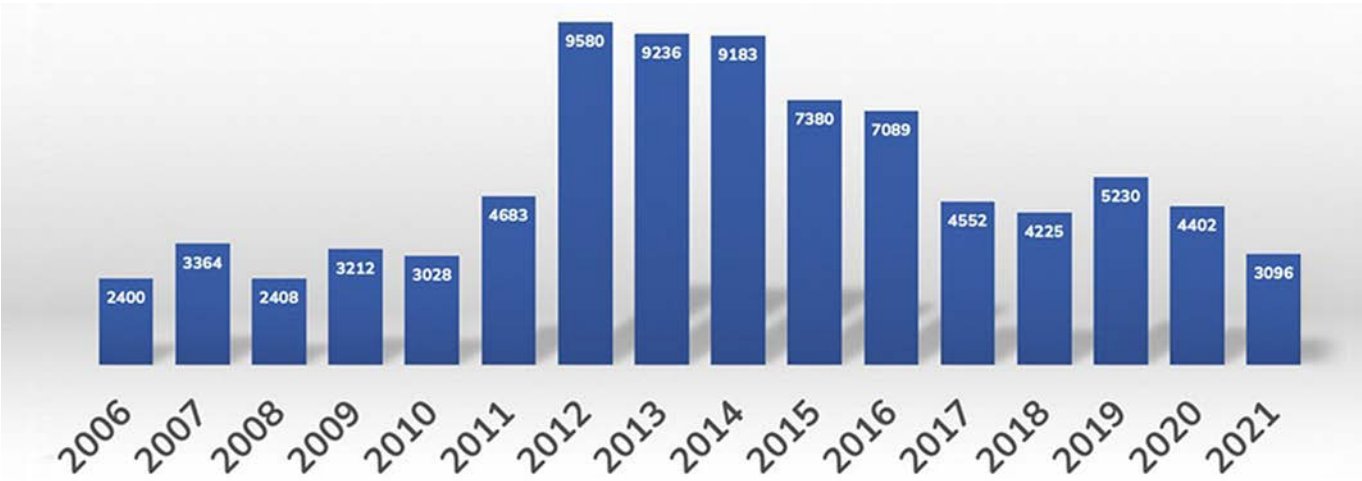

Figure 3 | Hydropower capacity (MW) in Europe under construction since 2006 (according to Hydropower & Dams World Atlas 2022 without Turkey).

Furthermore, recent life-cycle analysis also confirms that hydropower can reduce greenhouse gas emissions (GHG) significantly, even by developing only a part of the remaining economically feasible hydro potential.

A study in Switzerland revealed that, for hydropower, the equivalent CO_2 emissions of greenhouse gases is very small compared to other energy generation types and is caused mainly by the acquisition of materials required for construction and maintenance[2, 3]. Run-of-river power plants produce 3.8 g CO_2 - equivalent/kWh and storage power plants 5.5 to 8.3 g/kWh. For nuclear energy, these emissions are between 14.2 and 15.9 g/kWh depending on the type of reactors. For the new renewable energy sources like wind and solar (photovoltaic) the values of emissions are 17.3 g/kWh and 41.7 g/kWh respectively. Biogas power plants with thermal-power coupling produce 77 g/kWh. These values are still relatively small compared to the emissions of gas power plants (613.7 g/kWh) and coal power plants (1108 to 1221 g/kWh).

Challenges for future development of hydropower and dams in Europe

The future development of hydropower and dams in Europe must overcome the following challenges[4]:

- The change of production potential due to the effects of future climate forcing, which are expected to impact water availability (glacier retreat, snow accumulation and melt, stream-flow regimes, and sediment production and transport) as well as the operational safety of structures in view of new natural hazards (floods, slope instabilities, etc.);
- The efficiency improvement of existing hydropower plants (HPPs) and reservoirs, which can be achieved by their expansion to allow more flexible operation to accommodate new and highly fluctuating demands;
- The contribution of new technological solutions to adapt existing infrastructure in view of increasing their efficiency of production and achieving higher operation flexibility during seasonal and daily peak demands, whilst maintaining the same level of (infra)structural safety and supply security;
- The assessment of the effects of HPPs new and harsher operation regimes and increased numbers of small hydropower plants on aquatic ecosystems and the development of strategies to reduce these impacts (e.g. by developing innovative strategies of environmental flow releases).

Hydropower and dam projects often provoke controversial discussions. To gain wide acceptance and to obtain a win-win situation between all stakeholders such large water infrastructure projects have to be designed as multi-purpose projects by multidisciplinary teams with a complex system approach. This requires excellence in engineering sciences and management and innovative planning approaches.

Hydropower Europe Forum: The vision for hydropower development in Europe

The ambitious plan for European energy transition towards becoming carbon-neutral by 2050 is one of the greatest endeavours of our generation. The uptake of renewable energy sources (RES), mainly solar and wind, is consistently growing in many European countries, proliferated by the mandatory phase-out of fossil fuels. This uptake of RES also creates obstacles, such as difficulty in aligning electricity generation with demand. Hydropower, as a reliable renewable, already supports integration of wind and solar energy into the supply grid through flexibility in generation as well as its potential for storage capacity. These services are and will be indispensable on the path to achieve the desired energy transition in Europe, and worldwide. Hydropower has all the characteristics to serve as an excellent enabler and catalyst for a successful energy transition.

There is still untapped potential in hydropower, which allows hydropower to perform this role even more strongly. However, this will require a more flexible, efficient, environmentally and socially acceptable approach to increasing hydropower production to complement other renewable energy production.

The Hydropower Europe Forum[5], supported by the EC under the Horizon 2020 programme LC-SC3-CC-4-2018, was started in 2019 with the ambition to develop 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 entire hydropower sector and stakeholders (including construction, production, environmental and social issues), the Hydropower 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 RIA and a SIR, towards implementation of the vision "Hydropower as a catalyst for the successful energy transition in Europe"[6]. In more detail, the vision for hydropower development in Europe as defined by the Hydropower Europe Forum comprises the elements shown in **Figure 4**.

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.

Figure 4 | Vision for the development of hydropower in Europe.

Research and innovation needs and strategic actions required for further develping hydropower in Europe

The Research and Innovation Agenda developed by the Hydropower Europe Forum provides recommendations on Research & Innovation (R&I) priorities for hydropower to the EU institutions and national authorities to contribute towards shaping public spending for R&I. Through wide consultation involving all relevant hydropower stakeholders, the priority R&I themes and topics, the rationale behind them and their expected outcomes were collected. These themes and topics covering the entire hydropower value chain and were clustered into the following seven thematic groups addressing the challenges which the European hydropower sector 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 80 detailed research topics spread across have been formulated, building from the wide consultation feedback. After several workshops with the Consultation Expert Panel the priorities, the suggested time horizon for when the call should be initiated, as well as the recommended funding scheme for all research themes were defined[7]. In **Figure 5** the research themes with high to very high priorities are illustrated and grouped according to the above-mentioned challenges.

The Strategic Industry Roadmap, also developed through a substantial programme of consultation, comprises in total 11 strategic directions including some 40 detailed actions (ranging from regulation framework to social acceptance and innovative environmental strategies)[8]. The most important three key strategic directions with actions needed to support the role and development of hydropower are summarized in **Figure 6**.

The full RIA and SIR reports and the corresponding extended executive summary brochures as well as a YouTube presentation on the main outcomes of the Hydropower Europe Forum can be found under https://hydropower-europe.eu.

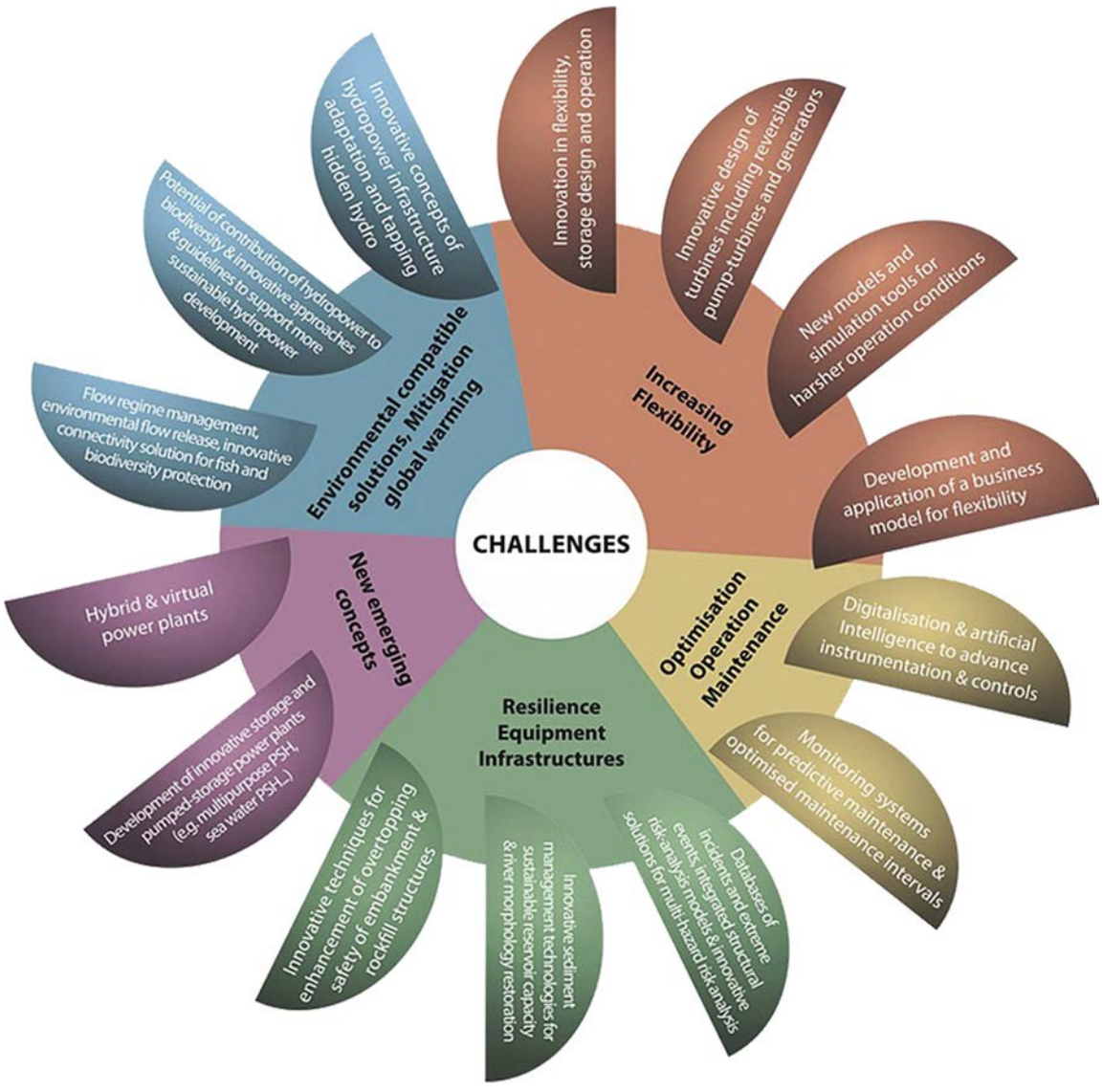

Figure 5 | Suggested research themes by Hydropower Europe with high to very high priority grouped according to the challenges which hydropower must address.

Providing economic and legal support for flexibility and storage

1 | Improvement of flexibility markets.

2 | Best practice for investing under uncertainties.

3 | Development of a more pertinent regulation framework.

Preserving biodiversity and improving river ecosystems

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.

Raising public awareness, increasing societal resilience and local employment

1 | Increase public awareness with communication and dissemination.

2 | Develop best practices for sustainability for successfull 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.

Figure 6 | Key strategic directions with actions needed to support the role and development of hydropower in Europe.

ETIP HYDROPOWER

Unifying the voices of hydropower in Europe

The European Technology and Innovation Platform (ETIP) is a community whose primary purpose is to define R&I priorities for its sector. Its secondary purpose is to overcome barriers to the deployment of R&I outcomes, e.g., industrial strategy, market opportunities, exploitation of research results, international cooperation, education, environmental and social impacts. There is a need for a unified hydropower industry to be represented and recognized at a European level. The Hydropower Europe Forum provided a first opportunity to gather some 650 stakeholders representing all the sectors of the value chain. Under the ETIP HYDROPOWER project (https://etip-hydropower.eu) started in September 2022, the hydropower forum will continue to grow and offers an ideal opportunity to help unify the voices of hydropower in Europe[9].

The ETIP HYDROPOWER aims to be a recognised interlocutor for the European Commission, Member States and Associated Countries about the hydropower sector specific R&I needs. ETIP HYDROPOWER foresees working relationships with the relevant national/regional/EU-level platforms to ensure synergies between EU, national and regional activities. In more detail, ETIP HYDROPOWER will answer the following questions:

- Which research and innovation projects are the most important such that hydropower can fulfil the role of an enabler and catalyst in the energy transition?
- Which strategic actions have to be taken when, such that hydropower can fulfil the role of an enabler and catalyst in the energy transition?
- How can public awareness be increased for hydropower in the transition to a clean energy system focusing towards a zero-emissions target?
- How can hydropower projects be carried out to create win-win situations with other renewables and other services contributing to the Water-Energy-Food Nexus and the achievement of the SDGs of the United Nations?
- What form of sustainable associate organisation representing the hydropower sector is required to ensure the vital role of hydropower in the energy transition?

ETIP HYDROPOWER will address these questions and challenges with working groups identified and launched based on consultation with the hydropower sector willing to participate with the sustainable associate organization beyond the ETIP lifetime. Potential working groups cover a wide range of topics: economy, environment, equipment, structures, pumped storage hydropower, small hydro, digitalization, communication, market rules, legal frameworks etc. depending upon the specific need of the sector. Working groups will also include Civil Society Organisations for the identification of potential social impacts of hydropower.

Conclusions

Built from the Hydropower Europe Forum, ETIP HYDROPOWER will help to ensure that hydropower can play the vital role of a catalyst and enabler in the transition to a clean and safe energy system in Europe. Hydropower has proven to be a reliable supplier in the energy crisis. Is important contribution to secure storage with the lowest indirect CO_2 emissions amongst all forms of renewable energy will become even more important in the energy transition towards the achievement of climate neutrality by mid-century. ETIP HYDROPOWER will help to unify the voices of hydropower in Europe and worldwide, to increase public awareness on its catalyst and enabler abilities, as well as motivate innovative collaborative research towards environmentally compatible solutions. Besides electricity supply, hydropower projects can offer other services which are important to help mitigate climate change effects, like water supply, contribution to flood and drought protection with potential for recreational and tourism activities and facilitating navigation on large rivers.

Acknowledgement

ETIP HYDROPOWER has received funding from the European Union's Horizon Europe research and innovation programme under grant no 101075620. Project partners are: International Commission on Large Dams (ICOLD), European Association for Storage of Energy (EASE), European Renewable Energies Federation (EREF), Association of Europe and Renewable Energy Research Centres (EUREC), International Hydropower Association (IHA), Samui France SARL (SAMUI), VGBE energy (vgbe) and ZABALA Brussels SPRL (ZABALA).

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Dr Anton J. Schleiss obtained a Doctorate of Technical Sciences on the topic of pressure tunnel design in 1986 at ETH Zurich. He worked for 11 years for Electrowatt Engineering Ltd (now Pöyry-AFRY). In 1997, he was nominated full professor and became Director of the Laboratory of Hydraulic Constructions (LCH) of the Ecole Polytechnique fédérale de Lausanne (EPFL). He supervised more than 50 PhD and Postdoc research projects. Since 2018 he is professor emeritus at EPFL. He is the honorary President of the International Commission on Large Dams (ICOLD) and has received IAHR Honorary Membership in 2022. With more than 40 years of experience he is regularly involved as a consultant and expert in large water infrastructures projects including hydropower and dams all over the world. He was the coordinator of Hydropower Europe and is part of the management team of ETIP HYDROPOWER project.

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Dr Mark Morris is an Engineer working at the interface between research and practice, focussed on environmental hydraulics, hydropower and flood risk analysis / management. Mark works on a mixture of both research and specialist consultancy studies, in particular focussing on European and wider International research collaboration. Recent and ongoing activities include supporting and coordinating European research projects – such as the Hydropower Europe, ETIP HYDROPOWER and EcoAdvance projects, strategic planning for UK reservoir safety research and industry driven research into dam and levee surface erosion processes.