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THE INTERNATIONAL ENERGY AGENCY TECHNOLOGY
COLLABORATION PROGRAMME ON HYDROPOWER

IEA Hydropower

IEA Hydro – Roadmap for best practise solutions for hydropower and fish

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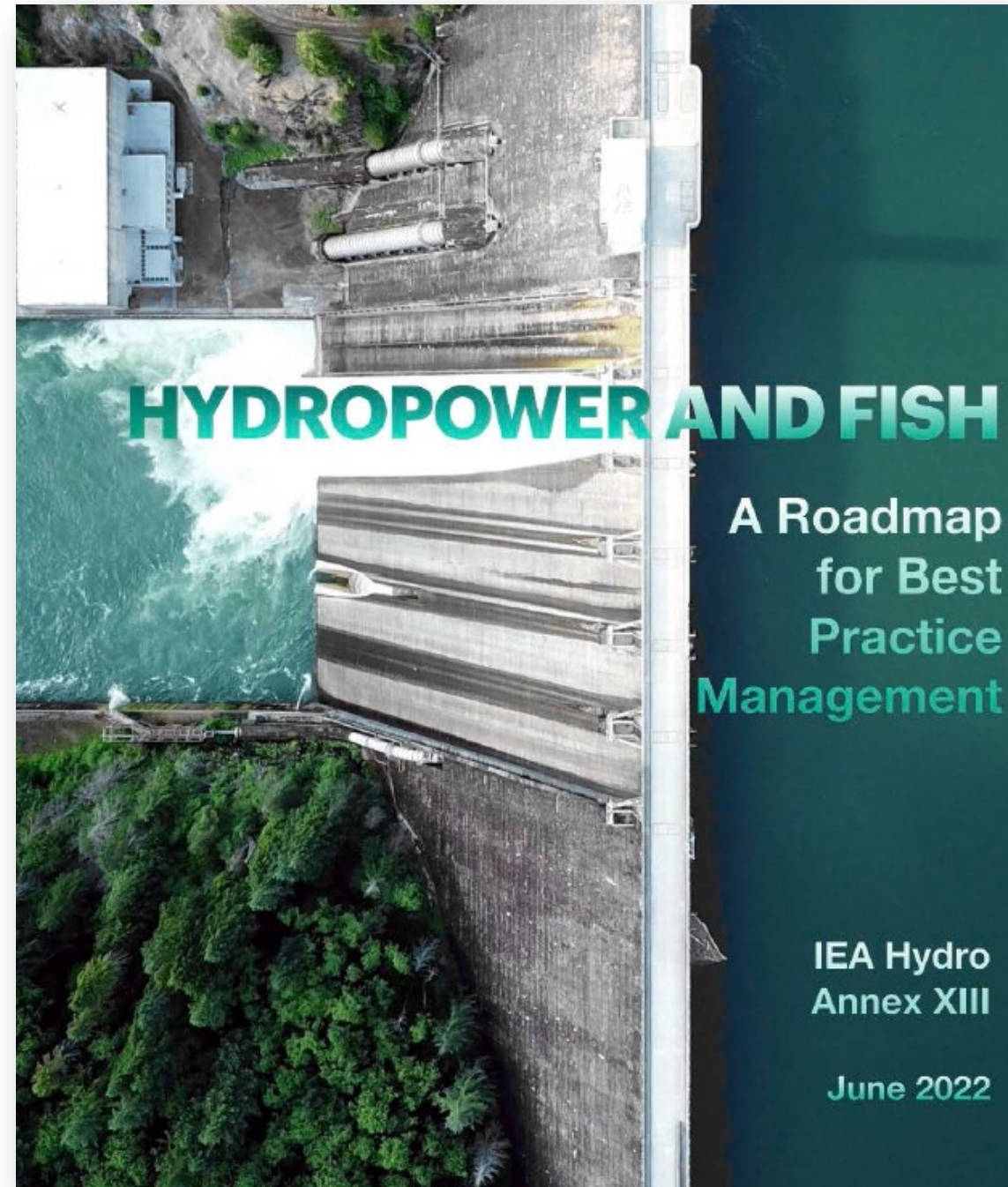


Commitment towards sustainable hydropower

Dedicated working group for Hydropower and Fish within IEA Hydro

- Main objective was to provide a better understanding of the effect of hydropower on fish
- Closing phase of Annex XIII (2020-2022), with one objective,

to compile and transfer knowledge in a Roadmap format





Joint collaboration

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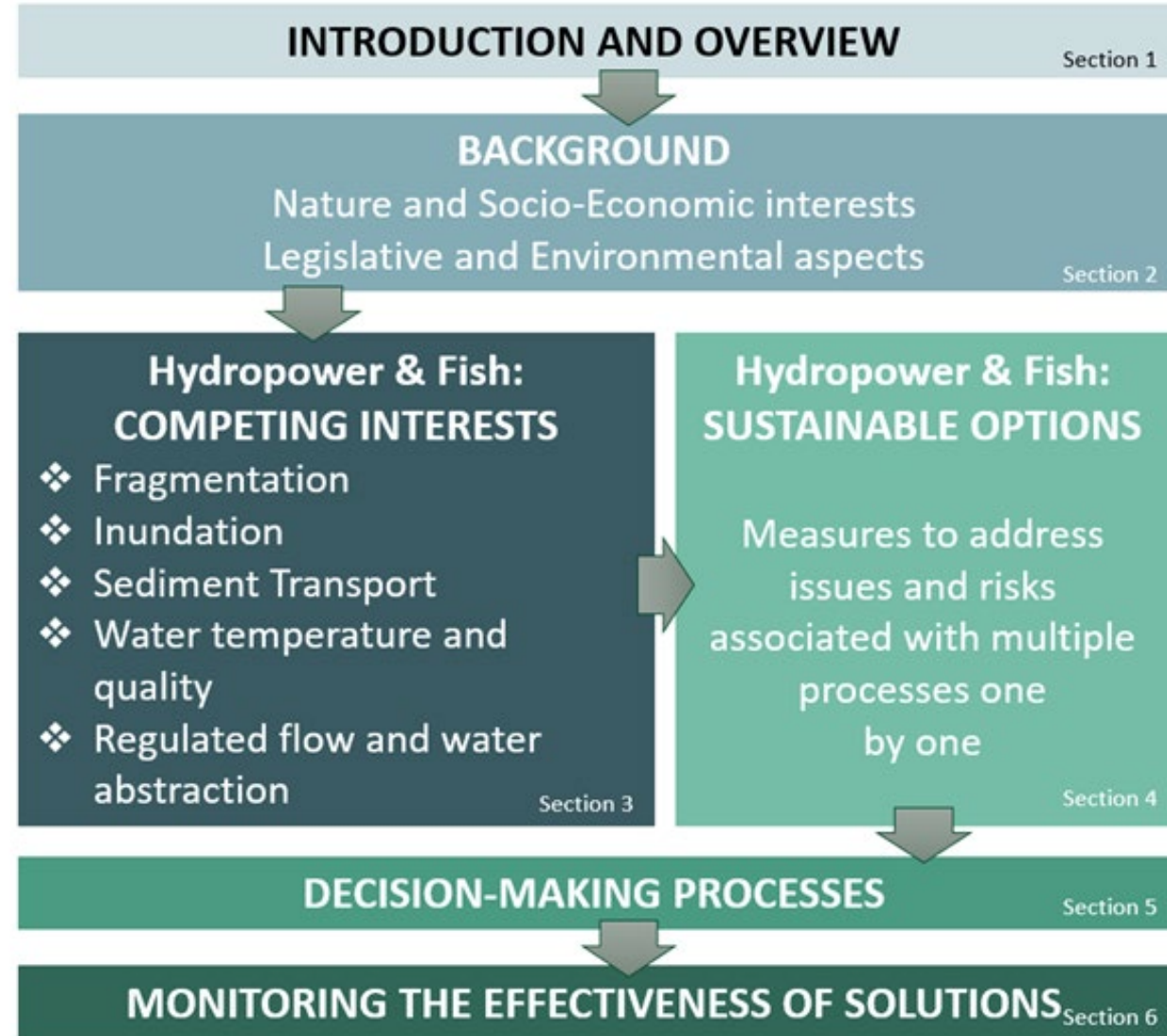


Roadmap overview

Knowledge basis on hydropower and fish interactions, discussed in the following parts:

- Background
- Problems and Solutions
- Decision-making processes
- Monitoring tools

Holistic approach to address key components





Background

- Presents socio-economic and nature's interest for water resource management
- Discuss the need for legislative practices that may set the maximum impact of hydropower on target species

SECTION 2. BACKGROUND

Section 2 presents the impacts of hydropower developments on fish. It starts with notes on social and natural aspects relative to watercourses, followed by a brief overview of the main interactions. The next part presents the policies and regulations that must be addressed, depending on the relevant jurisdictions. This is interlinked with environmental impact assessment and its role in evaluating the degree of hydropower impact on local fish. Based on the previous subsections, the final part discusses ecological aims: mitigation and conservation targets.

2.1 Socio-economic Interests: The Present and Future of Hydropower as a Renewable Energy Source

The rationale for hydropower is based on its past and present a significant contribution to global energy and its future importance towards a post-carbon civilization.

Hydropower is a long-standing, reliable, safe, and cost-competitive renewable energy source. It is essential in today's electricity mix, contributing more than 17% of electricity generation worldwide and about 85% of global renewable electricity (International Renewable Energy Agency). The contribution of hydropower is twofold: the primary benefit is the generation of clean, low-carbon, and renewable electricity. The secondary benefit is that hydropower complements the intermittency and uncertainty of wind and solar energy.

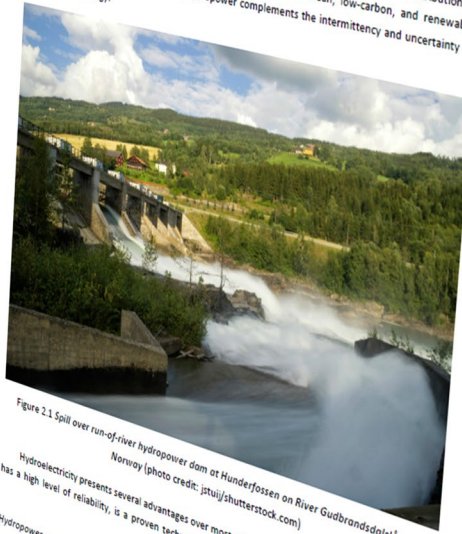


Figure 2.1 Spill over run-of-river hydropower dam at Hunderfossen on River Gudbrandsdalslågen, Norway (photo credit: jstuij/shutterstock.com)

Hydroelectricity presents several advantages over most other electrical power sources (Figure 2.1). It has a high level of reliability, is a proven technology, has high efficiency, relatively low operating and

loodplains, estuaries), while juveniles occupy feeding sites until they reach maturity. The four ranges from territorial to free-ranging and schooling foraging behaviour. Once mature, to spawning sites to reproduce. In species-rich watercourses, spawning migrations occur up am in rivers, between littoral and profundal lake zones and into pelagic zones. A great gamut s available for general descriptions of major potamodromous and diadromous fish groups ceptual model of the expected life cycles for eels is presented in Figure 2.2.

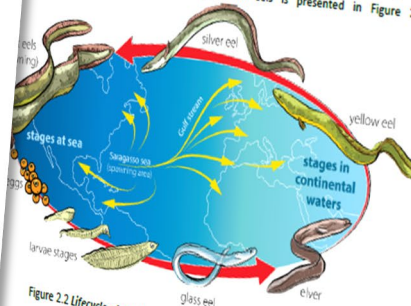


Figure 2.2 Lifecycle of catadromous European Eel (*Anguilla anguilla*) (Source: EreborMountain/shutterstock.com)

Awareness of Fish and Hydropower Interactions

ENVIRONMENTAL ASPECTS

water habitats cover only 0.01% of the planet's surface while accommodating over 100,000 over, freshwater ecosystems are among the most endangered ecosystems in the world. ly about one-third of the longest rivers in the world remain free-flowing [2.12].

development creates barriers, from high-head dams to low-head diversion weirs. The barriers ny species of aquatic organisms, from bacteria to mammals native to dammed watercourses. Fish es chosen as target organisms to measure the impact of hydropower development due to their es in both the natural and socioeconomic environments. Fish species are affected in various ways. e development of a hydropower project creates a barrier across a river, fish can be impacted at the construction phase. Although watercourse regulation poses similar problems to fish ies worldwide, each project presents site-specific issues and risks that must be addressed y.

hydropower system's design, construction, and operation are unique concerning its ture configurations (i.e., temporary and permanent) and how they divert water in the river e. Therefore, understanding the design and operation of a hydropower project is vital when g its impacts on fish in a regulated river. HPPs induce changes in water chemistry and hydro- gery, potentially affecting fish communities' structure and function.

Hydropower and Science-Policy interface

decision involving mitigating the impacts of hydropower developments on fish tory requirements. This section provides an overview of the general policies that

FOR A DECISION-MAKING FRAMEWORK

of the United Nations (UN) have adopted an agenda for sustainable development. of 17 defined goals for peace and prosperity for the planet and its people. The UN nt Goal (SDG) #6, «Ensure availability and sustainable management of water and ghts the importance of water management for the planet and society. Still, rivers ver are also touched by goal #7 «Ensure access to affordable, reliable, sustainable all». Also relevant is goal #15, «Protect, restore and promote sustainable use of sustainably manage forests, combat desertification, and halt and reverse land iversity loss». Since it is essential to life, water can easily be connected to almost all

ver and fish are embedded into all three dimensions of sustainability (i.e., social, nmental) and can be connected to various policies. Major policies of international te and Energy Policies and, more recently, Biodiversity. It is not always easy to es policies. Still, renewable energy and environmental protection policies can support er essential synergies if managed correctly. The topic of hydropower and fish is erent spheres of the total environment: in the biosphere (e.g., fish, biodiversity), the (e.g., river flow, hydropeaking) [2.13]. The need for more sustainable hydropower frameworks and market conditions is interlinked with the different spheres of the e three dimensions of sustainability. For example, sustainable hydropower must e energy supply and minimize negative impacts on aquatic ecology, including fish. ed holistic approach, also known as integrated river basin management, is critical to e of balancing the sustainable use of water resources to protect those vital ental spheres, the multipurpose uses of rivers, and energy. Forward-looking strategic nary research, and innovation are essential drivers for future sustainable policy and eed to account for regional particularities, in terms of the national energy and g the fish population, for example [2.13].

gical considerations need to be part of hydropower operation and management, it can rimize economic and technical hydropower operation and minimize adverse effects on r, an example of this is during hydropeaking (See [Section 4.6.3](#)). International g and cooperation in research will be an essential step for achieving a common e objectives of the decision-making framework, which can be generalized in best re the framework's relevance, it will need to differentiate between factors that are e board and factors that are important but applicable only in certain local areas. e fundamental to the comparative analysis of different river systems: concern g ecosystem characteristics. In this context, monitoring and reporting, as required by n be an essential tool in consolidating information on river systems in the context of sh, going beyond fish ecology per se, e.g., the Clean Water Act [2.14] in the United States Water Framework Directive (WFD) in the European Union (2000/60/EC) [2.15]. Guidance

Problems and Solutions

Presented along five processes:

- Fragmentation
- Inundation
- Sediment transport,
- Water temperature and quality
- Regulated flow and water abstraction

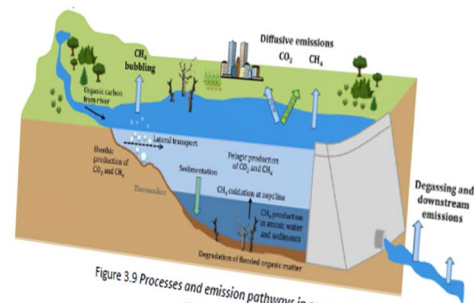


Figure 3.9 Processes and emission pathways in reservoirs (Source: [3.13])

Issues associated with nutrient loads, changes in dissolved oxygen, and production of greenhouse gases:

- Reservoirs become nutrient sinks and turn eutrophic, causing toxic algal blooms in extreme cases.
- Water diverted through storage HPP normally has low DO levels, which decreases oxygen levels downstream of the dam.

Risks associated with nutrient loads, changes in dissolved oxygen, and production of greenhouse gases:

- In general, chemical changes to water quality may affect fish survival and growth.
- Anaerobic processes in hypolimnion may reduce available habitats in the reservoir.
- Changes in water quality may affect fish reproductive success and the abundance of food organisms due to stressors such as water pollution and toxic algal blooms, particularly in high retention time reservoirs.
- When GHGs or under-aerated water are released downstream, it may decrease the oxygen content of the rest of the river and threaten aquatic life.

Supersaturation

In addition to the risk of releasing water with low DO levels, some impoundments may also be predisposed to releasing water with high dissolved gas levels. The solubility of gases correlates positively with pressure. When Total Dissolved Gas (TDG) levels in the water exceed 100% on a given ambient pressure, it becomes oversaturated. The state is referred to as supersaturation. Such a situation can negatively affect aquatic life. When fish and invertebrates are exposed to gas supersaturation, they risk the formation of gas bubbles in tissues and blood vessels. This condition can alter the behaviour of an individual fish, it might cause other sub-lethal or chronic effects (i.e., increased stress level, increased susceptibility) and increased mortality depending on the tolerance level of the species in different life stages. Some fish species may navigate themselves into deeper areas to compensate for oversaturation; however, if adequate depths are not available, the risk of gas bubble disease increases.

Overview of the principal fish passage facilities and their general application

FISH SPECIES	GENERAL APPLICATIONS	BENEFITS/ADVANTAGES	BARRIERS/DISADVANTAGES
VOLUNTIONAL MEASURES (III)			
Salmonids	- Potentially scalable to suit the head.	- Suitable for juvenile eels, lampreys, and some climbing fish species. - Relatively inexpensive and with low maintenance. - Relatively small footprint. - Can manage variable tailwater heights and can operate independently of headwater levels.	- Species (juvenile eel) specific particularly at large dam heights. - Suitable slope sensitive to substrate selection. - Lampreys can block some designs.
NON-VOLUNTIONAL MEASURES			
Trout	- Scalable to suit the head.	- Suited to a wide range of fish sizes. - Ability to lift fish across any dam size with limited space requirements. - Low footprint. - New technologies are promising based on the first tests.	- Complicated and expensive technology. - Requires power to operate. - It is technically complex. - May require continuous supervision or daily inspection and adequate maintenance.
Salmonids	- Not limited by the head, applicable for cascade systems.	- Suited to a wide range of fish sizes. - Potential to transport fish across any size or multiple dams, with relatively low capital costs.	- Requires transport infrastructure between the dam's base and upstream impoundment(s). - Labour-intensive, and potentially high operating costs.

4 RECOMMENDATION FOR UPSTREAM PASSAGE OPTIMIZATION

roadmap comments on developing "appropriate" policies to ensure safe passage, where they do not already exist or are ineffective. Where such policies requiring fishways to be developed exist, the steps require the systematization of knowledge about the target species' ecological requirements, the understanding of the spatial scale of movements, and the spatial context of the dam in the catchment. This information will define objectives and the monitoring programs to evaluate their performance. Next, the design and costs to implement the fishway and monitoring programs are added to the capital cost of the dam. There will also likely be an additional cost incurred where measures affect the operation of the hydropower plant. At the end of this process, stakeholders are encouraged to make well-informed decisions. Seeking a practical solution that provides value at a reasonable cost is an essential component of decision-making.

A wide range of factors must be considered when selecting the most appropriate type of fishway for a site. As mentioned before, these include but are not limited to site characteristics, including barrier size, topography, hydrology, target species or species assemblage and extent of ecological understanding.

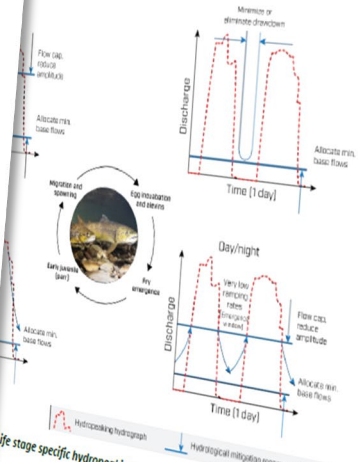
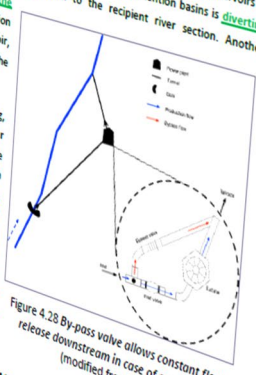


Figure 4.28 By-pass valve allows constant flow release downstream in case of emergency (modified from: [4.85])

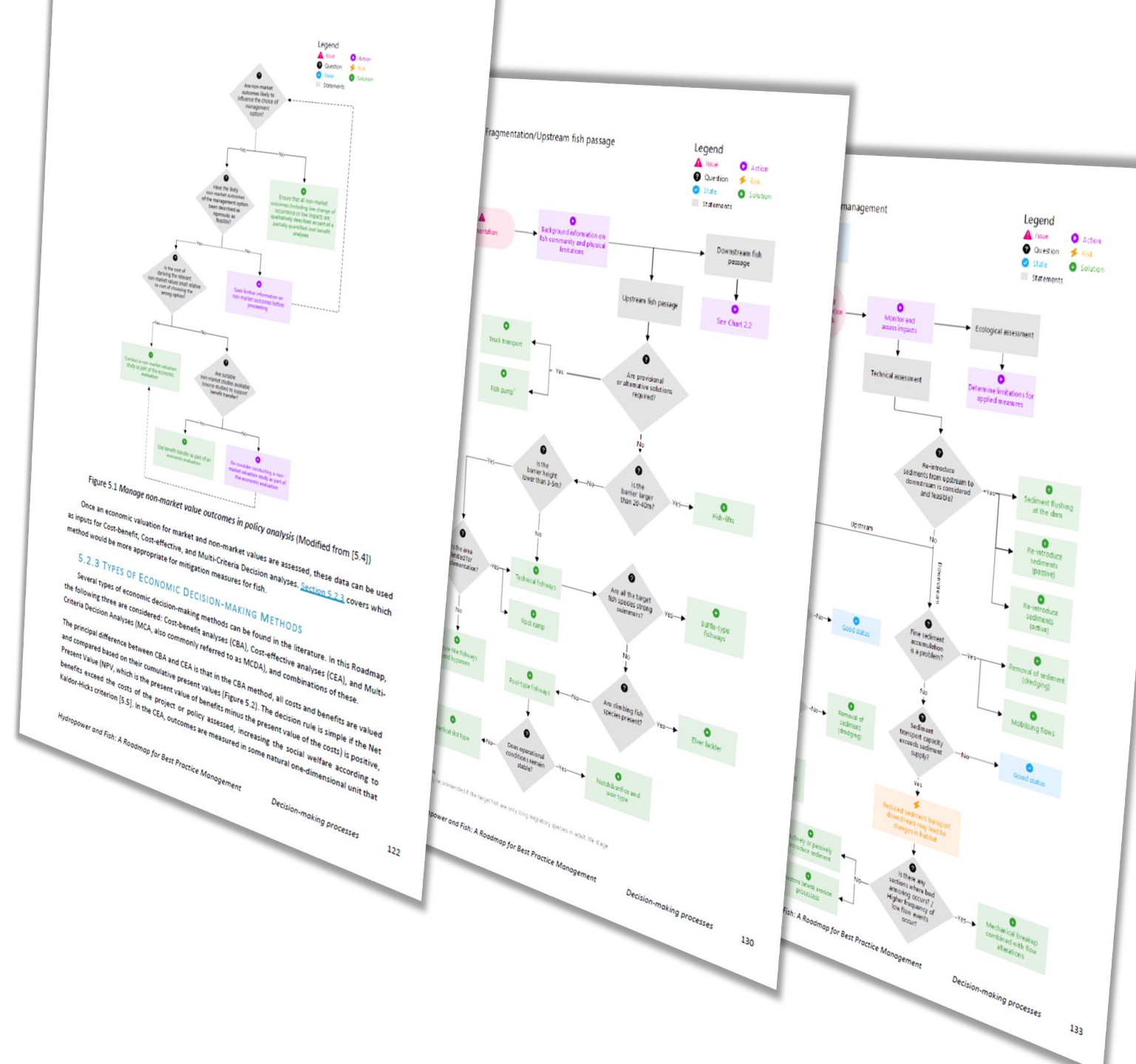


Decision-support tool

To guide and assist the users for considering mitigation measures: eight flowcharts with explanations supports this process.

Legend

	Issue		Action
	Question		Risk
	State		Solution
	Statements		





Summary of the Roadmap

It starts with a broad **background to hydropower and fish**, including **conflict** descriptions between them. Where there are challenges, the Roadmap **provides** options as **mitigation measures** for further consideration. Since there is often more than one suitable alternative, decision-support processes **guide the reader in considering options**. Although the main focus of the Roadmap has been to provide effective solutions for **fish populations**, many of the same measures may also be beneficial for viable **habitats** and for other **aquatic species**.

Available at:



The future of Hydropower and Fish working programme within IEA Hydro

The work will continue in a new Task
within IEA Hydro.





Task 19

Hydropower and Fish 2.0

Task 19: Hydropower and Fish 2.0



<https://getthematic.com/>



Environmental flows: applied methods on local and regional scale including trade-offs between ecology and power generation



Utilizing advanced techniques for monitoring: data abundance for enhanced knowledge on fish and their habitats



Risk assessment for hydropower operation and fish: importance of real-time information for mitigation measures

Environmental flows



- E-flows have been at the forefront of Ecohydraulic research for decades
- Several guidelines and international standards from the EU, North America and from the World Bank are available
- In recent years, a new approach has emerged from the EU to develop a **universal method** that can be applied **from a local to regional scale**.
- The main aim for the new Task 19 is to draw attention to the next level of e-flows and serve as a valuable forum for discussion and dissemination.
 - Combined with **economic considerations**, will provide an excellent basis for further discussions between the stakeholders



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Utilizing advanced techniques for monitoring



- Monitoring techniques have been in continuous progress for ages.
- For centuries, people wanted to know more about where to find fish and what might indicate their abundance in water.
- In the digital age, technologies have advanced, providing new, unique ways to follow fish's path and characterize their living habitats.
- The aim of Task 19 is to **raise awareness of new technologies**, such as the use and benefit of e-DNA, using AI techniques and new types of devices capable of collecting data from fish and on behalf of the fish (e.g., artificial sensor units).



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Risk assessment for hydropower operation and fish



- Risk assessment for hydropower operations is historically focused on preventing failures and securing stable power production.
- Ecohydraulics research tends to apply similar methods to assemble risk matrices for aquatic animals in relation to hydropower operation.
- Following **real-time information** from monitoring stations, such matrices provide valuable information to apply feasible and **cost-effective mitigation measures** at sites to improve the operational protocol of the local hydropower plant.
- The goal of Task 19 is to emphasize the benefit of such techniques that can increase social acceptance of hydropower operations in general.

Milestones

Phase	Description of milestones	Deadline
I	Kick-off meeting	M3
	Launch of Task 19 website	M5
	Proposal Task Force establishment	M6
II	Engage collaboration with IHA	M8
	Organized seminar/special session at a selected international conference	M12-M17
	Organized 1-day meeting (physical) with the expert group associated with an international conference	M20-M23
	Organized 1-day workshop associated with an international conference	M24-M27
III	Organized 1-day workshop to disseminate compiled knowledge of Task 19	M34



Deliverables

Phase	Description of deliverables	Deadline
I	Teaser of IEA Hydro Task 19	M7
II	Factsheet in alignment with the main objective of Task 19	M9
	Factsheet in alignment with the secondary objective 1 of Task 19	M9
	Factsheet in alignment with the secondary objective 2 of Task 19	M9
	Teaser to promote sustainable hydropower, produced together with IHA	M12
	White report on e-flows	M24-M28
	White report on monitoring techniques and risk assessment for hydropower operation	M24-M28
III	Final report from Task 19	M34
	Executive summary of the final report from Task 19	M36



The rapid expansion of variable renewable energy (VRE) resources combined with retirements of thermal generation give rise to increasing needs for flexibility at transmission, distribution, and the individual resource levels in the power system. The fundamental challenges associated with VRE integration and corresponding power system flexibility needs are similar across the world. Several different solutions are being developed to address these challenges, from infrastructure investments, improved forecasting, planning and operations, and improved electricity market design.

Flexibility Needs

The power system is dependent on flexibility to maintain overall reliability by balancing supply and demand and keeping frequency and voltage within their limits in a cost-effective manner. The following table presents an overview of different flexibility services, as defined by IEA Hydropower, with its unique operating characteristics, can provide flexibility across all the timescales, a capability that is likely to become more important in future power systems with high shares of VRE.



Survey of Flexibility Services in Current Systems

IEA Hydro Task 9 developed a survey of how these services are provided in different markets around the world. The resource portfolio in a system, the timescales, and the technologies available are key factors in determining the flexibility services that are needed.

Flexibility Services

Most timescales correspond to multiple types of flexibility services. The table below illustrates the distribution of flexibility services by timescale, based on survey in current systems.

Flexibility Services Provided

Various procurement methods including market-based interconnection agreements, tenders, and short-term services, dominates for short-term services, while long-term services are provided through long-term contracts.

Flexible Hydropower Providing Value to Renewable Energy Integration



Achieving low-cost, reliable, and environmentally sustainable electricity is a key part of the global decarbonization challenge. Variable renewable energy (VRE), like wind and solar photo-voltaic (PV) energy, are increasingly important to expand energy access and enable clean energy electrification.

Variable power production from VRE needs to be balanced against consumption, and this can be accomplished through multiple measures, including energy storage, demand response and management, generation flexibility, flexible transmission technologies, and smart grid solutions.

What flexibility is needed?

Power system flexibility is defined as the ability to effectively cope with variations in the supply or demand of electricity. In systems with high shares of wind and solar energy, system flexibility becomes increasingly important to maintain system balance.

Flexibility type	Short-term	Medium-term	Long-term
Time scale	Sub-seconds to seconds	Seconds to minutes	Minutes to hours
Issue	Ensure system stability	Short-term frequency control	More fluctuations in the supply/demand balance
Reference for system operation and planning	Dynamic stability; inertia; resource, voltage, and frequency	Primary and secondary frequency response	Day-ahead and intraday balancing of supply and demand (energy)

Contribution by Hydropower

Hydropower is the largest source of renewable energy in the electricity sector globally, representing 60 percent of total renewable generation in 2020. The technical potential for increased hydropower generation is large enough to meet substantial further deployment both in the medium (2030) and long term (2050). The International Energy Agency (IEA) expects hydropower generation to double by 2050. Hydropower is also by far the world's largest grid-connected storage technology. The International Hydropower Association expects that the current installed capacity of pumped storage hydropower of around 160 GW will increase to between 412 and 700 GW by 2050.

Reservoir, run-of-river, and pumped storage hydropower are already widely used for providing flexibility, energy storage and ancillary services in the electricity system and will play an even more important role in future systems with higher shares of VRE. Hydropower can deliver important flexibility services to support the provision of secure, reliable energy supply, whilst underpinning the effective integration of cleaner energy technologies. Hydropower is also used to provide base load energy in many countries and regions that have both high (Norway, Costa Rica, Venezuela, Tajikistan, Quebec, British Columbia, and Tasmania) and lower shares of hydropower in their grid (Sweden, Austria, Switzerland, Russia, China, India, USA, and Brazil).

A good indication of the types of flexibility required can be obtained by the phases of VRE integration as proposed by the IEA.



Factsheet coordination



- **Environmental flows:** Marie-Pierre Gosselin (Norwegian Institute for Nature Research)



- **Utilizing advanced techniques for monitoring:** Daniel Deng (PNNL)



- **Risk assessment for hydropower operation and fish:** Shannon Ames and Maryalice Fischer (Low Impact Hydropower Institute)



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be balanced shed through ge, demand ility, flexible ons.

Short-term
Months to years
Seasonal and inter-annual variability of VRE
Hydro-thermal coordination, adequacy, power system planning (energy reserves vary long durations)

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1st in-person Meeting Task 19 Edinburgh 19-20 October

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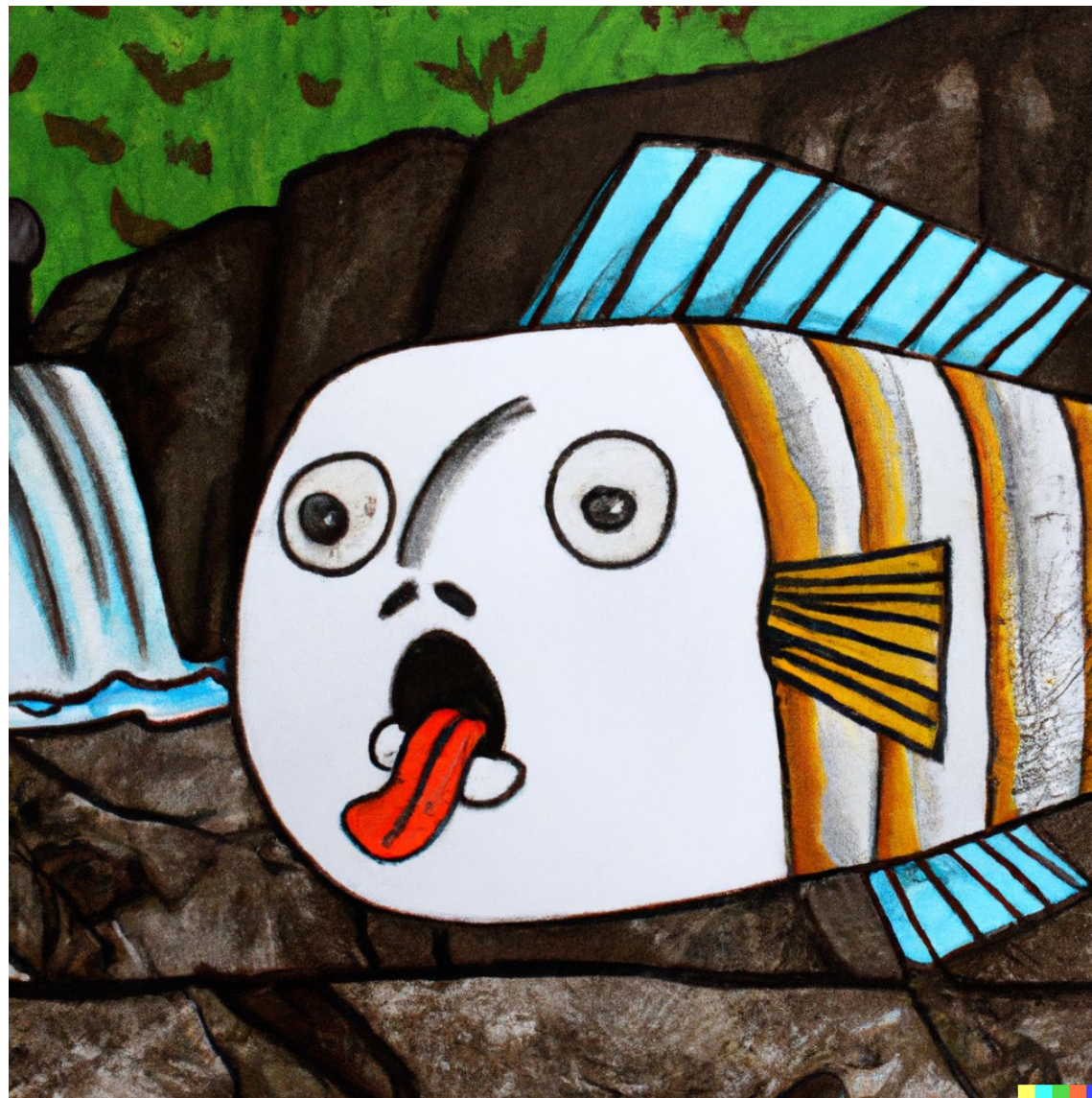
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