

# Evaluation of feasible additional hydro potential in Bavaria/ Germany

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## Introduction

Within the context of the European water framework directive 2006, the Bavarian Ministry for Environment, Health and Consumer Protection, the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology and major electric supply companies approved a key issues paper with the intention of increasing the usage of hydro power in Bavaria in parallel to maintaining or improving the ecological condition of the main water bodies.

A study was carried out for evaluation of unused hydro power potential, in which almost 150 existing hydro power plants at large flumes (1<sup>st</sup> degree) were evaluated in Bavaria. The annual generated hydro power of these operators represents about 37.8 % of current generated water power in Germany.

The licensing documents, the hydrological information and constructional details for all of these hydro power plants were examined to identify additional hydro potential. For the identification, the theoretical output of a hydropower plant can be calculated using information of discharge, head difference, together with the efficiency value of the used turbines and generators. One of these factors has to be increased to increase the output at any hydro power plant.

The determination of the theoretic additional water power potential promised a hydro potential of about 1024 GWh/a. In a second step the feasibility of this potential was identified regarding the local situation at the site. After this feasibility study it became clear, that only about 935 GWh/a of feasible additional hydro potential is available in Bavaria. This value corresponds to about 13% related to the annual hydro power generation.

## 1. Background

The master plan "The future of hydropower in Bavaria" consists of two parts: "*Passability Concept Bavarian Danube*" and the hydro power potential study "*Development Potential of Hydro Power in Bavaria*". Together they form the proposal of two major hydro power operators in Bavaria - E. ON Wasserkraft GmbH (EWK) and Bayerische Elektrizitätswerke GmbH (BEW) – for a further contribution for climate protection. In parallel to increasing the in hydropower production, the linear continuity of the Danube and its tributaries should be improved. Additionally, the Rhein-Main-Donau AG supports the master plan as owner of several hydroelectric power stations of E.ON Wasserkraft GmbH and Bayerische Elektrizitätswerke GmbH. Both above mentioned approaches need to go hand in hand and have to be considered as comprehensive proposal to achieve a win-win situation for society, environment, climate, public authorities and operators. In the following the part named "*Development Potential of Hydro Power in Bavaria*" will be summarized. It describes one of several possibilities to achieve a healthy balance between the demands of new environmental legislation and the compensation of private investment. Other compensation options are expressly neither limited nor should be replaced.

## Occasion

The EU Water Framework Directive was enacted on 22.12.2000. The directive creates a framework for the protection of inland transitional waters, coastal waters and groundwater. It provides a fairly new approach in water management. All participant parties - politics, government, society, water users and stakeholders – are faced with major challenges. The new requirements of the Water Framework Directive demand new necessary tools to achieve the required improvements for the ecology of Bavarian rivers professionally as well as financially within the set

deadlines. The hydro power operators will contribute to the implementation of the Water Framework Directive, of course. Within this contribution the operation of the hydro power plants and their corresponding contribution to climate protection in Bavaria should not be limited in any way. The presented potential study "*Development Potential of Hydro Power in Bavaria*" as part of the master plan present measures to enable the two Bavarian major hydropower operators E. ON Wasserkraft GmbH and Bayerische Elektrizitätswerke GmbH to invest early and voluntary – in the case of approval - into the continuity of waters along the Danube, Inn, Iller, Lech and Isar. This would be a significant professional as well as financial contribution to achieving the objectives of the EU Water Framework Directive for Bavaria. This means that in Bavaria climate friendly electricity generated from hydropower would be increased in parallel to private sector investments into the implementation of the Water Framework Directive. E. ON Wasserkraft and Bayerische Elektrizitätswerke GmbH thereby confirm their long-standing company policy for active improvements of the ecological state of Bavarian rivers. The master plan "*The future of hydropower in Bavaria*" proves that ecology and economics do not form a contradiction at Bavarian rivers. In contrary, only by means of approval of hydro power potential, which are cited in the present study, the proposed measures could create a financial scope to invest into the ecology. Otherwise this scope would not be available. It should also be clear, that the climate goals of the Bavarian State Government as well as the objectives for Implementation of the Water Framework Directive would not be accessible without these measures.

### **Hydropower and Water Framework Directive**

Any human action has an impact on environment and nature. In many cases these actions could have negative effects on the ecosystems in the surrounding of humans. This applies to the establishment of housing by building sites, to infrastructure projects such as roads and railway lines as well as to industrial uses for job creation or facilities to produce energy. As they are two of the largest water users in Bavaria, the hydropower operators E. ON Wasserkraft GmbH and Bayerische Elektrizitätswerke GmbH are already dealing critically and constructively with the effects of hydropower in Bavaria for many decades. Large investments into the installation of fish ladders and the renaturation projects of river sections already improved the ecological status of Bavarian rivers significantly - long before the policy has anchored the need for such measures in the EU Water Framework Directive 2000/60/EC. Moreover, the hydroelectric plants at the large Bavarian rivers meet necessary economic and social functions like safety for health and property of residents in flood events as well as safety of river landscapes by reinforcing the river beds.

### **Key issues paper "*Sustainable utilization of water power at national water bodies in Bavaria*"**

The Bavarian state government has set itself the aim to increase the hydro power generation in Bavaria by 10% compared to the reference year 2000. This corresponds to an increased annual production of 1,300 Gigawatt hours (GWh). This would mean that 371 000 households could be supplied with regenerative energy and more than three quarters of a million tons of CO<sub>2</sub> could be saved in comparison to the West-German generation mix. This amount would also be sufficient to balance the emissions of about 250,000 midsize cars.

E. ON Wasserkraft and Bayerische Elektrizitätswerke are basically willing to make the required investments to raise the hydro power potential if it could be clearly shown to be economical. In turn, the political and legal conditions should not preclude this aim. Therefore, the two Hydropower operators and the Bavarian State Government - represented by the Ministry of Economic Affairs, Infrastructure, Transport and Technology and the State Ministry for Environment and Health" signed in 2006 an agreement "*Sustainable utilization of water in state waters in Bavaria - Key issues paper*".

The key issues paper provides a coordinated framework and plan of action with objectives, principles and paths or strategic approaches to achieving the above mentioned objectives and tasks. It therefore answers all the controversial issues which have caused several problems in the past. This approach is dedicated to the coherent implementation of the different objectives and concerns.

### **Hydropower in Bavaria**

Hydropower is an energy source that has many indisputable advantages: It is emission free and always renewable, marked by sophisticated technology and high efficiency, not dependent on imports and locally distributed over the whole country. It is also the only type of production which could be used for basic, intermediate and peak load as well as for energy storage and power regulation. Hydropower is Bavaria's second largest electricity source following nuclear power. It supported significantly the industrial development in the first half of the 20th Century. Till the 60s of the last century more than the half of Bavarian electricity need was generated by hydropower. Today it avoids about 10 million tonnes of climate-damaging carbon dioxide per year and thus hydro power is contributing

significantly to climate protection in Bavaria. It covers about two-thirds of the electricity from renewable energy sources in Bavaria and therefore it is the basis for Bavaria's leading position for the ecological energy mixing.

The large hydropower operators E. ON Wasserkraft and Bayerische Elektrizitätswerke have made a high three-figure million Euro investment into their facilities and sustained thereby Bavarian construction, trade and service companies especially in difficult times. Moreover, the establishment of river power plants in parallel to water management tasks as well as the development of water ways was considered as appropriate in the *Bavarian State Development Program* published in 1974. The construction of several hydro power plants stopped the progressive erosion of the river beds and led to stable minimum flow conditions. By means of these measures a further decent of surface and ground water levels was prevented, which resulted in a huge amount of advantages for water dependent ecosystems like nesting places, floodplain forests, bogs and wetlands.

Another type of contribution to overall social benefits is the river cleaning of partially toxic and environmentally hazardous prosperity waste, the already explained protection of life, health and property by the support of controlled flood discharge conditions as well as the creation of additional natural areas of sometimes international importance. Without the support function of hydro power, the safety of living near Bavarian rivers and the development of beautiful natural landscapes with their benefits for environment and tourism would not be possible. Additionally, the existing power plants are the basis for a reliable, not dependent on any imports as well as decentralized climate-friendly renewable electricity.

## 2. Former Reports

The importance of hydropower for Bavaria was recognized early, which yields to a series of reports. At the beginning of the 20th Century, the “*Department for Utilization of Hydropower for Electricity*” in the Bavarian Ministry of the Interior performed in-depth studies on the best segmentation of river routes, the most appropriate type of development and most economical extension sizes. The result was summarized in a report of 1907. This report was followed in 1921 by a memorandum on the “*Hydro Power Industry in Bavaria*”, in 1926 by a “*General Plan for the Exploitation of Hydropower in Bavaria*”, in 1950 by a further “*General plan of the Water Power in Bavaria*” together with a “*Report on the Water Power Extension in Bavaria*” of the Supreme Building Authority in the Bavarian State Ministry of the Interior in 1988. The latest “*Report on the further Extension of Hydropower in Bavaria (hydro power reserves)*”, which was prepared in the year 1995, was initiated by the Bavarian State Ministry for Regional Development and Environment. The latest is the basis for this report.

The cited figures of the 1995 report are valid as before in terms of existing residual potentials. From the current perspective they are still economically viable concerning the cited magnitude.

Table 1 shows how the final development of hydro power utilization in Bavaria, which was estimated in the former reports, together with the potential increase related to the reference state of extension of 2001.

Report of	Estimated possible final extension in GWh/a	Potential with regard to the status of 2001 13.070 GWh/a
1926	14.000	+ 7%
1950	15.330	+ 17%
1988	13.800	+ 6%
1995	14.400	+ 10%

Table 1: Former Estimations for Bavarian hydro power generation

### 3. Development 1995-2000

Since the report of the year 1995, a series of measures were carried out to increase the use of hydro power. During these measures, existing plants were expanded as well as new equipment and engines were added to existing plants. Since 1995 the total annual output of Bavarian Hydro Power was raised by about 203 GWh/a.

In the year 2009 the hydro power plants at the river Inn between Rosenheim and Stammham were transferred from the E. ON Wasserkraft GmbH to a new owner. Measures in the area of the former property of E. ON Wasserkraft are listed in this study. Any future potential together with possible measure evaluation to raise this potential in the cited area will not be discussed, as the study only considers the hydro power plants in the properties of E.ON Wasserkraft GmbH and the Bayerische Elektrizitätswerke GmbH.

### 4. Actual hydro potential 2009

#### 4.1 Preliminary remark

The following classification is used similar to the names listed in the report about water reserves of 1995 [1]:

- New constructions at new locations
- New constructions at existing transverse structures
- Extension of existing plants by
  - Modernization: measures to increase the capacity / annual output without changing the scope of use
  - Retrofitting: extension of existing plants to increase capacity/ annual output by increasing the scope of use
- Reactivation: measures to restart of closed-down power plants

In the present report, the future of the Bavarian hydro power utilisation is discussed regarding the use of unused or expandable hydraulic potentials. To determine this potential, all sites have been studied technically concerning theoretical parameters such as discharge extension rate, licensed storage levels or heights of fall, together with the flow duration curves. Details of the procedure will be explained in the following section. Potentials were evaluated in terms of their feasibility and their efficiency. Potentials which are technically or economically not feasible are not included in this report.

#### 4.2 Basic Physics

The general benefit formula could be used to determine the technical performance of a hydropower plant:

$$P = \eta \cdot \rho g \cdot Q \cdot H$$

The power  $P$  of a hydroelectric power plant could be calculated multiplying the hydraulic head  $H$  between, represented by the difference of up- and downstream levels, the discharge  $Q$  and the efficiency  $\eta$  of the hydro power plant. To increase the potential a hydroelectric plant one of the cited factors should be increased. In the formula above the different factors seem to be linear. Against this impression the factors change in general over the year. Therefore, performance plans are used for determination of extension values, in which the seasonal fluctuations are input.

#### 4.3 Procedure for determining potential

In preparation of this report the degree of extension of each individual plant was calculated. In a first step the discharge duration curve was determined, as it is exemplarily shown in Figure 1. This was compared with the extension discharge, which is cited in the approval documentation, to get the degree of extension. The degree of well designed system should be in a range of 30-60 days, where the extension discharge will be exceeded [6].

The head is this also changing in the course of a year. The determination of the duration curves of water levels is much more difficult than that of the discharge duration curves, as the number of official gauging stations in the vicinity of hydro power plants is much smaller. Consequently, in the present study constant water levels were used. As the hydro power potentials represent only estimation, the coherent errors were considered acceptable.

The final factor affecting the hydropower potential is the plant efficiency. The extension efficiency was calculated using the other extension values and compared with a nominal value of 80%. Low efficiency values could signify bad plant efficiency values. As the extension efficiency is significantly influenced by the operational conditions of a power plant, it should be considered as an average efficiency value.

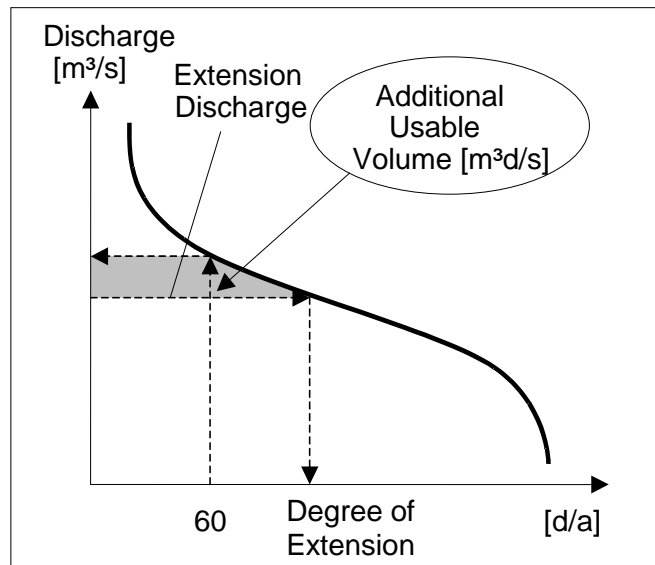


Figure 1: Former Estimations for Bavarian hydro power generation

#### 4.4 New plants at new locations

The large Bavarian rivers are largely extended for water power utilization. Only a few sites are still available for the construction of new large hydropower plants with a capacity bigger than approx. 1 MW. By means of new plants usually more hydro potential could be raised than by means of modernization or retrofitting measures.

On the other hand the realization of such power stations gets more and more difficult due to the conflict between benefits and disadvantages of hydro power.

The selection of possible plant locations should not anticipate regular approval procedures, including the necessary environmental and nature conservation assessments. However, possible locations represent potential which should be achievable from the perspective of hydropower operators, after weighing all the pros and cons - especially against the background of the economic and overall social additional benefit.

In the study altogether 8 new power plants at new locations were detected with a total potential of 248 GWh/a.

#### 4.5 New plants at existing weirs or steps

Apart from absolute new constructions, existing transverse structures could be expanded for hydro power purposes. The annual capacities of potential power plant sites are listed below. Once again it should be stated, that the potentials are only named without any anticipation of regular approval procedures.

In the study altogether 7 new power plants at existing weirs or steps were detected with a total potential of 95 GWh/a.

#### 4.6 Expansion of existing plants

The technical possibilities for potential increase at existing plants were already described in a previous section of the report. These possibilities could be divided up into modernization, retrofitting and reactivation, to connect semantically to former reports.

## Modernisation

Modernization refers to measures to increase electricity generation at constant scope of use. Possible measures therefore are:

- Modernisation of power plant technology - essentially turbine and generator - to improve the efficiency
- Optimization of operation

Modernization measures are implemented inside the existing power plant without any impact on water level or discharge conditions. Normally, no legal authorization should be necessary. The cumulative modernization potentials for the different river basins are listed in Table 2.

## Retrofitting

Retrofitting measures are measures to increase power generation in parallel to increase the scope of use.

Examples for these measures are:

- Improving the degree of discharge extension by replacement of existing turbines or addition of new turbines
- Improving the degree of discharge extension by increasing the maximum allowable turbine flow.
- Increasing the height of fall by increasing the storage level

Modernization measures usually have an impact on water level and flow conditions. Consequently water law approval and in most cases even environmental procedures are necessary for the most of the measures.

## Reactivation

Not any reactivation potential could be identified in the current study.

Hydropower production	EWK & BEW	
	Annual output GWh/a	Fraction related to existing plants
Existing plants	7.600	100%
New plants at new sites	248	3%
New plants at existing weirs or steps	95	1%
Modernization potentials	142	2%
Retrofitting potentials	551	7%
Total Potentials	1.036	14%
<b>Total water power potential</b>	<b>8.836</b>	<b>114%</b>

Table 2: Results for the different types of hydro potential

## 4.7 Priorities in the implementation

All actions of the master plan "*The Future of Hydropower in Bavaria*" – cited in the continuity concept (Part 1) as well as in the potential study (part 2) - require significant efforts for its implementation. This relates to planning, approval, funding and implementation alike. Hence, the measures have to be implemented gradually. Therefore a table of priorities concerning the projects is necessary, which has to be set up by evaluation of objective criteria.

The prioritization was evaluated for the concept of river continuity after the criteria of environmental benefits, investment and estimated approval effort. Technical aspects like feasibility, economic viability, multiple benefits (eg flood protection) and approval efforts play a leading role for the the development of hydro power.

In general, the implementation of measures from Part 1 mandatory requires the parallel realization of measures from Part 2.

## 5. Conclusion

The presented potential study shows that there is hydro power potential of 1,024 GWh per year for E. ON Wasserkraft and Bayerische Elektrizitätswerke in Bavaria, which is viable and valued for approval (see Table 8). This means, that the two major hydro power operators alone, together with the owner company of some plants , the Rhein-Main-Donau AG, could already be able to generate about 79% of the 1,300 GWh / year, the aim of the Bavarian State Government. In addition, almost 300,000 average households could be additionally supplied with renewable electricity together with extra savings of about 610 000 tonnes of carbon dioxide per year. It should be mentioned that the presented potentials denote upper thresholds. In some cases like mandatory capacity reductions according to demands after the EU Water Framework Directive, the potential could not be completely be raisable in the future.

Hydroelectric power was and still is a cornerstone for sustainable economic development in Bavaria. It bears the major part of the regenerative potential within an intelligent CO<sub>2</sub>-poor energy mix. Policy and society always confessed to use and to develop hydropower in Bavaria, from the first plans for hydro power extension on the current state development concept through to the key issues paper.

This way was previously successful and therefore should be pursued consequently. The present study demonstrates that the hydropower potential in Bavaria still could further contribute to climate protection and renewable electricity generation. Accordingly, the extension of hydro power should continue within the existing legal framework due to many additional benefits of hydropower to any citizen.

The balance between economy and ecology of Bavarian rivers is part the philosophy of E. ON Wasserkraft and Bayerische Elektrizitätswerke. Both companies will make the necessary efforts to raise all the cited potentials, which are feasible economically. The implementation of the master plan "*The Future of Hydro Power in Bavaria*" will be a probative example, that economy and ecology at Bavarian rivers are compatible and win-win situations for all water users are reachable.

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