

Strategic Industry Roadmap



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CONTENTS

Document Information	2
Document History	2
Acknowledgement	2
Disclaimer	2
Contents	3
Acronyms	10
Executive Summary	12
1 Background and methodology	16
1.1 Climate change: the unprecedented global emergency	16
1.2 The European Green Deal addressing climate challenge	16
1.3 The forgotten value of electricity flexibility and storage	17
1.4 Hydropower is key for flexibility and storage	19
1.5 The purpose of the HYDROPOWER EUROPE Forum	20
1.6 Hydropower as catalyst for the energy transition in Europe – The vision	20
1.7 The process of the roadmap	21
1.8 Objectives of the roadmap.....	21
2 SWOT analyses: foundations for the roadmap	23
2.1 “Hydropower is a mature technology but still has considerable potential for development and research is still needed.”	23
2.2 “Hydropower can overcome barriers to large scale deployment required by the energy transition.”	24
2.3 “Hydropower is one of the most sustainable renewable energy sources which can provide other services for civil society.”	25
2.4 “Environmentally friendly hydropower solutions could provide a stronger future business case for hydropower.”	26
2.5 “In a fully liberalised and undistorted market, hydropower is one of the cheapest renewable energy sources, which maintains its investment value in the longer term.”	27
3 Hydropower Europe in a complex world - A global approach system analysis to better understand the key factors involved	29
3.1 Introduction - Methodology.....	29

3.2	Identification of factors influencing the hydropower market with a focus on Europe	29
3.3	Combination and interconnection of the factors in a network	30
3.4	Analysis of the network and identification of active and critical factors	34
3.5	Potential criteria for the identification of actions with high impact level.....	36
4	Opportunities and challenges for hydropower deployment in Europe	38
4.1	Hydropower: a renewable and reliable energy	38
4.2	Hydropower: the backbone of emerging industry and electric systems.....	39
4.3	Hydropower in the EU.....	39
4.4	The Hydropower market	41
4.4.1	European companies are world leaders in the hydropower sector	41
4.4.2	The current global hydropower market	42
4.4.3	The current depressed EU hydropower market	45
4.4.4	The urgent political commitment tackling climate change	46
4.4.5	The future market of energy.....	47
4.4.6	Hydropower is vital to any future energy system	50
4.4.7	The European market focused on flexibility.....	52
4.5	The benefits hydropower can provide to the Green Deal	55
4.5.1	Hydropower contributes to climate change mitigation and adaptation.....	56
4.5.2	Circular economy	60
4.5.3	Sustainable development goals	62
4.5.4	High value creation and exportation leader	63
4.5.5	Hydropower boosts regional sustainable development	64
4.5.6	Hydropower is the largest contributor to flexibility	70
4.5.7	In conclusion - hydropower is a pillar for the net zero power system	71
4.6	Challenges and solutions for future deployment	72
4.6.1	Investments and new business models	73
4.6.2	Regulation	76
4.6.3	Social awareness	78
4.6.4	Innovative environmental strategies.....	82
4.6.5	Climate resilience and mitigation of the impact of climate change.....	83
4.6.6	Licensing and permitting.....	84

4.7	The opportunities for hydropower deployment.....	85
4.7.1	The Green Deal	85
4.7.2	The flexibility market	85
4.7.3	Mitigating the impacts of ageing and maintaining the high safety level of power plants and dams.....	86
4.7.4	Security, decentralisation and independence of the EU energy system.....	87
5	Hydropower as a catalyst for the energy transition in Europe - strategic actions required.....	89
5.1	Increase social awareness	89
5.2	Develop environmental mitigation measures	90
5.3	Better hydropower deployment	91
5.4	Adapt Regulation to Energy Transition	91
5.5	Greater investments thanks to new business models	91
5.6	Simplified approval procedures and legislation.....	92
5.7	Climate resilience and mitigation of the impacts of climate change.....	92
5.8	Capacity building	93
5.9	The most effective levers for the development of hydropower	93
6	R&I actions required for integration of hydropower as part of the European Green Deal	95
6.1	R&D priorities in the Research Innovation Agenda	95
6.2	The strategic priorities for fully integrating hydropower with the European Green Deal.....	97
6.2.1	Economy: development of new market design valuing flexibility.....	100
6.2.2	Environment and Society and increasing social awareness	100
6.2.3	Cross sectional solutions & examples.....	102
7	ROADMAP TO IMPLEMENTATION	103
7.1	Market, political and legal aspects.....	103
7.1.1	Improvement of flexibility markets	103
7.1.2	Best practice for investing under uncertainties	105
7.1.3	Development of a pertinent regulation framework	106
7.2	Social responsibility.....	110
7.2.1	Increase public awareness	110
7.2.2	Develop best practice for successful projects and win-win situations.....	112

7.2.3	Security, decentralisation and independence of the European energy system....	115
7.2.4	Increase capacity building and job employment.....	115
7.2.5	Develop strategies for cultural heritage and protected areas	115
7.2.6	Giving a collaborative platform to the sector.....	116
7.3	Environmental commitment	116
7.3.1	Collect best practice for biodiversity protection and regeneration	117
7.3.2	Increase knowledge on environmental impacts.....	117
7.3.3	Develop innovative environmental measures for the protection of biodiversity.	118
7.3.4	Development of comprehensive approaches allowing for compromises.....	119
8	Conclusions and outlook	121
9	REFERENCES	122

Tables

Table 1	Results of SWOT analysis on potential for research and development	23
Table 2	Results of SWOT analysis on the potential for large scale deployment.....	24
Table 3	Results of SWOT analysis on potential for sustainable services	25
Table 4	Results of SWOT analysis on potential for development and research	26
Table 5	Results of SWOT analysis on potential for maintaining investment value	28
Table 6	Yearly generation in European regions without Turkey according to Hydropower & Dams World Atlas 2021	40
Table 7	Consolidated flexibility service types by timescale (IEA, 2021)	51
Table 8	Required strategic actions for social acceptance	90
Table 9	Required strategic actions for the environment	90
Table 10	Required strategic actions for Hydropower deployment	91
Table 11	Required strategic actions for regulation.....	91
Table 12	Required strategic actions for investment and new business models.....	92
Table 13	Required strategic actions for approval procedures and legislation	92
Table 14	Required strategic actions for climate resilience	92
Table 15	Required strategic actions capacity building.....	93
Table 16	List of prioritised Research and Innovation Themes in the RIA (HPE, 2021d)	96
Table 17	Very High priority strategic actions in Economy from the SIR	100
Table 18	Required strategic development and innovation for Environment and Society (E&S) impacts from the 2 nd WSC	101

Figures

Figure 1	The 3 pillars of the new EU electric system (ETIP SNET, 2018)	17
Figure 2	The levelised cost of electricity for projects and global weighted average values for hydropower, concentrating solar power, SP, solar PV, onshore and offshore wind, 2010-2020 (IRENA, 2021b)	18
Figure 3	Development of electricity price for household consumers EU 2008-2021 (Eurostat)	18
Figure 4	Hydropower in Europe in a complex environment: Network of factors representing the sectors 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). 30	
Figure 5	Driving motor of the hydropower market within the complex system	31
Figure 6	Implementation of the European Green Deal within the network.....	31
Figure 7	Circular visualisation of network factors showing the activity (influencing intensity).....	32
Figure 8	Circular visualisation of network factors showing their reactivity (susceptibility to be influenced).....	33
Figure 9	Result of matrix analysis considering the second degree of influences (connections)	34
Figure 10	Hydropower plant at the toe of a dam (P.S. Bodger).....	38
Figure 11	Share of hydropower generation in EU Member States and non-member states in 2017 (source: ENTSO-E, 2018a)	40
Figure 12	Percentage of total number by capacity of existing hydropower plants (left) and percentage of total installed hydropower capacity for different plant sizes (source: EC, 2011)	41
Figure 13	Final investment decision for Hydropower in the last decade (IEA 2020)	42
Figure 14	Overview of renewable power investment (IEA, 2020)	43
Figure 15	Total installed capacity costs by hydropower project and globally weighted average, capacity factor and levelised cost of electricity 2010-2020 (IRENA, 2021b)	44
Figure 16	Average wholesale electricity prices in selected competitive market (Nord Pool is a European power market)	45
Figure 17	The impact and uncertainty of the strategic key actions for energy (WEC, 2019).....	46
Figure 18	(a) Renewable energy share in the Planned Energy Scenario (PES) and needed at minimum in the Transformation Energy Scenario (TES) (b) in electricity generation, electrification share (c) storage and (d) hydropower capacity from IRENA (2021)	48
Figure 19	Installed power generation capacity worldwide by source in the Sustainable Development Scenario (IEA, 2018)	49
Figure 20	Time domain hierarchy of the load-frequency control process	50

Figure 21	Unexploited versus developed hydropower potential on the European continent including Turkey (according to Hydropower & Dams World Atlas & Industry Guide, 2020).....	52
Figure 22	The six phases of flexibility required for VRE integration (IEA, 2018).....	53
Figure 23	Evolving flexibility needs by region, New Policies Scenario (IEA 2018).....	53
Figure 24	Electricity generation by source in the European Union in the New Policies Scenario (IEA, 2018).....	54
Figure 25	IRENA (2020) Global renewable outlook European Union (28 countries)	54
Figure 26	Targets of the European Green Deal	56
Figure 27	Comparison of the mean, min and max of the indicator "Climate Change" by technology (CIRAIG, 2014)	57
Figure 28	CO ₂ emission in 2018 (light blue) and in 2040: Stated policies (dark blue) and Sustainable development scenario (green) source EIA, 2018).....	58
Figure 29	Comparison of the mean, min and max values of the indicator "Destruction of the ozone layer" by technology (CIRAIG, 2014).....	59
Figure 30	Hydropower has the best EROI (Lambert, 2012).....	59
Figure 31	Recovery or gain factors for different electricity generation technologies (Schleiss, 2018)	60
Figure 32	The seven circularity principles (Circle economy, 2008)	60
Figure 33	Comparison of mean, min and max values of the Mineral Resource Extraction indicator between generation technologies (CIRAIG, 2014)	61
Figure 34	Hydropower directly supports SDG 6, 7, 9 and 13 (IHA, 2018)	62
Figure 35	Hydropower also contributes to the other SDG (IHA, 2018).....	63
Figure 36	Gross value creation by hydropower generation and equipment manufacturing in 2013 (source: DNV GL, 2015).....	64
Figure 37	Employment in the European hydropower sector in 2013 (DNV GL, 2015)	64
Figure 38	Serre-Ponçon dam and the EDF Canal of Durance (Photo J-M Gaude).....	66
Figure 39	Navigation locks coupled to a hydropower station on the Rhine River (Photo EDF)	67
Figure 40	Average CO ₂ Emissions by Passenger and Freight Transport Mode (Rodrigue, 2020)	68
Figure 41	Polder of Moder on the Rhine River stores water during floods (Junod & Rothan 1996)	68
Figure 42	Sailing on Lake Monteynard in the French Alps (Photo EDF)	69
Figure 43	Share of reservoir uses by purpose in Europe (ICOLD, 2020).....	70
Figure 44	Percent of respondents to the question of whether hydropower provides flexibility services across timescales (IEA, 2021)	71
Figure 45	Comparison of effective lifetime costs of energy storage technologies over 80 years for 10-hour duration and 2020 options (IHA, 2021)	75
Figure 46	Assessment of an HSAP assessment result – a Sustainability Profile (IHA, 2019a).....	81

Figure 47	Average LCOE of hydropower investments and average wholesale electricity price in Europe (IEA, 2021). Minimum, maximum and average yearly wholesale electricity price for EU from 2016-2019	86
Figure 48	On the 3 rd November 2006, pumped storage hydropower saved the grid in France	88
Figure 49	The three pillars of hydropower fully integrating into the Green Deal (aspects requiring innovation are marked in red)	98
Figure 50	Main drivers pushing developments and innovations for hydropower	99

Appendices

Appendix A:	List of factors considered in the global system network analysis as identified during wider stakeholder consultation	130
Appendix B:	Network representing hydropower in Europe in a complex environment	137
Appendix C:	Case studies of abandoned projects	138

ACRONYMS

AI	Artificial Intelligence
CAPEX	Capital Expenditure
CEP	Consultation Expert Panel
CO ₂	Carbon Dioxide
DDP	Deeper Decarbonisation Perspective
EC	European Commission
EIA	Environmental Impact Assessment
ENTSO-E	European Network of Transmission System Operators for Electricity
ETIP	European Technology and Innovation Platform
ETS	Emissions Trading System (EU CO ₂ certificates)
E&S	Environmental and Societal
FTE	Full Time Equivalent
FID	Final Investment Decision
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
GWh	Gigawatt Hour
HP	Hydropower
HPP	Hydropower Power Plant
H2020	Horizon 2020 European
ICOLD	International Commission on Large Dams
IEA	International Energy Agency
IFPSH	International Forum on Pumped Storage Hydropower
IHA	International Hydropower Association
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	Joint Research Centre
kW	Kilowatt
kWh	Kilowatt Hour
LCOE	Levelised Cost of Electricity
NDC	Nationally Determined Contribution
OPEX	Operating Expense
O&M	Operation and Maintenance
PCI	Project of Common Interest
PES	Planned Energy Scenario
PPA	Power Purchase Agreement
PSP	Pumped Storage Plant
PSH	Pumped storage hydropower

PV	Photovoltaics
RED III	Renewable Energy Directive III
REN	Renewable Energy Network
RES	Renewable Energy Sources
RIA	Research and Innovation Agenda
R&I	Research & Innovation
SCADA	Supervisory Control and Data Acquisition
SET Plan	Strategic Energy Technology Plan
SIR	Strategic Industry Roadmap
SSH	Social Sciences and Humanities
SWOT analysis	Strength-Weakness-Opportunity and Threat analysis
TES	Transformation Energy Scenario
TRL	Technology Readiness Level
VPP	Virtual Power Plant
VRE	Variable Renewable Energy
WACC	Weighted Average Cost of Capital (also known as 'discount rate')
WEC	World Energy Council
WFD	Water Framework Directive
WSC	Wider Stakeholder Consultation
WCD	World Commission on Dams
WWF	World Wildlife Fund

EXECUTIVE SUMMARY

Hydropower, which is still the most important renewable energy resource, already supports the integration of solar and wind energy into the supply grid through flexibility in generation as well as its high potential for storage capacity. To ensure a safe electricity supply and considering the threat of climate change, hydropower services which go beyond just energy generation will be in much greater demand. Hydropower must serve as a catalyst for a successful energy transition in Europe, and worldwide. However, this will require a more flexible, efficient, environmentally, and socially acceptable approach to increasing hydropower production to complement new renewable energy production; in particular through the following vision:

1. **Increasing hydropower production** through the implementation of new sustainable, multipurpose hydropower schemes and by using the hidden potential in existing infrastructure.
2. **Increasing the flexibility** of generation from existing hydropower plants by adaptation and optimisation of infrastructure and equipment combined with innovative solutions for the mitigation of environmental impacts.
3. **Increasing storage** by the heightening of existing dams and the construction of new reservoirs, which must ensure not only a flexible energy supply, but which also supports food and water supply and thus contributes to the Water-Energy-Food NEXUS and achievement of the Sustainable Development Goals of the United Nations.
4. **Strengthening the contribution of flexibility from pumped-storage power plants** by developing and building innovative arrangements in combination with existing water infrastructure.

Climate change is already an important issue for hydropower development in Europe. The effect of climate change will not only change the availability of water resources in time but will also change the behaviour of the catchment areas through increased sediment yield and more frequent natural hazards such as floods and droughts, thus endangering hydropower production in the future. It is recognised that the reservoirs associated with hydropower plants can, will have to, contribute more and more towards the mitigation of climate change effects.

Through an extensive programme of review and consultation addressing the whole hydropower sector and stakeholders (including construction, production, environmental and social issues), the HYDROPOWER EUROPE Forum has developed the present Strategic Industry Roadmap (SIR) towards implementation of the above vision accompanied by a Research and Innovation Agenda (RIA). During three regional workshops (Northern, Alps and Southern parts of Europe) the strengths, weaknesses, opportunities and threats for hydropower in Europe were analysed (Chapter 2). Based upon a wide stakeholder consultation event the critical factors for future hydropower deployment could be identified and also analysed with the help

of a global system analysis of hydropower in Europe (Chapter 3). This allowed the next consultation event to focus on refining the most promising strategic actions, as well as the most effective research and innovation directions and to formulate opportunities and challenges, for hydropower deployment in Europe (Chapter 4). In a final consultation step the prioritisation of the strategic actions required for hydropower to advance as the potential backbone of the European Green Deal, could be defined (Chapter 5), and some non-technical research priorities were also highlighted within the SIR (Chapter 6). Finally, the key strategic directions needed to support the role and development of hydropower could be assessed (Chapter 7). These strategic directions should help hydropower to deliver the reliable and secure provision of affordable renewable electricity whilst meeting environmental goals as well as contributing to the European Green Deal as a catalyst for the energy transition (Chapter 8).

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 still little emphasis on the role that hydropower can and must play in the future European energy system as a catalyst for the European Green deal. The present SIR outlines three deployment strategies for hydropower to overcome non-technical barriers to projects.

A. *Market, political and legal pathways to the 2050 net zero energy system*

There is a large consensus concerning the necessity to re-design the electric market. A new energy system, where only renewable energy sources will be used, requires a new market model. Fundamentally, storage and flexibility are externalities of Variable Renewable Energy supplies (VREs). 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 recognise 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 help ensure the economic viability of the European Green Deal. An economic model giving a value to flexibility within the European power system is needed. Such 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 good tools to ensure fulfilment of the European energy policy objectives. Multi-criteria analyses could 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.

B. 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 understanding 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 improve public awareness and support. 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 (SSH) are needed to help balance the European energy market rules and European environmental goals. Large reservoirs provide important electricity system security services such as prevention of network crashes, black-start, and regulation capabilities. Decision-makers and regulators should as soon as possible, take action to protect and secure the independence and flexible operation of the European Electricity System. New pumped-storage power plant solutions well-integrated in a transmission system across all regions, will contribute to more flexibility from existing hydropower schemes in Europe. Long-term support for hydropower ‘know-how’ is required to maintain and enhance hydropower in the future and to support continued employment in the sector.

C. 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, minimise, 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 of big data will help develop and share enhanced knowledge on ecosystems and how hydropower affects and mitigates 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 minimise 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 showing 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.

Stakeholders from the whole hydropower value chain are represented within the HYDROPOWER EUROPE Forum and its sustainability is important for promoting hydropower as an important player in the European Green Deal. The collective knowledge of the stakeholders of the HYDROPOWER EUROPE Forum is precious and essential for developing the role of hydropower as a catalyst for the energy transition and for disseminating key messages of both SIR and RIA efficiently and effectively.

1 Background and methodology

1.1 Climate change: the unprecedented global emergency

Climate change due to global warming poses the biggest threat to society in the 21st century. In 1992, the Union of Concerned Scientists, including the majority of living science Nobel laureates, penned the “World Scientists’ Warning to Humanity”, which implored that we cut greenhouse gas (GHG) emissions and phase out fossil fuels, reduce deforestation, and reverse the trend of collapsing biodiversity. The United Nations confirmed this unprecedented global emergency: “We face a direct existential threat...Our fate is in our hands” said António Guterres, the UN Secretary-General. “The world has never seen a threat to human rights of this scope... The economies of all nations, the institutional, political, social and cultural fabric of every state, and the rights of all your people, and future generations, will be impacted” insisted Michelle Bachelet, UN Human Rights Chief.

If we do not address the causes of climate change in time, communities across the world stand to face multiple simultaneously intensifying climate hazards that pose a broad threat to humanity.

To make a better world, protected from climate hazards, our energy consumption has to be reduced and our energy system has to decarbonise. This can only be done through energy efficiency, energy sobriety and a massive deployment of renewable energies.

Hydropower, where available, has to play an important role in any fully renewable energy system, as hydropower is one of the most efficient technologies to mitigate climate change (i.e. global warming) and to integrate the impressive growth of other intermittent and non-dispatchable renewable energy sources into the electricity system.

Moreover, further deployment of hydropower can and must incorporate sustainability criteria, with measures including protecting the environment and its biodiversity, to be built into projects.

1.2 The European Green Deal addressing climate challenge

European Union policy (EC, 2018) has led the way in the fight against global warming and climate change, courageously showing actions that other countries can take to help save the planet. The European Commission’s vision has been **an economy with net-zero GHG emissions**. The first European Climate Law (EC, 2021a) leads the way to climate neutrality aiming to enshrine the commitment to making Europe **the first carbon-neutral continent by 2050**.

Hydropower plays an important role in a Net Zero economy by 2050, as it is the largest low-emissions electricity source in the world generating almost 4 500 TWh in 2020, far more than wind (1 500 TWh) and solar (800 TWh) (IEA, 2021).

The European Commission’s vision outlines seven strategic building blocks showing the road to a net-zero greenhouse gas economy. The purpose of the second strategic building block is to maximise the deployment of renewable energy and the use of electricity to fully decarbonise Europe’s energy supply (EC, 2018).

A new electric system proposed in the ETIP SNET Vision 2050 (ETIP SNET, 2018) comprises three pillars (ETIP SNET, 2018):

1. Secure, resilient and reliable supply
2. Protected environment
3. Affordable and market-based energy services

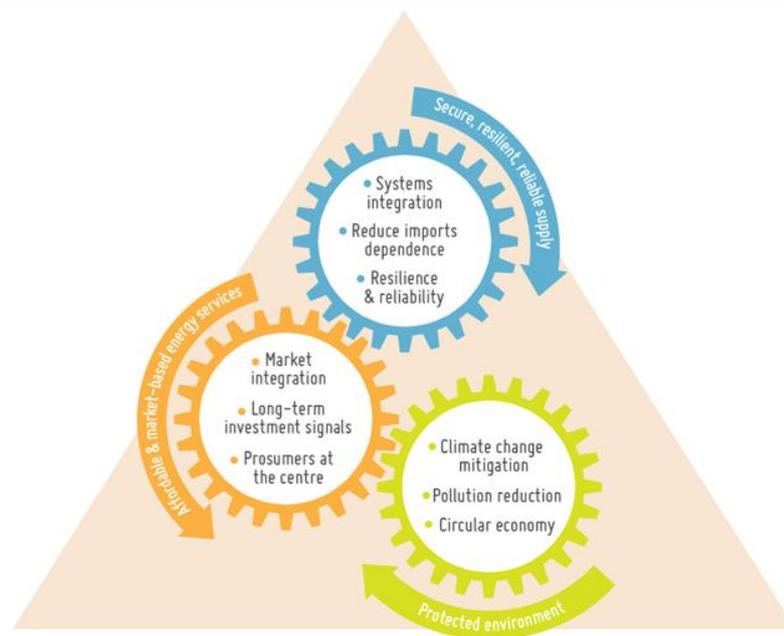


Figure 1 The 3 pillars of the new EU electric system (ETIP SNET, 2018)

The European Green Deal represents a global first as a regional framework of regulation and legislation (‘Fit for 55’) to fight the climate crisis and reduce its dependence on fossil fuels, particularly with a goal of net-zero emissions by 2050 and a 50-55% reduction in emissions by 2030, compared to 1990 levels (EC, 2021c). It can therefore influence not only other national and regional targets and pathways, but also a possible Global Green Deal, setting the world on a climate-safe pathway towards carbon neutrality by 2050 aligned with the Paris Agreement (UNFCCC, 2016).

Article 4 of the Climate Law (EC, 2021a) reported that “when proposing the Union 2040 climate target, the Commission shall consider the best available cost-effective, safe and scalable technologies and energy efficiency and the ‘energy efficiency first’ principle, energy affordability and security of supply”.

Hydropower, together with wind and solar, are the best available cost-effective, safe and scalable renewable technologies (Figure 2). Moreover, hydropower has excellent efficiency, energy gain or pay back factor and can be easy adapted to the demand.

1.3 The forgotten value of electricity flexibility and storage

The decreasing levelised costs for solar and wind energy sources are a success (Figure 2).

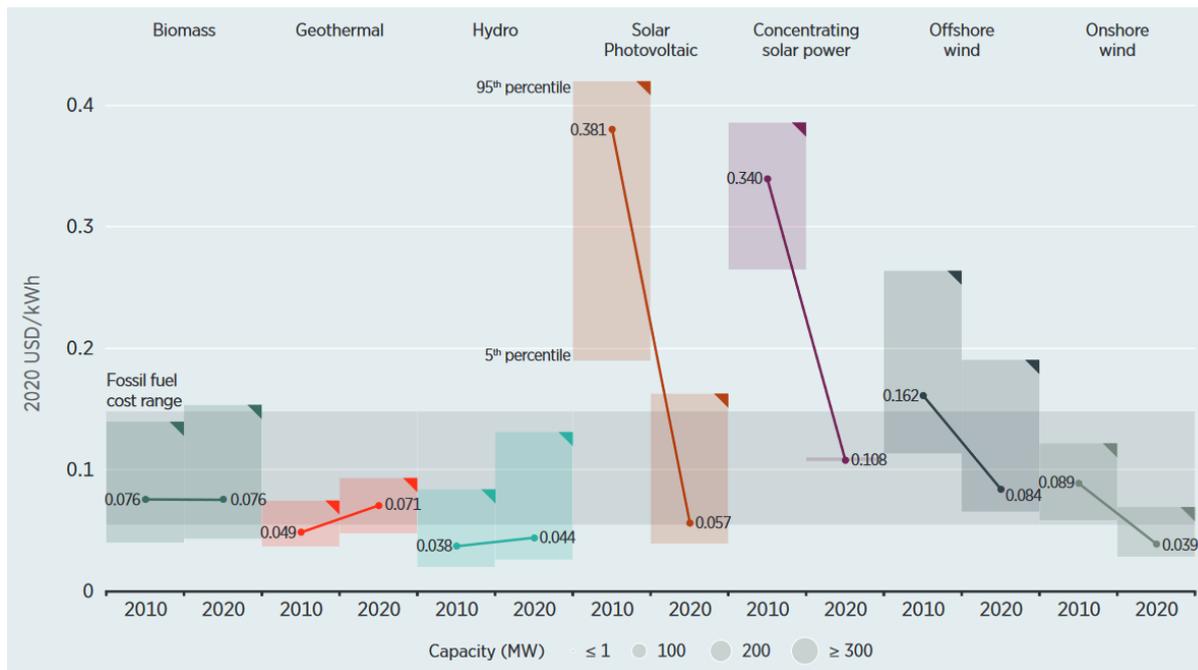


Figure 2 The levelised cost of electricity for projects and global weighted average values for hydropower, concentrating solar power, SP, solar PV, onshore and offshore wind, 2010-2020 (IRENA, 2021b)

During the same period, the price of electricity rises, mainly due to taxes (Figure 3).

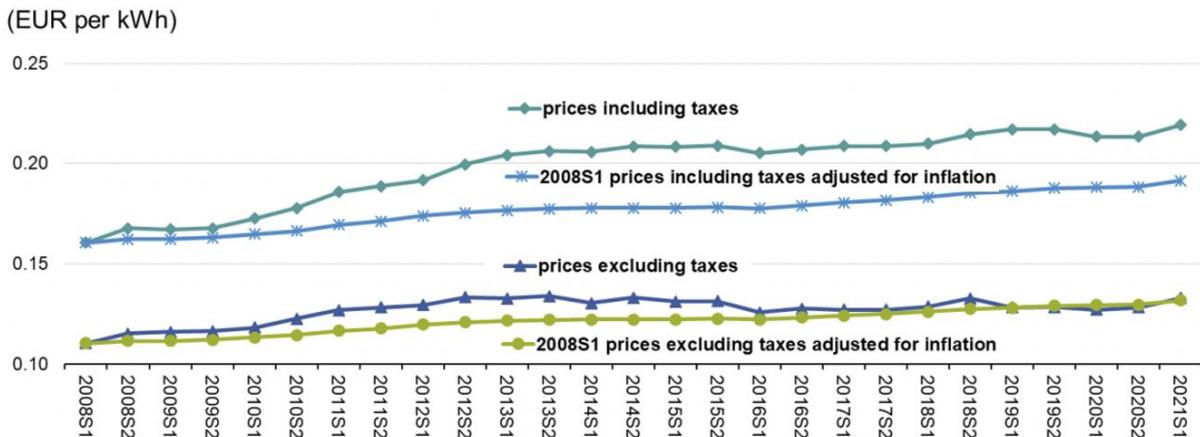


Figure 3 Development of electricity price for household consumers EU 2008-2021 (Eurostat)

This trend reminds us that the final cost of electricity is the sum of generation cost plus transport cost plus grid balancing cost.

Storage and flexibility ensuring grid balancing are externalities of variable resource energies (wind and solar). Externalities are neither included in LCOE nor paid by the market but have to be compensated by regulations.

Externalities of intermittent energies such as flexibility and storage impact the future decarbonised energy system for the EU. The reference case of 100% of renewable energies

will require the investment in installations whose total rated capacities could be six times greater than the average power delivered (Grand et al, 2016). This electrical mix will require large installations that would be used only for short and discontinuous periods.

Energy storage is the “*ignored crisis within the climate crisis*” warned M. Turnbull (2021). The massive increase in renewable energy generation is accelerating the **need for huge investment in energy flexibility and storage solutions for long periods.**

Maroš Šefčovič (2021), Vice-President of the European Commission in charge of Interinstitutional Relations and Foresight, highlighted the critical role of energy storage in the green transition: “*It is essential we develop our vertically integrated energy storage ecosystem in Europe and strive towards open strategic autonomy in this critical sector of the economy*”.

Energy storage has emerged as a key enabling technology in, firstly, addressing the flexibility requirements when integrating intermittent and non-dispatchable renewable electricity into the grid, and secondly providing green electricity for electrified transport, industry and buildings sectors.

It should also be noted that deployment of some technologies (e.g., for electric vehicles or batteries) raises concerns in terms of future supply of raw materials. These issues make the need for efficient, reliable and economical flexibility and storage solutions more important.

According to the Energy Directive (EC, 2021b), hydropower with Pumped Storage Hydropower has the capacity to integrate a large share of renewables-based generation in a coordinated and economic way.

1.4 Hydropower is key for flexibility and storage

Hydropower is the most sustainable used solution for flexibility and large storage (IEA, 2021). Europe is a world leader in hydropower technology. However, hydropower has not often been mentioned, or even properly considered (JRC, 2013) within EU energy development perspectives, until recently (SET Plan, 2007).

Mr Turnbull stated that “politicisation of climate policy has delayed global action and disrupted the orderly planning needed to move to a future of zero emissions and affordable and reliable energy” (IHA, 2021).

This situation requires an updated analysis to develop a decarbonisation strategy where hydropower is fully integrated within the Commission’s political priorities, which notably focuses on jobs and growth, further integration of the internal market, and a fairer and more sustainable economy.

To fulfil these objectives and build a secure and reliable electric system, with a large share of intermittent and non-dispatchable RES, Europe needs to integrate the storage potential and flexibility capacities of hydropower into the current and future energy system. Ambitious research and innovation (R&I) targets will be critical in achieving this, and in bringing forward the next generation of sustainable, efficient and cost-effective hydropower technologies.

1.5 The purpose of the HYDROPOWER EUROPE Forum

The HYDROPOWER EUROPE Forum was launched through the Horizon 2020 research programme call LC-SC3-CC-4-2018: “Support to sectorial fora (to Hydropower)”, bringing together the relevant stakeholders of the hydropower sector from 2018 to 2021.

The purpose of the Forum is to identify research and innovation needs and priorities for hydropower deployment, including contributions to the high flexibility of the 2050 neutral carbon energy system, as a key driver.

The Research and Innovation Agenda (RIA) is the first deliverable of the Forum which outlines the prioritised developments and research needs, intended to make hydropower more flexible for integrating intermittent and non-dispatchable renewable energy sources in the electric system and even more productive over the coming decades.

The present Strategic Industry Roadmap (SIR) is the second deliverable of the Forum which outlines deployment strategies for hydropower, based on services to the energy system, evidence of direct contributions to economic and social wellbeing as well as sustainability improvements to overcome non-technical barriers to projects.

1.6 Hydropower as catalyst for the energy transition in Europe – The vision

We believe that the next generation deserves a healthy planet, and hydropower, as an important renewable energy, has a crucial role to play in building the future Green Deal. In particular, the key strategic avenues that we envisage for development are outlined in the following vision:

1. **Increasing hydropower production** through the implementation of new sustainable, multipurpose hydropower schemes and by using the hidden hydropower potential within existing infrastructure.
2. **Increasing the flexibility** of generation from existing hydropower plants by the adaptation and optimisation of infrastructure and equipment combined with innovative solutions for the mitigation of environmental impacts.
3. **Increasing storage** through the heightening of existing dams and construction of new reservoirs, which must ensure not only flexible energy supply, but which also support food and water supply and thus contribute to the Water-Energy-Food NEXUS and achievement of the Sustainable Development Goals of the United Nations.
4. **Strengthening the contribution of flexibility from pumped-storage power plants**, by developing and building innovative arrangements in particular in combination with existing water infrastructure.

This vision must be based on an environmentally and socially acceptable approach with the goal to enhance biodiversity with innovative solutions regarding aquatic ecosystem protection and river continuity restoration resulting in the best possible balance between impacts and benefits.

1.7 The process of the roadmap

The Forum organised consultation events at a European level. This has included bringing together relevant stakeholders from the research community, industry value chain and civil society, in discussions through meetings held online and during three workshops in the Nordic, Alpine, and Mediterranean regions. These discussions aimed to better define the regional issues for hydropower within Europe.

A SWOT analysis identified opportunities and threats (external factors to the hydropower industry) and strengths and weaknesses of our industry (internal factors), with regards to the sector's needs and trends. It consolidated and enriched our vision.

A group of 34 experts has also been established; it is called the Consultation Experts Panel (CEP). This panel has several specific functions including: (i) assessment of draft documents, (ii) initiation of technical contributions, (iii) editing of position papers, (iv) moderation of workshops, (v) feedback analyses and (vi) processing of inputs and synthesis of research needs. The CEP is involved in the overall research prioritisation process. Criteria for prioritisation have been discussed to ensure a truly interdisciplinary approach including the integration of SSH, crucial to help solve global challenges and to create jobs and growth.

The synthesis of the SWOT analyses and opinions gained during the online consultation events outlined the needs and trends, which were prioritised and discussed with the CEP over three major cycles of consultation during the three years of the project.

Building on this momentum, the SIR will focus, strengthen and give coherence to the contribution of hydropower in Europe, with the objective of accelerating integration of intermittent and non-dispatchable renewable energy sources into the energy system with both high flexibility and renewable share. In doing so, it will facilitate achievement of the 2050 vision of the Green Deal for Europe.

1.8 Objectives of the roadmap

After a century of deployment, hydropower can be at the forefront of the new energy transition but must convince society that it can ensure the reliable and secure provision of affordable renewable electricity, flexibility and ancillary services whilst also meeting environmental goals.

To convince policy makers and civil society, hydropower deployment of all sizes needs an innovative roadmap tackling four key challenges:

1. Analysing lessons learnt from unsuccessful projects.
2. Gathering, promoting and applying best practice for bridging the gap between parties. The goal is to place hydropower as a tool being at the service of non-energetic uses of water for the mitigation of climate change (agriculture, non-energetic uses of water) in association with stakeholders on test cases.
3. Solving environmental issues related to water bodies becoming of significant concern.
4. Finding finance and new business models for storage and flexibility, fair and open to all technologies.

The objective of this strategic industry roadmap is to provide a synopsis of the relevant framework conditions for the sustainable development of hydropower projects in Europe and for a successful contribution to the energy transition and the Green Deal (EC, 2021b).

The target audience are policy makers, the hydropower industry, regulators, system operators, researchers, and other stakeholders of the hydropower value chain.

2 SWOT analyses: foundations for the roadmap

With regards to the Strategic Industry Roadmap (SIR), five statements reflecting the main chapters of the document were discussed during the three regional workshops. The participants analysed the strengths, weaknesses, opportunities and threats for hydropower related to the five statements. Their analyses provide a key basis for the roadmap.

2.1 “Hydropower is a mature technology but still has considerable potential for development and research is still needed.”

Hydropower is a climate friendly technology, very well suited for flexibility and integrating VRE, with excellent European universities and industry, providing export and regional development opportunities, but suffering from a lack of an appropriate business model and needing environmental progress (Table 1).

Strengths	Opportunities
<ul style="list-style-type: none"> Well suited for flexibility. Climate-friendly technology. Providing jobs and regional development. High European exports. Low technological risks. Excellent research infrastructure. Considerable ‘sleeping’ untapped potential. 	<ul style="list-style-type: none"> Increasing VRE penetration. Climate change challenge. Increasing sustainability. Increasing safety assessment. Modernisation of large fleet of HP schemes. Hidden potentials recovering. Future needs. Optimisation thanks to AI and big data. Public research funding increase.
Weaknesses	Threats
<ul style="list-style-type: none"> Long term uncertainties, investment and implementation time. Ecological continuity. Hydropeaking impacts: more flexible operations might generate more local environmental impacts (to be balanced with the environmental benefits given by the flexibility and to be discussed with stakeholders). Conventional thinking that mature technology cannot be improved. Impacted by Climate Change. Not enough communication. 	<ul style="list-style-type: none"> The changed merit order on the spot-market. No willingness to pay for flexibility and storage (especially mid to long duration). High investment risk in an unclear market. Lack of R&I to design business market. Lack of R&I to environmental protection. Too specific and severe environmental regulations for hydropower. Support policies to technologies already established (SET Plan for example). Generation reduced by other water uses. Interpretations of directives and regulations. Lack of interest of universities.

Table 1 Results of SWOT analysis on potential for research and development

There is large potential for research and innovation on the:

- best use of different technologies for storage considering sustainability and the **circular economy**,
- design of appropriate business models,

- cost effectiveness and resilience of civil works, and
- use of **big data**, **artificial intelligence (AI)** and **digitalisation** for optimisation of generation, impact mitigation and climate resilience.

2.2 “Hydropower can overcome barriers to large scale deployment required by the energy transition.”

Hydropower has the potential for large scale deployment, but this is often restricted today by many constraints (Table 2).

Strengths	Opportunities
<ul style="list-style-type: none"> • High availability and flexibility easily dispatched to meet demand. • Large storage and peak energy capacity with PSP. • Climate-friendly technology. • No backup is needed due to high reliability of energy supply (unlike other renewable sources like solar and wind). 	<ul style="list-style-type: none"> • Change of energy policies promotes only deployment of neutral carbon resources. • Electricity and flexibility demand increasing. • Public awareness on global warming increasing. • Need of water storage coping with loss of water availability and increasing risk of droughts triggered by the global warming HPPs may be multipurpose, with a range of water services provided: irrigation, drinking water, tourism, recreational uses, fisheries, environmental/watershed protection, etc. • Global warming provides new large, sustainable storage capacities after retreat of glaciers. • Most existing large hydro schemes are well-integrated into nature and society. • Old mines may be used as PSP.
Weaknesses	Threats
<ul style="list-style-type: none"> • Large CAPEX and long time to market. • Generally larger environmental impact on fauna and flora compared to solar and wind. • Larger storage may affect flow regimes in rivers with increased environmental impact. • Arrogance: too successful over the last century, hydro sector has exaggerated self-conviction; not enough communication. 	<ul style="list-style-type: none"> • No market redesign in view of the energy transition hence no incentive to produce more flexible power (MW) within the system. • Strong opinions block the discussions which hinders compromises and pragmatic solutions. • Increase financing for dam and operational safety upgrading required with more water fluctuations in the reservoirs.

Table 2 Results of SWOT analysis on the potential for large scale deployment

Two key elements can unlock the large-scale deployment of hydropower regarding (1) economics and (2) education and corporate social responsibility (CSR).

1. Large scale hydropower projects and long-term investor’s need (a) **levelised playing field** between energies (i.e. addressing differences in subsidies), (b) **unified and stable European Energy Policy**, (c) **new market solutions** (Project of Common Interest, incentives for power not energy, extreme conditions, insurance policy).

- The question of future **carbon neutral energy transition** is large and needs significant **education** and ambitious solutions. **Communication campaigns** are needed to increase public awareness targeting society (platform of good examples), new generation (schools/open doors) and politicians (campaigning, re-direct the discussion).

2.3 “Hydropower is one of the most sustainable renewable energy sources which can provide other services for civil society.”

Sustainable hydropower provides other services in addition to energy generation (Table 3).

Strengths	Opportunities
<ul style="list-style-type: none"> Uniquely amongst renewable energy sources, hydropower provides local communities with additional social-economic benefits such as flood and drought protection, water supply, irrigation, navigation, recreation, tourism, improved sightseeing, water storage for firefighting, etc. Reservoirs boost regional development, creating jobs and providing facilities (transportation infrastructures, cities and leisure attractions, etc.) and improving public acceptance to greenfield projects. Reservoir operators have experience in managing water in a multi-purpose way. Dams provide a blockage for invasive species to spread upstream and store beneficial nutrients in the colder regions. 	<ul style="list-style-type: none"> The new low carbon economy can rely on hydropower. Global warming increases the value of water stored in reservoirs. New business models can consider the economic value of non-power services. Long term public disclosure and broad information transparency overcome conflict of interest and public acceptance. Legislation can prioritise the uses of energy and water and mitigate conflicts of interests. Implementation of R&D outputs through mitigation measures will lower the environmental impact. Restoration of old mills for use as hydropower plants can provide funds to preserve cultural heritage.
Weaknesses	Threats
<ul style="list-style-type: none"> Multipurpose reservoirs impact profitability because other uses of water impose constraints to their normal operation with services to be shared with other stakeholders. Public and government are taking additional benefits of HP for free. There is not enough communication between stakeholders underlining the benefits of hydropower and no evaluation and recognition of its benefits to the community. Sedimentation decreases reservoir capacity, sustainability and sand availability downstream, even in coastal areas. Very expensive measures ensuring fish and sediment migration. Reservoirs can stop nutrients in warmer regions and can favour algae blooms. 	<ul style="list-style-type: none"> Profitability is reduced by increasing constraints due to multipurpose use. Climate change introduces uncertainties to originally planned reservoir operation. Lack of rules and framework for decisions about the use of water among conflicting interests. Incentives from governments are reducing for small hydro. Movement toward dam removals is getting stronger.

Table 3 Results of SWOT analysis on potential for sustainable services

Three main directions are proposed:

1. **Transparent shared communication** (with NGOs and other stakeholders) will help clarify the benefits of multipurpose reservoirs and pave the way towards their acceptance.
2. **Optimisation of reservoirs** and assessment of new multi-purpose reservoirs will be improved by clarification and quantification of water and energy needs, based upon shared information with transparency to the communities.
3. **Governance of water use** depends upon legal frameworks and requires a specific organisation that governs the use of water with an integrated perspective. HPP providing water for public services is key for incentivising hydropower.

2.4 “Environmentally friendly hydropower solutions could provide a stronger future business case for hydropower.”

Environmentally friendly hydropower solutions could provide a stronger future business case for hydropower (Table 4).

Strengths	Opportunities
<ul style="list-style-type: none"> Low carbon electricity can provide companies with PPAs. Lower environmental impact means better public acceptance, prioritisation and implementation. There are many hidden hydro opportunities. Multipurpose schemes are necessary, e.g. in Southern Europe. 	<ul style="list-style-type: none"> Greater sustainability leads to higher public acceptance. Creation of eco-labelling systems for “green” electricity production permits to sell this energy at a higher price. Additional services could be monetised.
Weaknesses	Threats
<ul style="list-style-type: none"> Extra costs of environmental mitigation measures result in higher prices. Lack of monetisation of environmental services. Lack of widely accepted environmental indicators. Lack of long reliability studies for assessing the cost of flexibility. No business case in the absence of regulation. No political will, unclear prioritisation of compelling services impedes flexibility. Lack of common interpretation and application of Directives. 	<ul style="list-style-type: none"> Lack of data, research outputs and feedback. Lack of political commitment. All additional services could be forced on operator in order to get a license. Costs and time increase too much and will not be economically profitable in some cases. Systems that are too complicated will not be used. Very high cost for decommissioning of existing plants. Environmental requirements increase and could not be met. Risk of bad ranking by new ecolabel. Unfavourable reporting of hydropower in the media.

Table 4 Results of SWOT analysis on potential for development and research

Research and innovation can support a stronger future business case with:

- (1) **use of R&D outputs**, data mining, ecosystems monitoring and big data to reduce environmental impacts, improve mitigation and optimise flexibility;
- (2) **European eco-labels** promoting best energies and schemes and supporting the market uptake of sustainable technology;
- (3) **development of modelling tools** for project design, optimisation and operation of multi-purpose schemes;
- (4) **improved market rules and concessions framework** for supporting long term investments for new schemes and uprating of existing ones with concession renewal and;
- (5) **developing hidden hydropower** in existing water infrastructure with low to zero impacts.

2.5 “In a fully liberalised and undistorted market, hydropower is one of the cheapest renewable energy sources, which maintains its investment value in the longer term.”

In a fully liberalised and undistorted market, hydropower is one of the cheapest renewable energy sources, which maintains its investment value in the longer term (Table 5).

Strengths	Opportunities
<ul style="list-style-type: none"> Most of the existing hydropower is cost effective, very economic for all types of services that the power system requires today and will be needed even more in the future. Hydropower is in a better position to contribute to the decarbonisation of energy than other conventional sources: in contrast to fossil sources generation (coal/fuel/gas), hydropower does not produce direct CO₂ emissions. Indirect CO₂ emissions in Europe are also lower than for solar and wind power generation. Large hydropower plants with high flexibility can stabilise the grid and ensure supply safety. Considering the lifetime CAPEX, batteries remain more expensive in the longer term. 	<ul style="list-style-type: none"> “The structure of the market economy is responsible for the inability to combat climate change and it advocates technology and regulation” (The Economist). To guarantee a new free carbon electric system a new clear and stable legal framework oriented towards its objectives of safety and sustainability is needed. Hydropower will be a very competitive energy source as soon as the legal framework considers the cost of externalities. Regional development will implement hydropower solutions merged with other renewables. An economic model can simulate different scenarios and regulatory approaches to assess the cost and benefits of externalities.
Weaknesses	Threats
<ul style="list-style-type: none"> The capital requirement (CAPEX) for storage is higher than batteries for an investment return of 20-25 years. The current market structure is unable to foster the energy transition because it does not take into account the cost of the externalities. 	<ul style="list-style-type: none"> Current energy policy with high subsidies is distorting the spot market. Excessive changes in safety regulation impede the long-term return on investment. The volatility in the energy market creating a large number of stop - starts for pumps and turbines is unpaid compared to the value given

<ul style="list-style-type: none"> • Uncertainty about changes in regulations (concessions, energy prices, safety, environment, and water restrictions under climate change) may dissuade utilities from developing hydropower infrastructure in Europe. • The deployment time for projects is very long. • Slow innovation in the deployment cycle: it takes a long time to bring new hydropower technologies to the market. • The lifetime of the asset (>100 years) is not aligned with the usual investment cycle (20-30 years). 	<p>which is increasing the risk of fatigue failure for equipment and civil structures.</p> <ul style="list-style-type: none"> • The key value for pumped storage now is in the arbitrage opportunity. The low-price difference between high and low prices (small spread), endangers the benefits of pumped-storage plants. Similarly, the lack of long-term revenue streams for energy storage is a challenge to the business case. However, record high prices for storage can lead to negative public perception. • Inertia in political and regulatory decisions create difficulties for implementing change. • Climate change impacts resources and operation.
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Table 5 Results of SWOT analysis on potential for maintaining investment value

The key element that supports the long-term value of hydropower is a consistent legal framework. Therefore, a priority is to further **develop a stable and clear legal framework** which should be oriented towards the transition to a carbon-neutral, safe and flexible energy system, based on the ETS as the key driver. The current market structure is unable to foster the energy transition because it does not take into account the cost of the externalities during the lifespan of power generation.

Consequently, the following actions are suggested:

- Gather a group of interdisciplinary experts across different power industries (hydro, wind, solar, geothermal ...) to agree on a **fair and transparent assessment method for the direct and indirect generation costs that takes into account the full lifecycle of the energy generation infrastructure** (including decommissioning, recycling and other externalities).
- **Advocate public awareness at the EU level, highlighting the advantages of hydropower** (dispatchability, flexibility) to develop remuneration schemes for providing grid support and multi-purpose services (water management) with carbon neutral services.

3 Hydropower Europe in a complex world - A global approach system analysis to better understand the key factors involved

3.1 Introduction - Methodology

Hydropower projects are not only complex, but they interact within a complex environment. To obtain wider public acceptance, critical factors influencing the complex situation need to be identified, which will then allow identification of the most promising design actions, as well as the most effective research and development directions. Thus, to assess the complex environment for hydropower within Europe, a complex system analysis was undertaken using the network thinking approach developed by Gomez & Probst (1995). This approach had already been successfully applied within the hydropower sector to identify project design strategies, as well as to find the best synergies within multi-purpose projects (Heller et al., 2010).

Application of the global approach system analysis to the hydropower market in Europe is described in detail in a HYDROPOWER EUROPE report (HPE, 2020); the main results are presented in the following sections.

3.2 Identification of factors influencing the hydropower market with a focus on Europe

Based upon the feedback received from the wider stakeholder consultation of the first drafts of the Strategic Industry Roadmap (SIR) and the Research and Innovation Agenda (RIA), a list of 103 factors were identified which were considered relevant for the system analysis. These represent seven sectors, namely:

- (i) Hydropower,
- (ii) Energy and Economic Policy,
- (iii) Electricity Market,
- (iv) Environment and Public Society,
- (v) Research and Development,
- (vi) Legal Framework, and
- (vii) Climate Change.

The definition and a detailed description of each of these seven sectors, can be found in Appendix A.

improving the *Market Opportunities*. This driving motor of course can turn in an increasing or decreasing sense. All the factors of the different sectors influencing the hydropower market outside of this driving motor are creating a kind of friction, inertia or acceleration and finally stabilising the system.

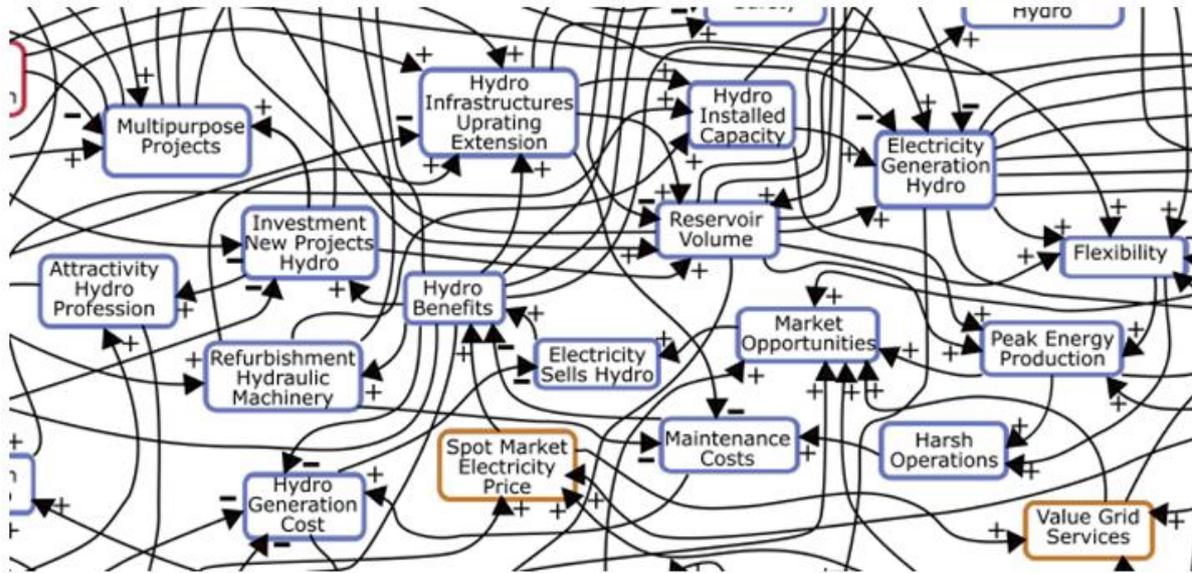


Figure 5 Driving motor of the hydropower market within the complex system

Since, without doubt, the European Green Deal will have an influence on future hydropower development in Europe; it has been integrated into the network as shown by the enlarged cut-out part in Figure 6 below.

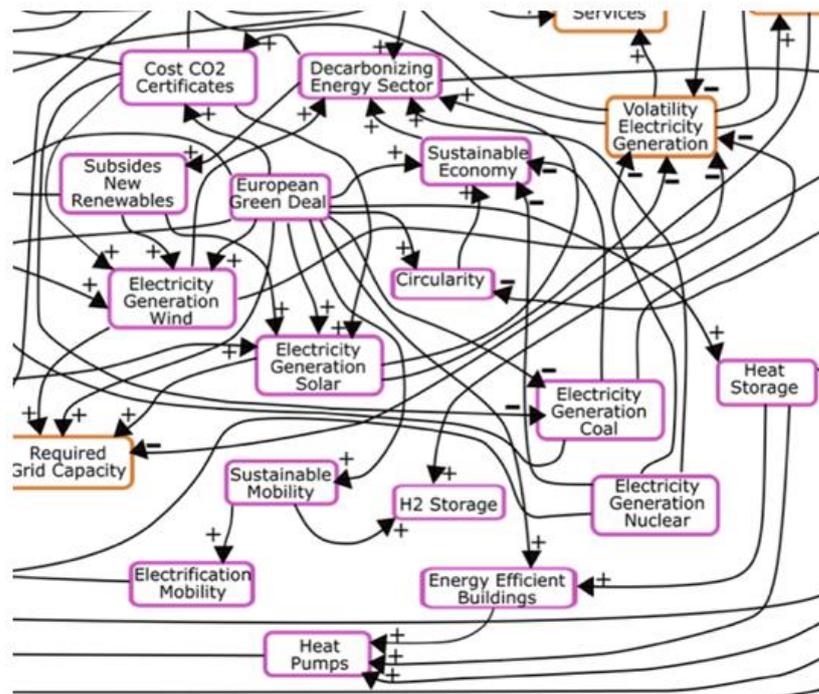


Figure 6 Implementation of the European Green Deal within the network

An alternative possibility to represent the network is to use circular visualisation according to Gu et al. (2014). Nevertheless, the circular visualisation cannot show in one single figure the activity of the factors (those who are influencing) as well as the reactivity of the factors (those who are influenced). Thus, two different circular visualisations are required to highlight either the activity or the reactivity.

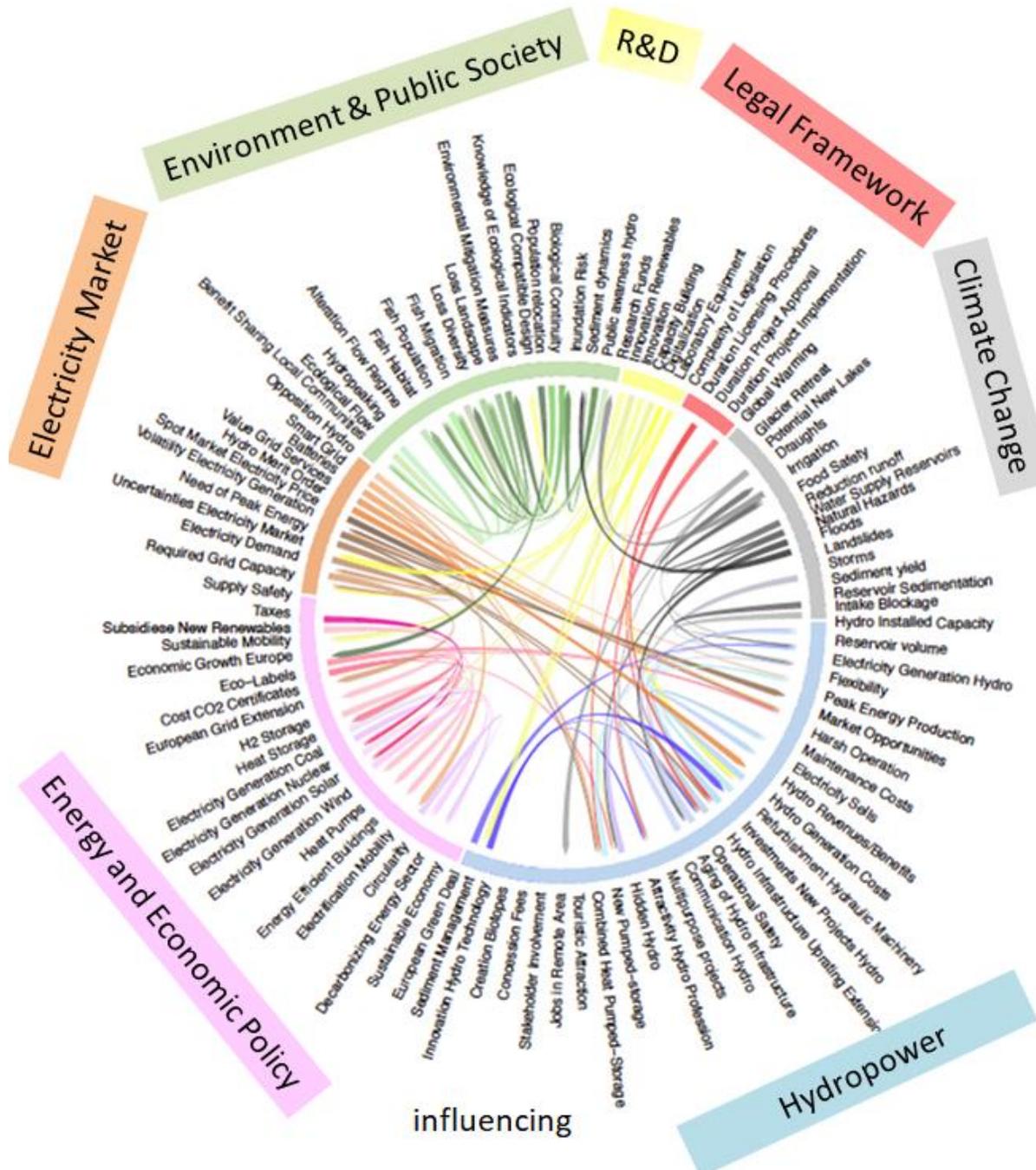


Figure 7 Circular visualisation of network factors showing the activity (influencing intensity)

Figure 7 shows the activity of the factors in a circular visualisation while Figure 8 depicts the reactivity. Compared to the network map, these visualisations allow the factors with the most influence (Activity) and those who are most influenced (Reactivity) to be seen more clearly.

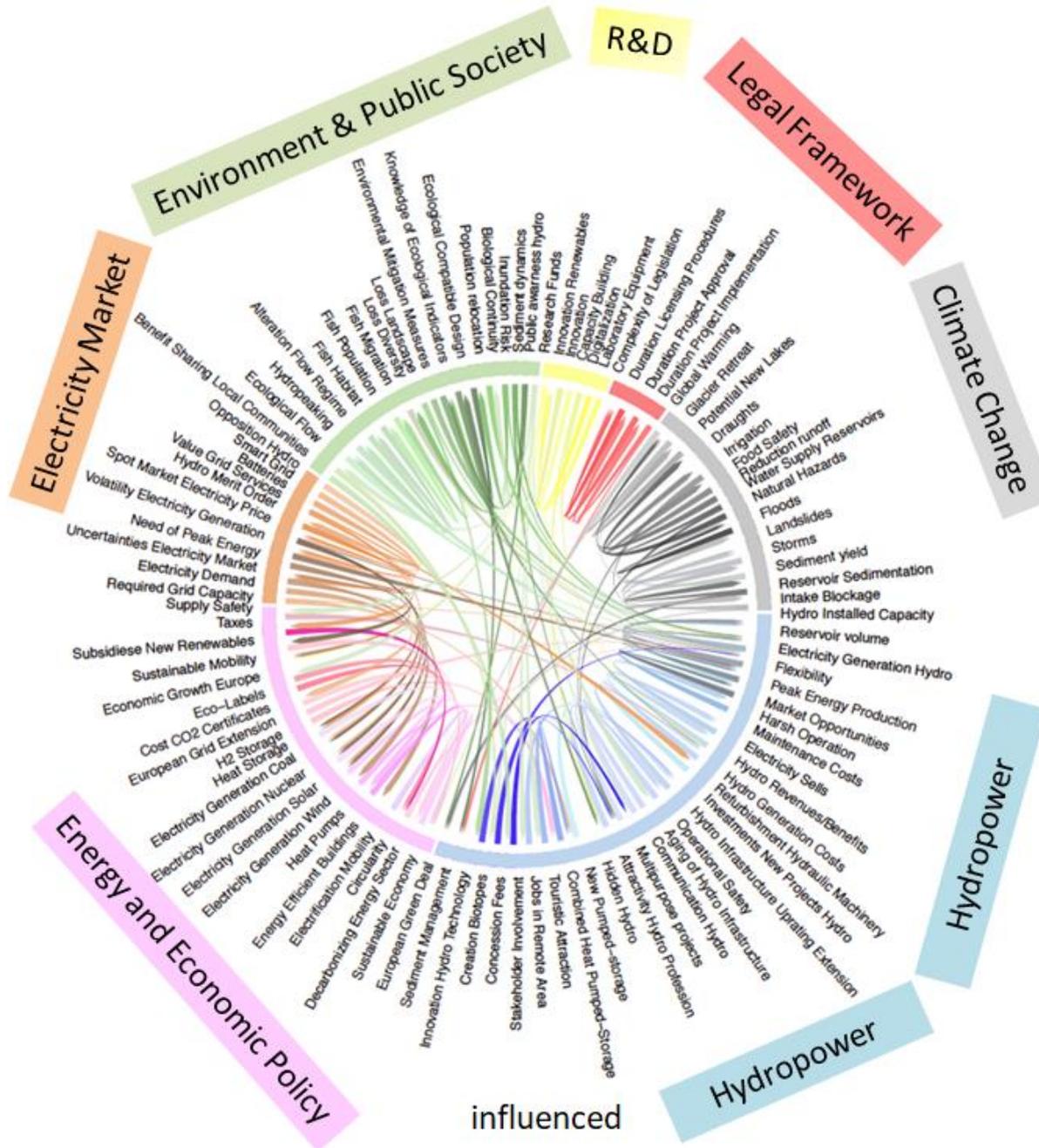


Figure 8 Circular visualisation of network factors showing their reactivity (susceptibility to be influenced)

3.4 Analysis of the network and identification of active and critical factors

The network map, as well as the circular visualisation plots, reveals the complexity of the situation and the challenge to draw direct conclusions. Thus, the interconnections of all factors in the network are mapped into a matrix (Figure 9) which highlights the activity and reactivity of each factor. Normally the analysis starts by considering only the direct connections, namely the first degree of influences. Then, to have better insight, the second-degree connections are also analysed.

In the matrix, the activity and reactivity of each factor has been summed up. For the active or critical factors, it is important to distinguish between two categories: those that can be controlled directly by an action and those that cannot. In the following discussion the factors which can be directly controlled are underlined in the text. They can be used as a lever and are therefore important for the prioritisation of any actions.

Figure 9 shows the matrix analysis for the second degree of influences (connections) within the network. The factors have been numbered according to the detailed list given in Appendix A.

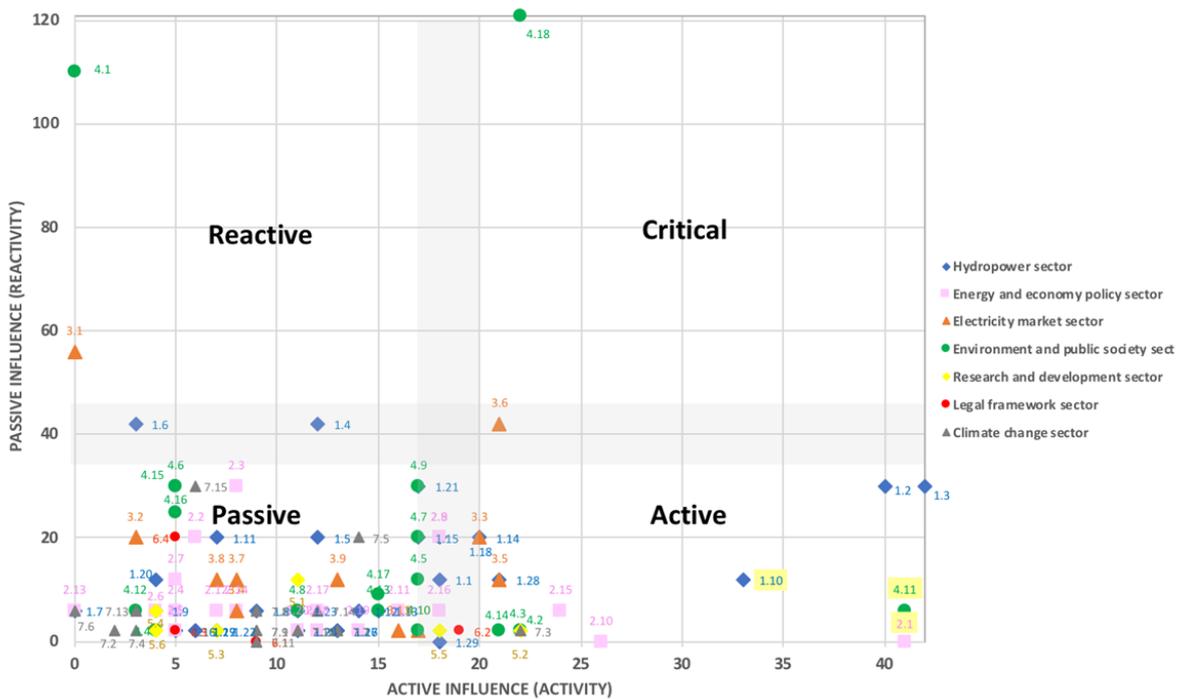


Figure 9 Result of matrix analysis considering the second degree of influences (connections)

- Critical Factors:** *These elements have a strong influence on the system but, at the same time, are strongly influenced by other elements if controllable. They can be used as levers, but they have to be operated with care in order not to provoke a system overreaction.*

Two factors are in the critical domain namely *Volatility of the Electricity Generation* (3.6) and *Public Awareness Hydro* (4.18). In principle both cannot be controlled directly. Nevertheless, the latter may be indirectly controlled by investing more in *Communication Hydro* (1.17).

- **Active Factors:** *These elements have a strong influence on others. They can play an important guiding role for management of the 'system' by using them as levers. (These are underlined in the following text).*

Reservoir volume (1.2), *Electricity Generation Hydro* (1.3) and *Hydropower Benefits* (1.10) are clearly within the domain of active factors. Since they are also quantitative factors, they can be considered as so-called indicators of the system. Reservoir volume (1.2) is characterising existing power plants and is a design parameter for new projects which can be controlled (thus underlined in the text). Nevertheless, it cannot be freely chosen and is influenced by many other factors and constraints. *Electricity Generation Hydro* (1.3) and consequently *Hydropower Benefits* cannot be controlled directly and are the result of a certain design or the performance of a hydropower plant. Nevertheless, they are important indicators for the system state. Environmental Mitigation Measures (4.11) has a very high activity and is a promising lever since it can be controlled by innovative project designs. Also, the European Green Deal (2.1), which is not directly controllable, has a very high activity, but is not influenced passively by other factors.

Several factors from the Environment and Public Society sector have quite high activity, namely Benefit Sharing Local Communities (4.2), Ecological Flow (4.3) and Population Relocation (4.14). Nevertheless, having a small reactivity, they are little influenced by other factors. Also, Innovation Hydro Technology¹¹ (1.28) and *Innovation Renewables* (5.2) are clearly within the active domain, which underlines the high importance of research and development actions. From the Electricity Market sector, the factors *Need of Peak Energy* (3.5) and *Electricity Demand* (3.3) became active when considering second degree influences, being passive before (analysing only first-degree influences). Both are indicators but cannot be controlled directly. The factors *Cost CO₂ Certificates* (2.15) and *Electricity Generation Nuclear* (2.10) have a relatively high activity but are little influenced by other factors. Finally, the *Potential New Lakes* (7.3) has significant activity, already confirmed by new dam projects underway in the Alps.

Several factors are on the border between the passive and active domains and can also be used as levers for action to increase hydropower success in the future. These include:

- Hydropower sector: Hydro Installed Capacity (1.1), Multipurpose Projects (1.18), New Pumped-Storage (1.21), Sediment Management (1.29)

¹ Innovation Hydro Technology can be only indirectly controlled.

- Energy and Economic Policy sector: *Electricity Wind Generation* (2.8), *Eco-labels*² (2.16).
- Electricity Market sector: *Electricity Demand* (3.3)
- Environment and Public Society sector: *Alteration Flow Regime* (4.5), *Fish Habitat* (4.7), *Loss of Biodiversity* (4.9), *Loss of Landscape* (4.10)
- Research and Development sector: *Digitalisation* (5.5)
- Legal Framework sector: *Duration Licensing Procedures* (6.2)

The active factors, which can be directly controlled (underlined in the text), can be used as a lever and therefore they are important for the prioritisation of any actions.

- **Reactive factors:** *These factors have a weak influence, but they are strongly influenced by others. They do not allow for control of the situation, but they may be used as indicators or fixed points for the analysis of the development of the system.*
Opposition Hydro (4.1) has the highest reactivity. Thus, investing more in sustainability and communication is highlighted. *Supply safety* (3.1) is also a factor with high reactivity. The most reactive factors from the hydropower sector are *Flexibility* (1.4) and *Market Opportunities* (1.6).
- **Passive factors:** *These factors are not influenced and do not influence other factors significantly in the system hence they can normally be neglected in the search for solutions or actions.*

3.5 Potential criteria for the identification of actions with high impact level

The analysis of the network, considering the second degree of connections between the factors, gives a clear and coherent picture. The following conclusions can be drawn.

- a) Two critical factors can be identified which are influencing the success of hydropower development in Europe in a dominant way, namely the *Volatility of the Electricity Generation* (3.6) and the *Public Awareness Hydro* (4.18). Both factors are not directly controllable and have to be influenced by other active factors in the system in a direct or indirect way. The *Public Awareness Hydro* (4.18) can be influenced directly by *Communication Hydro* (1.17). Any strategic action or research initiative, which has a direct or a close indirect effect on Communication, has the **first highest impact level**.
- b) The controllable active factors are *Reservoir Volume* (1.2) and *Environmental Mitigation Measures* (4.11). These have a very high activity and are also amongst the **first highest level** when ranking strategic actions or research initiatives.

² Eco-labels (2.16) can be only indirectly controlled.

- c) Also amongst the controllable active factors are **Benefit Sharing Local Communities** (4.2), **Ecological Flow** (4.3) and **Population Relocation** (4.14) from the environment and public society sector. These can be used as levers and are very important when defining strategic actions and research initiatives. Any actions which can influence these factors are among the **second highest impact level**. This is also the case for **Innovation Hydro Technology** (1.28), but which depends highly upon the available research funds.
- d) Finally a certain number of controllable factors are situated at the border between the passive and active domains, including **Hydro Installed Capacity** (1.1), **Multipurpose Projects** (1.18), **New Pumped-Storage** (1.21) and **Sediment Management** (1.29) from the hydropower sector. Regarding energy policy, also **Eco-labels** plays an important role but is difficult to control directly. **Fish Habitat** (4.7), **Loss of Biodiversity** (4.9) and **Loss of Landscape** (4.10) can also be used as levers when defining actions. Finally, **Digitalisation** (5.5) of the Research and Development sector is an important factor on which actions should also concentrate. Thus, all the factors mentioned under d) may be among the **third highest impact level** when ranking strategic actions or research initiatives.

This identification of the controllable, active factors having an impact level within the hydropower system can be used, together with the feedback obtained through the wider stakeholder consultation, to propose a final prioritisation of the strategic actions and research initiatives in both the Strategic Industry Roadmap (SIR) as well as in the Research and Innovation Agenda (RIA).

4 Opportunities and challenges for hydropower deployment in Europe

4.1 Hydropower: a renewable and reliable energy

Hydropower is a renewable energy as it is based on the water cycle, which is an endless, constantly recharging system (HPE, 2021a).

Hydropower plants convert the potential or gravitational energy stored in water within a reservoir first into kinetic energy in the form of running water, then into mechanical energy via a rotating turbine, and finally into electrical energy through an alternator or generator (Figure 10).

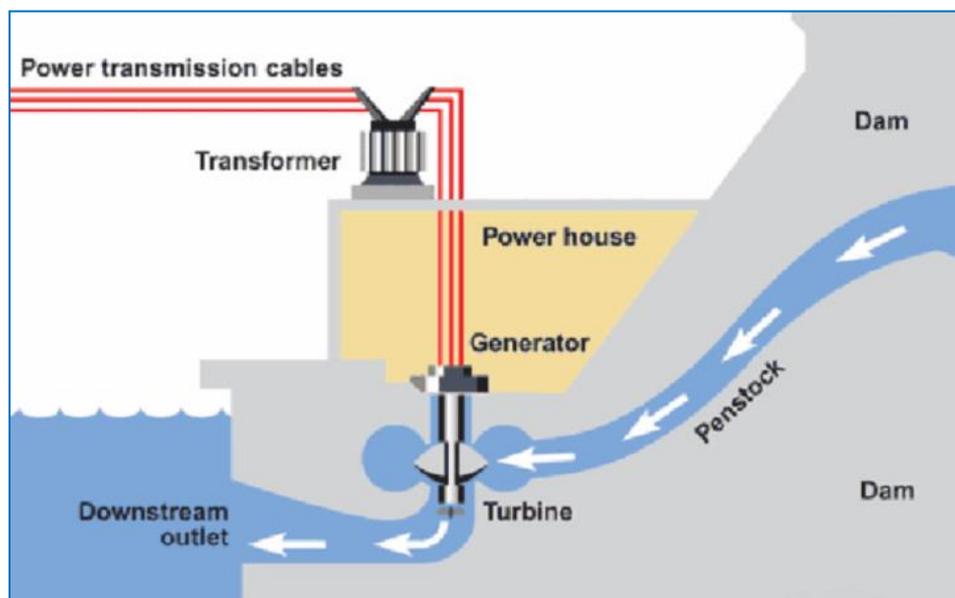


Figure 10 Hydropower plant at the toe of a dam (P.S. Bodger).

Hydropower plants consist of three basic types: (a) run-of-river powerplants (RoR) without having significant storage capacity, (b) storage powerplants having a reservoir created by a dam, and (c) pumped storage powerplants.

Small reservoirs serve for short-term storage over days and weeks, whilst large ones can provide seasonal or even inter-seasonal storage. Plants associated with a dam and reservoir can be divided into storage power plants (SPP) with storage ranging from hours to seasonal or even yearly storage, or pumped-storage hydropower (PSH), for both pumping to store water and subsequent electricity generation. They offer two very desirable characteristics in today's electricity systems: built-in storage that increases the system's flexibility, and a fast response time to meet rapid or unexpected fluctuations in supply or demand on the grid network.

The power generated by one turbine ranges from some kW to 1 000 MW installed capacity per machine. Hydropower plants can also be classified according to their size. Nevertheless, there is no universally accepted definition of these categories. In most countries in Europe 'mini hydro' is defined to be below 1 MW, 'small hydro' below 10 MW and 'large hydro' above 10 MW. It is important to highlight that the great variety in the size of power plants allows hydropower to meet both large centralised urban energy needs as well as smaller decentralised rural needs. All hydropower plants, and even run-of-river plants, can contribute to flexibility, balancing local grids and meeting smart energy communities' demands.

Hydropower plants have a very long asset life, with the oldest facilities now operating for more than 100 years. Labour cost is low as facilities are automated and controlled remotely so few personnel are required on site.

4.2 Hydropower: the backbone of emerging industry and electric systems

At the end of the 19th century, the deployment of hydroelectric plants boosted the electrification of cities and the development of industry in western countries.

In the middle of the 20th century, after the Second World War, the industrial and economic recovery of Western countries was based on massive dam and hydropower plant development.

In the beginning of the 21st century, developing countries in Asia and Africa are developing their untapped hydro potential for meeting growing demand and increasing access to electricity. Hydropower generation increased 60% in Africa and 153% in Asia (Bartle, 2021) between 2005 and 2020.

4.3 Hydropower in the EU

Hydropower supplies clean, renewable energy at competitive rates. It is one of the main sources of renewable energy in Europe (EU-28 + Switzerland, Norway and Iceland). Hydropower accounted for 10% of gross electricity generation in 2018 (8 billion EUR), and for 36% of all renewable electricity generation in Europe (including Turkey), representing 653 TWh in 2019, with a total installed capacity of 251 GW (including Pumped Storage Capacity, IHA, 2020a).

The share of hydropower generation in EU Member States and non-member states can be seen in Figure 11.

Pumped-storage plants account for about 20% of the total installed hydropower capacity. In 2019 pumped-storage plants in Europe had a generation capacity of about 55 GW and a pump capacity of about 51 GW (IHA, 2020a).

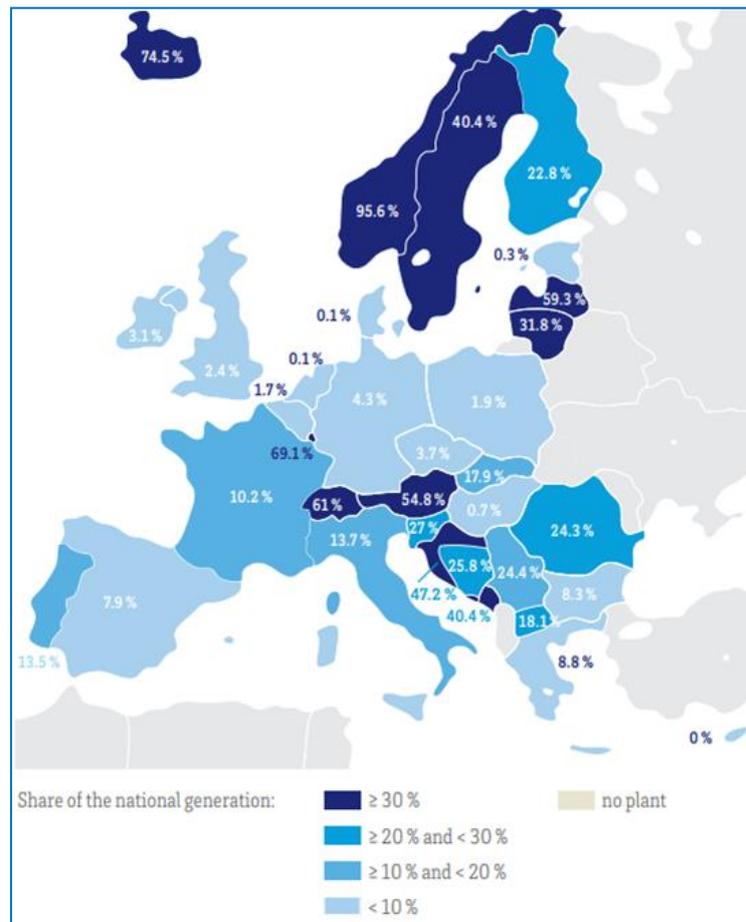


Figure 11 Share of hydropower generation in EU Member States and non-member states in 2017 (source: ENTSO-E, 2018a)

Due to climatic conditions, large differences in terms of hydropower resources and hydropower share of the total electricity mix exists across Europe. Nordic countries contribute to 44% of the European hydropower generation, Alpine countries contribute to 37% and southern countries provide 12%, and Eastern Countries 6%. The largest capacity is installed in the Alps (Table 6).

European Region	Installed capacity (GW)	% of Installed capacity in Europe	Yearly generation (TWh/y)	% of generation in Europe
Nordic	59	30%	254	44%
Alpine	81	42%	217	37%
Southern	38	20%	77	13%
Eastern	16	8%	33	6%

Table 6 Yearly generation in European regions without Turkey according to *Hydropower & Dams World Atlas 2021*

The majority of hydropower plants are of a small size (< 10MW). However, the big bulk of electricity generation comes from larger plants. Hydropower plants with more than 10 MW capacity contribute from 60% to over 90% of the total installed capacity in most countries (Figure 12).

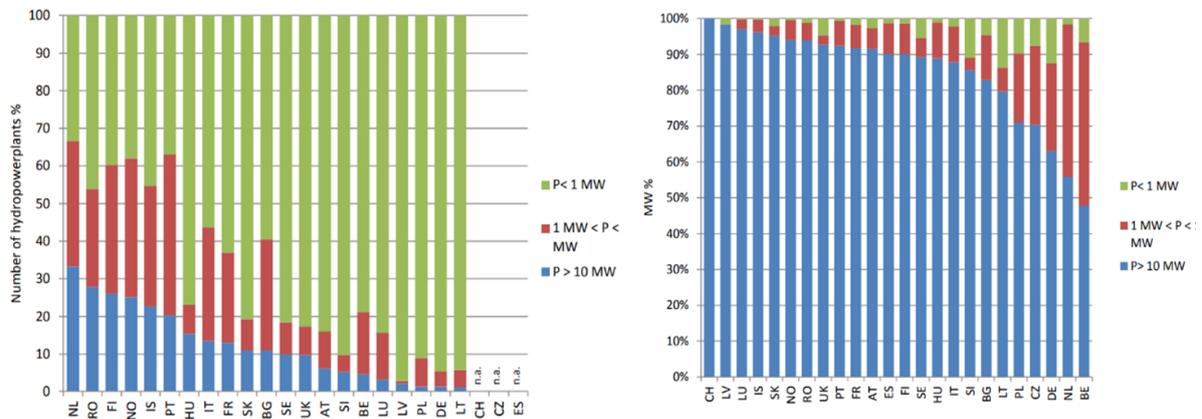


Figure 12 Percentage of total number by capacity of existing hydropower plants (left) and percentage of total installed hydropower capacity for different plant sizes (source: EC, 2011)

About two thirds of Europe’s economically feasible potential hydropower has been developed (Hydropower & Dams, 2021).

More than 6062 large dams in Europe (including Ukraine and without Turkey of which 4451 are in the EU according to the ICOLD 2020 register of dams) store about 440 billion m³, 25% of them for multipurpose water use (33% respectively in the EU). Amongst the 6 062 large dams, 2743 store water for hydropower generation (respectively 2125 in the EU).

4.4 The Hydropower market

4.4.1 European companies are world leaders in the hydropower sector

Europe is the cradle of hydropower. Europe has maintained a leading position in the field of hydropower design and manufacturing, as European hydropower equipment manufacturers command an estimated two thirds of the world market (DNV GL, 2015). By developing technology and production methods in a fast-growing domestic market, European manufacturers have maintained a leading edge over other parts of the world. Very little non-domestic equipment has been installed in European hydropower plants. At the same time, European engineering and consulting companies have been designing dams and hydropower schemes all around the world thanks to their leading position.

Three large European companies lead the large to medium-scale electromechanical and hydromechanical equipment supply market worldwide, namely Alstom Power Hydro (recently acquired by General Electrics), Andritz Hydro and Voith. Over 50 other European companies hold a recognised industrial position worldwide in the small turbine segment,

which represents the bulk of the European market. These industries are mainly located in Austria, France, Germany, Italy, and Sweden, but are also well represented in the Czech Republic, Poland and Slovenia amongst other countries. The activity of all these companies is largely geared towards export. Altogether these companies cover more than 50% of the world market (DNV GL, 2015). Many manufacturers provide specialist equipment, new materials and treatments (ABG, Bauer, Carpi, Hydroplus, Siemens, Soletanche, amongst others).

While investments into new plants are slowing down in Europe (major investments into extension, refurbishment and maintenance, but still some new projects), the large European operators (EDF, EDP, ENEL, ENGIE, ENBW, IBERDROLA, PPC, STATKRAFT, UNIPER, VATTENFALL, amongst others) continue to invest in many hydropower projects outside of Europe. Many European engineering and consultancy companies offer knowledge, expertise, or consulting to hydropower projects outside of Europe, where there is considerable growth in the hydropower sector (Artelia, Lombardi, ISL, AFRY (former Pöyry and AF), Sweco, MESY-Solexperts, Tractebel (former Lahmeyer and Coyne et Bellier), amongst others). Meanwhile many construction companies (Impregilo, Salini, Skanska, Strabag, Vinci, Walo, amongst others) act as civil contractors or even as EPCs in the framework of turnkey projects.

European companies have been essential actors across the entire value chain of hydropower development around the world, which has led to significant exports.

4.4.2 The current global hydropower market

The global installed hydropower capacity at the end of 2020 was 1350 GW (IEA, 2021). Clean electricity generation from hydropower achieved a record 4500 TWh in 2020, the single greatest contribution from a renewable energy source in history (IEA ,2021).

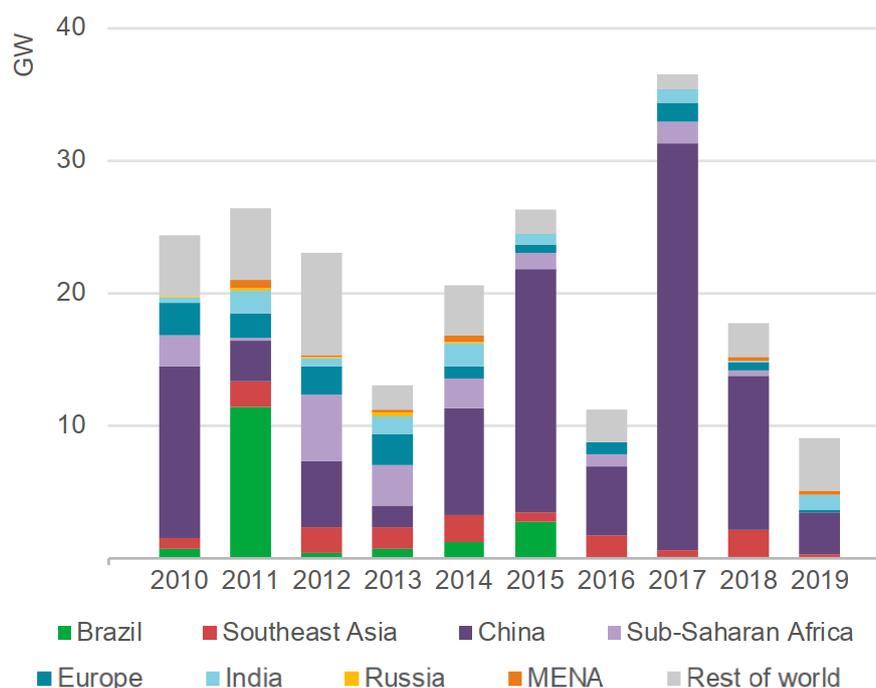


Figure 13 Final investment decision for Hydropower in the last decade (IEA 2020)

Global hydropower generated 4500 TWh worldwide in 2019 (46.5% of the 9669 TWh economically feasible potential and 28% of the 15797 TWh technically feasible potential). Current hydropower generation accounts for 16% of global electricity generation (IEA, 2021). However, FIDs capacity for new hydropower fell to the lowest level of this decade (Figure 13) according to IEA (2020) calculations.

In the five years between 2015 and 2019, the average year-on-year growth of installed capacity was 2.1%. In 2019, the growth rate was 1.2% (IHA, 2020a). To limit the global temperature rise to below 2°C above pre-industrial levels, IRENA (2020) in its “Transforming Energy Scenario” suggests global hydropower capacity would need to reach an estimated growth of 2.0% a year on average.

In contrast to rising investment in wind and solar, annual global investment in hydropower is relatively constant (Figure 14) at around 50 billion USD, supported by ongoing green-field and refurbishment projects around the world, and completion of mega hydropower projects in China (IEA 2021).



Figure 14 Overview of renewable power investment (IEA, 2020)

Most of the costs in hydropower projects are associated with intensive civil works (ground works, tunnelling, dam and powerhouse construction) and with the procurement of bulk electro-mechanical equipment (turbines, generators and all auxiliary systems). Although the technology of hydropower is still advancing and enabling higher efficiencies for electricity generation and increased flexibility, the global weighted-average total installed cost of new hydropower rose from 1269 USD/kW to 1850 USD/kW between 2010 and 2020 (Figure 15). The increase has been driven by rising installed costs for projects in Asia, Africa and South America. The data appears to suggest that many countries in these regions are now developing hydropower projects at less ideal sites, where such projects are located further from existing infrastructure, or the transmission network, resulting in higher logistical costs,

as well as boosting grid connection costs. This results in higher overall installation costs (IRENA, 2021b).



Figure 15 Total installed capacity costs by hydropower project and globally weighted average, capacity factor and levelised cost of electricity 2010-2020 (IRENA, 2021b)

The global number of reported large dams reached 59 667 in 2020. About 22% of the single purpose reservoirs store water for hydropower and 16% of the multi-purpose reservoirs provide water for hydropower (ICOLD, 2020). The global number of very large dams (h>60 m) under construction worldwide shows little variation since 2000, from around 350 in the first decade of the 21st century to 306 in 2019. These are building the ‘safety belt around the world’, ensuring food, water and energy (Nexus and SDG’s, see Schleiss, 2018).

Since 2000, there have been over 10200 new installed hydropower plants globally and 480 GW of new hydropower commissioned capacity. The private sector owns nearly 70% of these projects. The public sector owns over 70% of the capacity (IEA, 2021). The larger a project’s capacity, the more likely it is to be developed or sponsored by a government or a government owned utility. Large projects are capital intensive and can face local opposition and social acceptance concerns along with lengthy and complex permitting processes, significantly increasing the project risk. Some of these projects are also multi-purpose, assisting in flood control or irrigation, areas of water use and conservation that are usually managed by public authorities (IEA, 2021).

Private sector investment in projects over 500 MWs occur in markets with strong policy schemes to de-risk large investment. In developing countries, private-public partnerships also contribute to developing large-scale plants (IEA, 2021).

The private sector focus on smaller hydroelectric capacity is the result of policies encouraging small hydropower development, through auctions or feed-in tariffs, eliminating off-taker risk by guaranteeing a stable revenue stream (IEA, 2021).

4.4.3 The current depressed EU hydropower market

Although the development of hydropower capacity under construction in Europe was boosted after the 2008 financial crisis and the 2011 Fukushima accident (2400 MW in 2006, 9580 MW in 2012 and 4225 MW in 2018), the hydropower market in Europe is currently in a degree of stagnation since electricity prices on the European spot market are very low (Figure 16).

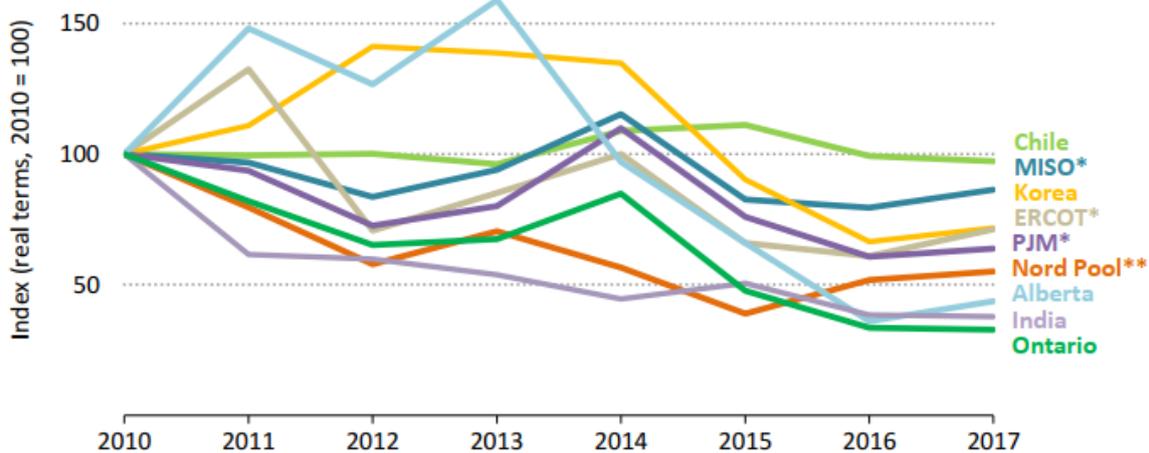


Figure 16 Average wholesale electricity prices in selected competitive market (Nord Pool is a European power market)

Three main factors caused the drop in electricity price:

- 1 The main generation mixes in Europe are in overcapacity (IEA, 2018), due to the stabilisation of electricity demand (resulting from energy efficiency, changes of use and low economic growth). It is unclear how the phase out of nuclear and coal-fired generation combined with the development of VRES will affect this situation.
- 2 Cost of CO₂ market price (EU Emission Trading System) is still very low.
- 3 The market has been distorted due to high subsidies and priority in the merit order for new renewable energy such as solar and wind.

Consequently, the increase of capacity was +12% up to 200 GW and the increase of generation was +4% up to 550 TWh over the 15 past years (Bartle, 2021).

Meanwhile, in Europe, the number of very large dams (h>60 m) under construction has decreased from around 35 before 2010 to 24 in 2018 (Schleiss, 2019). The current potential for green-field projects in Europe lies with low-head (less than 40 meters) and medium-head (40 to 200 meters) plants.

At the moment, investments are focusing mainly on refurbishment, extension or rehabilitation of existing facilities and pumped storage (PSP) as part of the energy transition. The potential of the modernisation of the existing hydropower fleet in Europe is estimated with 8.4% for European Union and 9.4% for the whole Europe compared to the generation in 2019 (Quaranta et al., 2021)

4.4.4 The urgent political commitment tackling climate change

The negative effects of climate change are becoming more evident year by year (WMO, 2021). The gap between aspiration and the reality in tackling climate change remains as significant as ever. The health, humanitarian, social and economic crises set off by the current COVID-19 pandemic could either widen the gap or accelerate the decarbonisation of our societies.

At the same time, governments are embarking on the monumental task of devising stimulus and recovery packages (IRENA, 2021a). The goals set out in the United Nations 2030 Agenda and the Paris Agreement can serve as a compass to show the pathway to create a sustainable future energy system. Amongst the four key strategic priorities for political and energy leaders to consider, the two top priorities are (WEC, 2019):

1. **Market design rules will need to be updated** to incorporate the growing move towards decentralisation.
2. **Electrification** is being used to **decarbonise the energy sector**.

Update of the market design rules is the most crucial key strategic priority, but it is the most difficult to design (Figure 17). Electrification based on renewable energies is the easiest key strategic priority to achieve right now!

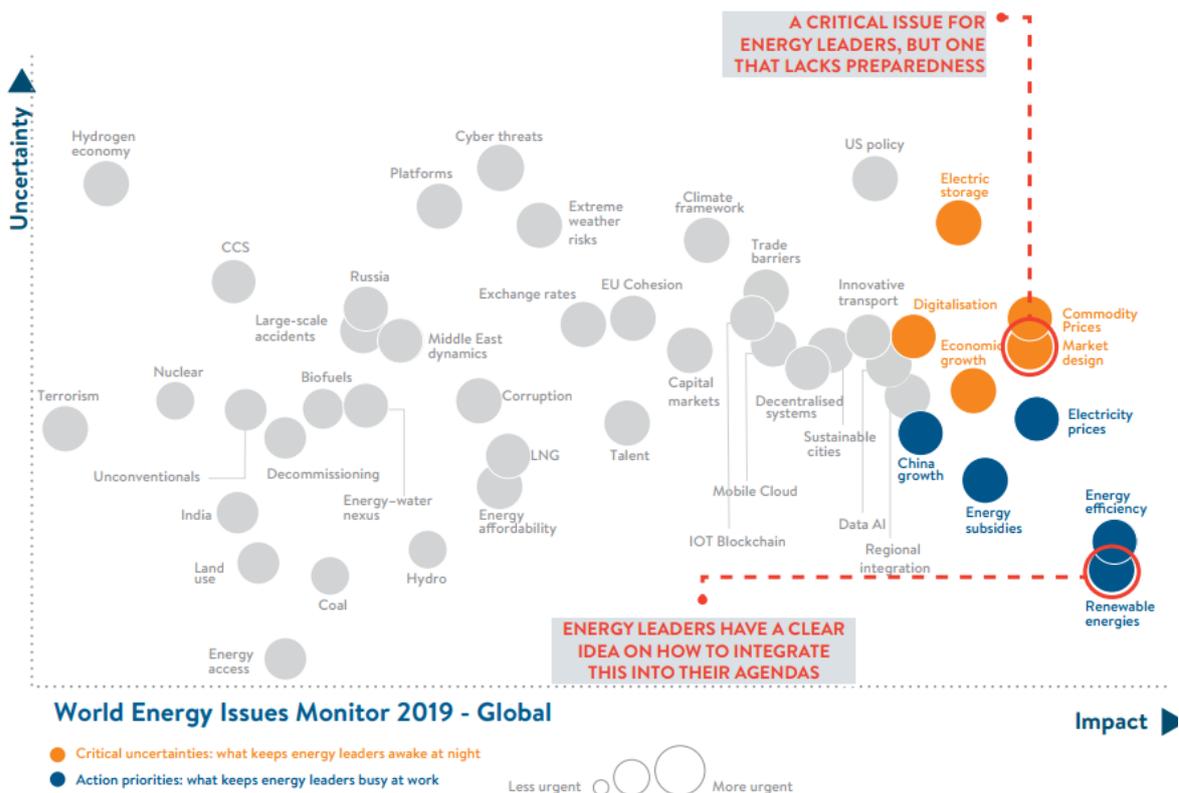


Figure 17 The impact and uncertainty of the strategic key actions for energy (WEC, 2019)

In the EU, political leaders face another challenge for reaching the target of zero emissions by 2050. They have to strengthen EU cohesion, which is currently an issue of critical uncertainty.

Concerns revolve mainly around the possible impact of changes in the current status of EU membership on the regulation and commercialisation of energy across the region.

4.4.5 The future market of energy

The IRENA Transforming Energy Scenario (TES) shows how to achieve stable, climate-sustainable long-term energy and economic development, keeping the expected temperature rise well below 2°C (IRENA, 2021a).

In the Transforming Energy Scenario, the share of modern renewable energy in global final energy consumption would increase to 28% by 2030 and 66% by 2050. Therefore, the share would need to increase six-fold compared to today and two-and-a-half times compared to the Planned Energy Scenario.

The success of the Transforming Energy Scenario is based on five technology pillars (IRENA, 2021a):

1. **Electrification.** Renewable technologies are dominating the global market for new power generation capacity. Solar PV and wind are increasingly the cheapest source of electricity in many markets.
2. **Increased power system flexibility.** In the Transforming Energy Scenario, 73% of the installed capacity and over 60% of all power generation would come from intermittent and non-dispatchable resources (solar PV and wind), up from 10% of the power generation mix today. The amount of stationary storage (which excludes electrical vehicles) would need to expand from around 30 GWh today to over 9 000 GWh by 2050 (Figure 18).
3. **Renewable sources development.** One technology that can play a particularly important role is hydropower. **Hydropower can counteract the short-term variability of wind and solar generation. Hydropower can bring seasonal complementarities in resource patterns and important synergies to the energy system of the future (floating PV and covering gravity dams by PV).** In the Transforming Energy Scenario, global hydropower capacity would need to increase to 1444 GW in 2030 and to 1822 GW in 2050.

The targets identified for “Stationary Storage” by IRENA, both for 2030 as well as for 2050, are quite ambitious. The economic feasibility of such massive battery storage has not been demonstrated. This provides a potential opportunity for PSH projects to cover part of the unrealised battery share. At least, pumped storage hydropower (PSH) capacity would need to increase to 225 GW in 2030 and to 325 GW in 2050 (Figure 18).

When including both types of hydropower, **around 850 GW of newly installed capacity is required in the next 30 years**, which represents a considerable development of hydropower (2147 GW in 2050).

4. **Green Hydrogen:** Hydrogen can offer a solution for types of energy demand that are hard to directly electrify.
5. **Innovation to address challenging sectors.** The Deeper Decarbonisation Perspective is an enhancement of additional technology options on top of the Transforming Energy Scenario.

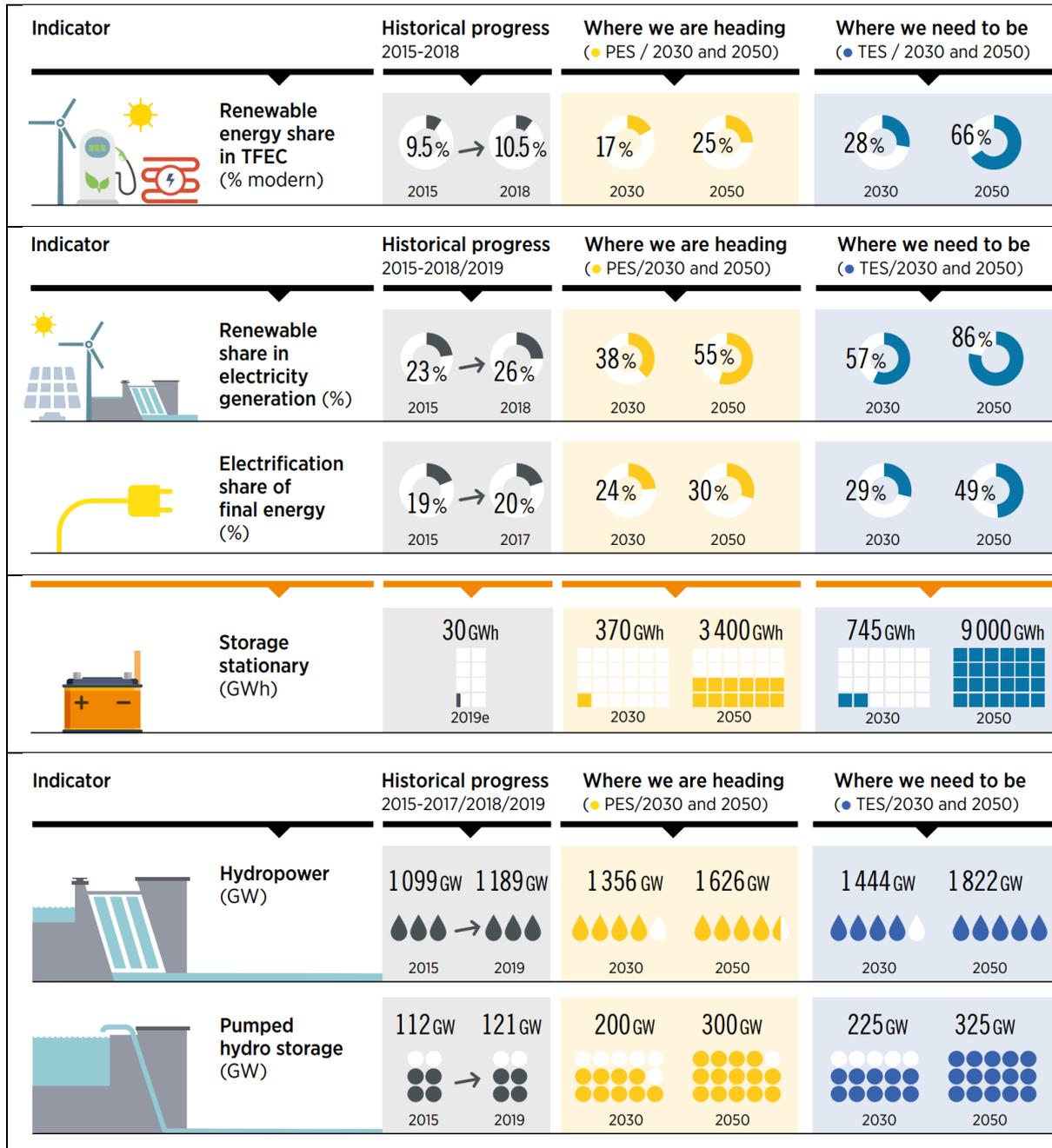


Figure 18 (a) Renewable energy share in the Planned Energy Scenario (PES) and needed at minimum in the Transformation Energy Scenario (TES) (b) in electricity generation, electrification share (c) storage and (d) hydropower capacity from IRENA (2021)

Meanwhile, the IRENA Transforming Energy Scenario (TES) is not enough to keep the expected temperature rise below 1.5°C. The IRENA **Deeper Decarbonisation Perspective**

(DDP) would reduce emissions to zero by as early as 2050 or latest by 2060, consistent with holding the line at 1.5°C. In the Deeper Decarbonisation Perspective (DDP), the worldwide growth of pumped storage hydropower plants would be more considerable: it could be three to five times the current capacity of pumped storage hydropower plants.

The IEA sustainable development scenario estimated the worldwide hydropower development potential to reach 7000 TWh by 2050 (IEA, 2018) (Figure 19). This increase of more than 60% on today generation (4500 TWh) is confirmed by IRENA (2021).

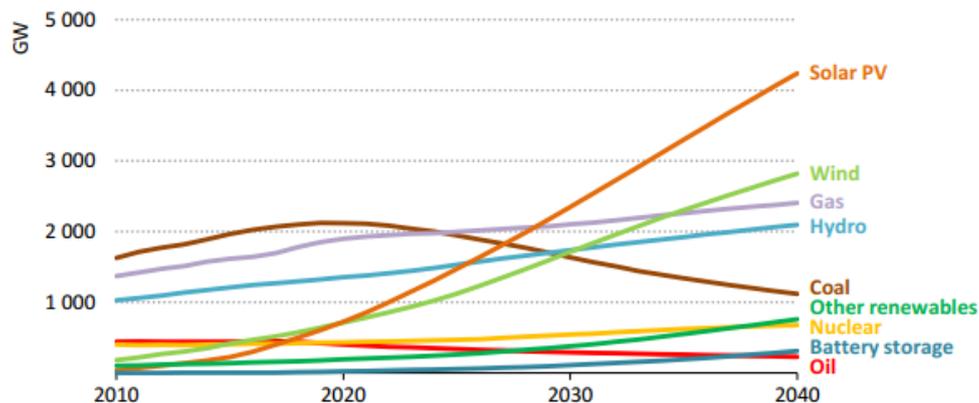


Figure 19 Installed power generation capacity worldwide by source in the Sustainable Development Scenario (IEA, 2018)

In addition to the new capacity, it is estimated that more than **600 GW of the current ageing worldwide hydropower fleet will require refurbishment**. This offers a timely opportunity to modernise hydropower to provide greater flexibility to support the intermittent and non-dispatchable sectors (IRENA, 2021a).

In the IEA's Sustainable Development Scenario (2018), which includes additional policy measures to support increased deployment of renewable-based electricity across all regions, cumulative investment in renewables-based power generation is \$12.8 trillion over 23 years, with wind accounting for 34%, followed by solar PV (33%), and hydropower (18%).

These prospects are signs of the dynamism of the global hydropower market.

In conclusion, solar PV and wind sources development is the streamline pathway for tackling climate change. As the share of wind and solar photovoltaics (PV) grows, so does the need for flexibility to ensure a reliable power supply. **The larger the development of variable renewable sources, the larger the need for hydropower development to counteract the variability of VRE.** Thus, in the future global market, hydropower is vital. However, hydropower needs innovation to bring important synergies to the energy system and to reduce emissions to zero by 2050.

4.4.6 Hydropower is vital to any future energy system

Power system flexibility is defined as the ability to effectively cope with variations in the supply or demand of electricity at any time. Flexibility maintains overall reliability by balancing supply and demand and keeping frequency and voltage within their limits in a cost-effective manner. The shortest timescales focus on system stability and frequency control. The intermediate timescales focus on dispatch and scheduling processes to meet current and projected electricity demand across minutes, hours, and days. The long-term time horizon addresses supply adequacy over months to years through coordinated long-term scheduling processes and ultimately investments and capacity planning.

A common European balancing market was established by the European Commission in 2017. It specifies the regulations for provision of ancillary services, to ensure secure operation of the electricity grid at a constant frequency of 50 Hz.

The multi-stage control procedure for balancing the European power system is illustrated in Figure 20. Each control procedure coordinated by dedicated international platforms for the corresponding market products (EC, 2017), is briefly outlined below.

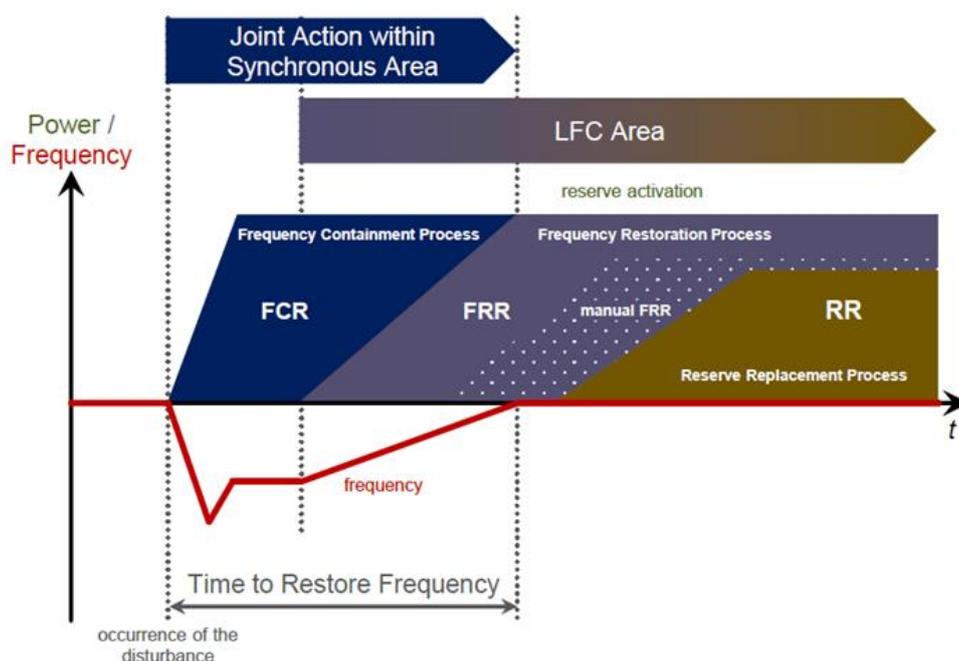


Figure 20 Time domain hierarchy of the load-frequency control process

- **Frequency Containment Reserve (FCR)** requires a fully operating response to the power system within 30s (primary frequency control).
- **Frequency Restoration Reserve (FRR)** is activated to restore the system frequency to its set point value (i.e. nominal value of 50Hz) and to restore the balance between the active power generation and demand within the Load Frequency Control (LFC) area. Firstly, it is automatically activated (**aFRR**) corresponding to secondary frequency control in the connected power stations by the central grid controller after a few

seconds and is typically completed within a maximum time of 5 minutes to restore the system frequency back to its set point value. And finally, it is activated by individual TSO instructions (manually, **mFRR**) and requires a full activation time of less than 15 minutes.

- **Replacement Reserve (RR)** progressively replaces the activated FRR and/or supports the FRR control process with an activation time of less than 30 minutes.

Hydropower operates at all timescales (Table 7) supporting power quality (monitoring and regulation of voltage fluctuations, frequency disruptions and harmonic distortions), power management (short-term power supply for critical demands) and energy management (energy storage for extended periods of time: storing energy during periods when the retail electricity price is low and discharging when prices are high – “retail energy time shift”).

Timescale	Services	
Subsecond-seconds	1) Inertia 2) Reactive power 3) Voltage control	4) Frequency support 5) Spinning reserve 6) Special protection Systems
Seconds - minutes	1) Frequency support	2) Last minute dispatch
Minutes - hours	1) Energy 2) Frequency support	3) Black start 4) Power unit dispatch
Hours - days	1) Energy 2) Ancillary services	3) Long term reserves 4) Demand response
Days-months; Months-years	1) Resource adequacy	2) Storage

Table 7 Consolidated flexibility service types by timescale (IEA, 2021)

In 2017, around 375 GW of flexibility supply were in operation worldwide. The ability of **thermal (very limited) and hydropower plants to ramp up and down their own generation provides more than 85% of the flexibility** available to power systems: interconnections provide around another 5%, and pumped storage a further 4% (IEA 2018).

Pumped storage hydropower currently accounts for 97% of global storage capacity (4 GW of battery in 2017 (IEA, 2018)). Pumped hydropower storage plays an important role in integrating and balancing VRE and in creating jobs.

In future energy systems with high shares of wind and solar energy, power system flexibility will become increasingly important to maintain balance in the system due to the variability and uncertainty in these resources. Available resources for this purpose will double by 2040 (IEA, 2018).

Hydropower is the only available renewable and national resource ready to provide climate-neutral flexibility particularly over long durations (thermal plants, interconnections, battery storage and demand responses will play increasingly important roles but with increasing impacts on the environment and / or customers).

Hydropower is the key technology for flexibility and climate change mitigation in the coming decades. Its deployment requires enabling policies, market conditions, common frameworks to scale investments and well-prepared projects.

4.4.7 The European market focused on flexibility

The EU potential for storage and run-of-river plants is already relatively well exploited. Many of the main sites have already been developed and in 2019 capacity remained relatively stable. A series of new small-scale projects opened in 2019. Over the last five years, hydropower has grown by around 10 GW (5% in 5 years) and future growth is expected to increase modestly (10% in the rate of deployment in the coming 30 years is estimated by IRENA, 2021a).

However, there are several projects in the pipeline, and green-field potential is still significant in specific countries, mainly in Nordic and Eastern countries (besides Turkey), as shown in Figure 21.

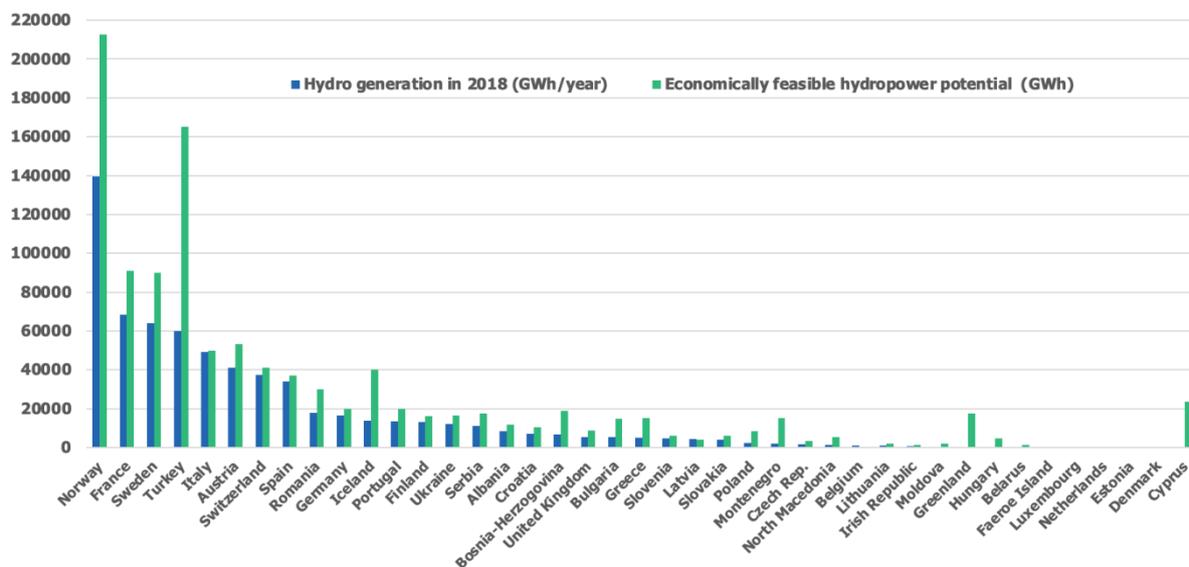


Figure 21 Unexploited versus developed hydropower potential on the European continent including Turkey (according to *Hydropower & Dams World Atlas & Industry Guide, 2020*)

Meanwhile, the future deployment of hydropower will come from the flexibility market. A first good indication of the types of flexibility required by the power system can be obtained by looking at the phases of VRE integration as proposed by IEA (2018). The phases framework is defined by the typical sequence of challenges faced by system operators as more and more VRE sources are connected to the grid. Figure 22 briefly describes the different phases of VRE integration.

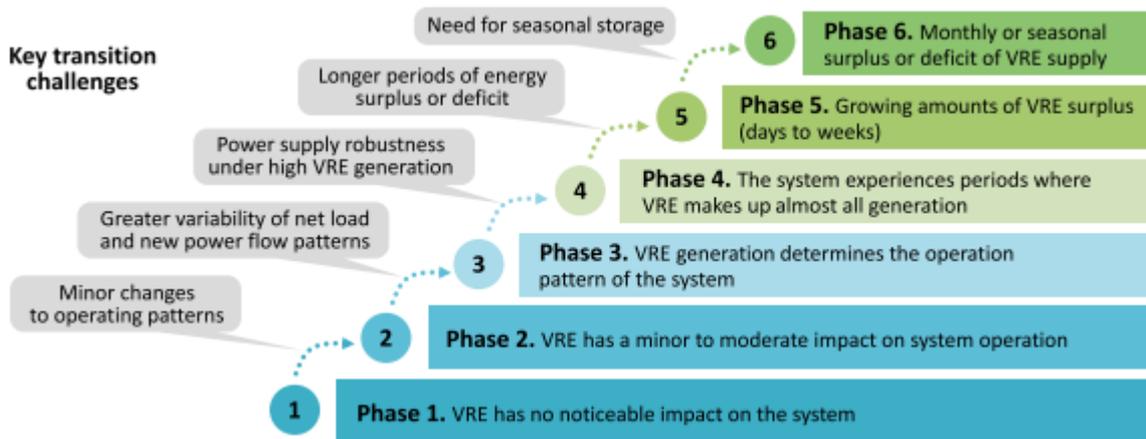


Figure 22 The six phases of flexibility required for VRE integration (IEA, 2018)

The market trend in Europe sees a step change in the need to source flexibility. Many countries in Europe will see frequent periods of VRE production exceeding electricity demand (Figure 23).

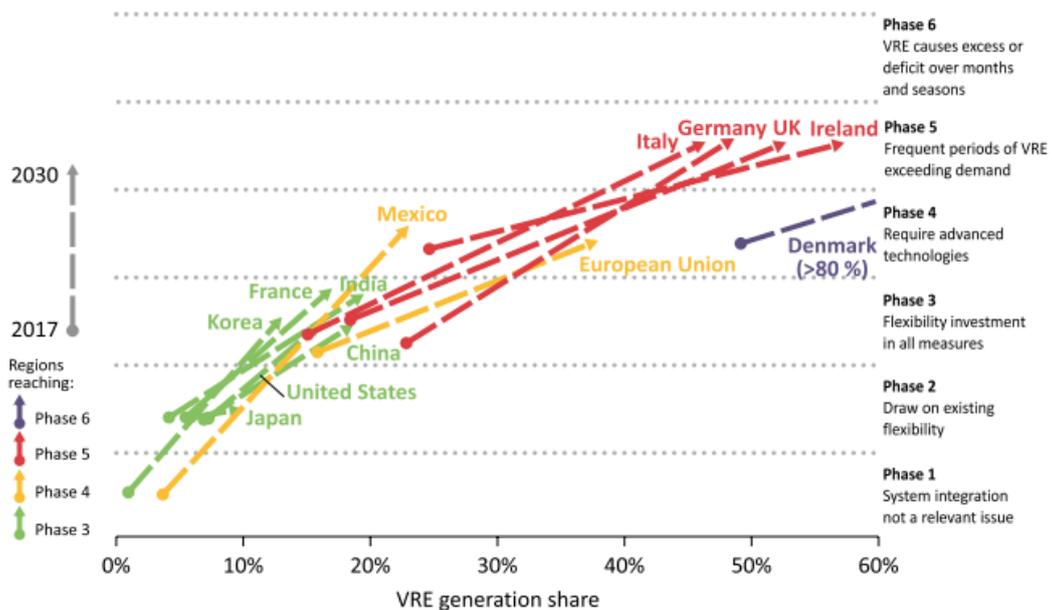


Figure 23 Evolving flexibility needs by region, New Policies Scenario (IEA 2018)

A wholesale transformation of European electricity generation pushes wind out in front, whilst gas and hydropower become the main sources of flexibility (IEA, 2018, Figure 24).

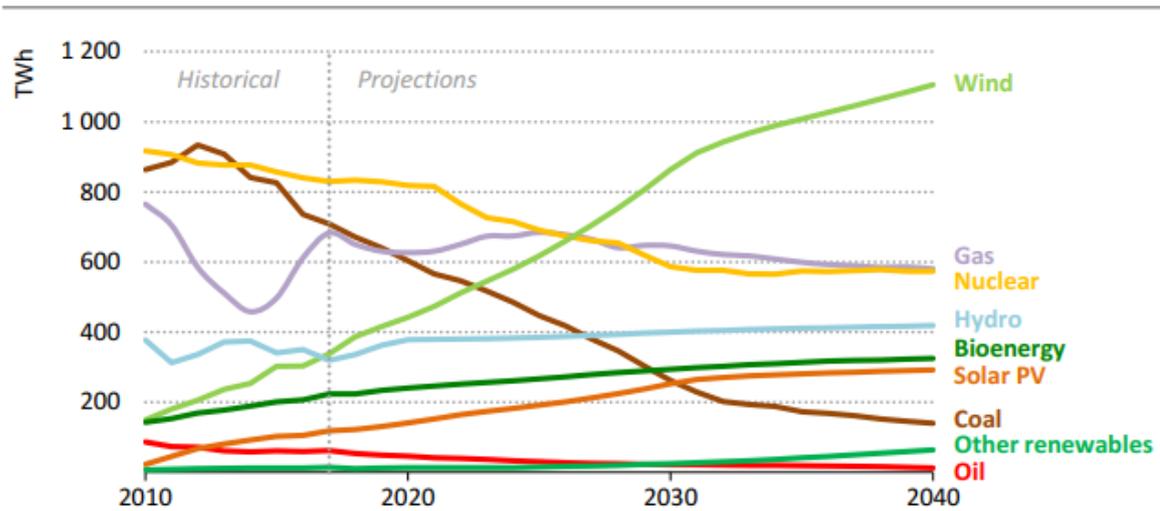


Figure 24 Electricity generation by source in the European Union in the New Policies Scenario (IEA, 2018)

The power grid and system flexibility market will become considerable in the coming decades (IRENA, 2021a, Figure 25). The Sustainable Development Scenario of IEA (2018) estimated that annual investment for hydropower will double between 2017 and 2040 (57 billion EUR in 2017 to 104 billion EUR in 2040).

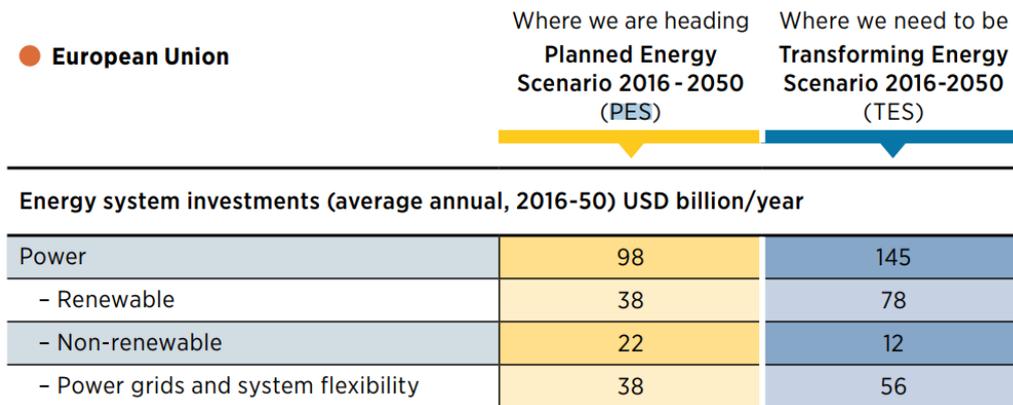


Figure 25 IRENA (2020) Global renewable outlook European Union (28 countries)

Europe has enough potential for pumped-storage capacity to cope with these needs for flexibility. A 2013 study by the EC Joint Research Centre estimated the potential for pumped-storage capacity in Europe (Gimeno-Gutiérrez and Lacal-Aránategui, 2013) and concluded that the European theoretical potential reaches **123 TWh in Europe, of which 60 TWh is in the EU**. When existing regulatory restrictions on the use of land are applied, the potential is reduced to a technical potential of 80 TWh in Europe, of which 33 TWh is in the EU.

The share of flexibility investment devoted to hydropower will depend upon the commitment of policy makers to reduce emissions to zero and to keep the expected temperature rise below 1.5°C.

The European Parliament is aware of the challenge and call on the European Commission to act:

“whereas the Commission estimates that the EU will need to be able to store six times more energy than today to achieve net-zero greenhouse gas emissions by 2050;

whereas pumped storage has accounted for more than 90 % of the EU energy storage capacity;

whereas pumped storage currently plays an important role for balancing electricity demand and supply, large-scale storage with a high round-trip efficiency and short and medium-term flexibility with a high range of capacity;

whereas the energy modelling used by the European Commission for assessing decarbonisation pathways and associated policy options is key as it determines future legislation and market design; whereas the current modelling significantly underestimates the positive impact of energy storage and therefore needs improvement;

the European parliament: a) calls on the Commission to develop a comprehensive strategy on energy storage to enable the transformation to a highly energy-efficient and renewables-based economy taking into account all available technologies as well as close-to market technologies, keeping a technology neutral approach to ensure a level playing field; and b) calls on the Commission to establish a task force involving all relevant Directorates General to develop this strategy which shall be based on a comprehensive analysis of:

- a. the **carbon footprint and life cycle**, taking into account at least the extraction and/or production of raw materials including human rights and labour standards, sourcing of components, the manufacturing process, transport and the recycling process, where applicable*
- b. the technology’s energy capacity, power capacity, storage duration, Capex, Opex, roundtrip efficiency and conversion efficiency;”* (European Parliament, 2019)

In the EU, existing coal-fired facilities will remain competitive as long as they are indirectly subsidised, while gas CCGTs will also continue to be attractive. The value of their contributions to system flexibility and adequacy, alongside other sources of electricity, means that the competitiveness of existing plants persists even as fossil fuel prices increase. In order to achieve environmental and climate-related objectives, government action is required to reduce the contribution of these assets (IEA 2018). **Policy makers, investors and planners would need to start thinking now about new projects, due to the longer planning cycles needed for hydropower dams.**

4.5 The benefits hydropower can provide to the Green Deal

The European Green Deal aims to transform the European Union’s economy, environment, and energy system, while improving prosperity and people’s well-being, through cleaner air and water, better health, and a thriving natural world.

Hydropower is the largest source of low-carbon electricity today. Hydropower, supplying clean, affordable and secure energy, supports the main climate and energy targets of the European Green Deal (Figure 26).

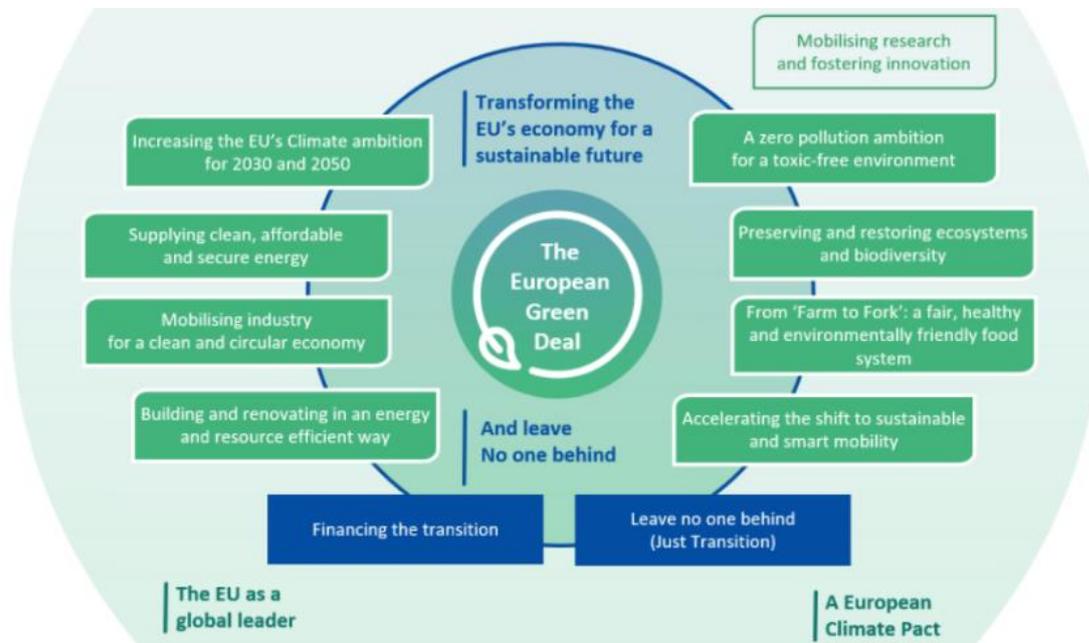


Figure 26 Targets of the European Green Deal

4.5.1 Hydropower contributes to climate change mitigation and adaptation

Achieving high penetration levels of renewable energy within the electric system by 2050, consistent with the Green Deal, would decrease the EROI of the global system from currently $\sim 12:1$ to between $\sim 3:1$ and $5:1$ by the mid-century. This would translate into a substantial energy over-demand reaching a peak of $+35\%$ during the transition towards a carbon-free economy. The increase in energy investments would imply higher primary energy consumption which in turn would intensify the issues of environmental impacts and resource depletion. Hence, if not properly managed, the transition to RES could imply a strong reduction in the net energy available for society. In relation to material investments, the RES deployment would exacerbate the risk of mineral availability in the future. In particular, the estimated cumulative extraction demand would surpass the current level of reserves for tellurium, indium, tin, silver and gallium. As a corollary, the results obtained put into question the consistency and viability of the Green Growth narrative (Capellan-Perez et al., 2019).

Several environmental indicators used in a global survey carried out by Ciraig (2014) demonstrate that **hydropower is the form of energy to use as much as possible to sustain the consistency and viability of the Green Deal**, threatened by energy overconsumption and mineral depletion. These indicators are:

- The Climate Change indicator (also called Global Warming Potential),

- The Ozone Layer Depletion indicator,
- The Energy Returned on Energy Invested.

The Climate Change indicator is related to lifecycle greenhouse gas (GHG) emissions into the atmosphere per kWh. Estimating the total quantity of GHG emitted over the lifecycle can be compared between each type of generation technology.

The CIRAIG (2014) study concluded that hydropower plants have the lowest Climate Change indicator of generation technologies in Nordic countries (Figure 27).

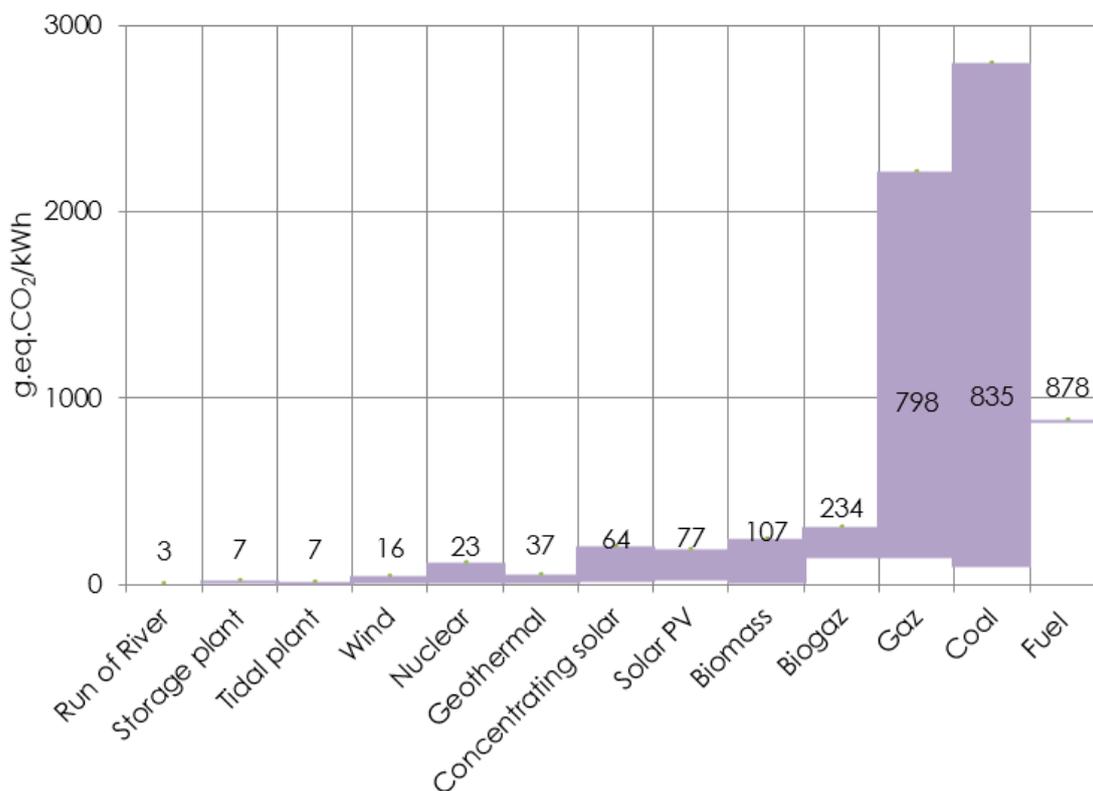


Figure 27 Comparison of the mean, min and max of the indicator "Climate Change" by technology (CIRAIG, 2014)

A global study of hydropower GHG emissions by IHA (2018) showed that the median life-cycle carbon equivalent intensity for hydropower was 18.5 gCO₂-eq/kWh. In comparison to other technologies assessed by the IPCC (2011), the GHG emissions from hydropower are lower than those of solar PV (48 gCO₂-eq/kWh) and slightly higher than those of wind (12 gCO₂-eq/kWh).

According to the CIRAIG study (2014), the typical range varies from 3 to 17 grams of carbon dioxide equivalent (gCO₂-eq.) per kWh in areas with the same latitude as in the European Union, mainly linked to the construction input in terms of concrete and steel. The upper range corresponds to the more common power plants with a storage reservoir, whilst the lower range corresponds to RoR installations. A more recent study by Bauer et al. (2017), also concluded that the carbon footprint of hydropower projects in Europe is the lowest amongst

all new renewable technologies such as solar and wind, as well as emerging storage technologies such as batteries.

The hydropower equivalent CO₂ emission is impressively lower than the average CO₂ emissions intensity of hourly electricity supply types in the European Union in 2018 (240 gCO₂-eq./kWh) and is also lower than the 2040 Sustainable development scenario (28-80 gCO₂-eq./kWh – IEA (2018) shown in Figure 28).

Average CO₂ emissions intensity of hourly electricity supply in the European Union, 2018, and by scenario, 2040

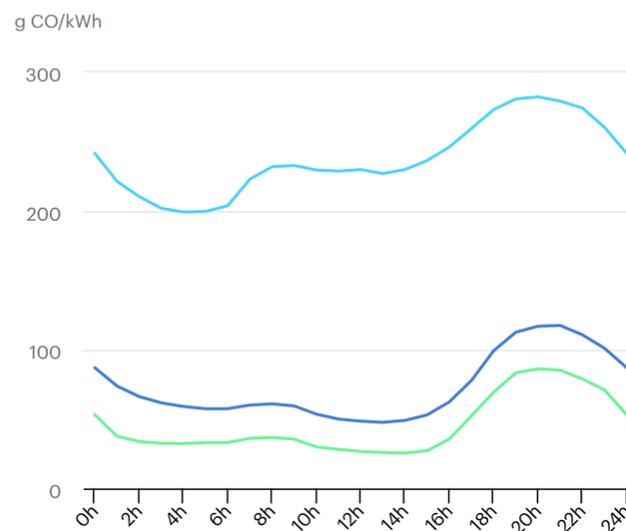


Figure 28 CO₂ emission in 2018 (light blue) and in 2040: Stated policies (dark blue) and Sustainable development scenario (green) source EIA, 2018)

The Ozone Layer Depletion indicator is related to the depletion of the stratospheric ozone layer, which results in an increase in ultraviolet (UV) radiation reaching the earth. The Ozone Depletion Potential (ODP) is measured in kilograms of trichlorofluoromethane equivalent (kg/kg CFC-11). **Hydropower is the resource which has the lowest impact on the stratospheric ozone layer** (Figure 29).

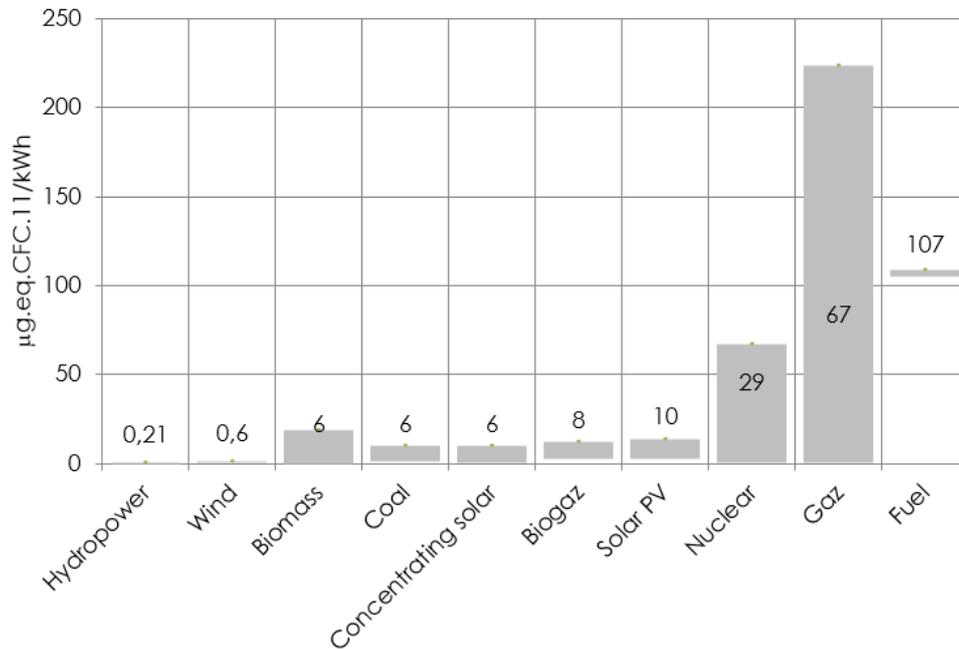


Figure 29 Comparison of the mean, min and max values of the indicator "Destruction of the ozone layer" by technology (CIRAIG, 2014)

EROI, also sometimes called the energy returned on energy invested (ERoEI) or recovery factor of energy or gain factor of energy and is the ratio of the amount of usable energy (the energy) delivered from a particular energy resource to the amount of energy used to obtain that energy resource.

Hydropower generation systems have the highest return on energy invested, with a mean EROI value of 82:1 (from 12 publications - see Figure 30), from electric power generation systems (Lambert et al., 2012).

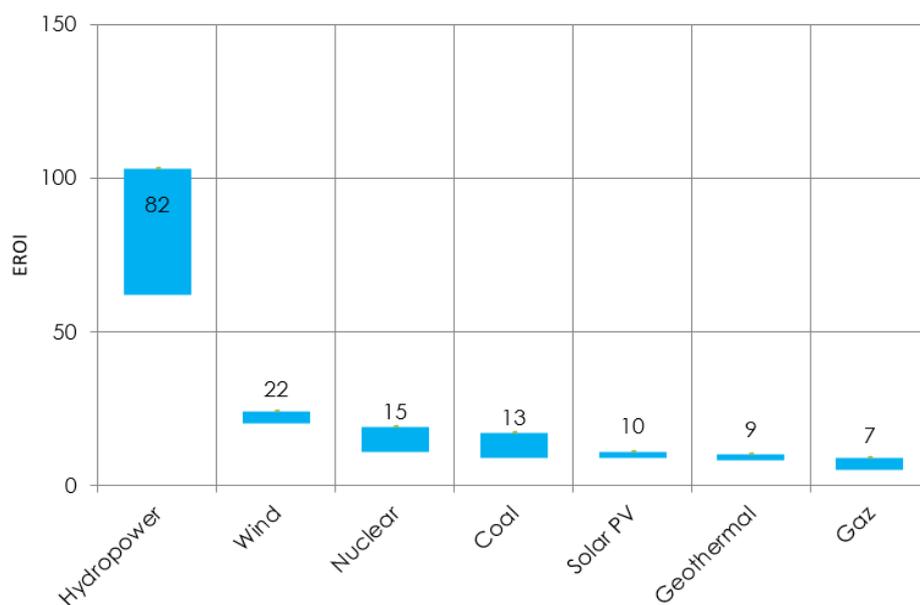


Figure 30 Hydropower has the best EROI (Lambert, 2012)

Most of studies found that hydropower generation systems have the best gain factor of energy (e.g. the Swiss study introduced by Schleiss (2018) Figure 31). It must be noted that the gain factors of wind and especially solar are improving considerably with time due to technological development.

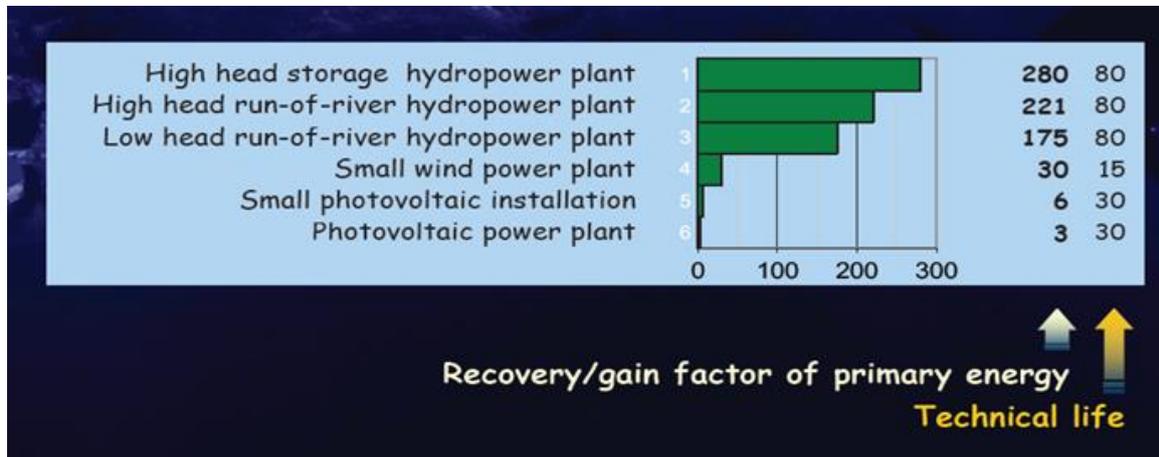


Figure 31 Recovery or gain factors for different electricity generation technologies (Schleiss, 2018)

4.5.2 Circular economy

One of the main blocks of the European Green Deal is the circular economy (EC, 2020). By decoupling economic growth from resource use, the circular economy will make a decisive contribution to achieving climate neutrality by 2050.

Hydropower has demonstrated its compliance with most sustainability principles and has the ambition to fully contribute to the 7 key elements of circularity (Figure 32).



Figure 32 The seven circularity principles (Circle economy, 2008)

Design for the future: Hydropower plants and dams have a very long technical lifetime, often exceeding 100 years. At the end of their lifespan, plants and dams may be theoretically

decommissioned and removed, allowing the site to regain its natural appearance. Whilst hydropower has impacts that are clearly visible during operational life, these are in general reversible, and sites could be restored. Nevertheless, after more than 100 years of operation hydropower schemes often become historical monuments and new rich biotopes are often created in the reservoir area.

Preserve and extend what is already made: Due to this very long lifespan, maintenance, surveillance and safety are key issues that have to be addressed continuously for improving durability, upgradability and reparability (ICOLD, 2017).

Prioritise regenerative resources: Among renewables, **Hydropower has the best Climate Change indicator, Zone Layer Depletion indicator and Energy Returned on Energy Invested indicator. Hydropower is also the best renewable energy for reducing pressure on mineral resources** (Figure 33). The Extraction of Mineral Resources indicator is measured in kilograms of antimony equivalent (kgeq.Sb) per kilogram extracted to take into account existing reserves, the rate of extraction and the "depletion" of each mineral substance (CIRAIG, 2014).

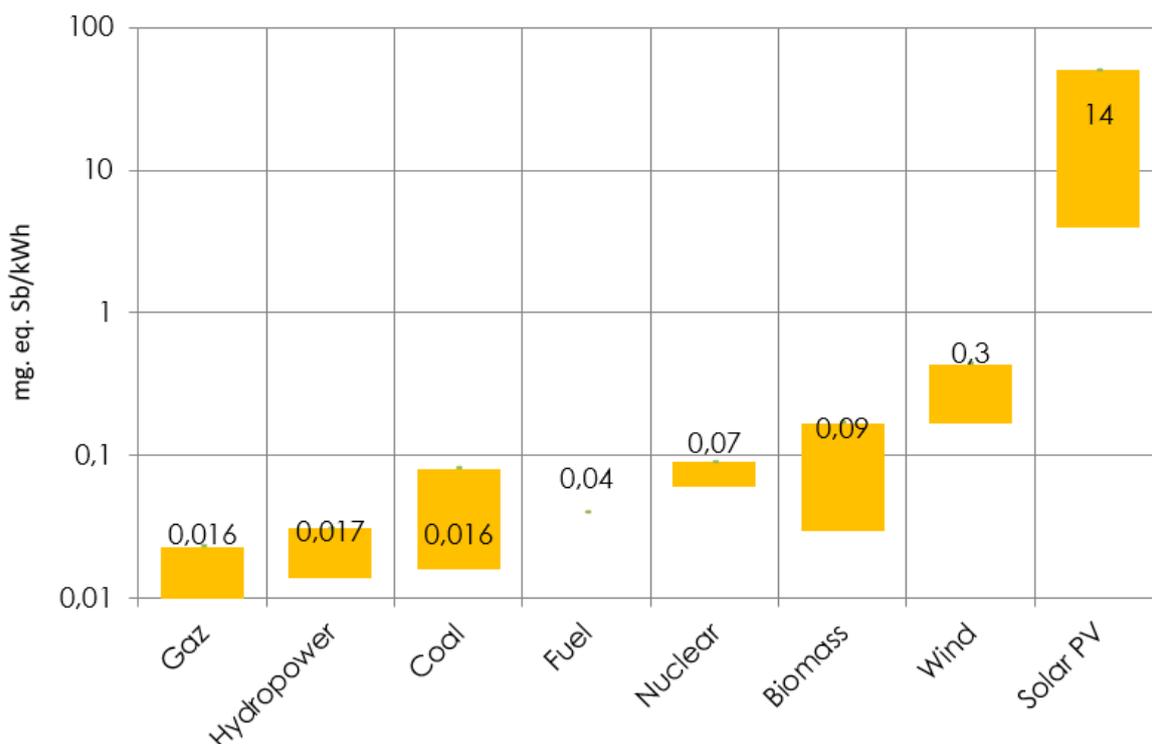


Figure 33 Comparison of mean, min and max values of the Mineral Resource Extraction indicator between generation technologies (CIRAIG, 2014)

Hydropower is the best renewable source minimising energy losses. Due to the high electricity conversion efficiency, which typically reaches from 85% to 95% (70% to 80% for

pumped-storage), hydropower minimises losses of energy and heat release in the transformation process.

Use waste as a resource: Hydropower plants can contribute towards cleaning rivers. The plants are equipped with trash racks and automatic cleaning machines, which remove floating debris including waste and garbage. This waste is then sorted and sent to waste disposal plants for recycling. Water is oxygenated at the outlet. Demolished or broken materials are sorted out and reused.

Incorporate digital technology: Digitalisation is increasingly implemented for optimising water and energy uses.

Collaborate to create joint value: Owners of multipurpose reservoirs are used to creating joint value from water and energy. Today, hydropower creates additional value working with solar PV and wind energies.

Rethink the business model: Hydropower is considering opportunities to create greater value with flexibility and water through business models that build on the interaction between services.

4.5.3 Sustainable development goals

The 17 Sustainable Development Goals were adopted by all member governments of the United Nations and provide a blueprint of priorities for national governments, multilateral organisations, business and civil society. It is outstanding to note that **hydropower can contribute to all 17 of these societal and environmental goals**.

When developed and operated responsibly, hydropower projects directly support the achievement of Sustainable Development Goals (SDG) 6, 7, 9 and 13 (Figure 34).

Sustainable hydropower plays an important role in helping to manage freshwater resources and provides affordable and low-carbon energy. Using hydropower instead of electricity produced from fossil fuels, we can mitigate GHG emissions and help combat climate change. Hydropower can also provide adaptation services for flood control. Hydropower modernisation and digitalisation supports SDG 9 in gaining efficiency, increasing generation output, extending auxiliary capacity and creating more resilient infrastructure.



Figure 34 Hydropower directly supports SDG 6, 7, 9 and 13 (IHA, 2018)

Hydropower projects can also contribute towards economic development, social investment and environmental outcomes which support goals 1, 2, 3, 4, 5, 8, 10, 11, 12, 14, 15, 16 and 17 (Figure 35).



Figure 35 Hydropower also contributes to the other SDG (IHA, 2018)

4.5.4 High value creation and exportation leader

The EU has a leading academic position globally in the hydropower sector, contributing to around 30% of the world's publications (Morris, 2018).

Hydropower creates significant value for the European economy and contributes to massive exports. On average, each employee in the European hydropower generation sector creates an annual value of more than 0.5 million EUR. This value is ten times more than in the construction sector.

Hydropower is also a considerable source of investment in the European economy. Hydropower is a capital-intensive generation technology and requires high long-term investments both for the construction of dams and hydropower plant infrastructure as well as for maintenance and refurbishment. The sector invests 8-12 billion EUR a year, of which 5-6.3 billion EUR is in the EU-28 between 2010 and 2013 (DNV GL, 2015).

As shown in Figure 36 the contribution of hydropower (including electricity generation, manufacturing and VAT revenues) to the European gross domestic product (GDP) is estimated to be about 38 billion EUR (EU-28, Norway, Switzerland, Turkey), of which 25 billion EUR is in the EU-28 (DNV GL, 2015).

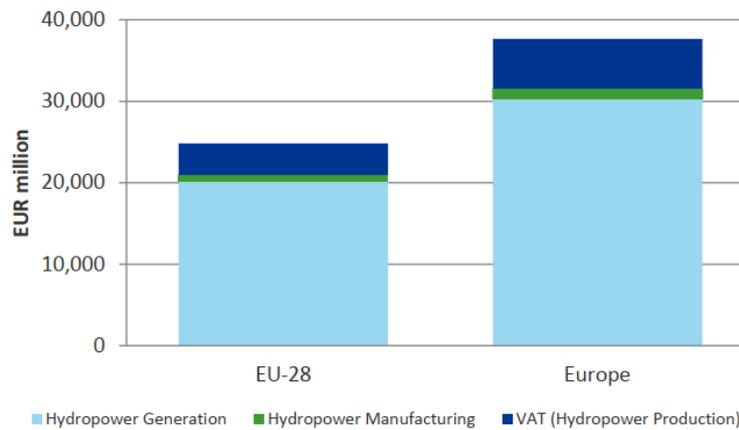


Figure 36 Gross value creation by hydropower generation and equipment manufacturing in 2013 (source: DNV GL, 2015)

Hydropower contributes to employment in Europe with more than 100 000 full time equivalent jobs (FTE) (Figure 37). Of these, more than 50 000 are directly related to hydropower generation (42 000 in EU-28), 7000 in manufacturing (5000 in EU-28) and the remaining part in other sectors providing external services to the hydropower sector, including operations and maintenance, planning, engineering and consulting.

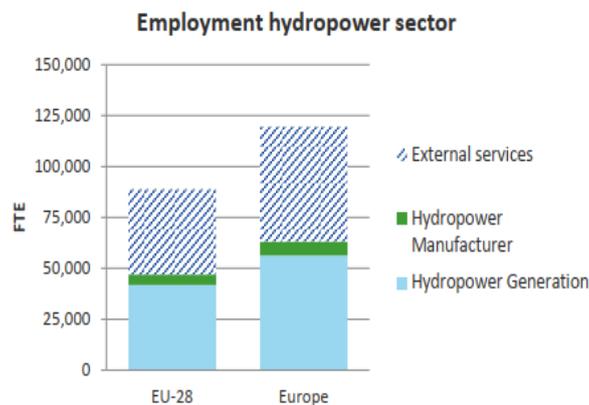


Figure 37 Employment in the European hydropower sector in 2013 (DNV GL, 2015)

4.5.5 Hydropower boosts regional sustainable development

Hydropower is not only a renewable, low carbon, cost effective, mature and long asset life technology, but **hydropower also provides for the sustainable development of European remote regions**. A lot of large hydroelectric plants associated with dams have a remarkably beneficial impact on territories where they are located.

They are reservoirs, which store a valuable natural resource, the water, and support its use for many economic services: irrigation and drinking water storage, sustainable transport, prevention of flood and drought, tourism, recreation and sport, fisheries, improvement of infrastructures etc.

But first and foremost, **hydropower is a money-maker for communities** near the dam and the power plant, not only producing revenues from electricity but also creating jobs and providing taxes and licence fees.

4.5.5.1 A historical pillar of the society

In contrast to other forms of energy, and particularly renewable energy, a key feature of hydropower is its strong link with social and industrial development. At the turn of the 19th century hydropower launched the global electrification of cities, in the middle of the 20th century it supported large-scale industrial development. Currently, in the 21st century, large hydropower schemes contribute towards integrated social development, in different parts of the world.

In that sense, the maturity of hydropower is not only its sound reliable technology, but also its support to regional development by the construction of infrastructure such as schools, roads, bridges. **Hydropower is the only renewable energy which can offer a large range of major additional services and multipurpose benefits.**

4.5.5.2 Financing resource for local communities

Hydropower is an economic sector providing a source of revenue for shareholders, water fees for public bodies and jobs for the local communities.

Hydropower projects play a significant role in accelerated GDP growth. A substantial share of generation revenues is transferred to the economy in the form of value added tax (VAT), local shareholder income, taxes and job employment.

Total revenues for governmental budgets amounted to more than 8 billion EUR for EU-28 or 14 billion EUR when also including Norway, Switzerland and Turkey. In other words, more than 32% and 37% of the gross value created by hydropower in the EU-28 and Europe respectively, are directly transferred to national or regional budgets (DNV GL, 2015).

4.5.5.3 Irrigation and drinking water supply

Hydropower provides important societal services. For centuries, South-East France for example, suffered from droughts and diseases such as the plague, due to water scarcity and a lack of hygiene. Solutions to these problems were sought for centuries. Only the Serre-Ponçon dam and the EDF Durance canal, which runs for more than 250 km, have managed to address the droughts and their associated impacts (Figure 38).



Figure 38 *Serre-Ponçon dam and the EDF Canal of Durance (Photo J-M Gaude)*

Hydropower reservoirs have always been used for water security and purposes consistent with the sustainable development goals. As hydropower stations are often located in rural areas, the water used by these power stations is usually shared and/or reused for irrigation and for aquatic ecosystems (Marsh & Sharma, 2007).

The GAP project (7500 MW Southeast Anatolia, Turkey) is an example of integrated regional development, based upon the construction of 22 large dams across a wide arid desert area. It now resembles a market garden. The irrigation of an area of about 17000 km² doubled Turkey's area of irrigable farmland. And there have been major improvements to the quality of life in the region. New crops have been introduced, and cotton production has vastly increased. Entrepreneur support and guidance centres opened to encourage investors to develop new agricultural practices. Training in animal husbandry was established. Special women's centres were created from the outset to help them develop new skills and to develop cottage industries. Previously they would have been confined to housework (Bartle 2021).

4.5.5.4 *Sustainable transport*

Rivers act as a key source of economic activity: from trade to agriculture and energy, as well as many other activities that can be developed along a water course. The history of the Rhine River is a good illustration of this relationship between mankind and rivers, which is too often forgotten.

At first a wild river, like the Rhine, meandered between marshlands bringing malaria and catastrophic floods that cut off villages up until the 19th century! Populations then protected themselves by building reliable levees (19th century). These helped provide better protection and also increased the agricultural surface area, whilst on the other hand the water flow rate

and erosion issues increased making navigation impossible in some places. To solve this, the Rhine was first channelled by rows of groins and then by a wide canal, which was financed by hydropower (20th century) (Figure 39). The canal reduced the transport of solids and sediments but also increased the risks of floods. Polders were built to slow down the flooding, and water releases were made more frequent to revitalise sediments; reserved flows with fish ladders (side rivers) were added to improve ecological transfers (21st century) Figure 41).

From this history we learn that the symbiosis between people and the river goes through three phases. First is providing protection against dangers from the river, second is exploitation of the river potential (for navigation, irrigation, energy, water supply, industrial water, recreation) and the third and final phase is preservation of the river ecosystems.

Hydropower development has led to the taming and controlling of stretches of some of the world's major waterways, making otherwise wild stretches of river navigable, and hence providing the opportunity to increase waterborne transport and enhance national and regional development. A recent example in Europe is the harnessed Douro River with a total of 15 dams and hydropower plants which have been built on the 900 km long Douro, which flows through Spain and Portugal on the Iberian Peninsula. Vessels up to 83 m long can now pass through the locks, and the highest lock, at Carrapatelo dam in Portugal, has a maximum lift of 35 m. The Douro is especially important for the transport of agricultural produce, and of course the famous Port wine, but also for tourist boats (Bartle, 2021).



Figure 39 Navigation locks coupled to a hydropower station on the Rhine River (Photo EDF)

Compared with road and air transport, shipping stands out as the best performing considering CO₂ emissions (Figure 40).

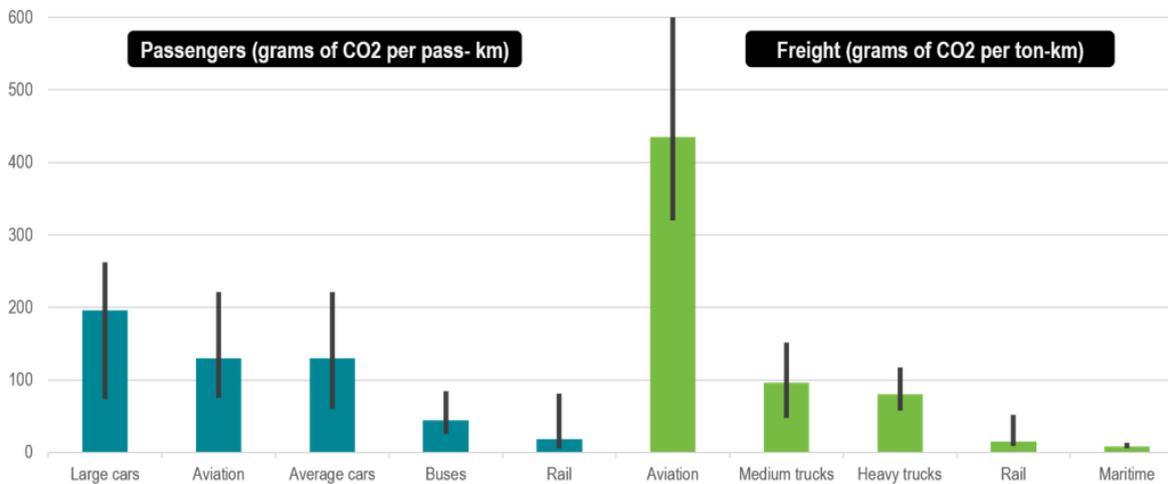


Figure 40 Average CO₂ Emissions by Passenger and Freight Transport Mode (Rodrigue, 2020)

4.5.5.5 Prevention of floods and droughts

Flood control is provided by the ability of dams and reservoirs to retain water during floods. With adequate warning, they can also release water in advance and store additional volumes during extreme floods.



Figure 41 Polder of Moder on the Rhine River stores water during floods (Junod & Rothan 1996)

Drought can severely affect the ecosystem and agriculture. Many dams and their associated reservoirs supply additional water to mitigate this detrimental impact.

4.5.5.6 Tourism and sports

Water bodies provided by many reservoirs often allow some form of recreational use such as swimming, windsurfing, fishing, sailing, water-skiing, canoe, and kayaking (Figure 42). These activities are increasingly important for people living close to the reservoir and can also attract tourists to the site.



Figure 42 Sailing on Lake Monteynard in the French Alps (Photo EDF)

4.5.5.7 Fisheries and creation of spawning grounds

In addition to recreational fishing, some reservoirs created by dams support commercial fisheries. As a result of intensive fishing in oceans, the development of commercial fish farming has also recently increased.

Creation of spawning grounds is implemented through fishers-owners partnerships. Guillaud (2003), Vice-president of the National Union for Fishing in France, describes actions for the preservation of aquatic habitats:

- creation of spawning grounds, for trout or pike for example, as well as for operations of improvement of the fish habitat.
- diversification of too uniform flows by the installation of riprap in order to increase the surfaces favourable to the reproduction of fishes.
- renaturation of watercourses allowing the crossing of obstacles (dams, weirs) by fish.
- restoration of aquatic ecosystems following certain climatic catastrophes.

4.5.5.8 Improvement of local public infrastructure

The realisation of a hydroelectric development requires good transport infrastructure. A new project often presents the opportunity to rebuild the road network at the beginning of the project, if sufficient in size, or at the end of the project, if roads have deteriorated. Bridges and roads are therefore built or consolidated alongside hydropower infrastructure activities. It is also an opportunity to build residential housing when workers are assigned to hydropower projects in remote areas, as well as local schools and other social infrastructure that can be left to the local communities after project construction finishes.

4.5.5.9 Shared use of reservoirs

The shared use of all reservoirs (single or multipurpose) in Europe is shown in Figure 43. Within the 3319 reservoirs in Europe (and 2326 in the EU) without hydropower plants, there is certain potential for ‘hidden hydro’ at non-powered dams.

Legend:

- C = Flood
- F = Fisheries
- H = Hydropower
- I = Irrigation
- S = Water Supply
- N = Navigation
- R = Recreation and tourism
- T = Tailings
- X = Unknown or unclassified

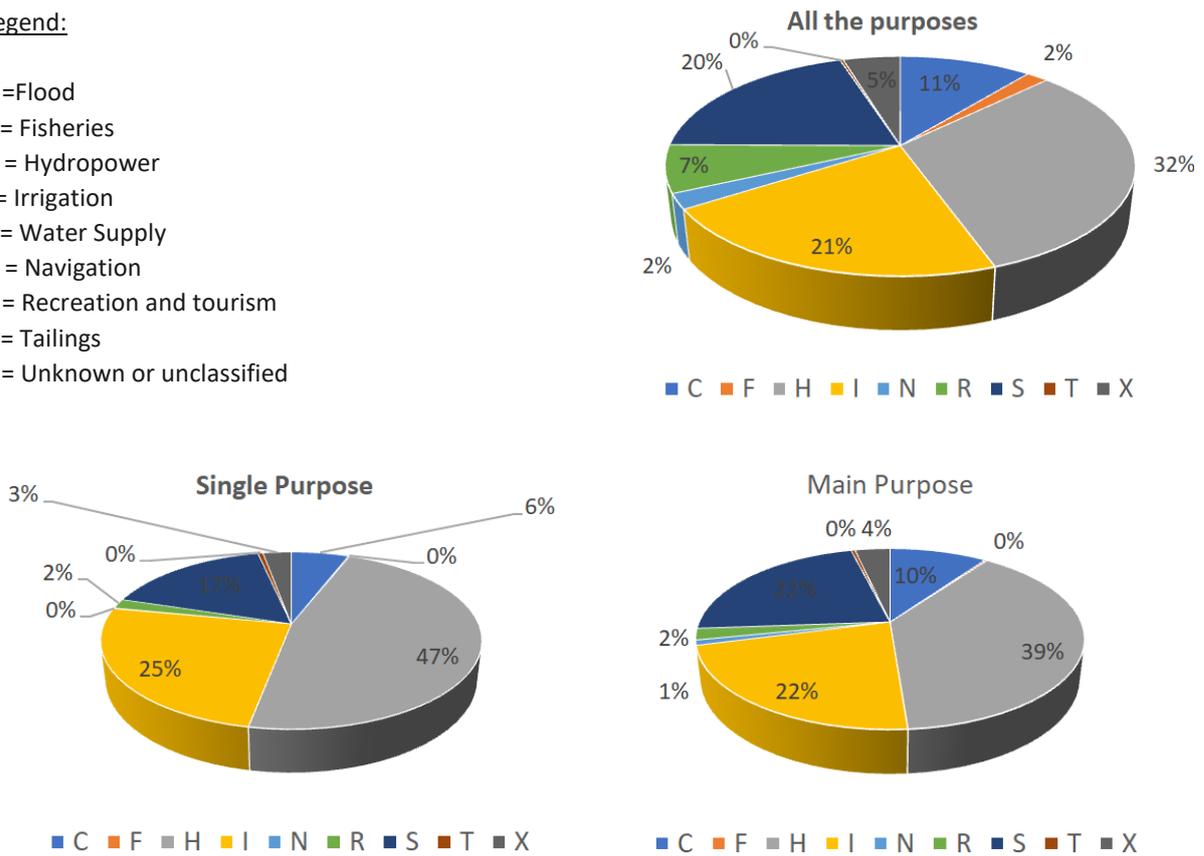


Figure 43 Share of reservoir uses by purpose in Europe (ICOLD, 2020)

4.5.6 Hydropower is the largest contributor to flexibility

Hydropower is the most flexible power generation technology which can be used to balance and store electricity generated by intermittent and non-dispatchable renewable sources. Hydropower supplies around 90% of global flexible dispatchable capacity.

Hydropower will provide an essential link for integrating wind and solar within the future carbon-neutral power system. No other single renewable electricity technology can offer all of these benefits and services (Figure 44).

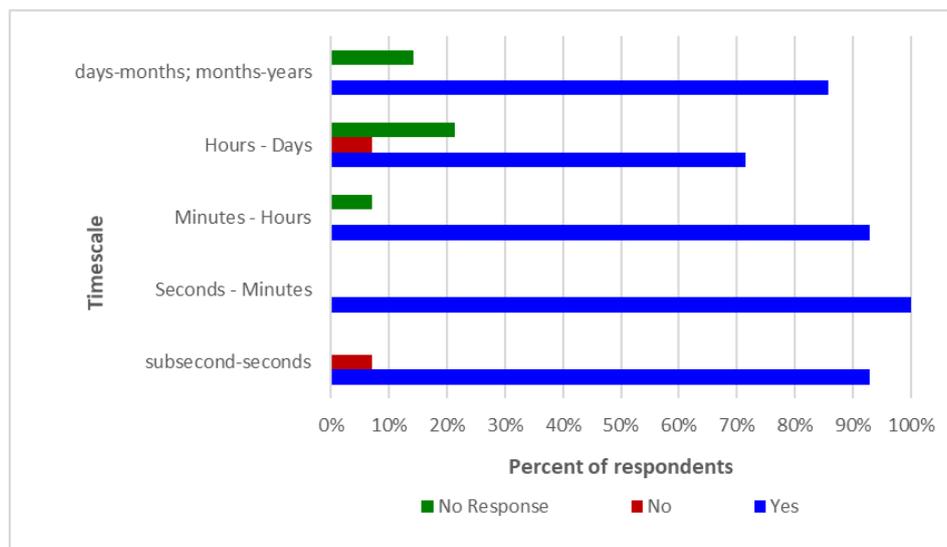


Figure 44 Percent of respondents to the question of whether hydropower provides flexibility services across timescales (IEA, 2021)

The European Commission wants to develop the four main flexibility sources that include dispatchable supply, grid connections, storage and demand side management.

The advantages of hydropower are:

- **Contribution to two main flexibility sources: dispatchable supply and storage.**
- **Reservoir hydropower plants are usually the most cost-effective option to provide flexibility on the supply side in many power systems (IEA, 2021).**
- **Pumped storage hydropower (PSH) is the only reliable commercial option for long duration storage and the most cost-effective option for very long-term investment (Figure 45).**

4.5.7 In conclusion - hydropower is a pillar for the net zero power system

The hydropower sector considers that the value of hydropower is high and will get higher with the deployment of intermittent and non-dispatchable renewable sources, because of the auxiliary services that it can provide to the grid. As a result, the World Bank and many other financing institutions back the sustainable development of hydropower.

Finally, hydropower is key for implementing the Green Deal:

- **Hydropower is key to reaching the Paris Agreement climate targets.**
- **Hydropower is essential for facilitating the integration of intermittent and non-dispatchable renewable energy.**
- **Hydropower has a key role to play in improving regional integrated water resources management, mitigating and adapting to climate change.**

4.6 Challenges and solutions for future deployment

This section analyses the main challenges that hydropower faces in its deployment. As the remaining hydropower potential is significant, the potential capacity for storing VRE surplus is tremendous. However, the commissioning of new hydropower capacity is years behind schedule (IEA, 2020). How can we explain that hydropower, so useful for the Green Deal (see Section 4.5), is not better deployed in Europe?

Electricity is increasingly the “fuel” of choice for society, but a dramatic transformation of the power sector is underway. Innovative technologies are disrupting traditional ways of producing, transporting and storing electricity, creating opportunities for new actors and business models.

Ensuring the reliable and secure provision of **affordable electricity, whilst meeting environmental goals, is at the heart of the 21st century economy** and is increasingly a central pillar of energy policy making (IEA 2018).

The renewable energy revolution does not signal an end to hydropower development, but a significant shift in its role.

- On the one hand, low-impact hydropower plants, which provide storage capabilities and flexibility, could become an important component of the world’s transition to deploying considerably more intermittent renewable energies (WWF, 2018).
- On the other hand, hydropower development based on the careful application of hydropower sustainability assessments and the rise of reliable alternatives should diminish the need for high-impact dams.

In Chapter 3 (the hydropower system analysis...), two main critical factors influencing hydropower development in Europe were identified: **Generation Flexibility**, which is an opportunity (see Section 5.3) and **Public Awareness**, which is the first challenge (including Benefit Sharing Local Communities and Population Relocation). For example, hydropower potential in the Balkans faces environmental and social opposition, particularly where proposed schemes are seen more as a problem than a solution, due to the lack of information, public participation and benefits sharing (HPE, 2021b).

In Chapter 3 it is quoted that **Environmental Mitigation Measures** is one of the two controllable active factors which have a very high activity, and which can be considered also as the second highest challenge, including, Environmental Flow.

Main barriers to large deployment comprise **Electricity Market Conditions** with low price associated to increasingly high installation costs, strong volatility and no long-term visibility and **Social and Environmental Acceptance**.

These barriers create challenges whose solutions are introduced in the following sections.

4.6.1 Investments and new business models

4.6.1.1 *The current lack of investment in Europe*

Much of today's European hydropower fleet was developed before the opening of the European power market. Many hydropower projects in the European Union have been abandoned over the past 20-30 years or completely stopped, because of a lack or unpredictability of return on investment. Some projects remain incomplete due to a lack of funding (Romania, Greece).

Investments in hydropower have been decreasing in Europe due to several barriers against the development of hydropower projects. These include:

1. the low prices of the European electricity spot market (prices remaining below 40 EUR/MWh for prolonged periods);
2. preferred investments in wind and photovoltaic generation; initially triggered by favourable support mechanisms (subsidies), and now fostered by continuously decreasing costs;
3. unclear economic perspectives for hydropower projects, including high revenue risks in long-term investments associated with strong volatility and uncertainty, discourage investments, particularly given the expected long lead time and pay-back time;
4. the most economically feasible hydropower potential has already been developed to date;
5. the lengthy permitting process, lengthy environmental impact assessments and lengthy construction process, which in the case of large hydropower plants, can amount to 10 years or more and which are often prone to delays.

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, hydropower was in competition with fossil fired thermal plants. Since, the decarbonisation policy has led to decommissioning of fossil fired plants, a **new energy system** where renewable energies sources (solar, wind, water) will be developed, **needs a new appropriate market model**.

Consequently, most current investments made by the leading European hydropower stakeholders are directed outside of Europe, under contractual mechanisms securing long term revenues.

A second challenge is the limited payoff in today's markets of HP flexibility. This **lack of compensation for many flexibility services** is called: **"the missing money problem"**. In France, the missing money problem for flexibility could reach 2.2 billion EUR in 2050 (FHE, 2020). The shortest timescale controls (<15 min) in particular need more compensation, and the incentives for long-run investments are currently limited (long duration flexibility under extreme climate is ignored).

A **new market design** based upon a **sound economic model** is absolutely critical to investment and to address the flexibility needs inside Europe.

4.6.1.2 *The need to increase CO₂ cost*

To increase hydropower investment inside Europe requires an efficient market model suited to the carbon neutral energy system where flexibility and storage are properly valued.

The EU greenhouse gas emissions trading scheme (ETS) was created in 2005. It should have had an impact on fossil-fuel power plant generating costs and would have improved hydropower competitiveness to the extent that carbon prices would have reached a relatively high level. In fact, they were only high enough to have an impact on the electricity market in the first phase.

Given that the carbon price will no longer have any impact on the price of electricity after 2050, in the post-fossil era, and given that the future market development is uncertain and that low price trajectories cannot be ruled out, the development of global fuel prices and of the European Emission Trading System are of central importance (WWZ, 2019).

The CO₂ market price (EU Emission Trading System) needs to undergo a step change, in accordance with the EU's strong commitment to reach carbon-neutrality by 2050.

Hence a **CO₂ cost that truly aligns with its social and environmental impact is yet to be realised**.

4.6.1.3 *A large consensus to redesign the electric market*

There is a large consensus concerning the necessity to re-design the electric market, due to:

- the missing money problem (Joskow, 2006);
- the decentralisation of the electric system: “Market design rules will need to be updated to incorporate the growing move towards decentralisation” (WEC, 2019);
- the production of large amounts of intermittent renewable energy: “the presence of distributed energy resources and large amounts of renewable, zero-marginal cost resources may require additional upgrades to nearly every aspect of these markets” (MIT, 2016);
- the need for flexibility: “the current regulatory framework needs a robust overhaul in order to deliver the needed price signals to trigger investments in capacities and to enhance flexibility” (WEC, 2019). “Changes in policy and regulatory frameworks, as well as economic incentives, are essential to ensure timely investment in flexibility assets and to make the most of the flexibility potential of existing power plants (IEA, 2018);

ENTSO-E comes to the same conclusions (ENTSO-E, 2018b).

Hydropower needs a **new market model**. The main issue will be to switch from an energy market, based on fuel costs, to a market with investment signals suited to CAPEX dependant, low-marginal cost and environmental indicators for renewable technologies.

4.6.1.4 Need for long-term Power Purchase Agreement

In the current context, electricity prices will be driven by the stabilisation of power demand, the development of solar and wind generation, the reduction of their costs, the development of interconnections, and the provision of additional flexibility and back-up generation to support the grid. **The power market**, which has been designed in a situation of over-capacity, without VRES nor carbon pricing, with its on-going evolution of new products (such as “capacity market”), **does not give an adequate and stable long-term signal**, that is necessary for the development of long lead-time and long pay-back projects, such as for hydropower generation.

Capital costs form between 80 to 90% of levelised costs of energy (LCOE) and the remaining costs are limited to operation and maintenance (O&M), which on average, amounts to about 2% of the initial investment cost annually (IEA, 2021). Hydropower is penalised by ignoring the long life of the asset in the LCOE. Therefore, a **low weighted average cost of capital**, (WACC) model is a good lever in providing the expected return on investment (Figure 45).

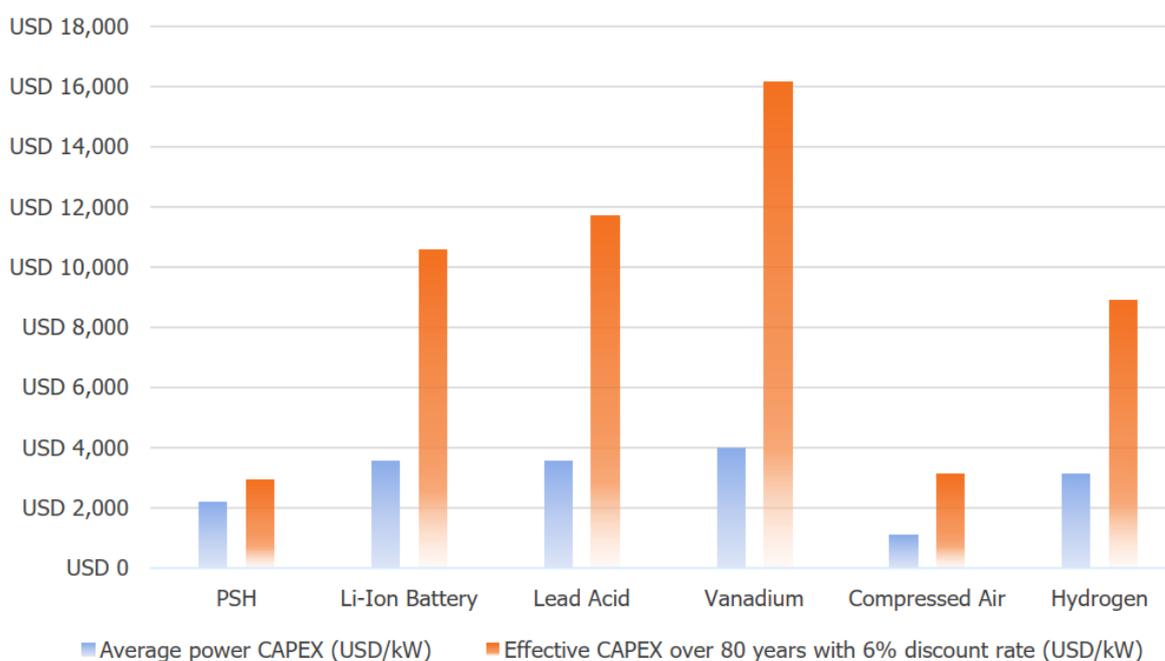


Figure 45 Comparison of effective lifetime costs of energy storage technologies over 80 years for 10-hour duration and 2020 options (IHA, 2021)

*Source: US DOE, 2020 Grid Energy Storage Technology Cost and Performance Assessment.

** : considering the value of initial investment at end of lifetime including the replacement cost at every end-of-life period (thanks to Slocum@MIT)

When considering all strategies for energy storage, Israel has selected pumped storage hydropower remunerated with a long-term Power Purchase Agreement.

EU and Member States should consider long term Power Purchase Agreements.

4.6.1.5 Need for innovation

Innovation is necessary to fulfil the increasing demand for ancillary services that arises with the phase-out of conventional fossil fuel and nuclear power plants as well as increasing RES. To compete with other sources of flexibility, existing hydropower infrastructure must adapt to the flexibility market.

A contribution of innovative solutions adapted to the new market model is required.

4.6.1.6 The need for balancing environmental protection and climate friendly energy

The European Parliament (2019): *“notes with concern that there is only an indirect reference to energy storage projects in the Guidelines on State aid for environmental protection and energy 2014-2020”*.

It is well known that increasing the storage capacity of the hydropower fleet, as well as its capacity to produce and absorb peak energy, will contribute to enhancing the flexibility of power systems and help integrate a higher share of intermittent and non-dispatchable renewable sources and will only be done through compliance with environmental requirements, and negotiations to solve conflicting interests.

To do this successfully, we have to refer one more time to the European parliament (2019): *“underlines that it is important to ensure **a level playing field for all energy storage solutions** in line with the **technology neutrality** principle in order to allow market forces to drive the best choices of technology and foster innovation, and that the **main factors** having an impact on the development of different technological solutions should be indicators of **energy consumption, carbon footprint and costs of the production, exploitation, recycling and decommissioning**”*.

4.6.2 Regulation

The energy market is a regulated market and governments have to be involved. Regulation should recognise the value of green flexibility.

4.6.2.1 A level playing field for all energy solutions

Up to now, the European energy system based on renewable resources, supporting the Green Deal, has been accelerated with subsidies. Now the market has come to a point where these technologies compete well with hydropower. Thus, the European hydropower industry deserves a place in the SET plan and future research plans, making sure that Europe gets the most out of the services and in particular, flexibility, that it can offer.

Tax policies need to be revised to secure a level playing field amongst all electricity generation technologies.

Furthermore, whilst European policy promotes some level of energy independence, vast amounts of subsidies have been directed to solar industries outside of Europe, **making Europe largely dependent on imports**. In contrast, the business case for hydropower remains exposed to the uncertainties and volatility of energy market prices, with only a marginal part of their

revenue secured from the capacity market, with a visibility of a few years ahead. These conditions discourage any new CAPEX-intensive investment with long pay-back periods.

In addition, although hydropower is one of the appropriate tools to meet all large needs for additional flexibility after 2030, there is no long-term price signal favourable to the development of new hydropower generation. Moreover, storage and flexibility are negative externalities of VREs, mainly addressed by hydropower, but not at the right cost. Externalities are not compensated by the market; they are only controlled by regulation. Consequently, public regulations are crucial to properly address the costs of these externalities.

The current situation results in an unfair preference for investments into solutions with short lead times (e.g., batteries), compared to investment into technologies with longer lead times (e.g. hydropower generation), that deliver the benefits needed and capacities required by the system.

4.6.2.2 *Abolishment of double taxation for pumped storage hydropower*

The European Parliament (2019) *“point out that most Member States require operators of storage facilities, including active consumers, to pay network charges or energy taxes and other levies twice; is convinced that the abolishment of this burden would lead to more energy storage projects being deployed; calls on the Member States to abolish any kind of double taxation by developing efficient taxation schemes and redesigning charges related to energy storage in a way that the societal benefit from storage is reflected and barriers for storage projects to access the market are removed”*.

Many pumped storage hydropower projects are penalised by double taxation.

4.6.2.3 *Revision of the Energy Taxation Directive*

The European Parliament (2019) *“calls on the Commission to differentiate between end-use and storage or conversion and to develop an efficient taxation system prohibiting double taxation related to energy storage projects in its upcoming proposal for a revised Energy Taxation Directive”*.

The share of hydropower value between Asset Operator and State is no longer suited to the new energy world. It is a legacy of the past when hydropower was in competition with fossil fired plants. Civil society is currently benefiting from hydropower services, whilst it subsidises solar and wind and still even coal. This leads to market distortion and changes of merit order which strongly penalises hydropower at the moment.

For hydropower to continue to provide civil society and governments with a sustainable energy supply and cash flow for decades to come, governments must ensure a stable regulation framework. This framework should promote green power with a fair price, tax policy and subsidy model designed for a level playing amongst the different technologies (European Parliament, 2019).

4.6.3 Social awareness

4.6.3.1 Overview of public opinion on hydropower

For over a century, up to the 1980s, large dams and hydroelectric plants were considered as a basis for industrial and social development across the world. They provided clean energy and water. They helped develop local industry, agriculture with irrigation and employment. In the post-war years, they have boosted national economies and triggered resettlement without great concern, as they were required to progress and improve the livelihoods of many populations. Little was known about the environmental impacts.

At a turning point in the 1980s, the drive of some countries to appropriate the benefits of hydropower as quickly as possible, led some projects to fail to take sufficient account of the aspirations of local communities and to also not take the necessary measures to protect the environment. Consequently, the resettlement of local people and the environmental impacts became a major controversial issue. Political NGOs began to organise demonstrations and campaigns. Based on social and environmental issues of some critical historical cases, they claimed that dams were ineffective, damaging or unsafe.

There were some cases where it became clear that protestors were mobilising local people to protest against their will, as they could foresee the benefits, and the possibilities for compensation and employment. There were some ironies, in that the most active organisations, speaking with the loudest voices to condemn developments were from relatively developed parts of the world; they had heating in the winter, refrigeration for food and medicines in the summer, and of course clean drinking water supplies. They offered no feasible alternatives for water and energy supplies to the developing world (Bartle, 2021). This era culminated, at the turn of the last century, with a report issued by the World Commission on Dams (WCD, 2000), which was generally critical about dams, and quoted a few major cases from the distant past implying that no progress had been made since then. Again, no alternatives were offered to supply billions in the developing world with clean water and energy (Bartle, 2021). Following this report, even financing institutions such as the World Bank questioned the benefits of hydropower and significantly decreased investment in the sector. This provoked anger from the governments of most developing countries.

The situation has improved over the past 15 years. Professional associations, such as ICOLD, IEA, IHA, ICID, the Banks and the European Parliament committed to support sustainable hydropower and dams and made efforts to present more balanced information about the role of water infrastructure and hydropower plants.

The European parliament (2019) ***“Deeply regrets that infrastructure or larger storage projects which are crucial to the energy transition often face strong resistance and delays at a local level; encourages the Member States to actively encourage public support at the local level, for instance through early public participation, by enabling local communities to engage, financially participate or to be compensated, and close cooperation between sectors”***.

4.6.3.2 *The lessons learnt from unsuccessful projects*

Increased concern over the preservation of biodiversity and the questionable impacts of a few projects are two major reasons which have resulted in a loss of confidence by some stakeholders (WWF, 2020). To avoid repeating these errors, and the conflicts they have generated, a NGOs' roundtable was organised (HPE, 2021b) to identify them clearly.

Five types of conflicts (as illustrated by the case studies in Annex B) are the following:

- I. Type 1 - Generation losses in accordance with laws on nature protection.
- II. Type 2 – Projects not in accordance with laws on nature protection.
- III. Type 3 - Authorised projects stopped or attacked by continued activity of environmental or local activist groups.
- IV. Type 4 - Conflicts related to inter-basin water transfer.
- V. Type 5 - Questioning the efficiency of environmental legislations.

The five types of conflict differ, and each requires specific attention:

- I. In the EU, legally mandatory actions and the Water Framework Directive (WFD, EU 2000) are enforced. Hydropower plants in EU and EFTA countries must comply with the provisions of the WFD and plant owners have to and are continuously investing in environmental mitigation measures. Beyond legally mandatory actions and implementation of the WFD, investors can rely on best environmental practices, practical tools like the Hydropower Sustainability Assessment Protocol (IHA (2020) or other best Hydropower Sustainability Tools) and taxonomy supporting these best practices.
- II. In non-EU countries of the Western Balkans, some foreign investors have made profit from the absence of strict environmental legislation. The lack of enforcement measures by authorities is the problem. A sustainable hydropower project with the necessary ecological measures addressed at the site is the long-term solution.
- III. In cases where the project complies with legislation and has received its environmental licence, some groups of environmental activists can take a dogmatic stance. Short-term discussion does not advance positions. Investors lack the dialectical tools to change the dogmatic position: practical tools to implement life cycle analyses and compare all kinds of impacts and the energy recovery factors from alternative solutions should be very useful.
- IV. In cases where the negotiation is lengthy because it involves many stakeholders, it is advisable that the discussion be anticipated and framed by a national or international regulation that would be the result of negotiation at national level by high-level representatives of all stakeholders.
- V. In the case of questionable legislation, there are indeed aspects of the law that leave room for negotiation and interpretation. This is the case for the ecological flow and ecological continuity. Targeted scientific research is needed.

Although some of the previous issues can be solved, it is difficult to imagine a "new deal" for the full exploitation of hydropower potential in Europe, since there are not only

environmental and social barriers, but economic barriers as well. Economic and environmental pressures will continue to close the least profitable and least environmentally friendly plants.

What can be reasonably expected in the future is to **promote actions for the development of hydropower generation in connection with other renewable sources** (wind and solar essentially, and hydrogen later), the protection of the environment and water supply.

4.6.3.3 Tools for better sustainability

Several tools and methods have been developed to improve hydropower sustainability. For instance, a multi-stakeholder forum formed by the hydropower community, representative of environmental and social NGOs together with financing institutions and governments developed the Hydropower Sustainability Assessment Protocol (IHA, 2019a. Figure 46).

Launched in 2010, the HSAP facilitates social acceptance of new projects, supports shared benefits between different stakeholders and reviews sustainability issues. It also prepares clients to meet financing institutions requirements, reducing risk to investment and facilitating access to finance (IHA, 2020b).

New guidance has recently been published to support project developers and operators in achieving good international practice such as the “How-to Guide on Erosion and Sedimentation” (IHA, 2019b) and the “How-to Guide on Hydropower Benefits Sharing” (IHA, 2020b).

Climate change has put pressure on resources and creates further obstacles and social division amongst stakeholders. Hydropower is no longer considered only as an electricity production asset, but also as part of a global water management strategy, which contributes to regional development (agriculture, drinking water, local economy), particularly in the context of climate change to support other water uses. For this reason, the HSAP was updated in 2018 to include a topic on climate change resilience and mitigation to assess hydropower plants.

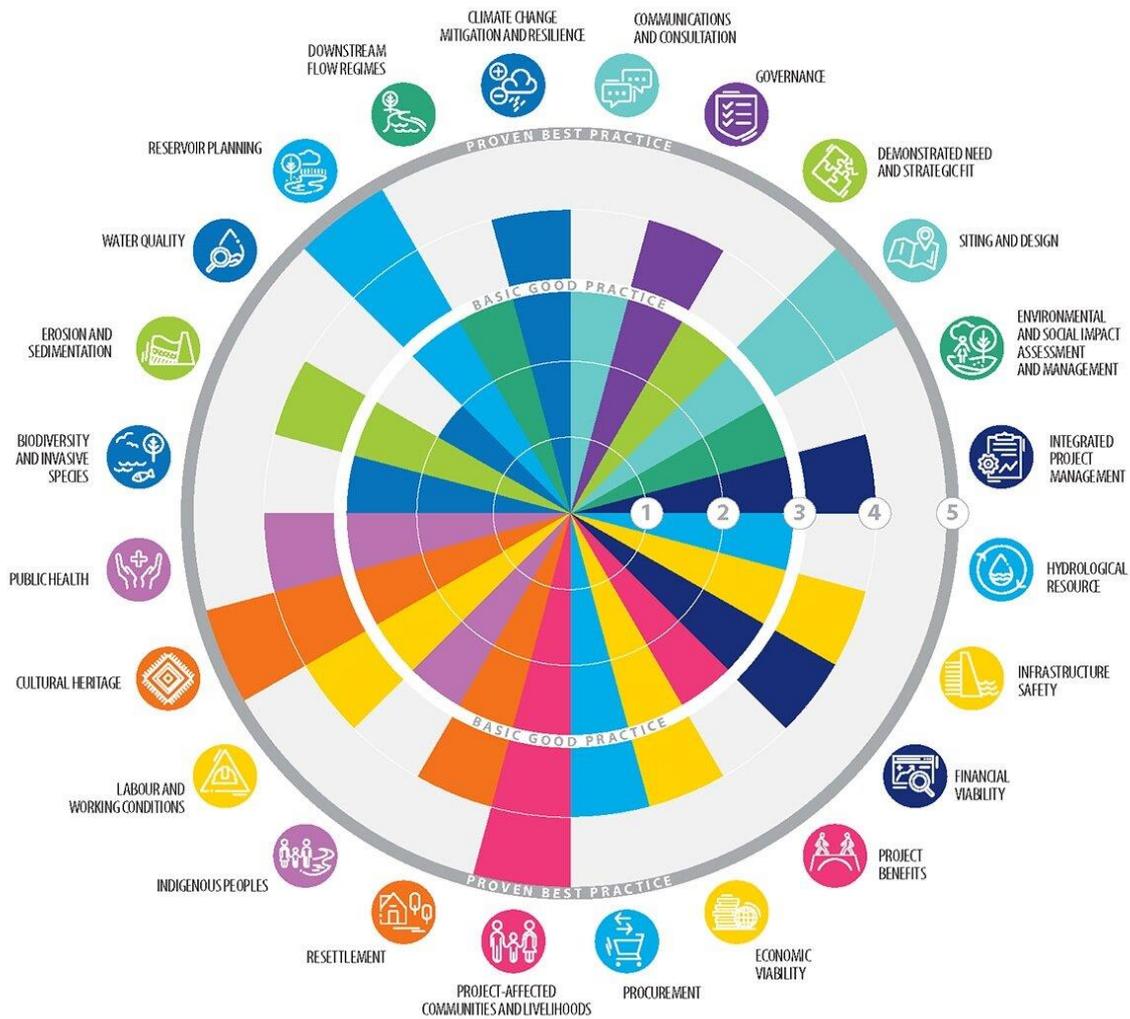


Figure 46 Assessment of an HSAP assessment result – a Sustainability Profile (IHA, 2019a)

4.6.3.4 Communication

Even though the hydropower sector is represented by a lot of associations internationally and within Europe (EASE, EREF, Eurelectric, IEA hydro, IHA, ICOLD, VGB, amongst others), the definition and communication of its research and innovation needs in Europe has not been undertaken recently.

One reason for this could be the cessation of activity of the Hydro Equipment Association (HEA) as well as the European Small Hydro Power Association (ESHA). In this context, the **HYDROPOWER EUROPE** project gathering the most important associations mentioned above is crucial, giving one voice to the sector for discussion with the European Commission, public authorities and civil society and especially providing a strategic research and innovation agenda as well as a strategic industry roadmap.

4.6.4 Innovative environmental strategies

When delivered responsibly, sustainable hydropower offers clean, climate-neutral affordable electricity.

4.6.4.1 River continuity and fish migration

All hydropower plants require construction of a dam or weir, which often obstructs fish movements. In general, hydropower impacts on fish can be described as: (1) direct impacts; (2) impacts on movements; (3) impacts on habitat. The direct impacts could be mortality or injury caused by turbine passage or flushing of sediments, whilst the dam will introduce challenges with respect to upstream and downstream migration (impacts on movements). Changes in the natural flow and sediment regime will change the habitat conditions, both in the short and long-time horizons (FITHydro, 2020).

The biology and composition of the fish population is unique to each site. As such, the environmental problems and any related measures are also specific to each location, posing challenges to presenting generic measures viable for all possible sites, and often the solution will be a combination of different measures.

The project FITHydro (2020) developed a decision support system to identify the risks, impacts, and appropriate mitigation measures at a specific site. Thanks to continuous research on new environmental mitigation measures, innovative measures and new type of turbines, innovations for fish migration emerged recently including:

- latest instream and kinetic turbines reaching fish mortality of less than 0.1%;
- the Hydroshaft concept (Rutschmann, 2019) suited to low grade rivers, with energy production increase using one bay of an existing, gated weir;
- the active fish path concept (Kalina, 2021) with two Archimedes screw systems ensuring two-way migration, and the positive energy balance enabling the solution to make a return on the investment;
- the “Fishlift®” concept (Pelikan, 2017 & Pelikan, 2021) adapted to a medium chute;
- the lack of use of oil and grease is one of the most promising lines of innovation;
- the 3D sensor less ultra-sonic fish tracking 200 m upstream and downstream of HPP;
- the IDA (Induced drift application) concept based on a copper electrode guiding fish into the turbine and reducing by 50% their injury on small chutes;
- the natural fish pass.

The assessment of increasing impact of environmental mitigation measures on HPP installation costs and the effects of new and harsher operation regimes on aquatic ecosystems and innovative strategies to reduce these effects are under development (e.g. by developing innovative planning of environmental flow releases - including cooling down the rivers, especially in summer, which may undergo heating due to climate change, as well as artificial flood pulses and mitigation measures to reduce the impacts on flow regimes in rivers).

4.6.4.2 *Sediment continuity*

Reservoir sedimentation is known as the process of gradual accumulation of the incoming sediment load from a river in natural or manmade reservoirs. It is one of the most serious problems endangering downstream ecosystems and challenges the sustainable use of the vital worldwide reservoir capacity (Schleiss et al., 2016).

Any new dam should be built with a reservoir intake combined with a flushing device to ensure the regular release of sediments and thus the sustainable operation of the reservoir. This is an ecological requirement to help maintain river morphology and biotope richness downstream of dams, thus improving the connectivity and ensuring the sustainability of floodplains. However, some old dams are not yet equipped with efficient flushing devices ensuring sustainable use of the reservoir volume. Sediment management strategies need to be improved and innovative methods are required (dredging robot, new sediment by-pass, whirl-up of fine sediments, controlled release through powerhouse, etc.).

4.6.4.3 *Biodiversity and freshwater ecosystem protection*

The Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019) has recently demonstrated that: “Nature makes human development possible but our relentless demand for the earth’s resources is accelerating extinction rates and devastating the world’s ecosystems”. The report 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 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 assessment of the most effective solutions. Technical and environmental innovations should guarantee that there will only be acceptable impacts; for example, on biodiversity or public safety, caused by larger or more frequent water discharges when balancing increasing levels of grid fluctuations caused by intermittent generation from wind and solar installations.

4.6.5 **Climate resilience and mitigation of the impact of climate change**

Climate change due to global warming is expected to reduce water availability in the Southern part of Europe. Moreover, natural hazards and extreme flood events are likely to occur more frequently. Changes in generation potential, as well as changes in operating procedures used to manage these climate effects and impacts, have to be anticipated and developed. For instance, new large, multi-purpose reservoirs built for natural hazard protection could also be used for energy storage and power supply, creating new sources of revenue and payback for investments.

Hydraulic infrastructure also needs to include resilience measures to cope with climate change related risks. To guide operators and developers to include resilience measures into the infrastructure and operations, the Hydropower Sector Climate Resilience Guide was released in 2019 (IHA, 2019c). This guide provides an approach to identify, assess, and manage climate-related risks so that operators and developers can prepare for the impacts and benefit from opportunities that may arise (e.g. increased flow in glacierised catchments). The benefits of hydropower reservoirs to mitigate the negative impacts of climate change on non-energetic uses (agriculture, drinking water, cooling of power station, etc.) must also be evaluated in socio-economic terms.

4.6.6 Licensing and permitting

Stakeholder consultation has highlighted that there are too many complex allowance and authorisation procedures in licensing processes. For example:

- In Germany, the Atdorf PSP project was abandoned after spending 80 million EUR over 10 years and a further estimated 15-20 million EUR for additional planning costs, spent on addressing complex approval procedures, when approval regulations did / do not recognise "pumped storage".
- In Switzerland, several upgrade projects intended to increase the installed capacity and reservoir volume by dam heightening have been abandoned due to concession renewal discussions not allowing the recovery of investments which cannot be paid back until the concession ends.
- In France, tenders launched by the government to develop small hydro, are only open to projects with the initial steps of the licensing procedure already completed, leading to a significant risk in the cost of failure.
- Large wind projects failed, when states did not assume the responsibility of environmental and social studies to gain public approval before launching the tendering process.

Hence, in Europe, one reason that there is no effective expansion of hydropower generation is due to the long and complicated approval procedures and legislation found in most countries.

The European Parliament (2019) *"highlights the public interest in developing new and upgrading existing storage projects, which should be reflected in a **swift, prioritised and streamlined permitting process** in the Member States"*.

The duration of concessions of Member States should be updated in accordance with the huge investment required by the Energy Transition and to Article 18 of the Directive 2014/23/EU on the award of concession contracts. "For concessions lasting more than five years, the maximum duration of the concession shall not exceed the time that a concessionaire could reasonably be expected to take to recoup the investments made in operating the works or services together with a return on invested capital taking into account the investments required to achieve the specific contractual objectives. The investments

taken into account for the purposes of the calculation shall include both initial investments and investments during the life of the concession.”

Too short a duration impedes new heavy and lengthy investment, due to a lack of return on the invested capital. In contrast, a **70-year concession in Portugal was attractive** for several companies over the last twenty years.

Reflection must continue to bring greater clarity and speed to the decision-making process.

4.7 The opportunities for hydropower deployment

Over the coming decades, deployment of new hydropower schemes will depend upon the balance between environmental and socio-economic considerations.

4.7.1 The Green Deal

The struggle against climate change (i.e., global warming) is now becoming a top priority to save our societies and their economies. The use and development of energy technologies will not only be driven by cost but also by their contribution to the mitigation of climate change effects. The most efficient solutions for decarbonisation will clearly be a priority. From this point of view, **one of the most efficient technologies for global decarbonisation, is hydropower.**

Developing energy sources that cost-effectively reduce overall carbon emissions of the electric power system will therefore be the priority. Two clear strategies to achieve this are to:

1. **Increase storage capacity** in combination with mitigation measures against climate change impacts (local economy associated to water uses, agriculture, drinking water, catchment areas connection etc.).
2. **Increase installed capacity**, upgrading and expanding existing schemes, and developing new hydropower and multi-reservoirs schemes associated with other renewable energies and integrated with multipurpose water uses.

Preservation of biodiversity, minimisation of footprint and improving social acceptance are the second priority. From this point of view, hydropower can integrate best practices and the latest research for improving biodiversity and continuity.

4.7.2 The flexibility market

The need for flexibility in power systems is growing faster than electricity demand due to the rising share of intermittent and non-dispatchable renewable sources and a growing demand for cooling and electric vehicles. The new energy world shifts power system operations from balancing demand variations to balancing fast and deep power ramping.

The development of a renewable power system regulated with **flexibility and storage will require more hydropower interactions, interconnections and more pumped storage**

hydropower plants. Hydropower will be one of the most crucial pillars as well as the backbone of the future electric system. However, it **requires the right investment and investment signals** for flexibility and storage services for the grid.

Hydropower investment opportunities are currently expansion of storage and harnessing hidden hydropower (existing infrastructure not yet powered), so achieving much lower costs for electricity generation than through greenfield projects (due to savings in civil works) and permitting (IEA, 2021. Figure 47).

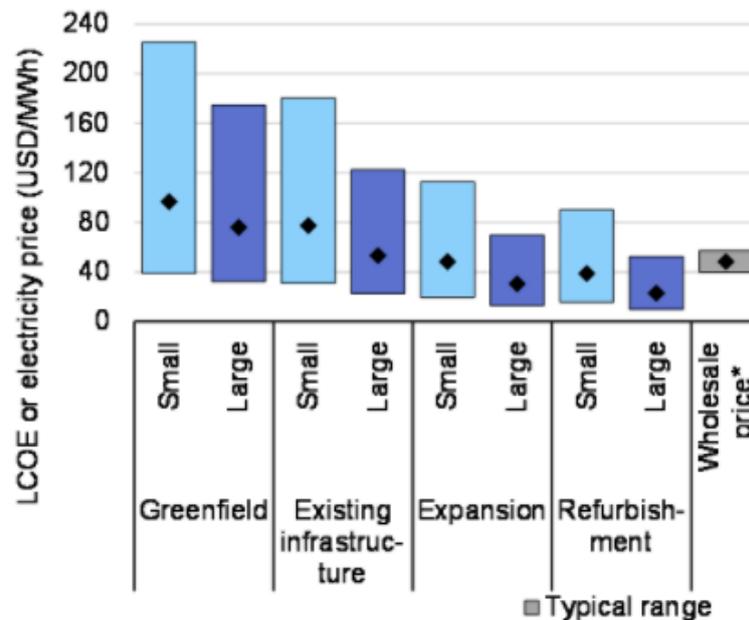


Figure 47 Average LCOE of hydropower investments and average wholesale electricity price in Europe (IEA, 2021). Minimum, maximum and average yearly wholesale electricity price for EU from 2016-2019

A future trend is to mix hydropower with other energies and storage solutions: for example, run-of-river plants can produce hydrogen when energy prices fall to zero. Batteries can ensure energy storage for several hours, whilst hydropower can store and release energy for days, and reservoirs can help produce additional power with floating PV.

4.7.3 Mitigating the impacts of ageing and maintaining the high safety level of power plants and dams

Stakeholder consultation highlighted that refurbishment, repowering, and extension of the lifespan of old plant is the first driver for short term hydropower development. Based on IHA's hydropower stations database, more than 2,000 hydropower plants are over 60 years old and represent greater than 60 GW of installed capacity, and with today approaches exceed the expected service life of many sites. Ageing can lead to fatigue of equipment and infrastructure. To address this problem, operations and maintenance (O&M) can rely on new materials and new rehabilitation techniques to maintain plant efficiency, while also reducing the risk of operational malfunction or failure.

Civil society is increasingly demanding greater security and reduced risks. New technologies for assessing and/or monitoring the state of hydropower infrastructure, and for informing the general public about hydraulic operating procedures in an effective way, will improve social acceptance and civil society's confidence in hydropower. Operational excellence and well-educated staff supported by monitoring and diagnosis of the generation equipment will help ensure and improve effective operation and maintenance of hydropower.

Increased efficiency and security aligned with climate change impacts by upgrading, digitalisation and energy loss reduction will be another driver for innovation.

4.7.4 Security, decentralisation and independence of the EU energy system

On Friday, November 3rd, 2006, at 9:48 pm, two 400,000V lines crossing the Ems River in Lower Saxony (Germany) were cut to allow a cruise ship to leave a shipyard. The western region, with its overconsumption of power, saw the frequency drop, with the risk of a total collapse of the network. The power demand was transferred to other lines. The authorised intensity of electric current was quickly exceeded which led to power cuts. The western region, with its overconsumption of power, saw the frequency drop, with the risk of a total collapse of the network. The consequences were felt as far away as Morocco in less than 2 minutes. Fortunately, the rapid start-up of the PSH and hydropower plants stabilised the network 2 hours later. If this event had degenerated into a 24-hour blackout it would have cost 21 billion EUR to 8 European countries (Mund, 2018). Since that time, other “near miss” events have occurred.

On 23rd December 2015, hackers compromised information systems of three energy distribution companies in Ukraine and temporarily disrupted the electricity supply to consumers. It is the first known successful cyber-attack on a power grid. On 23rd March 2016, the US Justice Department claimed Iran had attacked US infrastructure online, by infiltrating the computerised control of dam gates. The attacks in Saudi Arabia in September 2019 underlined that traditional energy security risks have not gone away.

In 2020 and 2021, the Covid-19 crisis has caused disruption in industry and has revealed how our economy is vulnerable to the breakdown of international supply chains.

Policy makers and regulators will have to move fast to keep up with the pace of technological change and the rising need for the flexible operation of power systems. Issues such as the market design for storage, the interface between electric vehicles and the grid, and data privacy all have the potential to expose consumers to new risks (IEA, 2019a).

Meanwhile, new hazards – from cybersecurity to extreme weather – require constant vigilance from governments (IEA, 2019a).

The European Parliament (2019): *“underlines that the transition to a climate-neutral economy must not endanger security of supply or access to energy; underlines the role of storage especially for energy isolated or island Member States; stresses that reliable energy supply, cost-efficiency and the energy transition must go hand in hand; stresses furthermore that*

energy efficiency, smart grids, participation and distributed flexibility options, including storage, **strengthen energy security; emphasises the potential of storage as an alternative to traditional grid expansion**".

In that sensible context, pumped storage hydropower backs security, decentralisation and independence of the European energy system.

- **Security:** PSH is a reliable technology which has demonstrated many times its ability to protect and stabilise the grid. On 3rd November 2006, hydropower saved France from black-out by releasing 5 GW in 40 minutes to the grid (Figure 48). More recently, in June 2019, a general blackout struck Argentina, Uruguay, Chile and Brazil. The thermal plants did not start. Thanks to hydropower, the frequency and voltage in the grid were recovered at a national level.
- **Decentralisation:** PSH offers an opportunity to store the energy produced locally by RES, ensures decentralisation of production and avoids costly investments in new power lines. RoR can be managed as distributed generation for communities. Small pondage hydropower plants also help to stabilise the local power network.
- **Independence:** PSH offers a guarantee of political independence in flexibility using European technology and national production.

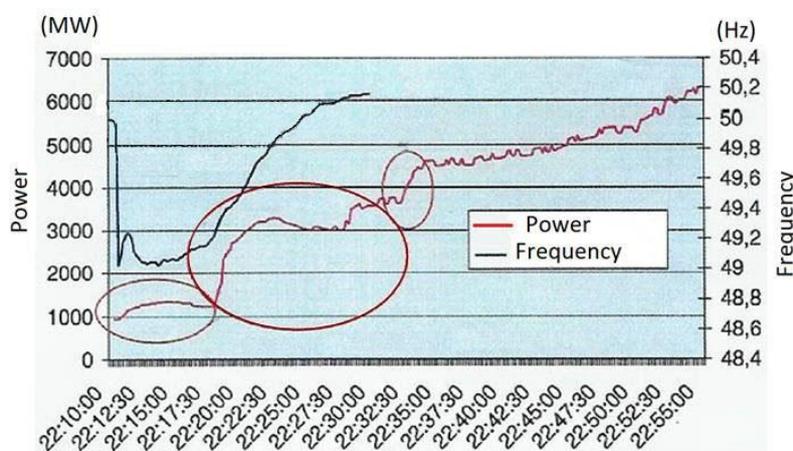


Figure 48 On the 3rd November 2006, pumped storage hydropower saved the grid in France

5 Hydropower as a catalyst for the energy transition in Europe - strategic actions required

The HYDROPOWER EUROPE Second Wider Stakeholder Consultation event (2nd WSC) that took place in 2020 and the subsequent Online Consultation Expert Panel (CEP) Consultation event in February 2021 rated every sub-theme, topic and action found in the previous chapters, with a number from 1 (lowest importance) to 10 (highest importance) in order to define the most strategic actions.

The following tables show the prioritised strategic actions resulting from the averages of the rating of the 2nd WSC and the subsequent review by the CEP.

All the strategic actions are high priority actions with a rate higher or equal to 7. They are presented and coloured according to their ranking:

- > 8.0: Priority Very High (intermediate colour in the following figures)
- 7.6 to 8.0: Priority High to Very High (light colour)
- 7.1 to 7.5: Priority High (no colour)

The strategic actions are gathered in 8 lists, initially presented in 11 themes but synthesised here in 8 themes that are not to be compared against each other.

5.1 Increase social awareness

Prioritised actions to **Increase Social Awareness** as reviewed by the CEP comprise:

Priority	Action
Very High	Collect a Catalogue of Examples of Best Practice of Successful Multi-Purpose Projects Creating a Win-Win Situation Between All Stakeholders
Very High	Develop Innovative Approaches to Address Environmental Issues and Biodiversity Protection with Comprehensive Approaches Allowing Compromises
Very High	Increase Awareness of European Citizens of the Importance of Hydropower Development
High to Very High	Develop Methodologies to Create Win-Win Situations Between All Stakeholders of Multi-Purpose Projects (linked to a catalogue of Best Practices)
High to Very High	Development of Regional Multi-Stakeholder Forums
High to Very High	Increasing the Availability of Information on the Environmental Impacts, the Energy Benefits and Other Water Uses Arising from Hydropower Plants
High to Very High	Development of Tools and Approaches to Increase Social Acceptance
High to Very High	Development of Strategies for Better Communication of the Value of Hydro for Society

High	Simplification and Reappraisal of Licensing Processes in Order to Favour Uprating of Existing Hydropower with Valorisation of Investment
High	Compiling, Disseminating and Implementing Best Practice for Investors for Hydropower Development Under Uncertainties
High	Developing Strategies on How to Successfully Address Issues Related to Hydropower in Cultural Heritage Sites and Protected Areas
High	Giving a Single Voice to the Sector Within Europe
High	Providing Details of the Business Case for New Hydro Generation Under Uncertainties

Table 8 Required strategic actions for social acceptance

5.2 Develop environmental mitigation measures

Prioritised actions to **Develop Environmental Mitigation Measures** as reviewed by the CEP comprise:

Priority	Action
Very High	Develop Sustainability Best Practices with the help of International Associations (IHA, ICOLD, World Bank, Etc) including taxonomy for sustainable finance and biodiversity strategies
Very High	Develop Sustainable Sediment Management Strategies for Ensuring Sustainable Reservoir Capacity and Sediment Dynamics in Rivers
Very High	Protection of Biodiversity in Hydropower Projects by Innovative Compensation Measures
Very High	Collect Experience with Water Framework Directive and Lessons Learnt Solutions to Maintain or Improve Water Quality in Rivers and Reservoirs
Very High	Provide Hydropower with Environmental Innovations thanks to Large Investments, such as Investment in Flexibility, to comply with the European Green Deal
High to Very High	Collect a Catalogue of Best Examples of Biotope Creation and Restoration through Uprating of Existing Hydropower or New Projects
High	Develop and Share Increased Knowledge on Ecosystems and How Hydropower May Affect These
High	Develop Innovative Determination and Planning of Environmental Flow Releases
High	Develop New Methods to Assess and Attenuate the Effects of New and Harsher Operation Regimes on Aquatic Ecosystems

Table 9 Required strategic actions for the environment

5.3 Better hydropower deployment

Prioritised actions to **Better Hydropower Deployment** as reviewed by the CEP comprise:

Priority	Action
Very High	Solve the “Missing Money” Issue with adequate Remunerations in Future Flexibility Markets and considering storage as a service
Very High	Contribute to supply Security, Decentralisation and Independence of the European Energy System with PSH
Very High	Increase Resilience by Mitigating the Impact of Ageing and Maintaining the High Safety Level of Power Plants
High to very High	Develop Technical, Social and Environmental Innovations for Supporting the European Green Deal

Table 10 Required strategic actions for Hydropower deployment

5.4 Adapt Regulation to Energy Transition

Prioritised actions to **Adapt Regulation to Energy Transition** as reviewed by the CEP comprise:

Priority	Action
Very High	Research and Development for Regulation Improvements (Increase CO ₂ Cost, Abolishment of the Double Taxation of Pumped Storage Hydropower, Concessions, Safety, Taxes, Etc)
Very High	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

Table 11 Required strategic actions for regulation

5.5 Greater investments thanks to new business models

Prioritised actions to **Greater Investment thanks to New Business Models** as reviewed by the CEP comprise:

Priority	Action
Very High	Research and Development for Mechanisms of Enhanced Revenues and Market Structures (Identification of Market Mechanisms and Regulatory Frameworks Necessary to Create Attractive Investment Conditions)

Very High	Research and Development for Re-Evaluation of the Market Design and its Ability to Provide Signals for Investments and Electricity Supply Security
Very High	Research and Development for Identification of New Financing Schemes (Green Bonds, Non-Conventional Project Evaluation Approaches, Portfolio/Bundling Approach, Long Term Investments, Etc.)
High	Development of an Efficient Market Model Suited to the Neutral Carbon Energy System Where Flexibility and Storage are Properly Valued (CO ₂ Market Price, Emission Trading System)
High	Assessment of Strength and Opportunities of Hydropower under Fully Liberalised Conditions, without Distortion by Subsidies Suited to New Carbon-Neutral Technologies and Fair Evaluation and Remuneration of Flexibility and Storage Services

Table 12 Required strategic actions for investment and new business models

5.6 Simplified approval procedures and legislation

Prioritised actions to **Simplified Approval Procedures and Legislation** as reviewed by the CEP comprise:

Priority	Action
Very High	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

Table 13 Required strategic actions for approval procedures and legislation

5.7 Climate resilience and mitigation of the impacts of climate change

Prioritised actions to **Climate Resilience and Mitigation of the Impacts of Climate Change** as reviewed by the CEP comprise:

Priority	Action
High to Very High	Design / Modification of New Large, Multi-Purpose Reservoirs Built for Natural Hazard Protection Used for Energy Storage and Power Supply, Creating New Sources of Revenue and Payback for Investments
High to Very High	Collect a Catalogue of How Hydropower Reservoirs Can Attenuate the Effects of Climate Change Under Regional Climate Conditions
High to Very High	New Approaches to Identify, Assess and Manage Climate-Related Risks so that Operators and Developers are Prepared for the Impacts and Opportunities that may Arise from Climate Change

Table 14 Required strategic actions for climate resilience

5.8 Capacity building

Capacity Building is a critical issue as reviewed by the CEP and comprises:

Priority	Action
High	Identification of the Need for Training and Education in Order to Maintain and Enhance Hydropower Know How in the Long Term

Table 15 Required strategic actions capacity building

5.9 The most effective levers for the development of hydropower

According to the complex system analysis (in Section 3.5), two identified 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 all the high strategic actions increasing public acceptance listed in Table 8. These should be considered in the future roadmap 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, decentralisation and independence** of the European energy system with PSH
4. Giving a **collaborative platform** to the hydropower sector

Amongst the first highest level, controllable active factors, there are also “**Environmental Mitigation Measures**” and “**Reservoir Volume**” which actively influence the future of hydropower deployment.

Consequently, all the high priority strategic actions listed in Table 9 “**Environmental Mitigation Measures**” can be considered in the future roadmap with the following strategy:

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.**

“**Reservoir volume**” can be increased by new hydropower installed capacity, new multipurpose projects, new pumped-storage, dam heightening and by effective sediment management. The implementation of new capacity should be boosted by the high priority strategic actions supporting better hydropower deployment (Table 10), adapting regulations to the energy transition (Table 11), investing more thanks to new business models (Table 12), and simplifying approval procedures and legislation (Table 13). Reservoir capacity also needs

future resilience to climate change (Table 14). 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 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 practices for investing under uncertainties
3. Development of a more pertinent regulation framework.

These levers gathered in three axes should constitute the framework of the roadmap.

6 R&I actions required for integration of hydropower as part of the European Green Deal

Through a substantial programme of consultation, the HYDROPOWER EUROPE Forum has defined seven key research directions and challenges respectively under the RIA and SIR needed to support the role and development of hydropower for providing an effective contribution to climate change adaptation, preserving the environment, and increasing societal resilience and local employment. The following challenges must be addressed by hydropower in Europe, namely:

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

6.1 R&D priorities in the Research Innovation Agenda

The 2nd WSG Consultation, and the CEP Consultations, have rated every R&I action, with a number from 1 (lowest importance) to 10 (highest importance) in order to define the priority for actions.

Table 16 below shows the prioritised Research and Innovation themes within the RIA. They are presented according to their ranking in a similar way to the key actions of the SIR (> 8.0: Priority Very High; 7.6 to 8.0: Priority High to Very High; and 7.1 to 7.5: Priority High).

When analysing the RIA recommended research themes to see if they meet the needs of the SIR, several observations can be made:

- **All very high priority Research and Innovations themes show good agreement with the global approach system analysis conclusions, showing that they are the most active levers to affect hydropower development by controlling the most important active factors “*Reservoir Volume*” and “*Environmental mitigation measures*”.**
- All Research and Innovation themes prioritised by stakeholders and listed in Table 16 are technical topics except two themes which are environmentally oriented. Both of these environmentally oriented themes are important levers.
- Half of the sub-themes prioritised by stakeholders and listed in Table 16 are related to innovation on flexibility which provides the main opportunity for hydropower, helping ensure that it can support the integration of increasingly intermittent and non-dispatchable renewable generation.

- There are no Research and Innovation themes devoted to social aspects, although social acceptance across communication is the other most controllable active factor to deploy hydropower.
- Regarding market design, the development and application of a business model for flexibility is shown as a top priority in Table 16.

These observations introduce the fact that other Research and Innovation themes are required to overcome barriers to hydropower development, which are related less to technological aspects but rather to social challenges.

		Consultation Feedback		
Challenges	Research Themes	Priorities	Recommended Call	Recommended Funding Scheme
Increasing flexibility	3.1.1. Innovation in flexibility, storage design and operations	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 operation 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 infrastructures	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 useful 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	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 general impact and contribution of hydropower to biodiversity and identification of innovative approaches and guidelines to support more sustainable hydropower development	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

Table 16 List of prioritised Research and Innovation Themes in the RIA (HPE, 2021d)

6.2 The strategic priorities for fully integrating hydropower with the European Green Deal

Hydropower has the capacity to be the backbone of a low carbon, climate-resilient future.

Taking into account the fact that hydropower has both positive and negative impacts, and not all negative impacts can be suddenly erased, a dialogue between industry, civil society and the European Commission is required to define appropriate ways and tools to deploy more hydropower. Hydropower generation operating under harsher service conditions must be considered to allow for the added flexibility needed to balance the variability of increasing renewable sources such as wind and solar, and at the same time, moving to more sustainable generation processes.

Negative impacts need to be minimised, mitigated or compensated to an acceptable level for full commitment within the Green Deal. The identification of this acceptable level requires sustained research and innovation and wide public consultation to achieve the target of social acceptance and environmental protection. The sustainability of hydropower fully integrated in the Green Deal is based upon three pillars providing benefits and minimised impacts to (1) the economy, (2) society, and (3) the environment. An overview of these pillars is presented in Figure 49.

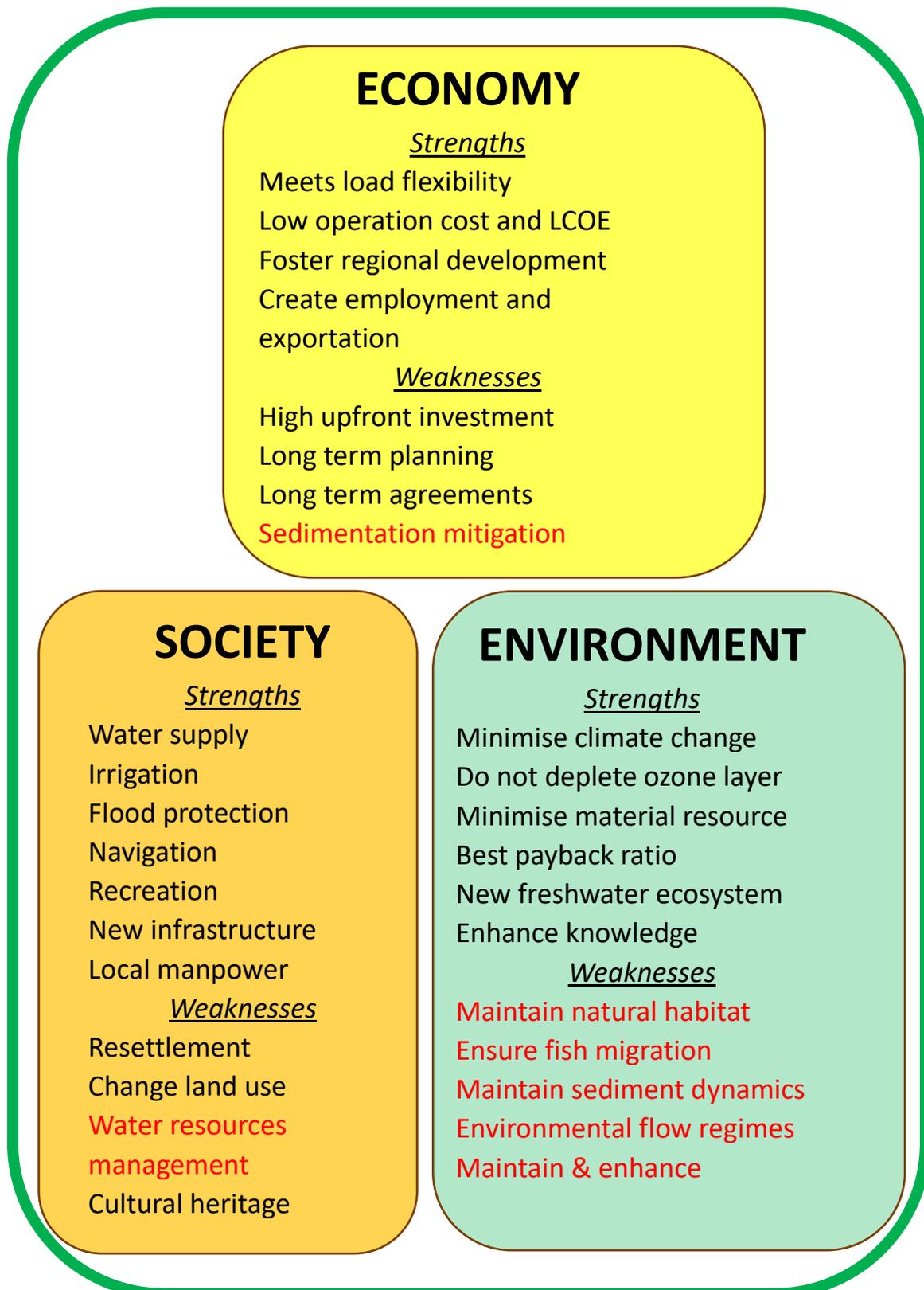


Figure 49 The three pillars of hydropower fully integrating into the Green Deal (aspects requiring innovation are marked in red)

Some impacts are not yet sufficiently reduced in some parts of the existing older power plant portfolio to reach the requirements of the Green Deal and deserve the attention of research and innovation: they are highlighted in red in Figure 49.

The technical, economic, social and environmental drivers of hydropower innovation have come from the need to reduce the weaknesses of hydropower combined with the opportunities of the market, society and the anticipation and prevention of climate change and global warming respectively. They are presented in Figure 50.

TECHNOLOGY	ECONOMY
<ul style="list-style-type: none"> • Need of high flexibility, rapid and steep ramps, hydraulic short circuit and low (zero) capacity drive the developments of new PHS schemes. • Rehabilitation and refurbishment of existing hydropower facilities with a reduction of O&M costs. 	<ul style="list-style-type: none"> • New market model with higher ETS and with a fair price and taxes policy for a level playing field among technologies. • Competition for harnessing new large hydropower plants on global market and maintaining small hydro European equipment industry.
SOCIETY	ENVIRONMENT
<ul style="list-style-type: none"> • The development of new innovative multi-purpose power plants which create win-win situations between flood protection, river restoration, recreation, water supply and energy production. • The share of benefits of untapped hydro where water infrastructures have been originally built for other purposes . 	<ul style="list-style-type: none"> • Global warming attenuation. • Preservation of the ozone layer and material resources. • Circularity. • Protection of ecosystems. • Protection of fish species. • Continuity of sediment transport.

Figure 50 Main drivers pushing developments and innovations for hydropower

These drivers provide the framework of the Strategic Industry Roadmap with four key research directions. On the one hand, technology research and innovation needs have been largely understood and taken into account within the RIA, whilst on the other hand economy, society and environmental issues deserve attention in the form of new Research and Innovation actions arising from the SIR perspective.

6.2.1 Economy: development of new market design valuing flexibility

By 2035, intermittent and non-dispatchable renewable energies will be fully under development and will require grid adaptation, addition of large storage capacities and the development of green technologies to ensure the security of a carbon neutral energy system. The cost of these adaptations are the externalities of RES. The externalities are not borne by the market, but by the regulator. At a certain point, the regulator must intervene. The hydropower sector must help the regulator to find the most economical way to guarantee the security of the network at the lowest cost for the consumer.

A comprehensive modelling exercise simulating a 90-100% renewables-based European energy system is needed to build quantitative evidence to support policymaking in pricing flexibility into future market designs.

To support the deployment of hydropower, stakeholders have ranked the following four strategic actions as very high priority within the second wider stakeholder consultation process (Table 17).

Priority	Required strategic actions for hydropower deployment
Very High	Need for Regulation Improvements (Increase CO ₂ Cost, Abolishment of the Double Taxation of Pumped Storage Hydropower, Concessions, Safety, Taxes, Etc)
Very High	Need for Enhanced Revenues and Market Structures (Identification of Market Mechanisms and Regulatory Frameworks Necessary to Create Attractive Investment Conditions)
Very High	Re-Evaluation of the Market Design and its Ability to Provide Signals for Investments and Electricity Supply Security
Very High	Identification of New Financing Schemes (Green Bonds, Non-Conventional Project Evaluation Approaches, Portfolio/Bundling Approach, Long Term Investments, Etc.)

Table 17 *Very High priority strategic actions in Economy from the SIR*

The four Strategic Actions, listed in Table 17, need Innovation, development and sometimes research.

They contribute to the most powerful reactive factors “flexibility” and “opportunity markets” controlling “reservoir volume”.

The probability of success is not high, but the consequences are so high that they justify a sound, deep and urgent investment.

6.2.2 Environment and Society and increasing social awareness

For the coming decades, the challenge is not only technology and economy but also **social awareness**, as the global approach system analysis demonstrated.

Stakeholders are aware of the need for social and environmental innovations for allowing compromises and for complying with the European Green Deal. They have ranked these R&I actions amongst the very high priority development and innovation actions within the second wider consultation process (Table 18), which have been considered in the research themes and topics in the RIA.

Priority	Required strategic actions and developments for E&S impacts
Very High	Develop Innovative Approaches to Address Environmental Issues and Biodiversity Protection with Comprehensive Approaches Allowing Compromises
Very High	Provide Hydropower with Innovations thanks to Large Investments, such as Investment in Flexibility, to Comply with the European Green Deal
High	Develop Innovative Determination and Planning of Environmental Flow Releases
High	Develop New Methods to Assess and Attenuate the Effects of New and Harsher Operation Regimes on Aquatic Ecosystems

Table 18 Required strategic development and innovation for Environment and Society (E&S) impacts from the 2nd WSC

The hydropower sector will need to strengthen knowledge in the social sciences and humanities to deepen public awareness and gain social licensing.

ITCOLD, understanding that public assistance is a key factor, started the organisation of workshops "Dams and Territories" in 2014. Their aim was to establish with stakeholders, better knowledge of the actions undertaken by dam owners to promote economically, socially and environmentally the territories where dams are located. At the same time, the workshops gave stakeholders the possibility to interact directly with dam owners. So far six regional workshops have been organised in Italy: Bolzano 2014, Catanzaro 2015, Bologna 2016, Rieti 2017, Genova 2018, Palermo 2019 (ITCOLD website 2020). Amongst others, good examples in Italy regarding public acceptance are Ridracoli Dam (owner: Romagna Acque) which supplies water in the Emilia Romagna region, and the dams of the Valtellina area in Lombardia region (Owner: A2A).

Another key to gain public **awareness** of new hydropower generation projects is preservation of the environment. Mitigation measures for hydropower plants are generally acknowledged by local citizens; however, knowledge about specific measures amongst the general public is relatively scarce. Hydropower operators and decision-makers should develop strategies that demonstrate how specific mitigation measures may enhance the ecological status of the river or reservoir ecosystems to better engage local citizens in the decision-making process around the future design of local hydropower plants (FIT Hydro, 2020).

Another effective way to gain public acceptance is to develop and disseminate life-cycle analyses of the different electricity generation resources and storage solutions. This can help to demonstrate the best technologies to lower CO₂ emissions.

More globally, research is required to establish multi-criteria tools to assess the energy returned on energy invested (ERoEI) along with the carbon, water and mineral footprints of any energy generation power plant. Such tools would help to benchmark the performance of hydropower with other renewable energy sources. This should be based on net approaches and a functional analysis of stress factors and a quantitative analysis of each stress-factor impact.

As a result of benchmarking and validation tests, one of these tools could become a European standard for providing an index rating environmental, social and even financial acceptability and the footprint of any energy generation power plant, based on readily available good international practice guidelines.

In conclusion, the 2nd WSG consultation and the global approach system analysis confirmed that Innovation, Development and Research for Strategic Actions listed in Table 18 are high to very high priorities to include in the SIR and the RIA.

6.2.3 Cross sectional solutions & examples

Finally, case studies or pilot projects integrating these various types of innovation would make it possible to demonstrate the technical and environmental efficiency of the new generation of hydropower.

7 ROADMAP TO IMPLEMENTATION

After a century of deployment, hydropower is at the forefront of the Net Zero Economy. However, it must convince society that it delivers the reliable and secure provision of affordable electricity whilst also meeting environmental goals. To demonstrate this, an innovative roadmap must build from lessons learnt from unsuccessful projects and recommend steps for bridging the gap between parties.

7.1 Market, political and legal aspects

Regulation is a major element of the energy transition required for achieving the targets of a carbon-neutral energy system by 2050. In this regard, the electricity market design and the development of regulation are recognised as some of the most pressing challenges to be solved.

This was confirmed by the second CEP consultation process conducted in 2020, where stakeholders considered market aspects along with political and legal aspects to be the most important issues. The importance of those drivers has been confirmed by CEP experts in 2021.

The following actions are market-based instruments to support markets prioritised by stakeholders to improve the competitiveness of hydropower.

7.1.1 Improvement of flexibility markets

7.1.1.1 *A large consensus to redesign the electricity market*

The flexibility markets and the development of an efficient market model suited to the carbon-neutral energy system, where flexibility and storage are properly valued, are the top priorities identified by stakeholders.

7.1.1.2 *Solving the “missing money problem”*

Hydropower, although unique in its ability for providing system flexibility across all timescales, requires a solution to the **“missing money problem”**.

Incentives for long-term investments are required.

Services have to be remunerated according to:

- shortest timescale controls (<15 min),
- voltage regulation on the distribution network,
- capacity made available,
- capacity deferred to deal with congestion,
- power made available for network restoration.

In the future, all services provided to the grid should be fully compensated according to their value.

7.1.1.3 Assessment of strength and opportunities under the new market conditions

Assessing the strengths and opportunities of hydropower under fully liberalised conditions without distortion by subsidies is required. These need to be suited to new carbon-neutral technologies and provide a fair evaluation and remuneration for flexibility and storage services provided.

7.1.1.4 Economic model giving a value to flexibility in the European power system

An economic model for flexibility is needed. Flexibility should be priced through improved day-ahead, intraday balancing and ancillary services markets. The design of the current balancing and intraday markets must be improved, introducing, for instance, possibilities for electricity trading, with a forward market and a pay-bid balancing mechanism and more sophisticated products, with timeframes that better fit the flexibility requirements (e.g. ramp-up, ramp down rates, etc.).

Current projections of the European energy system typically assume that the two ‘pillar’ renewable energy sources will be balanced primarily by battery storage and power-to-gas, with a contribution from demand side measures and sector coupling (EC, 2018).

This ignores or simplifies the reality, in which Europe has a wider portfolio of renewable energy sources - a mixture of wind, PV, hydropower, CSP, geothermal, ocean energy, heat pumps, solar thermal, etc. All of these will work together to ensure that EU citizens have the power when and where they need it. Flawless operation of such a system is, however, only possible on the back of greater interconnection and liquid power markets.

A system modelling exercise, which specifically considers this wider scenario, has not been identified to date.

A comprehensive approach for simulating a 90-100% renewables-based European energy system would build quantitative evidence to support policymaking in pricing flexibility.

The terms of reference of this system modelling exercise should take into account (IEA, 2021):

- 1) assessing what are likely to be the most important flexibility services for hydropower in future electricity markets;
- 2) identifying instances of long-duration energy storage solutions currently being provided by hydropower;
- 3) assessing impacts of climate change on precipitation, reservoir inflows, and hydropower operations (including frequency of draught and flooding events);
- 4) developing a set of more specific guidelines for the design of flexibility services and corresponding compensation mechanisms across the timescales in future electricity markets;
- 5) investigating price formation in a zero marginal cost world and its implication for different types of hydropower plants.

Based on such comprehensive modelling, future market designs should be further developed to reward energy, capacity and all ancillary services and associated benefits.

7.1.1.5 Recognising the value of storage in the European power system

The European electricity markets grant considerable importance to the energy-only market, which is in stark contrast with the US market design. Energy-only markets do not reward the full value brought by energy storage to the electric power system, thus jeopardising investments in storage installations (Gaudard & Madani, 2019).

A change of this vision at the European level about the role of hydropower and reservoirs, based on joint economic support at national and European levels, could represent a possible solution for the “missing money problem”.

7.1.2 Best practice for investing under uncertainties

Global policy trends (e.g., sustainability transition) put energy sector decision-makers at the forefront of risk and uncertainty management. Global issues are such that decision-makers should assess and manage a variety of risks and uncertainties. Due to increasing world complexity, the development of an adequate and innovative conceptual framework, anchored in literature, is required.

7.1.2.1 Best practice anchored in literature

In the short term, in parallel to the development of an economic model, a first stage consists of compiling, disseminating and implementing best practice for investors active in hydropower development under uncertainties.

7.1.2.2 Modernisation and ageing restoration are the more secure investments

The average age of the European hydropower fleet is 45 years old. This ageing fleet needs modernisation to ensure restoration of ageing performance, increase of availability, and adaptation of the plant to new operating conditions required by providing greater flexibility. These works are the more secure investments in the current electricity market.

7.1.2.3 Development of innovative approaches relevant to decision-makers dealing with risks

An original approach, suited to decision-makers dealing with threats of different natures, limited heterogeneous information, and experts’ assessments tainted by doubts (Gaudard, 2019), is needed to guide business case development for new hydropower generation under uncertainties. Analyses should be conducted to investigate four specific issues:

- i) the fact that renewable energy tends to reduce the price spread;
- ii) that further investment into interconnection promoted by the lack of flexibility is deterring private companies from investing in storage capacity;
- iii) that the possible shift towards small and decentralised installations, stimulated by the EC and the uncertainty surrounding investments, is affecting profitability in large power plants (Gaudard & Madani, 2019);

- iv) the need for identification, assessment and management of climate-related risks so that operators and developers are prepared for the impacts and opportunities that may arise from climate change.

7.1.2.4 *Special attention for risks induced by climate change*

Improvement in the resilience of hydropower to global warming is mainly related to adapting:

1. downstream safety to cope with increased extreme events.
2. operation and maintenance to minimise the impact of water resources changes on energy generation,
3. plant operation to meet the future flexibility needs in a changing energy system with more renewable resources,
4. hydropower schemes and reservoirs to play a role in societal adaptation to climate change, such as reducing floods and increasing water availability in dry areas.

Providing frameworks and scaling up new approaches for assessing climate change impacts will improve the ability of hydropower projects to operate under resultant increases in variability (e.g., temporal and spatial changes in water availability or water use). A key challenge is the uptake of new approaches (such as outlined in the Hydropower Sector Climate Resilience Guide, IHA, 2019c), capacity building and inclusion of management of the increased sediment yield into reservoirs by developing new, innovative techniques and approaches.

7.1.2.5 *Recommendations for investment strategies*

In the last step, the outputs of the previous steps described above will highlight the main drivers that influence the future profitability of hydropower considering the main impact of governmental policies and other stakeholder strategies.

7.1.3 Development of a pertinent regulation framework

Without risk mitigation mechanisms, investors are reluctant to invest in assets with long term pay back periods. Investors need a stable regulation framework, which promotes green renewable energy with a fair price, tax policy and a subsidy model designed for a level playing field amongst different technologies, based upon a comprehensive analysis of the carbon footprint and life cycle.

7.1.3.1 *ETS is a key driver for decarbonisation*

Coherent and integrated policy instruments based on the ETS as the key driver can best serve the EU's decarbonisation goal. It is believed that the effectiveness of the ETS would be enhanced if Europe's policymakers adopted ambitious, economy-wide greenhouse gas reduction targets for 2030 and beyond (Eurelectric, 2012).

A well-functioning single European energy market and an effective EU Emissions Trading Scheme are the best way of ensuring fulfilment of the European energy policy objectives

(Eurelectric, 2012). They will ensure a cost-effective transition to a low-carbon economy, whilst guaranteeing security of supply and system stability.

7.1.3.2 Ensuring that all technologies can participate in capacity markets without discrimination

According to the European Parliament (2019), an evolved market design must ensure a level playing field between conventional generation, renewables, demand response and storage to participate and to be remunerated in energy and capacity markets (such as in Canada or Brazil, where hydropower is the main energy source).

This means that a market-based deployment of RES is needed, phasing out fossil fuel subsidies and other market distortion sources to achieve competitiveness. With the decrease of their costs, intermittent and non-dispatchable renewable energy sources like wind and solar have to move from subsidised revenues to market-only revenues, long term PPA securing long term revenues, or a combination of both.

Such a model should put the hydropower industry on an equal footing with other renewable sources competitors and should consider fair evaluation and remuneration for flexibility and storage services.

Capacity products participating in capacity markets ought to generate energy during the periods where the risk for the system is at its maximum, which reveals their contribution to security of supply through reducing the shortfall risk. Adequate periods of availability, market arrangements and technology requirements will lead to the development of cost-effective solutions contributing to the system's needs. With the possible introduction of a capacity mechanism, it has to be ensured that current storage can participate in relevant procedures without discrimination (Weissrock, 2016).

According to the European Parliament (2019), it is important “to ensure a **level playing field for all energy storage solutions** in line with the **technology neutrality, multi-criteria analyses**, which should be considered in the tenders, giving indicators of **energy consumption, carbon footprint and costs of the production, exploitation, recycling and decommissioning**”. This principle should allow market forces to drive the best choices of technology and foster innovation targeting the 2050 net-zero economy.

7.1.3.3 Clarifying the definition and recognising the value of energy storage

Energy storage will be necessary to encourage in the renewable European energy system with more intermittent energy production. However, the way in which energy storage is defined in European regulations does not cover energy storage provided by hydropower reservoirs. Reservoirs store energy in the form of water that can be used for production whenever the European system needs it. This is storage on both long and short durations.

The definition of energy storage in pumped storage is currently not clearly defined by law. Energy storage is still classified as end user. End user consumption removes electricity from the grid, while PSH feeds it back to the grid. Accordingly, treating PSH both as a generation

asset (i.e. required to pay a grid fee for transmission grid access) and as a final consumer (i.e. required to pay the grid access for a second time) is not appropriate. **Double grid fees for PSH should be removed.**

Existing hydropower reservoirs in Europe help ensure the safety of the European energy system, which is often not adequately recognised in future storage scenarios. In addition to the significant storage potential which could be provided with upgrading and modernising existing hydropower assets, innovative energy storage solutions (including chemical, mechanical, electrical, thermal and hydropower storage) are a key element of such energy system and R&I actions will advance their technological readiness for industrial-scale and domestic applications.

Transmission system operators should be allowed and encouraged to procure PSH in cases where that would be the most efficient way of managing grids (IHA, 2021).

Market rules should be reformed to recognise that reservoirs in hydropower schemes act as energy storage and they are needed to develop the future energy system. Market rules should allow participation of technologies such as PSH in transmission and generation markets, if necessary, through the creation of a new storage asset category (IHA, 2021).

7.1.3.4 De-risking investment policies supported by government

Due to the long lifetime, high capital costs and long construction phase, HP investments usually require a long payback period in an environment that is characterised by easily scalable and swiftly installed renewable capacities. In the coming decades, new technologies are likely to increase the competitive pressure even further. The high operational flexibility of HP does not necessarily compensate for its lack of implementation flexibility (WWZ, 2019).

National governments and **European policy could bring back a long-term vision** and set long-term revenue streams securing future long-term investments.

In designing market products, policymakers must ensure that those **products provide enough long-term revenue visibility** to stimulate investment in the most efficient low carbon technologies (IHA, 2021).

Governments should consider recoverable grants that allow sharing of project risks between government and developers to support private investment and development (IHA, 2021).

Long-term power purchase contracts have ensured economic viability for hydropower making business cases possible.

WACC can be decreased by providing policies de-risking investment such as state guarantees, long-term contracts and other measures increasing remuneration certainty. Lower financing through policy measures is important to ensure competitiveness of hydropower generation (IEA, 2021). PSH should also actively participate in finance mechanisms like green bonds.

7.1.3.5 Taxonomy

PSH, and particularly PSH off river, charged with green power could comply with all the six environmental objectives of Taxonomy (EC, 2021d) defined in Article 3 of the Climate Law (EC, 2021a).

1. climate change mitigation;
2. climate change adaptation;
3. sustainable use and protection of water and marine resources;
4. transition to a circular economy;
5. pollution prevention and control;
6. protection and restoration of biodiversity and ecosystem.

Pumped Storage Hydropower could be fully supported by Taxonomy.

7.1.3.6 Water fees

Water fees are a remuneration to be paid by the operators of hydropower plants to the owners of the water resource and/or of the land.

On the one hand, water fees reduce hydropower profitability, and they are largely perceived as a significant cost to hydropower companies and as having a discriminatory effect on hydropower compared to other energy technologies. On the other hand, the water fee revenues play an important role in providing income and employment to the local economies and thus help foster regional development.

Accordingly, negotiations of water fees must include economic considerations of profitability and a comprehensive perspective of sustainable development (SD) through a comprehensive stakeholder process.

Considering that falling electricity prices benefit local consumers while they end up endangering the company, it is difficult to argue that the company is making a second contribution to consumers through constant water charges whatever the electricity price.

Negotiations usually take place in the concession renewal. In case of renewing the concession of an existing hydropower plant, evaluation of trade-offs linked to different options of flexible water fees fully or partly accounting for electricity price variations should be under consideration (WWZ, 2019).

National regulation could reform this regime and set the maximum water fee rate in accordance with the energy market.

7.1.3.7 Simplification of permitting and long duration licensing time

The example of Altdorf PSP shows that one of the priorities for further hydropower deployment is simplification of the authorisation procedures. **Simplification and reappraisal of the licensing processes is an efficient driver to favour flexibility investment** for upgrading of existing hydropower with valorisation of investment. European Union and member states

need to **provide a long duration concession framework** that enables companies to have an acceptable return on investment.

7.2 Social responsibility

7.2.1 Increase public awareness

Many experts from the CEP pointed to a lack of communication and public awareness of the potential benefits of hydropower projects.

Communication and dissemination are needed to clearly highlight benefits and further support new sustainable hydropower plants.

The purpose of the action is to:

- demonstrate and disseminate objective information on hydropower as a core renewable energy source for producing energy, ensuring grid stability and security, supporting other RES sources (e.g. solar PV, wind, etc.), whilst also minimising global warming;
- increase understanding of European citizens for the energy benefits and other water uses arising from hydropower plants and the importance of hydropower development;
- encourage inclusion of hydropower in clean energy planning and markets, as appropriate.

This action should be launched as soon as possible.

7.2.1.1 *Increasing the availability of information*

In the very short term, the first stage to help increase social awareness is to make information more readily available. This can be done in three steps:

1. Coordination between regional, national and European hydropower associations is required to collect and share existing information that incorporate success stories, most recent research outputs or following methodologies to quantify the impressive benefits of hydropower;
2. Compiling and editing information into digestible formats;
3. Disseminating this information through all kinds of social channels including public meetings, public agencies, social media, websites, fact sheets, educational and communication campaigns, etc.

7.2.1.2 *Development of strategies for better communication of the value of hydropower for society*

In the short term, the second stage is to quantify hydropower benefits and share the messages about the benefits of hydropower with society through the following nine specific strategies:

1. **Reference to success stories.** Compile and collect information and issue a report on success stories for improving hydropower in respect to generation, respecting the WFD, including fish passage; compensation measures provided by hydropower plants and emphasising the contribution of hydropower to optimise water reserves in a future with water scarcity; provide additional, stable and safe market penetration of renewable sources; mitigation of flood waves and protection of local communities from floods; supplying water for agriculture; development of other multi-use activities, such as tourism, recreational and sporting activities, transport and fish farming. Also stressing important elements such as favourable life-cycle analyses and the sustainability of hydropower through mitigation measures.
2. **Science and innovation.** Highlight the advances the hydropower industry has made in addressing environmental considerations and in meeting existing environmental regulations. Technological advances, like fish passage enhancement (FIT-Hydro & new turbines), innovative screens and trash rack design etc., make both energy production and biodiversity conservation possible at the same time, and need to be more widely disseminated.
3. **Give value to benefits.** Positive consequences are usually ignored or only partly appreciated, whereas negative consequences are often fully acknowledged. A similar evaluation of the corresponding benefits for the stakeholders must be made in a transparent and measurable way.
4. **Sustainability.** Civil society needs a clear document explaining how hydropower can be a sustainable technology.
5. **Transparency.** Conduct a full inventory and analysis of renewable energy incentives in each evaluated member country or non-European country or organisation and their impact on the growth of technologies.
6. **Green Deal.** Use tools and analysis explaining the advantages and role of hydropower in the Green Deal, including valuing the social and economic benefits of hydropower, life cycle analysis, recovery factor of energy, analysis of incentives, etc.
7. **Climate change.** Describe the increasing role of hydropower for the mitigation of climate change impacts: decrease of GHG emissions compared to other technologies, water availability, drought and flood control and conservation of freshwater habitats.
8. **Guidelines for Europe.** A common set of social and environmental guidelines for advancing hydropower (where appropriate) should be developed at a European level.
9. **New projects.** Enhance stakeholder engagement and understanding within the regulatory domain. Ensure all stakeholders have access to the knowledge necessary to participate effectively in planning, decision making, and regulatory processes, which will enhance the ongoing effort for individual hydropower projects to be designed and operated in the most environmentally responsible way possible.

7.2.1.3 *Development of regional Multi-Stakeholder Forums*

Every hydropower project is a unique opportunity to keep in touch with civil society, to understand the societal challenges and to inform best practice in new projects.

The investigations undertaken by ITCOLD, cited in Section 6.2.2, have identified and disseminated many best practices related to social-economic and environmental aspects.

These regional evaluations should be planned every year in EU countries, promoting experience of the ITCOLD regional workshops, matching dam owner pro-activity versus stakeholder perception.

These regional workshops, under an appropriate administrative framework, will explore and combat specific barriers and will promote the uptake of hydropower. The positive and negative externalities of hydropower generation will be fully acknowledged, transparent, and measurable. Past and future regional workshops will facilitate the dialogue and the intercommunication between two worlds, which often has conflicts and opposing interests.

7.2.2 Develop best practice for successful projects and win-win situations

7.2.2.1 *Promote and apply a catalogue of best practice for sustainability*

The first stage consists of identifying best practice and disseminating this in a catalogue.

Best practice is practice which has enabled top environmental and social performance or has been successfully applied to solving conflicts of interest on environmental mitigation, and water management.

The purpose of this formalised catalogue of best practice is to:

- promote win-win situations between all stakeholders;
- improve public acceptance of hydropower; and
- allow the industry to reduce risks of investment.

Many lessons have been learnt to help ensure not only payment of fair compensation when due, but more importantly, that the public directly gain from the project with improved living standards. **Stakeholder participation helps the public to build confidence in the project or in planning future national infrastructure.** Specifically:

- involving local and regional stakeholders in decision-making and delivering clear and long-term communication;
- local stakeholders should be well integrated into the communication process across all development phases, as well as responsibility and benefit sharing among communities;
- allowing displaced people, if any, to choose the layout of their resettlement places, as well as choosing the design of places of worship, sports centres, and other public buildings.

Such enhanced involvement leads to a **sense of co-ownership of the development** (Venus, 2020). Improved dialogue can also lead to a better assessment of local needs, so that assumptions are not made on behalf of others (Bartle, 2021).

Compiling and disseminating these lessons and methods from leading performers in all segments of the hydropower industry can drive improvements in hydropower performance. Identifying and disseminating best practice can help lead to successful energy, environment-related, and socio-economic outcomes of the hydropower regulatory process.

All hydropower projects must be developed and operated sustainably. Amongst the best practices, the recommendations of international associations should be noted:

- the **Hydropower Sustainability Tools**: Tools, including the Hydropower Sustainability Guidelines on Good International Industry Practice (**HGIIP**), the Hydropower Sustainability Assessment Protocol (**HSAP**) and the Hydropower Sustainability ESG Gap Analysis Tool (**HESG**), are managed by IHA (IHA, 2019a; IHA, 2020c), and were developed by a governing council representing industry, government, financial institutions and social and environmental NGOs;
- the **ICOLD technical bulletins** 37, 50, 65, 66, 90, 96, 100, 116, 128 and 149 prepared by the Technical Committee on the Environment related to environmental aspects, provide some useful insight and advice on preventing wildlife conflicts whilst building new dams and maintaining existing ones;
- the **Water Resources Strategy** - Strategic Directions for World Bank Engagement;
- the **Share Concept** (Branche, 2015), outlining a shared vision of the multipurpose water uses of hydropower reservoirs.

By capitalising on economic and financial trends, as well as improved technologies, we can secure a brighter future for people and nature with power systems that are low carbon, low cost and low impact on rivers and other ecosystems.

7.2.2.2 Develop innovative and comprehensive approaches

The second stage is to **develop innovative, comprehensive approaches, appropriate methods and tools to deploy more hydropower and to balance environmental protection legislation and climate friendly energy legislation**. While stimulating hydropower development is promising for its contribution to reducing greenhouse gas emissions, community acceptance requires regulation that balances trade-offs between renewable energy and ecosystems but also ensures distributive justice to local populations (Venus, 2020).

The objectives of these approaches are to:

- address environmental issues and biodiversity protection;
- enhance dialogue between industry, civil society and the European Commission;
- develop comprehensive approaches allowing for compromises.

A business-as-usual approach based on an engineering focus and energy uses alone is not sufficient to support the development of a clean, renewable and reliable European energy system. The hydropower sector needs to adopt a holistic and multi-disciplinary approach to

sustainable watershed management, taking into account the new social context, climate change, the new grid requirements and more generally the use of water in the watershed for increasing social welfare. In certain Southern regions, water – and no longer MWh – is becoming the key resource. This implies that the hydropower industry should be pro-active in identifying water challenges beyond the use of energy, in anticipating and mitigating the risk of resource shortages, their collapse and the ripple effects that could occur. In particular, design or modification of new, large, multi-purpose reservoirs built for natural hazard protection used for energy storage and power supply, should also create new sources of revenue and payback for investments. Social conflicts should also be mitigated, as they are induced by climate change and economic issues.

Water management and power generation are inherently complex topics. It is thus necessary for the public to be informed and educated about these challenges, so that in a time of public participation they are fully aware and able to understand and address the issues. To make this happen, the hydropower sector needs to share knowledge and set participative standards, not only for the development of new projects, but also for established sites.

Development of innovative social sciences and humanities (SSH) approaches could be helpful to find compromises (Mazzucato, 2018) compatible with the European energy market rules and environmental goals, and to evolve through drawing out the benefits of hydropower for social welfare, in line with the energy transition, promoting carbon neutral power generation and a fair national framework, which gives priorities to actions that help preserve the planet.

Innovative SSH approaches could start from the inventory of issues detected on existing or new projects. Hydropower projects are often rejected because of the poor performance of the investor himself in managing E&S impacts and social relations. This global evaluation should be useful to clarify support or opposition from residents, other stakeholders of water use and NGOs. On the one hand, this helps to minimise potential impacts and on the other, it can demonstrate the efficiency of current mitigating measures and reveal the newest research results.

Large hydropower development may only occur if it is included within a coherent national energy policy ensuring water and energy public service and security.

SSH innovative approaches will work on various factors, such as:

- the nature and amplitude of environmental and social impacts;
- the way that impacts are managed: avoided, reduced, compensated according to high standards / or to low performance;
- the social relationships undertaken by the investor;
- the local, national and international stakeholders involved.

Some groups consider hydropower as harmful and solely responsible for potential problems in a river system. However, the hydropower community advocates for a local **transparent and scientific debate on the best technology to mitigate climate change, respecting the limits of our planet's resources, whilst enhancing our collective well-being.**

7.2.3 Security, decentralisation and independence of the European energy system

The aim of this action is to demonstrate to decision-makers and regulators that they must quickly protect and secure the independence and flexible operation of electricity networks in the European Energy System by launching pumped storage station solutions throughout Europe. PSH can provide storage for several days up to a couple of weeks inside Europe and strengthen independence and security from international supply chains. However, they typically require long lead time and typically have to be decided 10 years before their commissioning.

Security, decentralisation and independence of Europe is supported by the expansion of PSH.

7.2.4 Increase capacity building and job employment

The objectives are on the one hand to maintain **and enhance hydropower know-how in the long-term** and on the other hand to develop regional job employment.

This action has several stages:

1. identification of industry needs for training and education, under potential growth scenarios, new technology deployment, involvement of the local population and better gender balance;
2. development of tools and techniques to effectively capture and transfer knowledge from workers leaving the workforce;
3. engagement with key high schools and universities through research projects in collaboration with industry and organising highly technical courses to inspire students to select hydropower as a professional field in engineering studies, and ensuring training for professionals from industry;
4. development of comprehensive training and education programs for entry-level positions, internships or hydropower-related curricula;
5. promotion of hydropower as a very interesting water and energy industry full of prospective jobs (DNV-GL, 2014).

7.2.5 Develop strategies for cultural heritage and protected areas

Past strategies which successfully preserved Cultural Heritage Sites and Protected Areas should be collated (For example, Abu Simbel temple removal with UN, Gap Project, etc.).

Innovative strategies promoting win-win situations should be developed. For instance, within the Gap Project, international groups of students worked on the restoration of mosaics, frescoes and artefacts from the submerged town, so that they could be preserved in a museum; thus, the cultural heritage has been retained in an area which would have been otherwise ignored (Bartle, 2021).

7.2.6 Giving a collaborative platform to the sector

Stakeholders representing the whole hydropower value chain are gathered for the first time via the Hydropower Europe Forum. This is a unique opportunity **for using their collective knowledge for developing the role of hydropower as a catalyst for the energy transition and for disseminating the key messages efficiently and effectively.**

All the technology sectors from equipment to civil engineering, and economy to environment are invited to contribute to improve the sustainability and the profitability of hydropower in Europe. A link from this forum to EERA hydropower as well as the Eurelectric WG hydro has been established (HPE, 2021c) and will be followed up.

The Research and Innovation Agenda and Strategic Industry Roadmap will be promoted by the Forum to political stakeholders, countries and local communities through stakeholder lines of communication as soon as possible.

The Forum will follow up on priorities of the RIA and the existing EU research and analysis in hydropower research and innovation investment decisions. The RIA can be used to guide the focus for actions under the Horizon Europe programme. The topics for research that are highlighted in the RIA and the SIR should be reflected not only in future calls for EU R&I research projects, but they should also be used by member state policymakers, research agency staff and industry in making national research investment decisions.

The SIR has to be maintained by the Forum in order to achieve the objectives of the HYDROPOWER EUROPE vision. Increased acceptance of hydropower as a renewable energy source is a very high priority goal. Demonstrating and communicating that hydropower is a pillar of the Green Deal and could be the blue backbone of the energy transition is key to increasing public understanding and to encouraging inclusion of hydropower in clean energy planning and markets, as appropriate.

Both, **the SIR and the RIA should be regularly updated** by tracking advancement of hydropower technology and deployment progress, and through regular prioritisation of research and development activities. Performance and impacts of funded RIA innovations and technologies shall be assessed and reported to the national and EU funding organisations. Validating performance of new hydropower and PSH technologies can increase investor confidence, thereby facilitating greater deployment of new capacity.

7.3 Environmental commitment

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has provided a report which represents a critical assessment of the status and trends of the natural world (IPBES, 2019). It is the first in almost 15 years and the first ever carried out by an intergovernmental body that highlights so clearly the critical need to integrate biodiversity considerations into global decision making on any sector or challenge, whether it is water or agriculture, infrastructure or business.

The hydropower sector has a long history of contributing to environmental studies and will continue to do so. Research on biodiversity consequences of hydropower and mitigating measures to identify the balanced solutions for protecting biodiversity while also providing Europe with clean and renewable power, energy storage, flexibility, water availability and ancillary services, is of utmost importance.

7.3.1 Collect best practice for biodiversity protection and regeneration

In the very short-term, a collaborative action between stakeholders is to share knowledge on environmental impacts at the European level and to support the discussion with up-to-date information. A lot has already been done, so dissemination of existing knowledge is of high importance.

Collecting, disseminating and applying sustainability best practice with the help of international associations (IHA, ICOLD, World Bank, IFC, amongst others), including taxonomy for sustainable finance and biodiversity strategy, is the top priority for stakeholders.

In particular, this action requires collecting and disseminating:

1. **best examples of biotope creation and restoration** through uprating of existing or new hydropower projects;
2. **lessons learnt from experiences with the water framework directive, drawbacks and limitations** articulated by researchers and practitioners, and solutions to maintain or improve water quality and biodiversity in rivers and reservoirs.

7.3.2 Increase knowledge on environmental impacts

The second stage is to **develop and share enhanced knowledge on ecosystems and how hydropower affects this whilst supporting the Green Deal**. EU member states are required by the EWFD to assess the hydro-morphological and ecological status of water bodies on a systematic and comparable basis. An important part of innovative solutions will be through increased knowledge on aquatic ecosystems, based on rigorous monitoring programs. Monitoring river and reservoir ecosystems and research projects on ecosystem protection will accelerate the ability of owners to innovate and enhance management of their environmental footprint.

It is key to advocate **a scientific programme investigating, monitoring and benchmarking the application of best practice for protecting biodiversity and addressing climate change impact** to improve knowledge, minimise impacts of industry and climate change on aquatic ecosystems and to inform the public.

7.3.3 Develop innovative environmental measures for the protection of biodiversity

The third stage is the improvement of biodiversity protection and river continuity in hydropower projects by implementing **innovative environmental measures**.

The objective is to find and implement balanced environmental measures to protect nature whilst providing climate friendly solutions, clean and renewable electricity, flexibility and storage.

Research on fish migration (FIThydro, 2020), **sediment continuity and biodiversity has to continue and further improve biological continuity** (flow regime management, assessment of environmental flow releases, innovative connectivity solutions for fish and biodiversity protection and innovative sediment management technologies for sustainable reservoir capacity and river morphology restoration).

7.3.3.1 *Fish migration*

Recent progress to enhance fish migration has been made (see Section 4.6.4.1). These solutions now need to be implemented on site. However, continuous research and new progress is required to enhance fish migration, fish friendly turbine designs and environmentally friendly generating units.

Analysis of biological continuity is a measure for reaching good ecological status. Research should also focus on the actual impact of hydropower on the ecological status and the cost-efficiency of water policy measures on it - especially for biological continuity.

7.3.3.2 *Develop and promote sustainable sediment strategies*

The development and qualification of sustainable sediment management strategies for ensuring sustainable reservoir capacity and sediment dynamics in rivers is the highest priority environmental action to improve conditions on site (according to the 2nd WSG consultation process).

Sediment management strategies need to be explored in greater detail to understand the cost-effectiveness of their implementation in terms of sediment continuity and maintenance of the power plant.

7.3.3.3 *Adaptation to climate change*

Another high priority strategic action is adaptation to global warming. The first step will be the collection of a catalogue of actions showing how a hydropower reservoir can help attenuate the effects of climate change for freshwater ecosystems and water supply under regional climate conditions.

Hydropower can increase societal resilience to climate change. It could be taken as a chance to develop accepted new multipurpose infrastructure, including hydropower schemes which are already known to provide many benefits such as flood control and serving as a water

supply reservoir during droughts. Based on the importance of flood control and ecological measures, operators could adopt strategies such as river widening and the reconstruction of secondary channels which help control floods, enhance ecological habitat and biodiversity as well as increase opportunities for recreation (Venus, 2020). Innovative concepts for hydropower infrastructure adaptation should be developed including pumping and storage of flood waters (Lempérière and Fry, 2020).

7.3.3.4 Development of innovative environmental flow releases

Development of innovative strategies for environmental flow release adapted to the local context is an important need which should be based on scientific studies undertaken for a wide range of conditions and sites (e.g. climate, geography, biology, etc.).

7.3.3.5 Development of innovative methods to offset new harsher operation regimes

The development of new methods to attenuate the effects of new and harsher operation regimes on aquatic ecosystems is another very important action that requires scientific focus.

7.3.4 Development of comprehensive approaches allowing for compromises

The **development of innovative and comprehensive approaches to address environmental issues and biodiversity protection allowing for compromises**, is of top priority.

The target of this action is to develop approaches and tools to balance out the different societal needs that European hydropower can address. Environmental issues associated with hydropower must be balanced against those of other energy sources including environmental consequences, contributions to climate targets and climate adaptation, as well as industrial and financial considerations.

This requires that we share knowledge on environmental impacts at a European level between basic science, industry, civil society and European and national authorities, to support discussions with up-to-date information in order to support a quick process for acceptance (or not) on rehabilitation or green-field projects.

This action will provide tools and a comprehensive approach for rating environmental, social and even financial acceptance, and for comparing the footprint of any energy generation power plant, based on readily available good international practice guidelines.

The ambition is to provide the best tools leading to environmental and social mitigation, which sets the tone for European E&S standards. The development will be done with the participation of the EIB.

The comprehensive approach will undertake a synthesis of lessons that can be drawn from best practice and the latest research outputs and should be implemented as the European Environmental, Health, and Safety General Guidelines (inspired from IFC on avoidance

measures; human rights; no-go criteria; hydropower benefits, multi-purpose facilities, GhG, eco-conception or ecological offset, etc.).

8 Conclusions and outlook

After three rounds of consultation with our Stakeholders, the Strategic Industry Roadmap sketches out the major non technological challenges hydropower faces to fully integrate with the European Green Deal. Solutions to the economic, social, and environmental challenges have been identified. They have been prioritised by both Stakeholders and the Consultation Expert Panel. The end result, together with the Research and Innovation Agenda, is a valuable tool for guiding appropriate R&D efforts and for helping the industry to navigate a path towards enhanced global technology leadership.

The Strategic Industry Roadmap is an important contribution to the growing debate on the net zero economy and the European Green Deal. It will be highly relevant for the discussions on finding the best solutions to provide the new energy system with flexibility.

It 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 could have a bright future in Europe under two conditions. Firstly, policymakers and regulators need to solve the “missing money” issue for all flexibility services and secondly, sustainable schemes balancing the protection of biodiversity, climate change and economic considerations must continue to be developed.

Hydropower technology is well 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 was born to be a catalyst for the Energy Transition.

But now new demands are being asked of it. Hydropower technology can and must evolve to respond to new environmental and societal challenges. By fostering innovative environmental approaches, hydropower will stay as a core element of the future renewable energy system. Without innovative hydropower we will not have a sustainable future.

Sustainable hydropower is not only the generation of sustainable energy but also brings huge added value to society by providing, in parallel, infrastructure in remote areas as well as vital services like water supply for irrigation and households, flood and drought protection, navigation, tourism and leisure activities. These services can be developed to provide civil society with greater resilience towards climate change impacts.

There should be no fully renewable energy system without hydropower, as hydropower is one of the best technologies to help combat climate change (i.e., global warming) and to integrate the impressive growth of other intermittent and non-dispatchable renewable energy sources into the electricity system.

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APPENDICES

Appendix A: List of factors considered in the global system network analysis as identified during wider stakeholder consultation

1. Hydropower sector

Factor	Description
1.1 Hydro Installed Capacity	Total installed capacity in all powerhouses or in a single powerhouse [MW].
1.2 Reservoir Volume	Total useful reservoir volume at all hydropower schemes or at a single scheme [hm ³].
1.3 Electricity Generation Hydro	Yearly electricity generation in all powerhouses or in a single powerhouse [GWh].
1.4 Flexibility	Ability of hydropower plants to respond to fast changing demand in the electricity grid by furnishing peak energy and grid services.
1.5 Peak Energy Production	Yearly electricity production of hydropower during peak hours of demand [GWh].
1.6 Market Opportunities	Yearly opportunities of hydropower at the spot market to sell electricity at high prices during periods of high demand [hrs].
1.7 Harsh Operation	Start-up and shut-down of hydropower plants or rapid changes of generation [number].
1.8 Maintenance Costs	Yearly cost of maintenance of hydropower plants [Euros].
1.9 Electricity Sales Hydro	Yearly revenues of electricity sales by all hydropower schemes or a single scheme [Euros].
1.10 Hydro Benefits	Yearly benefits of all hydropower schemes or a single scheme [Euros].
1.11 Hydro Generation Costs	Cost of generation by electricity produced in all hydropower schemes or a single scheme [EUR/MWh].
1.12 Refurbishment Hydraulic Machinery	Refurbishment or renewal of hydraulic machinery with the purpose of increasing efficiency, installed capacity and flexibility.
1.13 Investments New Projects Hydro	Investments in green field hydropower projects taking advantage of the untapped potential in Europe.

1.14 Hydro Infrastructure Upgrading Extension	Upgrading and extension of existing hydropower infrastructure with the purpose of increasing installed capacity, electricity generation and storage.
1.15 Operational Safety	Operational safety of hydropower plants, low risk of incidences with loss of production.
1.16 Ageing of Hydro Infrastructure	Ageing of hydropower infrastructure like hydraulic machinery and civil structures (intakes, dams, penstocks, tunnels, canals etc.).
1.17 Communication Hydro	Communication explaining technology and highlighting benefits of hydropower to the public domain.
1.18 Multipurpose Projects	Multipurpose hydropower projects comprising electricity generation, water supply for drinking and irrigation, flood protection, drought prevention, navigation, leisure activities and tourist attractions, biotope creation, hydropeaking mitigation, firefighting, artificial snow production, strategic water reserve, etc.
1.19 Attractiveness Hydro Profession	Attractiveness of the hydropower field for engineering students and young professionals.
1.20 Hidden Hydro	Untapped hydropower in existing water infrastructure like water supply wastewater networks, water diversion weirs, navigation locks, irrigation canals, tailrace channels etc.
1.21 New Pumped Storage	New pumped storage powerplants as greenfield projects or in combination with existing in-stream reservoirs.
1.22 Combined Heat Pumped Storage	Underground pumped storage taking advantage of heat stored in the water and in the rock of underground reservoirs.
1.23 Tourist Attractions	Tourist attraction of hydropower schemes with its reservoirs for leisure activities.
1.24 Jobs in Remote Areas	Jobs created by hydropower plants in remote areas for operation and maintenance.
1.25 Stakeholder Involvement	Involvement of stakeholders at early stages of planning of new or the extension of new hydropower plants; public hearings and information events.
1.26 Concession Fees	Fees paid by hydropower schemes for concession or license to use the energy potential of water.
1.27 Creation Biotopes	Creation or restoration of biotopes like wetlands and floodplains in the framework of multi-purpose projects.
1.28 Innovation Hydropower Technology	Innovation in the field of hydropower comprising equipment, construction, design, operation etc.

- 1.29 Sediment Management Management of sediments at hydropower infrastructure with the purpose to minimise reservoir sedimentation and the depletion of sediments in rivers downstream of dams.

2. Energy and Economic Policy sector

Factor	Description
2.1 European Green Deal	The European Green Deal is a roadmap for making the EU's economy sustainable. This will happen by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all.
2.2 Sustainable Economy	Sustainable economy favoured by a circular economy in all sectors: According to the European Green Deal there are no net emissions of greenhouse gases by 2050; economic growth is decoupled from resource use; no person and no place is left behind.
2.3 Decarbonising Energy Sector	According to the European Green Deal the key principles are to prioritise energy efficiency and develop a power sector based largely on renewable sources, to ensure a secure and affordable EU energy supply and have a fully integrated, interconnected and digitalised EU energy market.
2.4 Circularity	Circular economy toward sustainable economy with economic growth which is decoupled from resource use.
2.5 Electrification Mobility	European Green Deal actions will roll out cleaner, cheaper and healthier forms of private and public transport which directly result in an electrification of the mobility sector.
2.6 Energy Efficient Buildings	European Green Deal actions will ensure that buildings are more energy efficient.
2.7 Heat Pumps	Pumps for extracting heat from heat sources (water, air, soil).
2.8 Electricity Generation Wind	Yearly generation by wind energy triggered by investing in environmentally friendly technologies according to the European Green Deal.
2.9 Electricity Generation Solar	Yearly generation by solar energy triggered by investing in environmentally friendly technologies according to the European Green Deal.
2.10 Electricity Generation Nuclear	Yearly generation by nuclear energy; phase out decided by many European countries.
2.11 Electricity Generation Coal	Yearly generation by coal energy; phase out decided by many European countries.
2.12 Heat Storage	Energy storage by heating water or soil with overproduction of electricity of renewable sources.

2.13 H2 Storage	Energy storage by producing H ₂ from overproduction of electricity of renewable sources.
2.14 European Grid Extension	According to the European Deal decarbonising of the energy sector is based on a fully integrated, interconnected and digitalised EU energy market.
2.15 Cost CO ₂ Certificates	Cost of CO ₂ certificates under free market conditions.
2.16 Eco-Labels	Eco – Labels for electricity generation based on sustainability assessment (equivalent CO ₂ emissions and pay back factor).
2.17 Economic Growth Europe	Growth of economy in Europe favouring investments and consumption.
2.18 Sustainable Mobility	European Green Deal actions will promote sustainable mobility with modes of transport which are consistent with wider concerns of sustainability considering both social and environmental issues (reduced CO ₂ emissions among others).
2.19 Subsidise New Renewables	In general measures that keep prices of renewable energies for consumers below market levels or for producers above market levels or reduce costs for consumers and producers. In particular new generation from wind, solar and small hydropower is subsidised by guaranteed feed-in tariffs.
2.20 Taxes	Compulsory contribution to state revenue. Taxes paid by hydro companies to regional and state government.

3. Electricity Market sector

Factor	Description
3.1 Supply Safety	Continuous supply of electricity satisfying the instantaneous demand of the grid and avoiding black outs.
3.2 Required Grid Capacity	Grid capacity ensuring supply in all countries and all over Europe.
3.3 Electricity Demand	Yearly demand of electricity [GWh] and instantaneous demand [MW].
3.4 Uncertainties Electricity Market	Uncertainties of future electricity price and demand.
3.5 Need of Peak Energy	Yearly need of energy during peak hours of demand.
3.6 Volatility Electricity Generation	Volatility of electricity generation resulting from strongly varying generation some renewable sources as solar and wind.

3.7 Spot Market Electricity Price	Price level of electricity on the European spot market.
3.8 Hydro Merit Order	Merit order of electricity furnished by hydropower compared to other generation sources [Ranking].
3.9 Value Grid Services	Remuneration of grid services like frequency control, blind energy, reserves etc.
3.10 Batteries	Storage and supply capacity of batteries.
3.11 Smart Grid	Optimisation between electricity demand and supply in the grid by smart technology.

4. Environment and Public Society sector

Factor	Description
4.1 Opposition Hydro	Opposition of public society against hydropower projects (greenfield or extension and rehabilitation of existing plants).
4.2 Benefit Sharing Local Communities	Sharing of benefits of hydropower schemes with local communities by concession fees, taxes, infrastructure in remote areas, favourable electricity supply.
4.3 Ecological Flow	Required water flow in a river stretch downstream of dams with water diversion to maintain river ecology.
4.4 Hydropeaking	Rapid flow changes in rivers (water level fluctuations flow velocity change) downstream of power plants due to operation of storage hydropower plants or pumped-storage plants rapidly adjusting to the grid demand.
4.5 Alteration Flow Regime	Alteration of natural flow regime in rivers due to residual flow regime and/or hydropeaking.
4.6 Fish Habitat	Available space in rivers for fish habitat and reproduction.
4.7 Fish Population	Density of fish and number of species.
4.8 Fish Migration	Possibility of fish to migrate upstream across obstacles like dams and weirs.
4.9 Loss of Biodiversity	Loss of biodiversity due to hydropower infrastructure (and other infrastructure).
4.10 Loss Landscape	Loss of land surfaces due to hydropower infrastructure like reservoirs (and other infrastructure).
4.11 Environmental Mitigation Measures	Measures to mitigate environmental impacts such as fish migration (fish ladders, lifts, sluices, lateral rivers etc.), hydropeaking (retention basin, operational ramping of generation, river morphology restoration, etc.) and ecological flow (minimum flow, artificial flood release etc.).

4.12 Knowledge of Ecological Indicators	Knowledge of indicators to define acceptable environmental impact and mitigation measures.
4.13 Ecological Compatible Design	Design of hydropower plants and infrastructures compatible with ecological requirements keeping impacts on an acceptable level in view of hydropower benefits.
4.14 Population Relocation	Resettlement of population due to construction of large infrastructures like reservoirs.
4.15 Biological Continuity	Continuity of flora (seems etc.) and fauna (invertebrates etc.) over obstacles created by hydropower infrastructure (dams, weirs, reservoirs etc.).
4.16 Inundation Risk	Risk of flooding and related damages.
4.17 Sediment Dynamics	Sediment transport in rivers ensuring favourable dynamic river morphology and motion of sediment particles during their formation, transport, and settling processes.
4.18 Public Awareness Hydro	The public level of understanding about the importance and implications of the hydropower sector in the community.

5. Research and Development sector

Factor	Description
5.1 Research Funds	Available Research Funds from EU, public national and private foundations.
5.2 Innovation Renewables	Innovation in the field of renewable energies (including hydropower) to make them more efficient and competitive.
5.3 Innovation	Innovation in the field of energy and industrial technology.
5.4 Capacity Building	Long-term know-how build up and transfer to young professionals.
5.5. Digitalisation	Digitalisation in general and in the hydropower industry in particular.
5.6 Laboratory Equipment	High quality laboratory equipment for testing hydropower technology and infrastructures by hydraulic model tests.

6. Legal Framework sector

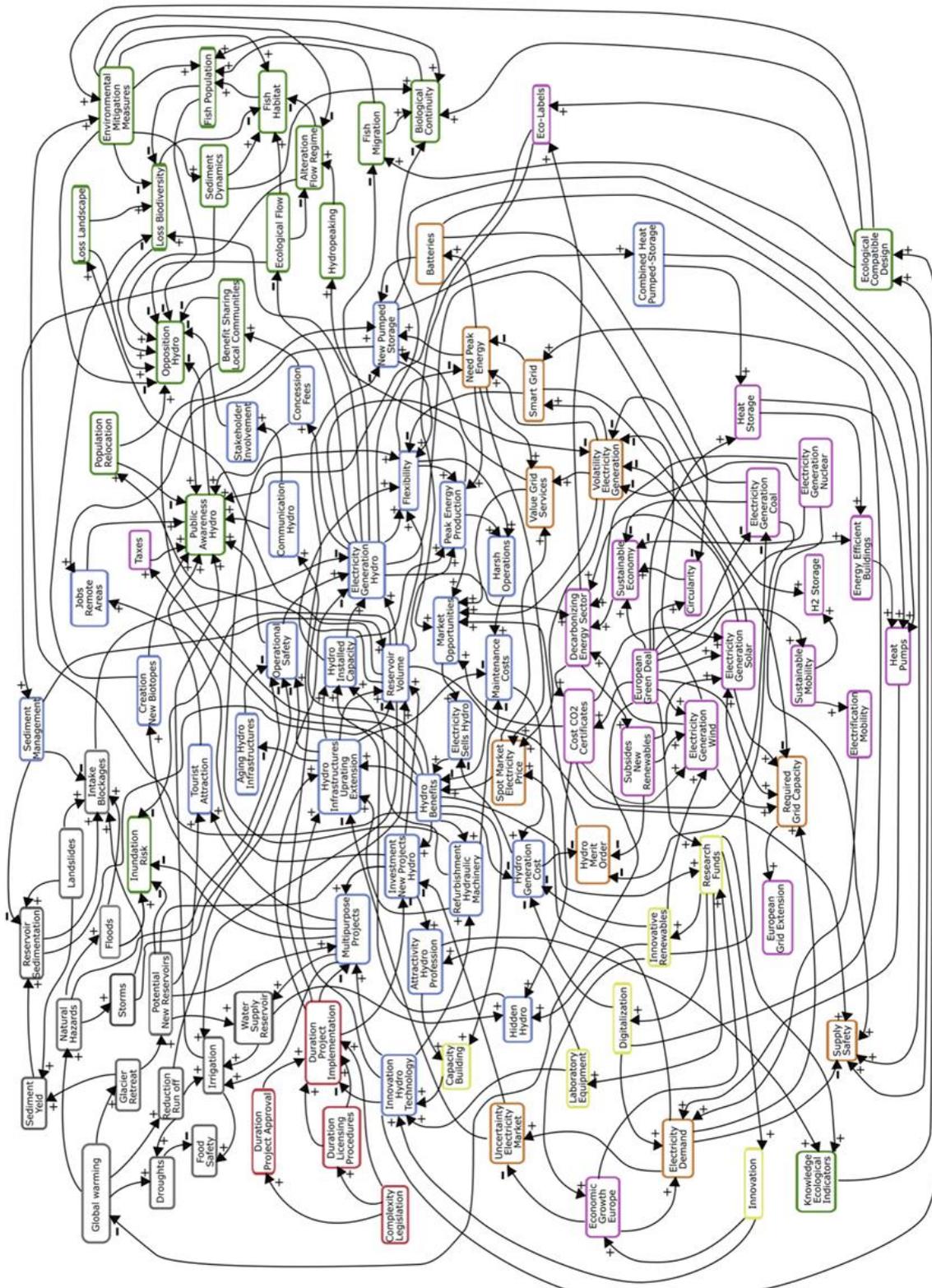
Factor	Description
6.1 Complexity of Legislation	Complexity of legislation at national and international levels in general and related to hydropower development in particular.

6.2	Duration Licensing Procedures	Duration until a greenfield or an extension project obtains the concession license (new or adjusted).
6.3	Duration Project Approval	Duration until a hydropower project is approved by the authorities including EIA etc.
6.4	Duration Project Implementation	Duration until an approved hydropower project is built and put into operation.

7. Climate Change sector

Factor	Description
7.1 Global Warming	Degree of global warming.
7.2 Glacier Retreat	Melting of glaciers.
7.3 Potential New Lakes	New lakes created by glacier retreat in alpine areas which have to be secured and can be exploited by multi-purpose projects.
7.4 Droughts	Periods of inadequate rainfall and run-off.
7.5 Irrigation	Irrigation of arable land for food production.
7.6 Food Safety	Safety of food supply locally, regionally and worldwide.
7.7 Reduction Runoff	Yearly or seasonal reduction of runoff.
7.8 Water Supply Reservoirs	Reservoirs for storage of water for agriculture, industrial and domestic use or for ensuring minimum flow in rivers.
7.9 Natural Hazards	Occurrence of natural hazards as floods, storms, heatwaves, droughts, landslides triggered by global warming.
7.10 Floods	Number and magnitude of floods.
7.11 Landslides	Slope instability due to heavy rainfall.
7.12 Storms	Storms and tornados with extreme wind velocities.
7.13 Sediment Yield	Volume of sediment transported through overland runoff and river flow.
7.14 Reservoir Sedimentation	Loss of reservoir volume due to sediment accumulation in reservoirs transported by rivers and overland flow.
7.15 Intake Blockage	Blockage of intakes in reservoirs and at weirs due to sediment and debris transport.

Appendix B: Network representing hydropower in Europe in a complex environment



Appendix C: Case studies of abandoned projects

1. Type 1 - Generation losses in accordance with laws on nature protection

- In Belgium, France and Germany, throttling and shutdown of turbines is required during the peak downstream migration periods for silver eels: e.g., practiced at Meuse, Dordogne, Main and Seine.
- In Austria, a number of measures have been implemented to improve the ecological status of Austrian rivers, which causes generation losses. An overview of measures during the first cycle of river basin management plans can be found online at: <https://oesterreichsenergie.at/der-nationale-gewaesserbewirtschaftungsplan-2009-umgesetzte-massnahmen-der-oesterreichischen-wasserkraft.html>

2. Type 2 – Projects not in accordance with laws on nature protection

On Tuesday 19th January 2021 an NGOs roundtable event was organised by the HYDROPOWER EUROPE Forum. The objective of this roundtable event was to listen to and enable discussion between NGOs concerning their issues with hydropower. It needs to be highlighted that the topics and discussions were dominated by problems with some rogue and irresponsible hydropower development in non-EU countries of the Western Balkans where foreign investors profit from the absence of strict environmental legislation and lack of enforcement measures by authorities. Hydropower plants in EU and EFTA countries must comply with the provisions of the Water Framework Directive and plant owners have to and are continuously investing in environmental mitigation measures.

3. Type 3 Authorised projects stopped or attacked by continued activity of environmental or local activist groups

- In Spain, in Caleao, on the Nalon river, a new dam was planned since 1992 for water and energy supply, and for compensatory flows to maintain biodiversity (enhancing water quality for salmonids downstream). After its approval, the dam project continued to be much contested by ecological and conservationist associations because it would affect the Natural Park of Redes (Natura 2000, LIC, ZEPA, Biosphere Reserve) and several protected species within it. On May 11th, 2018, the Asturias Parliament (Junta General del Principado) approved a Resolution for the Asturias Regional Government to officially renounce the Caleao dam project in the Plan of Water Supply. For more info: <https://amber.international/portfolio-item/river-nalon-spain/> <https://amber.international/no-more-dams-on-the-nalon-river/>
- In Western Germany, in 2012, Trianel planned to build (with the start of construction planned for 2016) the PSP Rur in the Eifel. Although the area is of

special environmental value, environmental organisations had a positive attitude towards the project. However, there was a citizen initiative fighting against further project development. The initiative was worried about environmental impacts due to the construction of the upper basin, increased water level fluctuations at the lower Rursee lake and related impairments to leisure activities and riverbank ecology. Trinael withdrew the project in 2013, also due to the difficult political and economic conditions for PSP. For more info: https://www.aachener-zeitung.de/lokales/eifel/energieversorger-trinael-hat-inzwischen-weitere-vorhaben-verworfen_aid-35563971 <https://www.bund-nrw.de/themen/klima-energie/hintergruende-und-publikationen/speicher> .

- in Germany there is a project on the Iller River between Ulm and Memmingen. The investor wanted to develop a hydropower station and improve the river continuity, which is not ensured at the moment. Environmental NGOs sued him, but the court ruled in his favour. The environmental NGOs are still pushing to review the project.
- Vattenfall had an extension project that went to public referendum in the local community. The project would decrease the water in a small river. A wind power project was included to give some extras to the community, but finally the referendum vote was a 'No', backed by national NGOs rushing in to support the No campaign.
- In North Macedonia, HPP Boshkov Most and HPP Lukovo Polje projects failed after complaints from environmental activists, although the World Bank explains its involvement in the project due to the importance of increasing Macedonia's reliance on renewable energy.
- Interestingly, in Germany it has been observed that **local communities and local environmentalists do not oppose projects for small HPPs** and even support them. **It is often federal NGOs or environmental organisations that oppose the project** and bring it to the public with very negative publicity. For instance, two positive examples for social participation processes are:
 - Planned PSP Heimbach at the River Rhein in Germany by Stadtwerke Mainz AG (ZEK Hydro Oct. 2014 p. 53-55 https://issuu.com/zekmagazin/docs/hydro_05_2014_72dpi).
 - In a village in the south of Germany a run-of-river plant has been refurbished with a new weir (it had been historical and not automated until 2017 - thus being very dangerous for the workers to set it up or take it down) and a fourth turbine was installed in order to increase productivity. Also, a fish ladder was integrated into the construction. The plant is in the middle of the village and during construction works of about one year the inhabitants had to deal with (sometimes severe) inconveniences. The operator had invited all inhabitants before starting construction works in order to inform them. Also during construction the operator constantly had an open ear and tried to make the disturbances as small as possible for individuals, mainly those living next to the

river. Afterwards their support was acknowledged. The village has accepted construction measures and supports the plant.

4. Type 4 - Conflicts related to inter-basin water transfer

- In Greece, the HPP Messochora on the Acheloos River faced considerable resistance from local and environmental groups. The civil and electromechanical works were finished in 2001 but impoundment of the reservoir and power plant commissioning are still pending after nearly two decades of hiatus. HPP Sykia, another part of the Acheloos diversion scheme, is practically abandoned. Part of the civil works is in place and its future remains uncertain. The main cause for its abandonment is its role as an impoundment structure necessary for the diversion of part of the water resources from the Acheloos basin to the prefecture of Thessaly in the Eastern part of Greece. A full redesign of the whole project (of the diversion scheme of the Acheloos River) is needed to transform this project from a one-way diversion scheme of water from Acheloos to the prefecture of Thessaly into a multi-basin water management scheme. In conjunction with the desired flexibility, a transparent framework for the water management of the affected basin is also needed to calm social resistance and to improve its environmental value. Although in theory this route of action seems promising, mistrust and animosity among the affected local groups makes the realisation of such a project difficult. A downgrade of this project to a simple large scale hydropower conventional reservoir stands a greater chance of success.
- In the Lulea workshop, from the Swedish perspective, the only way to solve this complex system and balance between objectives in the WFD and Habitats directive and to reach national and EU energy targets is to start with producing a national master plan and adaptive management. The master plan can maximise the environmental benefits and at the same time minimise the negative impact on the hydropower production. Case-by-case is not a good option. It is important to keep control of all scales from national scale to local scale. Adaptive management can make sure that changes in the boundary conditions (e.g. new storage capacity techniques, change in consumption, etc.) are managed within the system. Such a master plan for river basin management is a reliable long-term process clarifying and limiting administrative, social and environmental barriers (NIMBY) and providing flexibility and capacity of mitigation measures in hydropower.

5. Type 5 - Questioning the efficiency of environmental legislation

- One main issue concerns the conflict between Energy Transition targets and environmental targets (WFD and ecological continuity implementation). In general the cost-efficiency of measures is not established in terms of actual effect on water body biology. Continuity measures, especially fish migration devices and energy losses for ecological continuity, are often cost disproportionate. Hydropeaking in response to the increasing need of flexibility is threatened.

- In France, government mapping of hydropower potential development is reduced to one third because of ‘no go’ areas based on an extensive and abusive implementation of the WFD. In particular, the WFD set out the concept of a biological reservoir for good status of neighbouring water bodies. This concept is largely used, without fulfilling the legal and scientific criteria, to prevent hydropower development. Some local authorities raise administrative barriers to hydropower projects, although they are winners of government tenders for new small hydropower plants (e.g. A claim for justifying an alternative energy solution even if the government declares that the project is needed for the energy transition; an internal note to local administration describes how to prevent hydropower projects). Although most hydropower projects have been affected for environmental reasons, there is no real appraisal of the positive environmental impacts arising as a whole (birds, crawfish, etc.) and mostly only fish-related arguments are used against proposed projects. The lack of ecological flow pathway is also a common argument to shut down plants. However, the **calculation of this ecological flow is highly debatable**. The argument often leads to the termination of old water rights (that should not be vulnerable as they are supposed to give legal security to the operator). Some national administrations aim at terminating these rights and they are quite successful in it. Owners warned against decommissioning of existing hydropower infrastructure without set and clear criteria or metrics for what is considered ‘effective’ or ‘marginal’.
- Several small hydropower projects pointed towards prohibitively stringent and costly regulations regarding environmental protection, and further questioned the efficacy of some of the regulations. Certain structural solutions were pointed out to be cost-inefficient for very small projects, and therefore prohibitive.
- In Germany, there are several examples of small hydropower plants that had to be shut down, as the requirement for high environmental flows stopped the economic feasibility of the plants. In one case in Hessen, the allowance had faded out and to renew it there was the requirement to build a fish ladder. The municipality was pro hydropower and wanted to support the operator and applied for a municipal promotion programme at the state of Hessen. However, to get the support, this promotional programme had as a requirement an existing allowance (but the allowance would only have been given if the fish ladder was planned and financed). Also demands for fish passes with tremendous costs (about 100,000 Euros/per meter head) are often not bearable for operators. These demands have been made, though historically there had been a natural cascade at the site - so fish never had the chance to migrate. There needs to be an objective appraisal of all advantages and disadvantages and of real local (historical) conditions!

In Germany, in the licensing process, there is no judgment balancing environmental disadvantages with benefits in low carbon energy production. Efforts regarding project development and implementation are slowed down due to the difficult environmental, political and economic situation for PSP (<https://www.psw-heimbach.de/article/pumpspeicherwerk-stadtwerke-treten-auf-die-bremse/>).