



Fish-friendly Innovative Technologies for Hydropower

Key outputs from the FIThydro project

Hydropower is an important source of renewable and stable energy production. However, hydroelectric power generation also affects aquatic ecosystems, in particular fish fauna and hydro-morphology. There is therefore a need to find alternative methods and tools for optimising hydropower facilities and mitigating impacts. Read more about why this is important and how it can be achieved in this brief overview.

This policy brief presents summaries of selected key outputs of the FIThydro project, which are relevant for policy-makers, managers and operators involved in the commissioning and operation of hydropower plants. They are relevant to the impact assessment and planning of mitigation measures for specific hydropower plants (new or existing plants) as well as for broader processes such as river basin management planning under the WFD.





THE IMPORTANCE OF SUSTAINABLE HYDROPOWER

Hydropower production can make an important contribution to the reduction of CO₂ emissions in Europe within current climate protection and renewable energy policy. At the same time, the construction and operation of hydropower plants (HPPs) is generally linked to impacts on rivers and lakes. In particular the hydro-morphology and fish fauna of river reaches are affected by hydropower. The major impacts of HPPs include river fragmentation and impoundments due to barriers, with modified flows and habitat conditions, changes in water temperature, sediment transport and patterns and other physical factors. In addition, hydropower operation causes a number of problems for the fish fauna. These include: blocking or delaying up- and downstream fish migration and injury or mortality of fish when passing turbines or spillways.

Therefore, there is a need to optimise hydropower facilities to strike a balance with the ecological needs of the affected river systems, adjacent land ecosystems and wetlands. When planning or renewing HPPs, various measures can be used to mitigate impacts on water bodies, such as fish passes and fish protection facilities, alternative HPPs and turbine designs and operations, establishment of environmental flows and sediment continuity, and habitat restoration measures.

THE FITHYDRO PROJECT

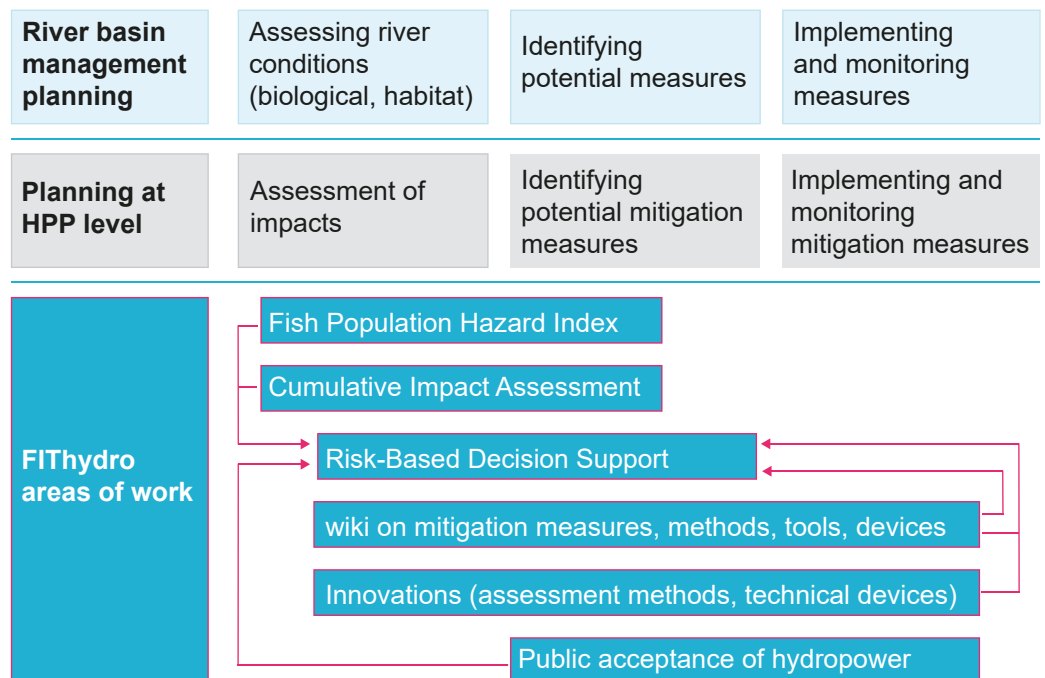
FIThydro (Fishfriendly Innovative Technologies for Hydropower) is a 4-year Horizon2020 research and innovation action (duration 2016-2020), which aims to support decisions on commissioning and operating hydropower plants (HPPs) by the use of existing and innovative technologies. It concentrates on environmental impact assessment and mitigation measures to develop cost-effective environmental mitigation measures and strategies to avoid fish damage and to support the development of self-sustainable fish populations, with the main emphasis on the more sensitive run-of-river HPPs.

More information
www.fithydro.eu

FIThydro brings together 26 partners (13 research, 13 industrial) from 10 countries, involving several of the leading companies in the renewable and hydropower energy sector in Europe. Solutions, methods, tools and devices are tested or applied and evaluated at 17 test cases, each with different HPP set-ups and different challenges, in four test case regions in Europe: Alpine region, Scandinavia, France/Belgium, Iberian Peninsula.

Scenario modelling in the four different geographic, climatic and topographic test case regions will allow the quantification of effects and resulting costs for different mitigation options in Europe.

The FIThydro outputs illustrated in the figure below can be used to support specific steps in the planning process. In addition, most of the key outputs of FIThydro feed into a risk-based Decision Support System and an online wiki information system, which systematically guide practitioners through the main steps of impact assessment and selection of appropriate mitigation measures for hydropower plants.



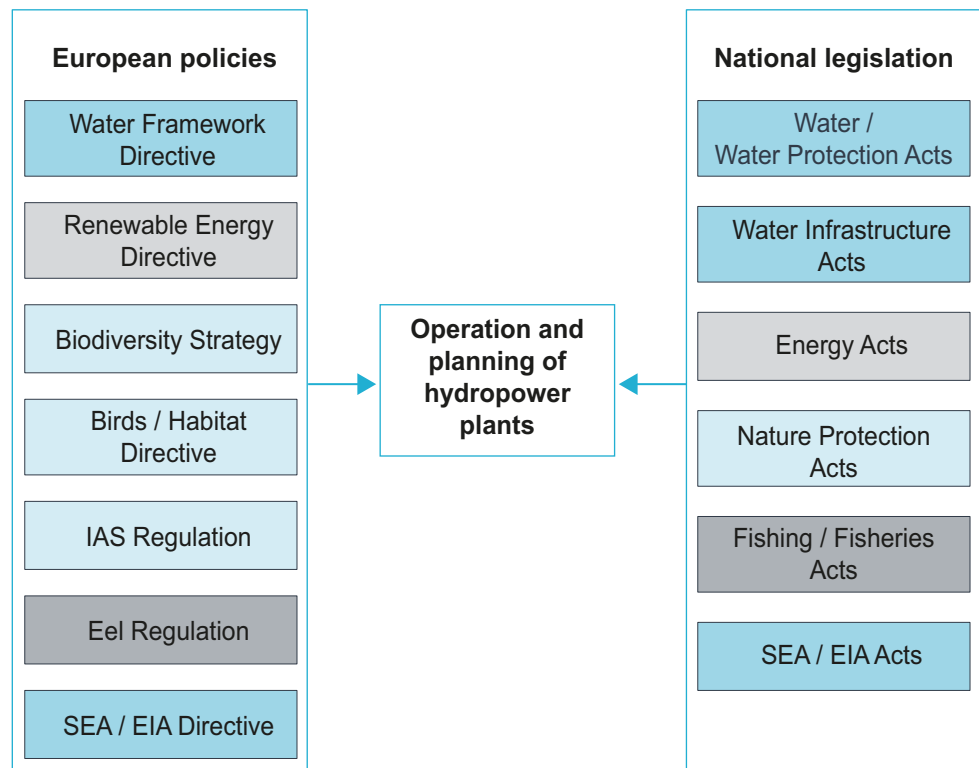
FIThydro outputs in relation to planning of mitigation measures at HPP level and to key relevant phases of river basin management planning

RELEVANCE TO EU POLICY

FIThydro aims to support the selection of cost-effective mitigation measures for new hydropower plants (HPPs) and for refurbishing existing HPPs to meet the environmental objectives of the EU Water Framework Directive (WFD), especially good ecological status or potential. This will provide direct support to the planning of mitigation measures for the 3rd cycle River Basin Management Plans of the WFD (2021-2027) and for the achievement of biodiversity protection targets (especially for fish species under the Habitats Directive).

At the same time, energy production that has an impact on water (e.g. from hydropower) will continue to play a key role for the EU to meet energy needs and climate mitigation targets beyond 2020. Therefore, the innovative environmental solutions developed and the mitigation measures tested in FIThydro also aim to support policies on renewable energy (Renewable Energy Directive) and climate change adaptation. Certain measures to mitigate the impacts of HPPs on fish do not lead to (significant) loss of energy production from hydropower, being therefore win-win cases to meet the requirements of different policies.

Other EU policies which are relevant to the planning and operation of hydropower include the Eel Regulation, the Invasive Alien Species (IAS) Regulation and the Strategic Environmental Assessment as well as Environmental Impact Assessment Directives (SEA/EIA).



Key policies relevant for the planning and operation of hydropower in the EU



National policies

The FIThydro project has also reviewed national policies concentrated in eight European countries (Norway, Sweden, France, Portugal, Spain, Germany, Switzerland and Austria), with a focus on legislation which is relevant to ecological improvements in water ecosystems and legislation relevant to renewable energy production. This review highlighted some important recent amendments to key legislation with relevance to the operation of existing HPPs or the commissioning of new HPPs, such as the revision of the Austrian National Water Act and the amendment of the Swiss Waters Protection Act, both in 2011 (Kampa et al., 2017).

Further reading:

Kampa, E. et al. (2017) [D5.1 Review of policy requirements and financing instruments](#)

Review of national policies in 8 European countries

- The WFD and recent revisions of national policy have been strong drivers for modifying commissioning procedures for new hydropower plants as well as for revising permits of hydropower plants. Authorisations for existing hydropower are being adapted or are expected to be adapted to meet the requirements of the WFD in most of the eight countries examined.
- Requirements for hydropower plants to mitigate the impacts of disrupted upstream fish migration and modified flow conditions are usually based on legislation. In some countries, there is a lack of requirements to mitigate impacts related to bedload / sediment transport, hydropeaking impacts and downstream fish migration, mainly due to still open questions which need clarification through research or pilot studies.
- Some of the key policy challenges relate to uncertainties in the interpretation of the legal framework (e.g. WFD objectives for heavily modified water bodies, or definition of disproportionate costs), or to the lack of specification of a timeframe for implementing mitigation measures in all existing hydropower plants.
- Although there is a number of innovative financing support schemes in place, the lack of adequate financing is a major bottleneck to the implementation of necessary mitigation measures at already existing hydropower plants in European countries.

RISK & IMPACT ASSESSMENT

FIThydro Fish
Population Hazard
Index

<https://www.fithydro.eu/fphi/>



Further reading:

Wolter, C. et al., (2018) [D1.2 Risk classification of European lampreys and fish species](#)

Treack, R. van et al. (2017) [D1.1 Metadata Overview on Fish Response to Disturbance](#)

Stoltz, U. et al. (2019) [D3.1 Guidelines for mortality modelling](#)

Wolter, C. et al. (2019) [D1.3 Fish Population Hazard Index](#)

Assessing the impact of hydropower plants (HPPs) on individual fish, different fish species and communities is a key-component of decisions during the planning process and operation of HPPs. FIThydro has extensively worked on quantitative assessments of fish mortality through hydropower turbines. Besides very complex numerical tools, also a new and more accurate equation has been developed to determine fish mortality at hydraulic machines (Stoltz et al., 2019). More innovatively and using these approaches, FIThydro has developed a Fish Population Hazard Index (FPHI) as a decision-support and management tool for environmental impact assessment of existing and planned HPPs. The index allows for risk assessment while considering site-specific effects of single HPPs and the sensitivity of fish species against mortality. The FPHI also serves cumulative impact assessment by providing the potential risk for fish for consecutive HPPs (Wolter et al., 2019).

The FPHI combines the outcomes of FIThydro research on fish species' natural sensitivity against mortality (Treack et al., 2017) and fish species at risk (Wolter et al., 2018) with site-specific water body, habitat and project parameters as well as mitigation measures. It is based on a population-biological sensitivity index, a conservation value index of European lampreys and fish as well as the hydropower-intrinsic and site/constellation-specific mortality risk for lampreys and fish.

The different components of the index are offset with each other and result in an overall hazard score between 0 (low risk) to 1 (highest risk). The tool is designed to screen the potential impact of a given hydropower constellation on fish relative to other constellations. It provides a coarse assessment classified into high, moderate and low risk. The assessment is based on a scoring system of a few key features that were identified to have the biggest potential impact on fish (Wolter et al., 2019). These key features are height of the barrier/dam, upstream migration facilities, plant type, modes of operation, installed capacity to mean discharge ratio, turbine type, turbine mortality and installed fish protection facilities for downstream migration.

The Fish Population Hazard Index

- FIThydro developed a Fish Population Hazard Index as a decision and management tool for environmental impact assessment of existing and planned hydropower plants. The Index can be used to assess the potential impact of a hydropower plant on fish.
- The Fish Population Hazard Index can be used as a fast impact assessment tool, which allows authorities and hydropower licensing bodies to derive informed decisions about environmental risk of a hydropower plant, as well as practitioners to get a quick idea about preferable sites to develop hydropower plants or to mitigate impacts from existing ones.

The European-wide usability of the FPHI allows comparability and standardization of impact assessments. The FPHI supports the implementation of mitigation measures for sustaining and improving local fish populations and thereby for meeting the requirements and targets under European environmental policy (especially the WFD, the Habitats Directive and Eel Regulation).



ASSESSMENT OF CUMULATIVE IMPACTS

Hydropower plants (HPPs) and dams are often not standing alone in a river system but several can be present on the main river as well as on tributaries. Therefore, cumulative effects of consecutive HPPs and dams, as well as in combination with barriers without electricity generation have to be accounted for. In this context, one of the major issues facing regulatory agencies is identifying the cumulative impact of multiple HPPs and dams in the same river basin.

FIThydro has developed a Cumulative Impact Assessment toolbox (CIA) to assess the impact of multiple plants and dams in a single river basin as well as to determine the population responses to different mitigation measures applied. The FIThydro CIA toolbox is based on fish population life history models and provides a spatial-analysis framework that can model potential basin-scale impacts for different species. The toolbox provides species-specific analytical frameworks to determine the cumulative effects of site-specific habitat impacts (impoundments), mortality and barrier passability impacts of hydropower on population dynamics at a population and catchment level (Cowx et al., 2020).

Further reading:

Cowx, I.G. et al., (2020) [D1.4 Cumulative Impact Assessment](#) forthcoming

By using this toolbox for the assessment of ecological impacts on fish from cumulative HPPs, more comprehensive and responsible decision-making concerning (re)licensing of HPPs should be feasible. In addition, the toolbox might serve for the siting and selection of improvement measures to existing and new HPPs, to reduce the impacts on biota and ecological functioning, and thereby meet WFD and other EU legislation requirements, e.g. on the conservation and recovery of eel and salmon. It supports the implementation of mitigation measures for sustaining and improving basin-wide fish populations and can aid policy and regulatory agencies in approving new and enhanced HPPs.

Cumulative Impact Assessment

- The cumulative impact of multiple hydropower plants in the same river basin should always be taken into account when assessing ecological impacts on fish from hydropower and when planning mitigation measures for existing and new hydropower plants.
- FIThydro has developed a Cumulative Impact Assessment toolbox (CIA) providing a framework to assess the impact of multiple hydropower plants and dams in a single river basin as well as to determine the population responses to different mitigation measures applied.

KNOWLEDGE SHARING VIA A WIKI

FIThydro wiki

<https://fithydro.wiki/>

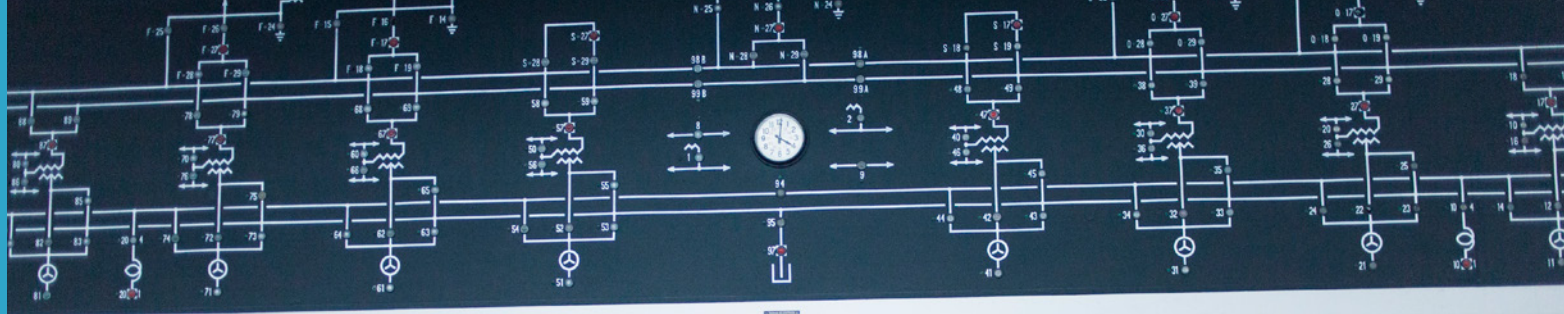
One of the objectives of FIThydro is to develop new, and to catalogue existing solutions (mitigation measures), methods, tools and devices (MTDs) to improve conditions for fish while at the same time maintaining hydropower production (examples of MTDs are given in the Innovation section in this Policy Brief). To make this information publicly available, an online wiki is being created (open access online platform). This wiki presents a catalogue of articles on the main types of mitigation measures that can be used to solve challenges related to environmental flows, habitat, sediment management, downstream and upstream fish migration. The wiki also describes which methods, tools and devices can be used to plan, implement and monitor mitigation measures.

Each mitigation measure (solution) is illustrated with a classification table that specifies elements such as technological readiness level (TLR), which river type the solution is suitable for, which fish species it is aimed at, etc. The range of costs associated with implementing a measure will also be available. It will be possible for a user to filter the solutions based on classification tables and select only the relevant ones - e.g. only solutions for steep rivers, for juvenile fish or for any other of the categories.

The FIThydro wiki presents a collection of information that is easily accessible online and can support users in selecting the appropriate mitigation measure when the actual problem to mitigate is defined. The wiki guides the user to potential measures that are able to improve conditions, taking costs of implementation and eventual changes in power production into account. It can support decision-making processes and contribute to a more transparent and easier communication and negotiation through clarification of terms. It also enables a deepening of knowledge regarding hydropower impacts and mitigation measures.

FIThydro wiki

- FIThydro created an online wiki which presents relevant mitigation measures (solutions) for various challenges related to hydropower and fish, namely environmental flows, habitat, sediment management, downstream and upstream fish migration. The wiki pages also describe which methods, tools and devices (MTDs) to use for each stage of implementation of measures (planning, implementation, monitoring).
- The FIThydro wiki can support decision-making by helping users implement the appropriate mitigation measures for environmental problems caused by hydropower production.
- The wiki also includes information of all the FIThydro test cases, including examples of mitigation measures and application of methods, tools and devices.



RISK-BASED DECISION SUPPORT SYSTEM

FIThydro has developed an online Decision Support System (DSS) as a risk-based assessment tool which can be used to guide fish-friendly hydropower production and safe fish passage. The DSS tool can be applied in the planning, development and operation of existing and new hydropower plants, including the revision of permits, thereby helping users to select appropriate mitigation measures based on characteristics of their hydropower plant (HPP) and of the river system (Noble et al., 2020).

Further reading:
Noble, R.A. et al. (2020) [D5.4 Decision Support System for environmentally friendly hydropower](#) forthcoming

This innovative DSS considers a range of HPP related impacts (impoundment, hydromorphological alteration, fish passage and turbine mortality), the sensitivity and conservation status of fish species as well as wider environmental / conservation policies and status aspects in undertaking a hazard analysis for an HPP. It supports informed decision-making on the design and operation of new and refurbished HPPs, enabling the evaluation of existing mitigation measures and the screening of potential new mitigation measures that could be appropriate for a specific HPP. The appraisal of potential mitigation measures considers the environmental effectiveness, the risks and potential economic / production costs in reviewing the benefits and costs of mitigation. Its systematic structure provides a single, transparent and structured framework generally applicable to all regions in Europe.

The FIThydro Decision Support System

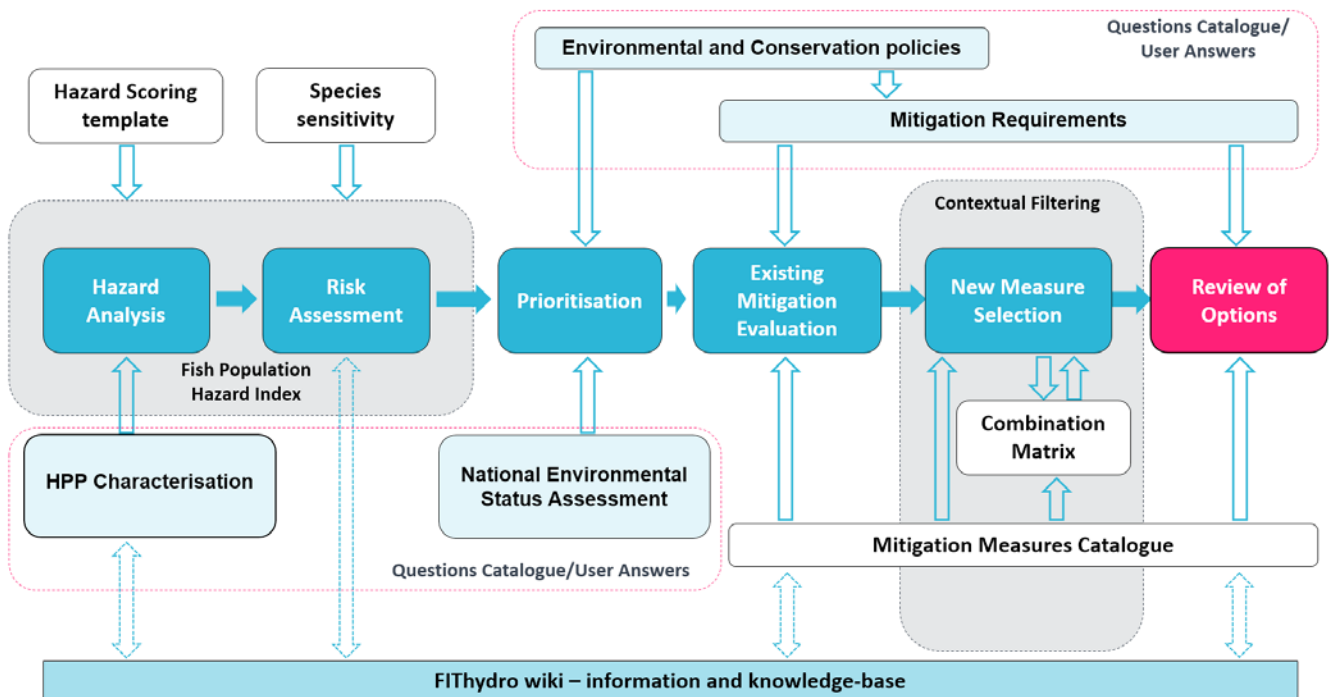
- FIThydro has developed an online Decision Support System (DSS) as a risk-based assessment tool of existing and new hydropower plants. It can determine the risk to fish and help users select appropriate mitigation measure based on characteristics of their hydropower plant and of the river system. It is closely linked to the Fish Population Hazard Index and the FIThydro wiki.
- The FIThydro DSS aims at supporting existing agency regulations and decision-support tools but, at the same time, harmonise the approaches, by providing a step-by-step procedure for the initial appraisal and screening of hydropower plants as well as for defining criteria for best practice in mitigation.

FIThydro Decision Support System
<http://www.dss.fithydro.wb.bgu.tum.de/home/ui.php>

Once users have entered information about their HPP and its surroundings, the DSS can determine the risk to the fish living in the upstream and downstream river system, identify priorities for mitigation based on the risks, environmental status and policy objectives for the HPP and evaluate the measures promising the most benefits to the ecosystem while enabling the HPP to operate cost effectively. The DSS consists of look-up boxes, measures database and effectiveness matrix and a catalogues of questions and risk-scoring template covering the following aspects:

- Characterisation of the HPP (key plant parameters, ecological sensitivity and hazard identification, key policy targets)
- Ecological status assessment and review of existing mitigation
- Risk-based identification of appropriate mitigation measures – potential solutions for priority hazards
- Review of costs / benefits and effectiveness/uncertainty information for mitigation scenario

The DSS of FIThydro implements and utilizes some of the key tools and outputs produced by the FIThydro project and thus acts as a structured gateway to the wider project results. It is closely linked to the Fish Population Hazard Index (p. 6) and the FIThydro wiki (p. 8), with direct links from the DSS to the appropriate wiki pages.



A test version of the FIThydro DSS is currently available at: <http://www.dss.fithydro.wb.bgu.tum.de/home/ui.php>. The final version is available in November 2020.



INNOVATIONS FOR SUSTAINABLE HYDROPOWER

FIThydro has developed innovative and improved methods, tools and devices (MTDs) to address key challenges related to the assessment of self-sustained fish populations and fish-friendly hydropower production. In FIThydro, solutions are the overall concept for how to solve or mitigate a problem, methods are typically descriptions of how to do something,

tools are methods embedded in for instance a computer program / model and devices are typically physical instruments used to measure/control something.

In the table on the next page, we highlight a few selected MTDs developed or improved by FIThydro. The table also outlines the type of activities which the MTDs can support water managers and hydropower operators with.

Innovative tools and devices

- FIThydro has developed several innovations (new or improved methods, tools or devices) to support more fish-friendly hydropower.
- Highlights of these innovations include devices to improve assessment of fish behaviour at hydropower plants, devices for downstream migration in particular for medium-to-large hydropower plants (fish guidance structures and fish protection systems), assessment methods for upstream and downstream migration facilities, as well as tools for the assessment of impacts from hydropeaking.



Selection of improved and innovative methods, tools and devices (I)

Additional Information on MTDs on the [EThydro wiki](#)

Method, tool or device (MTD)	How can MTD support managers and operators?
Improving fish migration	
<p>Curved-Bar Racks (Device)</p> <p>Curved-Bar Racks (CBR) with a bypass are mechanical behavioural fish protection and guidance structures. CBR consist of innovative vertical curved bars with an adjacent open channel bypass. CBR provide high fish protection and guidance efficiencies, as well as significantly reduced head loss and uniform turbine approach flow.</p>	<ul style="list-style-type: none"> Particularly suitable technical solution for medium-to-large run-of-river hydropower plants with high design discharges ($Q > 100 \text{ m}^3/\text{s}$) and high approach flow velocities Promising as an alternative to fine-screened horizontally- or vertically-inclined bar racks for small hydropower plants
<p>Induced Drift Application (Device)</p> <p>Protection system to increase survival probability of fish during turbine passage by a factor of two through guiding and immobilizing fish before turbine runner passage. Further improvement seems possible.</p>	<ul style="list-style-type: none"> Effective and cost-efficient way to improve survival of fish during downstream turbine passage at hydropower plants Especially of interest for retrofitting existing large-scale run-of-river hydropower plants
<p>Turbine fish mortality modelling using BioPA (Guidelines)</p> <p>Improvement of the BioPA fish passage modelling (developed in the US) and adaption to European conditions. Best practice guidelines for the application of BioPA have been developed.</p>	<ul style="list-style-type: none"> Modelling of turbine hazard Adaptation of turbine operation modes for certain time periods during fish migration
<p>3D fish-tracking systems (Device)</p> <p>i) Optical 3D fish-tracking system for etho-hydraulic laboratory investigations.</p> <p>ii) Sensorless 3D fish-tracking-system using ultra-sonic transmitters</p>	<ul style="list-style-type: none"> Investigation of fish behaviour Investigation of fish swimming behaviour and swimming paths and detection of species for scientific developments Adaptation of hydropower operation to needs of migrating fish
<p>Agent-based model in CASiMiR (Software)</p> <p>Habitat simulation model/software that makes use of physical as well as biological parameters to mimic fish behaviour in turbulent flow.</p>	<ul style="list-style-type: none"> Detection of fish migration pathways and analysis of attractiveness of fish upstream migration facilities Simulation of hydropower operation and hydropeaking and development/ design of mitigation measures Ecological assessment of habitat requirements

Selection of improved and innovative methods, tools and devices (II)

Method, tool or device (MTD)	How can MTD support managers and operators?
Improving assessment of hydropeaking impacts	
<p>Hydropeaking Impact Assessment tool</p> <p>Assessment of direct effects from hydropeaking as well as of the vulnerability of fish species to hydropeaking. The tool can be applied both to short river reaches with detailed information on local conditions, as well as to longer river sections with coarser resolution information.</p>	<ul style="list-style-type: none"> ▪ Assessment of impacts of hydropeaking on fish ▪ Development of operational, morphological and constructional mitigation measures ▪ Tailoring of mitigation measures to specific hydropower plants
Improving fish behaviour assessment	
<p>Artificial Lateral Line Probe (Device)</p> <p>New hydrodynamic pressure measurement technology to improve studies on fish sensing and behaviour in response to velocity fields. It provides a sense of how fish detect obstacles and react to large-scale turbulences in real-world conditions.</p>	<ul style="list-style-type: none"> ▪ For the study of hydraulic habitat preferences, fish swimming behaviour and energetics ▪ Design of fishways and testing the functionality of fishways ▪ To monitor hydraulic habitats, velocity and turbulence
<p>Barotrauma Detection system (Device)</p> <p>The Barotrauma Detection System (BDS) measures the hydraulic conditions which can lead to pressure-induced mortality of downstream migrating fish passing through hydropower turbines. The BDS is easily deployed in the field. It is possible to recover and re-use the sensors multiple times with ease.</p>	<ul style="list-style-type: none"> ▪ Investigating the physical effects of downstream passage of fish through turbines and subsequent adaptation of operation modes ▪ Environmental impact assessment of hydropower plants ▪ Definition of risk for fish by pressure fluctuations in hydropower environments





PUBLIC ACCEPTANCE OF HYDROPOWER

In many parts of Europe, the public becomes more engaged in questions about the future energy supply of nations and regions. This also applies to the development and operation of hydropower infrastructures. Public perceptions may thus influence the realization of projects, including the refurbishment of existing hydropower plants. FIThydro social scientists have explored public opinion on hydropower and hydropower technologies in four European case study towns located in Portugal, France, Sweden and Germany, representing regions with very different geographical characteristics (Hinzmann et al., 2019).

Further reading:

Hinzmann, M. et al. (2019) [D5.3 Public acceptance of alternative hydropower solutions](#)

The results of FIThydro research indicate that hydropower production is not a highly contested topic for local residents in the studied regions. However, conflicting views exist among the public on a number of issues, namely:

- ecological effects of hydropower
- plant ownership
- changes in electricity prices

These issues may drive public debate on hydropower and influence public acceptance. Therefore, hydropower operators and planners as well as politicians should be aware of these issues and consider them in their decisions.

Especially, negative environmental impacts of hydropower on river ecosystems are a central issue in public opinion. While the concept of mitigation measures is generally supported by local citizens, knowledge about specific measures among the general public is relatively scarce. Fish passes can be regarded as the only mitigation measure which is relatively well known among local residents. More complex mitigation measures are largely unknown. Designing and implementing environmental mitigation measures presents an opportunity to address public concerns. To this end, hydropower operators and decision-makers should develop strategies that demonstrate how specific mitigation measures may enhance the ecological status of the river ecosystem. Such information and awareness raising campaigns could be a key component of a broader public engagement effort, which aims to involve local citizens in the decision-making process around the future design of local hydropower plants.



Across all studied towns, hydropower was often (positively) perceived as a climate-friendly energy source and a crucial component for a sustainable energy transition. Yet, related research had pointed out that a generally positive attitude towards renewable energies is not necessarily equivalent to the acceptance of specific renewable technologies on the local level. This may be due to negative effects that are mostly felt by local communities, such as impacts on the landscape or construction noise (Botelho et al. 2016). Related to this, FIThydro research showed that the perception of economic benefits of hydropower production on the local level is decisive for acceptance. Various respondents in all of the four studied towns strongly believe that local hydropower plants should bring benefits – such as jobs or community income – to the region. To increase local support, communication and awareness raising campaigns related to the construction of new or refurbishment of existing hydropower technologies could inform about potential greenhouse gas savings as well as illustrate how the income generated by hydropower plants is distributed.

Further reading:

Botelho, A. et al. (2016) [Public Perceptions of Environmental Friendliness of Renewable Energy Power Plants](#)

The public's view on hydropower

- Public acceptance surveys carried out by FIThydro researchers have shown that hydropower production is largely accepted by local residents in the studied towns in Portugal, France, Sweden and Germany. However, conflicting views exist among the local population on ecological effects of hydropower, plant ownership and changes in electricity prices, which may drive public debate on hydropower and influence public acceptance of hydropower and hydropower technologies.
- Mitigation measures for hydropower plants are generally acknowledged by local citizens, however, knowledge about specific measures among 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 ecosystem to better engage local citizens in the decision-making process around the future design of local hydropower plants.



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Duration 1. November 2016 till 31. October 2020