SUSTAINABLE RIVER MANAGEMENT IN AUSTRIA

FRANZ GREIMEL[1], JÜRGEN NEUBARTH[2], BERNHARD ZEIRINGER[1], DANIEL S. HAYES[1], MELANIE HASLAUER[1], SIMON FÜHRER[1], STEFAN AUER[1], NORBERT HÖLLER[3], CHRISTOPH HAUER[4], PATRICK HOLZAPFEL[4], MARTIN FUHRMANN[4], MARKUS PFLEGER[5], PETER MATT[6], VERONIKA KOLLER-KREIMEL[7], STEFAN SCHMUTZ[1]

[1]*Institute of Hydrobiology and Aquatic Ecosystem Management, University of Natural Resources and Life Sciences, Vienna, Austria*

[2]*e3 consult GmbH, Innsbruck, Austria*

[3]*Center for IT Services, BOKU University, Vienna, Austria*

[4]*Christian Doppler Laboratory for Sediment Research and Management, Institute of Water Management, Hydrology and Hydraulic Engineering, University of Natural Resources and Life Sciences, Vienna, Austria*

[5]*VERBUND Hydropower GmbH, Vienna, Austria*

[6]*Vorarlberger Illwerke AG, Bregenz, Austria*

[7]*Austrian Ministry for Agriculture, Forestry, Environment and Water Management, Vienna, Austria*

The EU Water Framework Directive set environmental targets for all water bodies, which must be achieved till 2027 at the latest. To generate and use hydropower sustainably and to mitigate climate change, it is necessary to face the challenge of how to achieve the environmental objectives without significantly impacting hydropower use. This is especially relevant for the production of flexible electricity and the selection of appropriate measures to mitigate adverse environmental hydropeaking effects. To identify reasonable and efficient solutions, it is required to develop clear decision procedures and conduct an analysis of economic as well as environmental data to understand the multidimensional underlying interactive effects. For this study, scientists, hydropower plant operators and river basin management authorities cooperated in joint projects to assess the effects of hydropeaking mitigation measures on different levels. This study presents a tool which provides an evaluation methodology for an integrative assessment of the ecological impacts of hydropeaking mitigation measures and their consequences for the use of hydropower. We identified the potential impacts on the electricity system, their macroeconomic consequences as well as their impacts on business economy level. Based on this first step, we designed specific combinations of mitigation measures and analyzed their outcomes. Here, we present this novel integrative approach and describe the effects of mitigation measures for ecology, flexible energy production capacity, and CO_2 production.

1 INTRODUCTION

European climate policy requires an increasing production of wind and solar energy [1, 2]. This development raises the technical demands on the existing hydropower fleet. Due to their flexibility, especially hydropower plants are used to balance the unavoidable fluctuations of renewable energy generation [3, 4]. From the perspective of the electricity system, storage and pumped-storage hydropower plants perfectly complement other renewable energy sources such as wind and solar power because they can be operated more flexible than, e.g., coal- and gas-fired power plants. Moreover, they produce no additional CO_2 emissions while providing essential energy supply services to ensure system security. Due to favorable topographic and hydrological conditions in Austria, storage and pumped-storage power plants form the backbone of the national electricity supply, whereby their total installed capacity represents 33% of the entire energy generation capacity of Austria.

In the National River Basin Management Plan 2015 [5], 896 river kilometers in Austria have been identified as significantly affected by hydropeaking. Water bodies affected by hydropeaking are mostly designated as "heavily modified water bodies" according to the Water Framework Directive and must, therefore, achieve the "good ecological potential". To determine the good ecological potential, the ecological effectiveness of hydropeaking mitigation measures must be considered, and possible significant adverse effects on the use of storage hydropower plants must be assessed on a macroeconomic and business management level. This study provides a basis for an evaluation tool which can be applied on a national or larger scale. Here we present a unique tool which allows a comparison of the potential ecological effectiveness of hydropeaking mitigation measures as well as their combinations with their potential impacts on the electricity system on macroeconomic and business level.

2 STUDY AREA

We studied ten Austrian storage hydropower plants and power plant groups with an installed capacity of about 4,000 MW situated along the rivers Bregenzerach, Drau, Ill, Möll, Salzach, and Ziller. These case studies cover almost half of the installed power capacity of storage hydropower plants in Austria in 2014. We evaluated a total of 294 km of river stretches classified as heavily modified waterbodies due to hydropeaking.

3 METHODS

The hydropeaking mitigation measures evaluated in the study are (a) restrictions on the operation mode of hydropower plants, (b) retention basins (balancing reservoirs), and (c) new-build diversion power plants. We evaluated all three measures with or without (d) additional morphological rehabilitation measures.

Based on the actual state of hydrological conditions, we defined hydrological impact scenarios for all case studies, whereby we particularly considered the effects on fish ecology. The hydrological scenarios are evaluated for the hydropeaking mitigation measures mentioned above which are complemented by additional morphological rehabilitation measures. The “hydropeaking diversion power plant” scenario refers to the complete diversion of the hydropeaking wave through a newly built diversion power plant. Considering the topographic and environmental conditions, we analyzed the diversion power plant scenario only in four case studies, totaling 87 river kilometers. The “hydropeaking mitigation” scenarios include retention basins and graduated restrictions for the downramping phase of the pulsed-flow release, ranging from low to high mitigation level. After the mitigation analysis, we evaluated and compared the expected ecological, system-relevant and macroeconomic impacts.

3.1 Hydromorphological and ecological assessment

We evaluated the ecological outcomes of the mitigation measures based on hydromorphological changes. First, we detected artificial flow fluctuations (frequency, timing, intensity) by interpreting all hydrograph curves in the studied rivers including turbine flow data [6]. Next, we tracked source-specific flow fluctuations by describing the intensity changes between adjacent hydrographs. Hence, the current hydrological situation and hydrological effects of the mitigation measures can be modeled longitudinally [7]. Following, the resulting water level changes can be determined for each hydrological scenario through regression models based on the variables catchment size, runoff rate, river width, and altitude. Additionally, we determined the variation coefficient of the river width (at bankfull discharge conditions) through aerial photos to screen the morphological variability as an indicator for habitat availability and to evaluate the effects of morphological measures, e.g., river widening, along the investigated reach. In the next step, the hydromorphological information was summarized and the ecological effects of several mitigation scenarios were described.

Regarding fish ecology, the stranding of larvae and juvenile fish has, aside of the drift, been identified as one of the most significant adverse effect of peaked flow operations [8], impacting age structure and biomass [9, 10]. Furthermore, retention effects and habitat availability as well as seasonal and daily hydrological conditions have been identified to be of relevance in hydropeaking rivers [11, 12]. Therefore, it is crucial to evaluate the interaction between river morphology and hydropeaking waves to assess the effect of hydropeaking [13]. To describe the impact intensity of hydropeaking, flow increase and decrease events must be considered separately, several intensity parameters of the hydropeaking wave must be recorded, and the wave’s longitudinal trend must be assessed. The evaluation system developed in this study uses stranding of fish larvae and early juvenile stages caused by downramping as the main ecological indicator to describe the fish ecological status [14, 15], but can be adapted to assess other hydropeaking parameters and organism groups as well.

3.2 Assessment of system-relevant and economic impacts

Next to hydromorphological and ecological effects, the implementation of hydropeaking mitigation measures can exhibit system-relevant, macroeconomical and business economic effects, which must be analyzed to identify the overall most efficient mitigation measure. Hence, for each specific mitigation measure (e.g., caused by restrictions on the operation of high-head hydropower plants), this study considered potential effects on the Austrian climate targets, the security of supply referring to the national flexible energy generation capacity as well as the costs to maintain the current amount of flexible energy. From a business economical point of view potential investment costs (e.g., caused by the construction of retention basins or morphological measures) and potential reduction in earnings (e.g., caused by restrictions on the operation mode of hydropower plants) are determined for each mitigation scenario. Finally, system-relevant and economic impacts of the mitigation scenarios can be compared to the anticipated effects on aquatic biota.

4 RESULTS

In Figure 1, we present a summary of the most important results from the integrative evaluation of hydropeaking mitigation measures based on the developed method and referring to the ten case studies.

The ecological effectiveness (Figure 1-i) is described by the extent of expected ecological improvements compared to the total river stretches examined. Implementing a retention basin or operational restrictions without any additional morphological rehabilitation measures results in the elimination of the stranding risk in about one-third of all the examined river reaches. If habitat diversity is additionally improved through morphological rehabilitation measures, the amount of remediated river stretches substantially increases up to 75–80%. Diverting the hydropeaking wave through the construction of a diversion power plant results in the elimination of the whole hydropeaking impact, as the risk of stranding is entirely averted. The remaining ecological effects depend, therefore, on the morphological state of the river stretch and the environmental flow allotment. However, existing habitat diversity is only sufficient for fish larvae and juveniles in about 40% of the affected river stretches. In these cases, additional morphological measures can substantially increase the proportion of improved river reaches.

The changes resulting from the mitigation scenarios on the business economic level are described through the effects on the flexible energy generation capacity (Figure 1-ii). The construction of retention basins has no impact on the available flexible capacity, while the implementation of operational restrictions results in energy generation reductions of up to 2,200 MW, depending on the extent of the realized measures. In contrast, additional hydropeaking diversion power plants could provide an increase in generation capacity of more than 200 MW at the four possible case study sites.

The system-relevant and macro economic impacts of the mitigation scenarios are described through the effect on CO_2 emissions (Figure 1-iii). The construction of retention basins has no system-relevant impact on CO_2 emissions. The implementation of operational restrictions could increase the amount of CO_2 emissions substantially up to max. 2.3 to 3 million tCO_2eq/a, whereby newly-built hydropeaking diversion power plants could reduce CO_2 emissions by 0.23 million tCO_2eq/a.

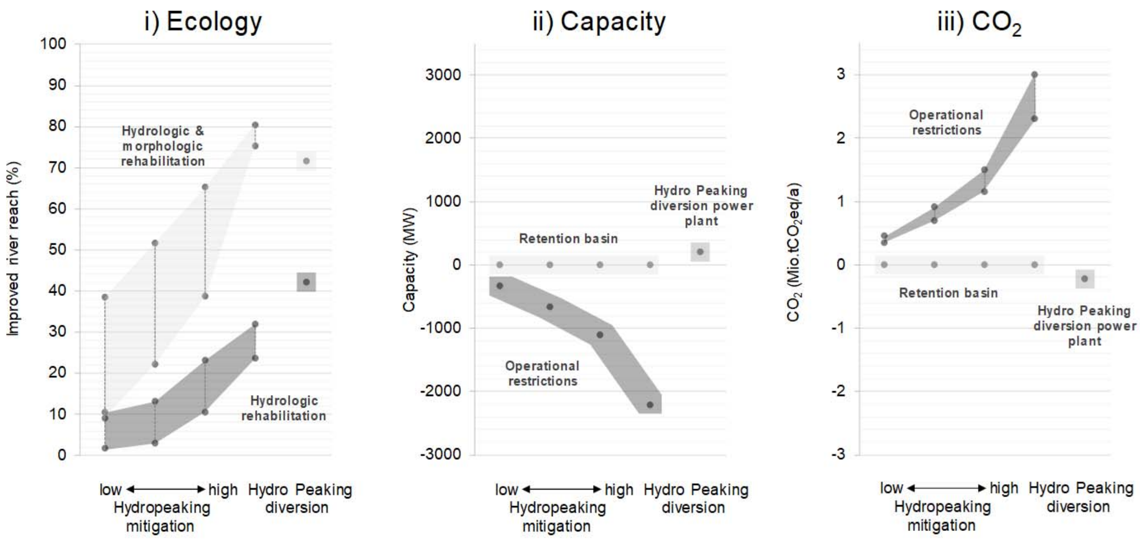

Figure 1. Comparison of ecological effects (i; dark grey – excluding morphological rehabilitation measures; light grey – including morphological rehabilitation measures), effects on the flexible generation capacity (ii; dark grey – operational restrictions; light grey – retention basin; middle grey – hydropeaking diversion power plant), and CO_2 production (iii; labeling conforming with ii) regarding the specific hydropeaking mitigation scenarios.

5 CONCLUSION

The developed tool provides an evaluation methodology for an integrative assessment of the ecological effects of hydropeaking mitigation measures and their consequences on a business economic, macro economic and system-relevant level. To our knowledge, this integrative approach is unique. Here, it has been applied on a national level, but it can also be extended to, e.g., European level. Furthermore, this methodology can also be used to assess the effects of upramping as well as other hydropeaking parameters, and can be adapted to other organism groups. It is, therefore, capable of evaluating manifold hydropeaking impacts in detail.

Due to the considerable differences between hydropower plants and the local conditions (i.e., status of hydrological or sediment regime, and river morphology), as well as the potential overlapping of hydropeaking waves released from other hydropower plants, a specification of the best possible combination of measures (i.e., type of hydropeaking mitigation measure and/or morphological rehabilitation measures) requires a detailed case-by-case evaluation.

6 REFERENCES

[1] European Commission, "*A Roadmap for moving to a competitive low carbon economy in 2050 (Energy Roadmap 2050)*", COM(2011) 122 final, (2001).

[2] European Commission, "*2030 climate and energy goals for a competitive, secure and low-carbon EU economy*", Press release, Brussels, 22. January 2014, (2014). http://europa.eu/rapid/press-release_IP-14-54_en.htm.

[3] Fraunhofer IWES, "*The European Power System in 2030: Flexibility Challenges and Integration Benefits. An Analysis with a Focus on the Pentalateral Energy Forum Region*", Analysis on behalf of Agora Energiewende, (2015).

[4] Agricola A-Cl., Seidl H., Heuke R., von Roon S., Hinterstocker M., Eberl B., "*Entwicklung der Erlösmöglichkeiten für Flexibilität auf dem Strommarkt*". Analysis on behalf of the German Energy Agency Ltd (dena), Munich, (2014).

[5] BMLFUW, "*Nationaler Gewässerbewirtschaftungsplan 2015*", Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, (2017).

[6] Greimel F., Zeiringer B., Höller N., Grün B., Godina R., Schmutz S., "A Method to detect and characterize sub-daily flow fluctuations", *Hydrological Processes*, Vol. 30, (2015), pp 2063-2078.

[7] Hauer C., Schober B., Habersack H., "Impact analysis of river morphology and roughness variability on hydropeaking based on numerical modelling", *Hydrological Processes*, Vol. 27, No. 15, (2013), pp 2209-2224.

[8] Young P. S., Cech J. J., Thompson L. C., "Hydropower-related pulsed-flow impacts on stream fishes: a brief review, conceptual model, knowledge gaps, and research needs", *Reviews in Fish Biology and Fisheries*, Vol. 21, No. 4, (2011), pp 713-731.

[9] Parasiewicz P., Schmutz S., Moog O., "The effect of managed hydropower peaking on the physical habitat, benthos and fish fauna in the River Bregenzerach in Austria", *Fisheries Management and Ecology*, Vol. 5, No. 5, (1998), pp 403-417.

[10] Liebig H., Céréghino R., Lim P., Belaud A., Lek S., "Impact of hydropeaking on the abundance of juvenile brown trout in a Pyrenean stream", *Archiv Für Hydrobiologie*, Vol. 144, No. 4, (2011), pp 439-454.

[11] Hauer C., Holzapfel P., Leitner P., Graf W., "Longitudinal assessment of hydropeaking impacts on various scales for an improved process understanding and the design of mitigation measures", *Science of The Total Environment*, Vol. 575, (2017), pp 1503-1514.

[12] Casas-Mulet R., Saltveit S. J., Alfredsen K. T., "Hydrological and thermal effects of hydropeaking on early life stages of salmonids: A modelling approach for implementing mitigation strategies", *Science of The Total Environment*, Vol. 573, (2016), pp 1660-1672.

[13] Hauer C, Unfer, G, Holzapfel P, Haimann M, Habersack H., "Impact of channel bar form and grain size variability on estimated stranding risk of juvenile brown trout during hydropeaking", *Earth Surface Processes and Landforms,* Vol. 39, No. 12, (2014), pp 1622-1641.

[14] Schmutz S., Fohler N., Friedrich T., Fuhrmann M., Graf W., Greimel F., Höller N., Jungwirth M., Leitner P., Moog O., Melcher A., Müllner K., Ochsenhofer G., Salcher G., Steidl C., Unfer G., Zeiringer B., "*Schwallproblematik an Österreichs Fließgewässern – Ökologische Folgen und Sanierungsmöglichkeiten*", Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, Vienna, (2013).

[15] Auer S., Zeiringer B., Führer S., Tonolla D., Schmutz S., "Effects of river bank heterogeneity and time of day on drift and stranding of juvenile European grayling (Thymallus thymallus L.) caused by hydropeaking", *Science of The Total Environment*, Vol. 575, (2017), pp 1515-1521.