Generation Investment Study

Volume 5: Generation and Transmission Appendices

Appendix 10: HYDRO SENSITIVITY ANALYSIS

Contents

A10.1 Introduction

There are a large number of potential hydro plants to be developed in the SEE region. In the WASP input files, these plants need to be ranked for implementation. The purpose of this appendix is to describe the methodology used for ranking different hydro power projects (HPPs) and to present the results.

A10.2 Methodology for Ranking Hydro Power Projects

The methodology is based on an estimation of the benefit to cost ratio for each proposed HPP. This ratio is then used as a priority index ratio for comparing the economic merit of different HPPs selected as candidates for the generating expansion programme.

A10.2.1 Benefit Analysis

A full life-cycle system analysis should be used for determining the economic benefits of a HPP. These benefits are dependent on: (i) the system's need for capacity and/or energy; and (ii) the hydro condition and the period of the year considered. An HPP could bring energy as well as capacity to the system. Three technical parameters are used for representing the operation of an HPP within the existing power system and for representing the operation of an HPP within the existing power system and for assessing the energy and capacity contribution from the station to the system: (1) **Firm Energy** from the station; (2) **Secondary Energy** from the station; and (3) **Dependable Capacity** of the station. These are defined as follows:

1. **Firm Energy**: is the energy output from a HPP available annually 80% of the time under dry hydro conditions;

2. **Secondary Energy**: is the surplus energy output from a HPP given by the difference between the average annual energy potential and the **Firm Energy** from the hydro unit; and

3. **Dependable Capacity**: represents the capacity available throughout the peak period (usually December – March in the SEE region) under dry hydro conditions.

The economic values to be assigned to these three parameters must be clearly established by usage; and actually realizable in the power system. Typically, it would include the following assumptions:

1. Capacity value of hydro systems will be zero when the system has ´surplus´ capacity;
2. Value of secondary energy will be zero where there is no financial advantages in backing down the energy output from existing thermal plants during the availability of secondary energy. Under such circumstances, water would be spilled if it cannot be stored.

However, for our analysis, we have assumed that new hydro projects would come on line starting in 2010 and at that time, there will be a need for additional capacity and energy.

Capacity and Energy Benefits: The starting point for determining energy and demand tariffs should be the economic efficiency of prices that is setting prices which maximize the net economic benefits of electricity consumption. For an electric power utility, this economic efficiency is best approximated by the system long-run marginal cost (LRMC), representing a structure of costs which reflects time of day, season, location, and voltage level.

For the ranking analysis, capacity and energy costs from typical power plant to be installed in the SEE region were used as proxy for LRMCs. Firm Energy was valued at the average production cost during peak period from an equivalent combined cycle power plant. On the other hand, Secondary Energy was valued at the average production cost during off-peak periods from a lignite power plant.

To reflect the existing and future generation mix in the SEE region, Dependable Capacity was valued as the average capacity value of a lignite-fired power plant and a combined cycle plant.

The following values were assumed for our ranking analysis:

Firm Energy: 25.8€/MWh (equivalent to fuel and variable O&M of a combined cycle plant), based on the following parameters:

Combined Cycle 300 MW
Construction cost: 579 €/kW
Economic Life: 20 years
Fixed O&M cost: 13.3 €/kW/year
Variable O&M cost: 1.3 €/MWh
Fuel cost (Bulgaria year 2015): 3.61 €/GJ
Average Heat Rate: 1620 kcal/kWh
Fuel cost: 3.61 €/GJ x 1/0.2389 x 1620 kcal/kWh = 24.5 €/MWh
Firm Energy: 24.5 + 1.3 = 25.8 €/MWh

Secondary Energy: 10.8€/MWh (equivalent to fuel and variable O&M of a lignite-fired plant), based on the following parameters:

Lignite-fired power plant 500 MW
Construction cost: 998 €/MW
Economic Life: 30 years
Fixed O&M cost: 25.2 €/kW/year
Variable O&M cost: 1.3 €/MWh
Fuel cost (year 2015): 0.88 €/GJ
Average Heat Rate: 2568 kcal/kWh
Fuel cost: 0.88 €/GJ x 1/0.2389 x 2568 kcal/kWh = 9.5 €/MWh
Secondary Energy: 9.5 + 1.3 = 10.8 €/MWh

Dependable Capacity: 106.19€/kW/year (equivalent to the average annual capacity value of a lignite-fired power plant and a combined cycle plant).

$$T\ (€/kW\text{-}year) = Investments \times (i \times (1+i)^t)/((1+i)^t - 1)) + O\&M_{FIX},$$

$$T = [579 \times \{(0.1 \times 1.1^{20})/(1.1^{20} - 1)\} + 13.3 + 998 \times \{(0.1 \times 1.1^{30})/(1.1^{30} - 1)\} + 25.2] / 2$$

T = 106.19 €/kW/year

The annual benefits of the HPP will be the sum of the values for firm energy, secondary energy and capacity. The present value of these benefits is given by:

$$\mathbf{B_i = \sum_{j=1}^{n} [(F_{i,j} + S_{i,j} + K_{i,j}) / (1 + k)^j]}$$

Where:

i - Index of the HPP considered as candidate

j - Year **1** to **n**, with **n** equals the lifetime of an HPP (**n** = 50 years)

k - Discount rate (assumed to be 10%)

$\mathbf{F_{i,j}}$ - Value of Firm Energy from HPP_i during year **j**

$\mathbf{S_{i,j}}$ - Value of Secondary Energy from HPP_i during year **j**

$\mathbf{K_{i,j}}$ - Value of Dependable Capacity from HPP_i during year **j**

$\mathbf{B_{i,j}}$ - Present value of annual benefit stream from HPP_i

A10.2.2 Cost Analysis

Costs of HPP includes: (i) capital costs; and (ii) fixed operating and maintenance costs. Capital costs must represent the construction cost of the power plant, excluding interest during construction.

Annual fixed operating and maintenance cost can be expressed as a percent of capital costs. An estimate of 1% of the total capital costs for annual O&M costs was used for ranking purposes. The total present value of total capital and O&M costs of the HPP is computed as follows:

$$\mathbf{C_{i,j} = I_0 + \sum_{j=1}^{n} [O_{i,j} / (1 + k)^j]}$$

Where:

$\mathbf{I_0}$ - Total capital investment of HPP_i
$\mathbf{O_{i,j}}$ - Fixed operating and maintenance costs of HPP **i** during year **j**
$\mathbf{C_{i,j}}$ - Present value of total costs of HPP_i

A10.2.3 Priority Index for Hydro Ranking

One approach to ranking different HPPs is to compute for each hydro scheme a priority index (**PI**) defined as the ratio of the present values of benefits to the present value of costs. Using the above equations, **PI** for candidate hydro project **i** can be derived simply as:

$$\mathbf{PI_i = B_i / C_i}$$

On the basis of the last equation, HPPs with a value of **PI** less than **1**.0 are uneconomic and, thus, should be either closely reviewed or eliminated from the expansion programme over the planning period considered. Ones with values of **PI** greater than **1**.0 should be considered in the investment programme and their economic merit ranked by value for **PI.**

The methodology for ranking hydro projects has been developed in order to overcome one weakness of the hydro module in the WASP expansion power planning model. Through the use of a priority index, it allows planning engineers and management the opportunity to make a sound decision to rank different HPPs by priority so that less important projects may be deferred, if necessary. The projects priority index does not solve all the problems of economic comparison of HPPs, but it does provide a better tool in deferring low priority projects when budget restrictions are necessary or eliminating uneconomic hydro projects.

A10.3 Description of Candidate Hydro Power Projects

Candidate plants proposed by the utilities and greater than 100 MW are described in the following paragraphs.

A10.3.1 HPPs in Bosnia & Hercegovina

Buk Bijela and Srbinje (BUKB)

The Buk Bijela project is located on the Drina River about 12 km upstream from the town of Srbinje with downstream compensating storage and HPP Srbinje. Other hydroelectric projects have been completed about 100 km downstream at Visegrad and upstream on the Piva River, which is one of two major tributaries of the Drina River. A cascade of projects along the Drina River was defined during various previous planning studies carried out by the Government of Yugoslavia. Feasibility studies were carried out for several of these projects and work for the Buk Bijela project had advanced to final design before the break up of the country in the early 1990's. A World Bank loan was assigned for the Project construction before interruption of the implementation programme.

The Buk Bijela Hydropower Project has a proposed installed capacity of 450 MW. The site works comprise a dam creating a generating head of about 90-m, works for river diversion during construction, spillway, stilling basin, and powerhouse. The reservoir proposed is relatively small and would provide a useful reservoir capacity of 328 M m^3 (about 22 days inflow at the mean annual flow). The streamflow is regulated by the upstream reservoir at Piva and provides about 174 m^3/s at the Buk Bijela site.

Average annual energy generation would be 958 GWh/year giving a plant factor of about 23%. Firm energy was estimated at 398 GWh/year.

The estimated HPP Buk Bijela project construction cost is €367.5 million, with a construction period of 5.5 years.

The downstream Srbinje Hydropower Plant has a proposed installed capacity of 55.5 MW and compensating reservoir with useful capacity of 4.6 million m^3.

Average annual energy generation of HPP Srbinje would be 161 GWh/year giving a plant factor of about 33%. Firm energy was estimated at 43 GWh/year.

The estimated HPP Srbinje construction cost is €114.7 million, with a construction period of 4.5 years.

During the session of 29 April 2004, the Government of Republic of Montenegro ratified the Agreement with Government of Republika Srpska concerning the construction of hydroelectric power plant Buk Bijela. On 30 April 2004, the Government of Republika Srpska opened an international BOT tender for the construction of Buk Bijela hydropower plant. The successful candidate in the tender for construction will probably operate the system under a long-term concession agreement, which would provide both a return on investment and would establish an appropriate position for the operator in the market for power.

Glavaticevo (GLAV) and Konjic (KONJ)

HPPs Glavaticevo and Konjic are HPPs on the Neretva river and a part of the project known as Upper Neretva consisting of: HPP Konjic, HPP Glavaticevo, HPP Ljubuca and HPP Ulog.

Project Glavaticevo has two dams, both positioned upstream of the town Konjic. The first one is a high dam and the second one is used as compensating basin only.

The Glavaticevo Hydropower Project is in the preliminary design stage and has a proposed installed capacity of 170 MW.

Average annual energy generation of HPP Glavaticevo would be 313 GWh/year giving a plant factor of about 21%. Firm energy was estimated at 5.8 GWh/year.

The estimated HPP Glavaticevo construction cost is €188.3 million, with a construction period of 6 years.

JP “Elektroprivreda BiH” has been awarded funds from the US Government to study completion of the HPP Project Konjic which will undergo some revisions. Proposed installed capacity of the HPP Konjic is 122 MW.

Average annual energy generation of HPP Konjic would be 292 GWh/year giving a plant factor of about 27%. Firm energy was estimated at 44 GWh/year.

The estimated HPP Konjic construction cost is €134.9 million, with a construction period of 5 years.

Dabar (DABA)

JP “Elektroprivreda BiH” is also investigating construction of a 160 MW hydro station at Dabar.

A feasibility study was undertaken in 1999. An update of this study is considering additional geological investigations.

Average annual energy generation of HPP Dabar would be 303 GWh/year giving a plant factor of about 21%. Firm energy was estimated at 204.6 GWh/year.

The estimated HPP Dabar construction cost is €171.7 million, with a construction period of 4.5 years.

A10.3.2 HPPs in Bulgaria

Gorna Arda Cascade (GARD)

The Gorna Arda scheme comprises a regulating reservoir and downstream hydroelectric plants in cascade, on the Arda River.

Design and other activities for Gorna Arda are well advanced. The available documentation for all three steps planned to be built within this cascade comprises detailed design and tender documents.

The first one, Madan Project, consists of a 92.4 m high dam and hydropower plant with installed capacity of 46 MW. The second one, Ardino Project, consists of a 102.7 m high dam and hydropower plant with installed capacity of 56.8 MW. The third one, Sarnitsa Project, consists of a 96.1 m high dam and hydropower plant with installed capacity of 68 MW.

Thus, Gorna Arda Hydropower Project has a proposed installed capacity of 170 MW.

Average annual energy generation of HPP Gorna Arda would be 434 GWh/year giving a plant factor of about 29%. Firm energy was estimated at 106.9 GWh/year.

The estimated HPP Gorna Arda construction cost is €196.1 million, with a construction period of 4 years.

A10.3.3 HPPs in Macedonia

Cebren (CBRL)

The location of the candidate HPP Cebren is on the River Crna, upstream of the existing HPP Tikves and upstream of the candidate HPP Galiste. There are two design alternatives for the HPP Cebren: (1) a low dam -- 90 m; and (2) a high dam --192.5 m alternative. The low-dam alternative was analysed within the GIS study.

The low-dam alternative would also include the candidate hydro project Skocivir (46 MW), which would be located immediately upstream of HPP Cebren, thus fully utilizing the hydraulic potential of the Crna river.

A detailed feasibility study was performed in 2002-2003, funded by the Phare programme.

The proposed candidate Cebren Low Dam Hydropower Project has a proposed installed capacity of 157 MW.

Average annual energy generation of HPP Cebren Low Dam would be 164 GWh/year giving a plant factor of about 12%. Firm energy was estimated at 94.8 GWh/year.

The estimated HPP Cebren Low Dam construction cost is €159.5 million, with a construction period of 6 years.

Galiste (GALI)

The location of the proposed HPP Galiste is on the Crna river, upstream of the existing HPP Tikves and downstream of the candidate project Cebren. HPP Galiste would have a maximum storage capacity of 344 hm3 and an operational volume of 260 hm3.

The plant would consist of the following structures: rock fill dam with clay core, diversion tunnel which would be used (after the construction) as foundation outlet, shaft spillway, intake tunnel, penstock and power house with three units.

A detailed feasibility study was performed in 2002-2003, funded by the Phare programme.

The expected average annual generation is 257 GWh giving a plant factor of about 15%. Firm energy was estimated at 155.9 GWh/year.

The estimated HPP Galiste construction cost is €200.7 million, with a construction period of 7 years.

A10.3.4 HPPs in Montenegro

Kostanica (KOST)

The candidate hydro power project Kostanica with a proposed installed capacity of 552 MW is located at the head of the river Moraca with water storage provided by two dams on the Tara river at Zuti Krs and Bakovica Klisura. This is then diverted by a tunnel into the Moraca river. The maximum net head is 706m with a useful reservoir capacity of 205M m^3.

Preliminary documentation for the Kostanica hydro power plant was first prepared in the early 1970s. A feasibility study was conducted in the mid 1970s. An update of the earlier studies was contracted in 2004.

The expected average annual generation of HPP Kostanica is 1120 GWh/year giving a plant factor of about 23%. Firm energy was estimated at 353 GWh/year.

The estimated HPP Kostanica construction cost is €266.1 million, with a construction period of 5 years.

Andrijevo and Zlatica (ANDR)

This candidate project is the most upstream hydro power plant on the Moraca river. It would consist of four hydro power plants in cascade on the Moraca river. The hydropower plant could be developed with two or three installed units depending on the adopted option, i.e. with or without rerouting the Tara river into the Moraca river. HPP Andrijevo with downstream compensating storage and HPP Zlatica, has by far the largest storage with a reservoir of 304 million m^3, which would be also fed from HPP Kostanica. The other two hydro power plants on this cascade have small water storages and would rely on feeds from the previous station in the cascade.

Preliminary design and feasibility studies were prepared in the middle 1970s. Actualization of the preliminary design was contracted in 2004.

Average annual energy generation of Andrijevo and Zlatica HPPs would be 717 GWh/year and installed capacity 255.5 MW giving a plant factor of about 32%. Firm energy was estimated at 296 GWh/year.

Hydro power plant Andrijevo has a proposed installed capacity of 200MW.

Average annual energy generation of HPP Andrijevo would be 517 GWh/year giving a plant factor of about 30%. Firm energy was estimated at 241 GWh/year.

The estimated HPP Andrijevo construction cost is €166.8 million, with a construction period of 6 years.

Ljutica (LJUT)

HPP Ljutica is the project on Tara river with location upstream of the Zuti Krs dam. The water storage is around 300 million m^3.

The available documentation is a preliminary feasibility study prepared in 1997.

The proposed candidate Ljutica Hydropower Project has a proposed installed capacity of 250 MW.

Average annual energy generation of HPP Ljutica would be 528 GWh/year giving a plant factor of about 24%. Firm energy was estimated at 252.8 GWh/year.

The estimated HPP Ljutica construction cost is €231.2 million, with a construction period of 6 years.

Komarnica (KOMA)

This candidate project is located on the Piva river upstream of the existing Piva power plant. HPP Komarnica would have a head of 153.4 m and an installed flow rate of 130 m^3/s. The useful reservoir capacity would be 160 M m^3.

Study on the selection and comparison of alternative sites for the construction of hydro power plant Komarnice was performed in the late 1980s.

Hydro power plant Komarnica has a proposed installed capacity of 168 MW.

Average annual energy generation of HPP Komarnica would be 232 GWh/year giving a plant factor of about 16%. Firm energy was estimated at 96 GWh/year.

The estimated HPP Komarnica construction cost is €95.6 million, with a construction period of 7 years.

A10.3.5 HPPs in UNMIK

Zhur (ZUR)

Zhur HPP has the characteristics of a peaking power plant with a rather large storage capacity (approx. 105 mcm), which amounts to nearly 40 % of the annual natural inflow. The Zhur HPP would use the stream coming from the Sharr mountain. Water abundance within this catchment area, feasible water storage on high elevations, and possible utilization of considerable concentrated head offer very favourable conditions for construction of a powerful hydraulic power plant.

Potential construction of Zhur hydro power plant was initially analyzed in a pre-feasibility study in 1988. Two alternatives were analysed.

The recommended alternative was conceived as a two power plant projects: Zhur I and Zhur II. The basic step is HPP Zhur I with rated capacity of 246 MW, and a maximum gross head of approximately 576 m. Annual generation under average hydro conditions is about 335 GWh/year. HPP Zhur II is the lowest step, with rated capacity of 46.8 MW, utilizing head of some 107 m. Annual generation under average hydro conditions is about 63 GWh/year.

Within the GIS study, HPP Zhur was modelled as one project with total installed capacity of 293 MW (246 + 46.8) MW and total annual generation of 398 a GWh/year giving a plant factor of about 16%. Firm energy was estimated at 121 GWh/year.

The estimated HPP Zuhr construction cost is €172.9 million, with a construction period of 5 years.

A10.4 Results of the Ranking of Hydro Power Projects

All new potential hydro power projects proposed by the utilities as candidates for development in the region have been ranked based on the methodology presented above. For each plant, a priority index has been computed based on the ratio of the present value of expected benefits divided by costs. Benefits are calculated from the sum of firm and secondary energy, and dependable capacity. Costs are the sum of investment costs plus the present value of O&M costs. The results are presented in Table A10.1. These results have been obtained using the medium gas price forecast.

Table A10.1. Ranking of the Hydro Power Plants for Medium Gas Price Forecast

Plant Name	Installed Capacity (MW)	Average Annual Energy (GWh)	Total Investment Euro x million	Construction Cost Euro/kW	Rank B/C
KOST	552	1,120	266.1	482	**2.039**
ZUR	293	398	172.9	590	**1.987**
KOMA	168	232	95.6	569	**1.641**
ANDR	255.5	717	227.9	892	**1.275**1/
GLAV	172	313	188.3	1,094	**1.156**
DABA	160	303	171.7	1,073	**1.137**
BUKB	511.5	1119	482.2	943	**1.020**2/
GALI	194	257	200.7	1,035	**0.958**
CBRL	157	164	159.5	1,016	**0.878**
KONJ	122	292	134.9	1,106	**0.850**
GARD	170	434	196.1	1,153	**0.783**
LJUT	250	528	231.2	925	**0.640**

1/ - with HPP Zlatica

2/ - with HPP Srbinje

The top ranked hydro power plants with a priority index greater than 1.0 were considered for inclusion in a WASP sensitivity case. These plants have been “forced” into the regional expansion plan between year 2010 and 2015, according to the following schedule:

2010: Zur
2011: Komarnica
2012: Buk Bijela + Srbinje
2013: Koštanica
2014: Glavatičevo + Dabar
2015: Andrijevo + Zlatica

The total installed capacity of these selected plants is 2,001 MW. The WASP results are described in Section 2.10 of the main report.