Technical Solutions and (Environmental) Mitigation Measures when Building New Energy Infrastructure (hydropower)

Authors: dr. Matjaž Eberlinc, Jure Šimic, Karina Medved, mag. Djordje Žebeljan
Introduction

Science and new technologies allow us to exploit numerous advanced options of energy sources with solutions for sustainable development. Sustainable development is where we avoid the danger caused by the focus on quantitative material development of resource depletion and environmental pollution and the expectation to maintain biodiversity. Let us use the definition, cited from the report of the Brundtland Commission: "Sustainable development meets the needs of the present human race, without compromising the ability for future generations to meet their own needs."1

Sustainable development concept comprises, more consistently after the United Nations (UN) Summit in 2005, the three pillars, namely economic development, social development and environmental protection. Sustainable development is also one of the main objectives of the European Union (EU) under the Lisbon Treaty2. The EU in 2006 also adopted a renewed Sustainable Development Strategy3, followed by the Europe 2020 Strategy4 with concrete objectives, including a 20% reduction in CO2 emissions by 2020. Achieving these goals is certainly associated with an increase in the share of renewable energy sources such as clean energy sources in power generation, where hydropower plants (HPPs) play an important role.

Nevertheless, it is necessary to take into account that HPPs influence water bodies, which become modified due to changes in hydraulic condition of the river flow. Any such interference has the effect of changing the habitat of local flora and fauna.

A parallel can be drawn between the impacts on natural habitats with construction of energy facilities and the impacts of climate change. The analysis of the European Commission on climate change5 shows that among the most vulnerable habitats in the context of climate change are fresh waters, and among that fish species. The guidelines6, which the EU has developed in the context of climate change adaptation in Natura 20007 sites, set the possibility of adaptation measures, which include changes in the natural habitat. Figure 1 shows the most vulnerable habitats in accordance with Ref. 7.

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5 The analysis of the European Commission on climate change.
Therefore, when considering large spatial planning, arrangements solutions and new technologies that reduce the changing impact of the environment should be adapted. A much greater importance is given to the requirements of the environment due to increased climate changes, which is evident from the coverage ratio of the territory of protected sites under the Natura 2000 network. Special attention needs to be directed to the environmental conservation issues. In the context of determining what impact a certain solution would have on the environment the necessary mitigation measures for those species and habitat should be considered.

From the definition of sustainable development, it is evident that a balance between the technological development and environmental protection needs to be maintained. The two are not mutually exclusive. In this paper, we would like to address availability of the sustainable technologies for the energy generation from renewable resources (e.g. hydro), enabling the biodiversity conservation and the development of HPPs. Examples of good practice cases and solutions, especially in river regimes, for the conservation of fish species in accordance with national legislation and guidelines of the EU, are considered.

1 Hydropower as a renewable resource in the EU

The 2020 Climate and Energy Package set a target of reducing greenhouse gas emissions by 20% by 2020, increasing energy efficiency by 20% and increasing the share of renewable energy to 20%. The aims are well followed by the EU Member States; some are already getting ahead, including Slovenia. The latest 2030 Framework for Climate and Energy Policies, takes the target of reducing the CO₂ emissions even further - by 40% below the

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1990 level by 2030. Renewable energy will play a key role in the transition towards a competitive, secure and sustainable energy. The European commission proposes an objective of increasing the share of renewable energy to at least 27% of the EU's energy consumption by 2030. Scenarios in the Energy Roadmap 2050\textsuperscript{10} show that the share of renewable energy rises substantially, achieving at least 55% in gross final energy consumption in 2050. Electricity will have to play a much greater role than now (almost doubling its share in final energy demand to 36-39% in 2050) and will have to contribute to the decarbonisation.

Water as a clean source of energy plays an important role in this respect, especially in achieving the EU climate and energy targets. By 2010, 16% of all electricity production in Europe accounted for the production of hydroelectric power, which accounts for 67% of total energy from renewable sources. World production of hydroelectricity has grown steadily by about 2.3% per year on average since 1980.\textsuperscript{11} According to various national renewable action plans an increase for 20 TWh by 2020 (a total of 370 TWh) is estimated. Unused water potential in the EU-27 amounts to 276 TWh, current production amounts to 338 TWh\textsuperscript{12}.

According to the estimations, there is around 40% of the unused hydropower potential in Slovenian rivers\textsuperscript{13} (7 to 8.5 TWh/year economic potential). It is anticipated that by 2030 large HPPs will present 1/3 of all renewable energy sources (share of RES in primary energy production: 54%, of this 34% large HPPs). As a result, it is even more important for the Member States to consider all aspects of sustainable development when it comes to a design and construction of HPPs, since the role of RES in primary energy production is of great importance.

### 2 Legislation framework

When planning a large scale HPP, Slovenian and the European legislation and guidelines need to be taken into account. The EU Birds Directive\textsuperscript{14} and the Habitats Directive\textsuperscript{15} constitute the main framework for the conservation of biodiversity and nature protection. Obligations under the EU Directives in Slovenia are being implemented through the Nature Conservation Act\textsuperscript{16} and the Environment Protection Act\textsuperscript{17}. The Member States are obligated to designate protected sites in the context of the Natura 2000 network, which currently covers more than 26,000 sites and 850,000 km\textsuperscript{2} in the EU or 25% of the entire EU territory\textsuperscript{18}. This amounts to more than 869 plant and animal species being protected. The Slovenian Government amended the Natura 2000 network in April 2013 and extended the current protected areas by 2.4% to 37.2% overall\textsuperscript{19}. Slovenia therefore represents the country with the highest coverage of protected sites in the EU.

Protected sites are partially covering the sites, where new HPPs are planning to be built in the future (e.g. one of the protected species under Natura 2000 network is a Danube salmon). The project of building new HPPs on the Sava River was defined as a priority national project by

\begin{itemize}
  \item \textsuperscript{10}Energy Roadmap 2050, European Commission 2011.
  \item \textsuperscript{11}Europe's hydropower potential today and in the future, Lehner, Czisch, Vassolo, http://www.usf.uni-kassel.de/hp/dokumente/kwws/5/cw_8_hydropower_low.pdf.
  \item \textsuperscript{12}Hydropower for a Sustainable Future, Eurelectric, 2013.
  \item \textsuperscript{13}Draft National Energy Program, 2011.
  \item \textsuperscript{14}The Birds Directive, 2009/147/EC, 2009.
  \item \textsuperscript{15}The Habitats Directive, 92/43/EEC, 2007.
  \item \textsuperscript{16}The Nature Conservation Act, OJ RS, No. 56/99.
  \item \textsuperscript{17}The Environment Protection Act, OJ RS, No. 41/04.
  \item \textsuperscript{18}Natura 2000 Good practice exchange, 2014.
  \item \textsuperscript{19}Natura 2000, the Government of Slovenia, 2014.
\end{itemize}
the Slovenian Government\textsuperscript{20}. Therefore, it is even more important to find suitable solutions for building new HPPs and conservation of the species, respectively.

The obligations and procedures with regards to the Natura 2000 network are identified in Article 6 of the Habitats Directive. These are the relevant management plans (if necessary) and statutory, administrative or contractual measures to prevent the deterioration of the situation, suitable management of all plans or projects (even if it is planned outside the area and may affect the species in the area), and under special circumstances overriding public interest if no alternative solutions suffice. The conservation objectives should be met while taking into account economic, social, cultural, regional and recreational requirements.

An important legal framework for sustainable development in the EU is also the Water Framework Directive\textsuperscript{21} (WFD), which is being implemented in Slovenia with the Water Act\textsuperscript{22}. The aim of the WFD is to achieve a good ecological status of all water areas by 2015. A good ecological status is a status, which is slightly lower than the one, which can be achieved without significant changes during a water use in relation to the modification of the surrounding environment. ‘Good status’ means both ‘good ecological status’ and ‘good chemical status’.\textsuperscript{23} Analyses show that Europe has a high proportion (20\% of all water bodies in 2006) of heavily modified water bodies (HMWB) due to hydro morphological changes, mainly for the storage for HPPs\textsuperscript{24}, which is shown in Figs. 2 and 3.

\textsuperscript{20} Government Decision 35000-12/2013/6, 27.12.2013.
\textsuperscript{22} Waters Act, OJ RS 56/99.
\textsuperscript{24} Heavily Modified Water Bodies, CIS Workshop Discussion Paper, 2009.
Figure 2: Water uses for which water bodies are identified as HMWB (ref. 26).

It is evident from the Figure 2 that storage for hydropower along with the water regulation and flood protection are the water uses, which have the largest influence on water bodies. The Member States may designate a water body as HMWB and implement a river basin management plan.
Figure 3: Percentage of designated HMWB within each water body category shows that in Slovenia nearly 10% of rivers are designated as HMWB (Ref. 26.).

However, there are a number of recommended actions, measures and best practice cases on how to best and utmost preserve the natural characteristics of water bodies and biodiversity of the habitat in which we intervene, even in more protected areas.25

3 Solutions: restoration and mitigation measures in the EU Member States

In the framework of the Common Implementing Strategy (CIS)26 for the implementation of the WFD the European Commission, in 2006 produced guidelines in the form of a technical report27 with the aim to identify how to manage the synergies and antagonisms between the planning of hydro morphological changes in rivers and other requirements and policies., Impact assessments and their comparison between the EU Member States are also included in the report. One of the key focuses was the use of rivers for the energy generation with the HPPs. Possible negative effects of the construction of HPPs and the risk of failure to achieve a good ecological status of the water body might lay in structural barriers to the movement of aquatic flora, the risk of fish being caught in turbines, an altered flow regime and a river flow, amended sediment dynamics, modified chemical conditions and modified structure of coastal habitats.

Barriers across rivers often have negative impacts on natural fish populations and, along with other factors, may contribute to the diminished abundance, disappearance or even extinction

of species. An example of this is the extinction of the salmon (Salmo salar) in the River Rhine.\textsuperscript{28}

In most cases, there is not only one appropriate measure to mitigate the negative environmental impact of the HPPs, but a set of measures that complement each other. In Sweden, Norway and Finland, the storage of fish and fish eggs in regulated watercourses proved as one of the most cost-effective method to mitigate the effects of the reduced natural reproduction and to remedy the situation. Known mitigation and restoration actions are also fish passes, which allow the movement of fish in both directions of the river flow. It is, however, necessary to take into account the conditions on a case-by-case study; technical capability and cost effectiveness of the solutions are normally shown through the planning process.

Table 1 presents some of the case studies in the EU Member States, the impacts on water bodies and adopted mitigation measures and the impact of these measures on the environment. The effect varies depending on the specific features and steps from case to case. There is no single regulatory measure that would be suitable for all habitats; also a removal of HPP does not necessary have the best ecological impact. Two cases, presented in Table 1, can be found in Slovenia.

<table>
<thead>
<tr>
<th>Title of case study</th>
<th>Country</th>
<th>Pressure and Impact</th>
<th>Measure</th>
<th>Ecological efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitigation measures in and downstream of Halnefjorden Reservoir in River Numedalslaagen</td>
<td>Norway</td>
<td>Cross profile construction, minimum flow requirements, erosion of the littorial zone</td>
<td>Installation of minimum water flow, fish pass, erosion protection</td>
<td>high</td>
</tr>
<tr>
<td>Dam removal of the Mirna River</td>
<td>Slovenia</td>
<td>Damming, interruption in the river continuum</td>
<td>Removing of obsolete dam and construction of rocky glide</td>
<td>medium</td>
</tr>
<tr>
<td>Restoration of migration path on the Sava River, Tacen</td>
<td>Slovenia</td>
<td>Damming interruption in the river continuum</td>
<td>Reconstruction of dam and construction of rocky glide</td>
<td>high</td>
</tr>
<tr>
<td>Fishway as a mitigation measure</td>
<td>Findland</td>
<td>Damming interruption in the river continuum</td>
<td>Installation of fishways</td>
<td>Medium-low</td>
</tr>
<tr>
<td>Replacement construction of a large scale HPP Rheinfelden</td>
<td>Germany</td>
<td>Dam, impaired continuity, loss of the specific riverine habitats</td>
<td>Installation of a bypass channel, fish ladders, removal of bank reinforcement, improvement of habitat structures</td>
<td>medium</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hpp Allbruck-Dogem</th>
<th>Germany</th>
<th>Dam, insufficient residual water flow, interrupted continuum and fish migration</th>
<th>Creation of a fish ladder, installation of dynamic minimum water flow</th>
<th>high</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimiziong energy generation and ecological measures</td>
<td>Austria</td>
<td>Cross profile construction, disruption in river continuum</td>
<td>Providing fish migration by establishing a vertical-slot-fish ladder</td>
<td>high</td>
</tr>
<tr>
<td>Fish compensation measures in the regulated River Klaralven</td>
<td>Sweden</td>
<td>Damming, hydromorphological changes affecting habitat and species diversity</td>
<td>Fish stocking, restoration and installation of fishways in tributaries</td>
<td>high</td>
</tr>
</tbody>
</table>

Table 1: List of case studies potentially relevant to the improvement of ecological status by restoration/mitigation measures; hydropower²⁹

Table 1 presents fish passes in different forms and variants with the most common mitigation/restoration measure. In accordance with the WFD, all water bodies in the EU need to reach good ecological status by 2015. One of the conditions for that is a horizontal continuity of water population. Since most of the rivers are affected by dams, a horizontal continuity can be assured with fish passes. In 2009, along with the construction of the new HPP in Slovenia, the first fish pass on the Sava River was constructed. Figure 4 presents a technical solution, used in this case.

![Fish pass on the lower Sava River, Slovenia]³⁰

Figure 4: Fish pass on the lower Sava River, Slovenia³⁰

Researching possible mitigation measures in Europe and globally, fish passes in different forms proved to be most commonly used and most effective. There are approximately 380 fish passes in England and Wales, more than 500 fish passes have been built or retrofitted over the last 17 years in France, Germany and Austria, design and construction of fish passes

has also been actively used over the last 15 years. The most common fish pass used is the natural-like bypass channel. A total of 115 fish passes were catalogued in Spain, about 50 new fish passes were built in Portugal after 1991. Norway has a very long tradition for building fish ways and has been the predecessor in fish way construction in Scandinavian countries. There are now about 420 fish ways, most of them for salmon. Fish pass design involves a multidisciplinary approach. Engineers, biologists and managers must work closely together. Fish pass technique is also empirical, i.e. based on feedback from experience.\(^{31}\)

### 3.1 Fish pass/ladder

Fish passes are facilities that help fish (and aquatic invertebrates) to overcome/bypass artificial barriers\(^{32}\). This will restore the upstream and downstream migration, which is relevant to the needs of nutrition, seasonal migration and spawning search of a new habitat. Under the name of fish passes several arrangements are available, which may reasonably be separately presented (bypass channel, semi natural and technical fish pass). Their efficiency varies depending on the environment\(^{33}\). Detailed descriptions of the use of certain fish ladders in different natural environments (especially in Natura 2000 sites) are presented in the Technical Guidelines\(^{34}\).

### 3.2 The Natural bypass channel

The natural bypass channel is a type of fish pass for making the natural stream look alike fish pass. The function is to restore and replace a portion of the flowing water habitat, which has been lost due to the impoundment\(^{35}\).

For the design of such a channel, detailed knowledge of the state of the stream prior to the procedure is required. Therefore, it is necessary to identify at least the following conditions on the part of the stream, which will be replaced: (i) existing fish species, (ii) areas with faster and slower flow, (iii) flow in the channel, (iv) speed in the section considered, (v) the number and size of accumulation, (vi) the size of shoals and their composition, (vii) rainy composition of the river bottom, (viii) type of riparian and aquatic vegetation, (ix) segments of the turbulent flow.

In addition to these physical properties of the stream also chemical and biological control of the water (especially oxygen and the presence of other elements) is needed. All define what kind of a living space is suitable for certain fish population in certain section, but is not necessarily the most favorable. With partial modification of certain parameters the state (especially for the more vulnerable species) is also likely to improve. The planning of a bypass channel must be carried out simultaneously with the hydraulic model, which can show the adequacy of planned arrangements within the bypass channel.

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\(^{31}\) Europe's hydropower potential today and in the future, Lehner, Czisch, Vassolo.


\(^{33}\) Fish passes – design, dimensions and monitoring; DVWK, 2002; Fishways: biological basis, design criteria and monitoring; BFPP, 2000.


\(^{35}\) Fish passes: Types, principles and geographical distribution an overview; Laeinier m., Marmull G., 2014.
3.3 Spawning grounds

Spawning grounds are one of the most important areas for the conservation of fish populations. It is therefore essential that the investor checks the status of a spawning ground in the existing part of the water body, as well as in the areas, which in planned arrangements represent migration paths to the spawning grounds. If the intervention affects the existing spawning grounds and the surrounding area and there are no other suitable spawning areas around, it is necessary to artificially create such zones. For a proper performance of spawning areas a more detailed analysis of the species is needed, since conditions vary among types. In addition, an analysis of existing granulometric composition of the river bottom (in order to create the conditions for fish eggs, which must not be washed away) and a hydrological analysis of the river flows with required levels at the right time of the year. When correctly designed, but even more so, when properly executed, this measure is proving to be very successful.

3.4 Renaturalisation of canalized rivers

Almost all water bodies as well as their riparian areas have been regulated for various reasons (increased flood protection, the acquisition of a new habitat, changes in water regime). Implementation of these measures is consistent with the regulations, which have changed significantly over time. Today, a much greater importance is given to the requirements of the environment and nature; defects in spatial planning have also been proven. Therefore, this area intended to be returned to the original status, while the purpose of the measures, which have in the past led to interference, is preserved with the most natural arrangements. These include the restoration of aquatic phenomena and vibrancy of the stream. This allows the creation of different hydraulic conditions that are of interest to aquatic organisms. An important aspect of renaturalisation is also riparian vegetation, because it gives a sense of security for the fish, allowing the presence of riparian life and replaces the technical implementation of protection of riverbanks. Figure 5 shows the example of the construction of a nature like fish pass.

![Figure 5: Efficiency of nature like fish passes and their role for the integrity of running waters](image)

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36 Efficiency of nature like fishpasses and their role for the integrity of running waters; A. Zitek & S. Schmutz; BOKU – University of Natural Resources and Applied Life Sciences.
3.5 Removal of existing inactive dams

One of the measures that have the potential to improve the health of fish populations is the removal of existing inactive dams, which would again allow the natural migration of fish. This measure is often referred to as a solution to environmental problems, but, like other interventions in space, the measure has both positive and negative consequences. The measure has a positive effect on migration species, since it allows the remigration; the negative effect can be expected on the existing state of biodiversity, which has over time established behind the barrier. Therefore, before such interventions, it is necessary to verify the status above the barrier and check what impact the implementation of such a measure would have on the environment.

3.6 Arrangements of the water thresholds, not transitive for fish

Due to the influence on the rivers, the rivers often begin to deepen, which affects the slope of the river channel and the level of groundwater. To prevent the occurrence of these impacts the thresholds are used in the river channel, which dissipates the energy of water, otherwise used for the deepening of the river channel. With the implementation of the threshold, an additional barrier to the migration of fish occurs. Arrangements can be implemented in two ways: (i) part of the water threshold is rearranged and a small fish pass constructed, with which in the extended portion and in a lower slope an overcome of the change in altitude is done, the remaining part shall be maintained in its present condition, (ii) the existing higher threshold is replaced with a larger number of smaller ones, where there are sections for resting (the case of a larger number of smaller thresholds is given in the Figure 6 below).

![Figure 6: Smaller river thresholds](image)

As mentioned, not all measures are suitable for all species. Further on, focus is made more on the Danube salmon, a fish species protected under Natura 2000 network in Slovenia, which can be found in rivers Sava, Drava, Kolpa, Mura, Krka and Savinja.38

Based on observations of Danube salmon, it has been established that the Danube Salmon survives in reservoirs (examples from the accumulation of Orava, the accumulation of Bicaz and Vidraru in Romania, accumulations in the Drava River and the lake in Zalatar in the former Yugoslavia). It has also been noted that it leaves the accumulation only during the spawning period and after it returns. Even during the spawning period the offspring of the Danube salmon returns into the reservoir, where it remains – the example from the

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38 The Fish Institute Slovenia, BIOS 2014.
accumulation of Orava and the accumulation Rudno\textsuperscript{39}. Despite the fact that the Danube Salmon can survive in reservoirs, it is necessary to plan several mitigation measures, which have been proven across Europe as examples of good practice cases.

(i) Implementation of appropriate fish ladders: the examples of good practice show (especially in Austria, the Mura River, the Danube River, the Upper Drau River Life+ project) that for this species no specific fish passes are needed.\textsuperscript{40} The only condition is that they are large enough. The Figure 7 shows that it migrates also within the technical versions of fish ladders.

![Figure 7: Transfer of the Danube Salmon 1.050 mm length, head 15 x 35 cm through a fish pass channel\textsuperscript{41}](image)

(ii) The bypass channel can also represent the spawning grounds: by providing a proper status, such as before the construction of HPP, migration in the sustainable riparian river channel is made possible. With rivers and their water levels, the area is also suitable for spawning. In this case, other criteria must be met (granulometric composition of the river bottom, riparian zones). The Figure 8 below shows an example of sustainable riparian channel.

![Figure 8: Efficiency of nature like fish passes and their role for the integrity of running waters\textsuperscript{42}](image)


\textsuperscript{40} Enature multistructure slot fishpass – function analyses for »Hucho hucho« and »Silurus Glanis«, H. Mader, J. Kern, M. Schober – University of Applied Life Science, Austria, 2012).

(iii) Renaturalisation of streams: this mitigation measure is not tied to a single area but to the tributary, which would be arranged in a way that the Danube Salmon can be resettled. It would be necessary to examine all possible causes of the disappearance (excessively modified water body, excessive abstraction of water, pollution of the stream) and on the basis of these observations to act according to the principles of sustainability.

Prior to the determination of possible mitigation measures further research related to Danube salmon is needed - the estimated number of individuals within a population, its age structure, the connectivity between populations due to the exchange of genetic material needs to be scientifically examined. One of the most suitable analyses for the determination of these criteria appears to be a genetic analysis, with which it can be established whether the measures taken to ensure a favorable state of the species are suitable in the present condition.

Possible technical solutions for restoration/mitigation measures, which are most often used in practice, the legal basis for them is the WFD, have been examined. But the EU Member States have another possibility in case that no suitable alternative measures for habitats preservation can be found – the overriding of public interest (Article 6 of the Habitats Directive). This exception has only been used in a few cases so far, only one is connected with HPP (La Brena, Spain).43

4 Conclusion

The main objective of this paper was to present good practice cases among the EU Member States when it comes to combining the development of energy infrastructure (e.g. HPPs) and the measures, which could mitigate the negative environmental impact.

The EU Member States have adopted the European directives both from the field of nature conservation and environment protection as well as in the field of energy. The targets, especially in the field of renewables, are becoming more ambitious. In line with the EU climate and energy targets (2020 Climate and Energy Package and the 2030 Framework), hydropower as a renewable source of energy plays a crucial role.

While recognising the importance of hydropower as a low-cost, effective, sustainable and renewable energy resource which can be stored in large quantities and which plays a major role in power system management, environment obligations on the other hand need to be met. The EU legislation framework in this field obliges the Member States to take into account various protective/mitigation/restoration measures, especially when it comes to energy infrastructure.

There is a need for further research in this field, with scientific approach being one of the most crucial elements. With this regard, a genetic analysis, especially in the case of the Danube Salmon in Slovenia, could prove effective.

42 Efficiency of nature like fish passes and their role for the integrity of running waters; A. Zitek &S. Schmutz; BOKU – University of Natural Resources and Applied Life Sciences.