Technical and Economic Analysis of a Hydroelectric Plant

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Abstract — Portugal is currently complementing its electricity generating infrastructure with new hydroelectric power facilities due to the energy needs that the country is facing. EDP has accepted the challenge and the opportunity to implement the Baixo Sabor Hydroelectric Plant (BSHP) project, currently under construction in the Douro River Watershed. This thesis’ case study is the BSHP, which is subjected to a technical approach (only the upstream dam) and an economic analysis, taking into account the regulation regarding the sale of electric energy in a competitive market environment and the ancillary services that can be supplied to the technical manager. The technical approach focused the characterization of the main building structures and the hydromechanical and electromechanical installed equipment which allowed to understand of the general working process of this pumped-storage plant, both in generation and pumping modes. The economic approach consisted of an economic analysis based on quantitative and qualitative criteria, starting from the planning and discrimination of payments and receipts during the construction and exploitation phases. Generally, an investment only advances if the Internal Rate of Return (IRR) outweighs the return demanded by the investors, Weighted Average Cost of Capital (WACC). Although classified, the WACC has accepted the BSHP. This indicates that the international credibility maintained by the company has allowed the banking institutions to grant credit with appealing interest and that the shareholders view this investment as a future opportunity integrated in the strategic and responsible position of the EDP Group.

Index Terms — Baixo Sabor Hydroelectric Plant (BSHP), EDP, Weighted Average Cost of Capital (WACC), Pumped-Storage

I. INTRODUCTION

With the electricity sector deregulation, new hydroelectric plants should be seen in a perspective of execution and operation costs minimization and maximization of the revenue from the sale of electric energy in a competitive market during the operation phase.

The economic evaluation of an investment is indispensable to determine the viability of a project which has to be appealing to the investors. However, an investment can’t be evaluated only by its economic indicators but also by criteria that qualify the option, such as strategic vision and future opportunities for the promoting company. Since the investment in a hydroelectric plant is very large, not every company dares to risk it, if it hasn’t credibility with the shareholders and banking institutions so that they can have the investment financed.

This work presents, as the main objective, a technical approach and an economic evaluation of one of the new hydroelectric plants being built in Portugal: the Baixo Sabor Hydroelectric Plant.

II. HYDROELECTRIC POWER IN PORTUGAL

The Portuguese electricity generating infrastructure continues to evolve till today, and is comprised of several technologies, such as thermal, wind and solar power. Regarding the hydro power plants, the installed power in 2010 in Ordinary Regime was 4678 MW and in Special Regime was 414 MW. [1]

The several national and international energy policies converge in a need to improve the generating infrastructure with clean and renewable power plants. Targeting the year of 2020, the European Union has the 20-20-20 Climate and Energy Package, which aims on ambitious goals of reducing greenhouse emissions and increasing renewable energy generation. Accordingly, Portugal has established goals on the National Energy Strategy (ENE 2020), such as the installation of new hydroelectric plants/improvement of the existing ones and new wind parks. [2]

Hydroelectric plants have a near instantaneous starting time and, for that reason, allow ensuring the permanent balance between generation and load, as they help to guarantee the supply during peak hours (Plot 1) and to replace thermal power during those hours.

Water is considered as a renewable, clean and endogenous power source. When stored in great quantities, water can be used to various purposes, such as domestic supply, farming fields’ irrigation and electric power generation.

Hydroelectric plants are responsible for the generation of electricity from stored rain water.

A hydroelectric plant project must comprehend a technical analysis and an economic analysis. The technical analysis should allow for an evaluation of the best building, hydromechanical and electromechanical equipment solutions, having in account the intended characteristics and functions. However, the cost minimization can’t impair high standards of reliability and operability.
Hydro power growth is still possible in a country where there is still great potential to explore (50% in 2007), Figure 1.

For the previous reasons, Portugal is currently building/licensing 14 new hydroelectric plants/installation power improvements which add up to a total of 4,117 MW to be installed until 2016, Table 1. Most of them are pumped-storage type and located the Douro River Watershed. [3]

### A. Pumped-storage

About 3,064 MW from the 4,117 MW to be installed in the new hydroelectric plants will be installed in pumped-storage generating sets.

Pumped-storage hydroelectric plants have the capability of pumping water, during the night, from a downstream reservoir to an upstream reservoir, so it may be used to generate power during peak hours. Electricity is bought for pumping at a low price, and sold at higher prices during generation on peak hours. Excess generated wind power may be used to feed the pumping process.

Pumped-storage plants are always ready to generate electricity because they are less dependent on natural water flows to work and can, thanks to the near zero starting time, aid the load diagram during demanding hours.

### B. Douro River Watershed

Out of the 14 planned hydroelectric plants/improvements, 8 will be implemented in the Douro River Watershed.

Although the Portuguese portion of the Douro Watershed has significant installed power which accounts for more than half the annual national hydroelectric generated energy, the relation between the predicted storage capacity in that portion and the storage capacity currently used is very far from desirable: only 9%.

The new plants to be installed in the Douro Watershed until 2016 will increase its storage capacity to 1,560 hm³, which means that 35% of the predicted storage capacity will be used instead of the current 9%.

The predicted power increases in the International Douro region won’t contribute to a useful storage capacity increase. However, they are intended to take advantage from the streams nowadays being dumped which should be used to generate power.

### C. Baixo Sabor Hydroelectric Plant

The Baixo Sabor Hydroelectric Plant (BSHP) is one of the new pumped-storage hydroelectric plants currently being built in the Douro River Watershed. The BSHP has a strategic value, not only as an energy resource used to generate electricity during peak hours, but also as an important water reserve.

The BSHP reservoirs will be capable of storing about 660 hm³ of water, which is the equivalent to 1.6 times the present installed capacity in the Portuguese Douro Watershed. The majority of the dams existing in the national Douro portion are Run-Of-The-River type and unable to store water streams, so they depend on other upstream dams operating in Spain for the generation of electricity. Thus, the stored water will be a great instrument to manage the National Douro Watershed, resulting in a maximization of electric power generation in the plants downstream, like Valeira, Régua, Carrapatelo and Crestuma-Lever plants.

The BSHP will have a significant capacity to regulate the Douro River flows, making possible the storage of water in wet months so that it can be used to generate electricity during dry seasons. It will allow significant control of peak flood.
flows, mainly the most frequent floods, which will tend to reduce their severe effects. [5]

III. TECHNICAL ANALYSIS

The Baixo Sabor Hydroelectric Plant is located in Bragança district and is composed by two dams: the upstream dam and the downstream dam. The technical approach will only focus on the upstream dam, also considered the main dam. [6]

Upstream Dam General Characterization

The BSHP upstream dam consists of a double curvature arch dam in conventional concrete (limits the upstream reservoir, with 630hm3 of useful storage capacity, from the downstream reservoir). In the central portion it is installed the spillway (“free blade” type) controlled by gates and which body is crossed by the bottom outlet. Downstream from the dam it is located the stilling basin and energy dissipation on discharged water blades, Figure 2 [7]

Figure 2 - Double curvature arch dam

In the right bank of the river, immediately downstream from two independent hydraulic circuits (each one consisting of a water outlet, a loaded channel and a restitution channel) there is the hydroelectric power plant in a well that houses two generator-pump sets (each one consisting of a turbine-pump and an alternator-motor, directly coupled), Figure 3.

Figure 3 - Hydraulic circuit [7]

The exterior substation is situated on a platform above the plant. In addition to the protection equipment, in the substation there are the two main tree-phase transformers with a ratio of 15/220 kV.

Regarding the generation sets, as they are pumped-storage type, they can work in two different modes, depending if the plant is generating or pumping, only needing to change the machine rotating direction.

The nominal flow in generation mode is 170 m3/s and in pumping mode is 140 m3/s. Given the flow split by the two generating sets (85 m3/s each), the unit power was established in 76.5 MW/85 MVA.

\[ P = 9.8 \times Q \times (H - \Delta h) \times \mu \]  \hspace{1cm} (1)

- \( P \) – Nominal power [MW]
- \( Q \) – Nominal flow in generation [m³/s]
- \( H \) – Nominal static drop [m]
- \( \Delta h \) - Hydraulic loss [m³/s]
- \( \mu \) - Hydraulic efficiency [%]

Each generator set consists of a turbine-pump directly coupled to an alternator-motor, Figure 4.

Figure 4 – Generator group [7]

The nominal static drop of 94 m has determined the choice of the turbines-pumps. So, for drops above 50 m, it is recommended the use of a Francis turbine-pump, Figure 5. The cylindrical valve, located between the ante distributor and the distributor, will be the safety and isolation organ of the turbine-pump upstream. [8]
The alternator-motor is a synchronous three-phase machine of vertical axis. For each machine, the stipulated apparent power, as an alternator, is 85 MVA, with a power factor of 0.9. The stipulated generation voltage is 15 kV; the grid frequency is 50 Hz. For a machine that rotates slowly (214.3 rpm) (which corresponds to the turbine-pump rotation speed) the number of poles pairs is 14.

For the pumping process, the preferential start of the generator sets is carried out by a static frequency converter (Figure 6), with a free wheel, working together with the cylindrical valve.

The speed regulation system has to guarantee, for every moment, that the generator and grid frequencies are constant and equal to 50 Hz. The high precision, stability and quickness criteria have determined the use of an electronic regulator, of electro-hydraulic type, for each generator set. [10]

Each alternator-motor has a static excitation system that allows regulating the excitation current so that a stable working of the sets can be obtained in normal operating conditions, with a good answer quality against little disturbances from the exterior. In order to maintain generation voltage of the alternator-motor constant against load demands it is needed a voltage regulator for each generator set, capable of command and control functions, among which the Power System Stabilizer (PSS), Figure 7. [11]
IV. Economic Analysis

After the investment planning is defined and the payments and receipts are discriminated, the Baixo Sabor project will be subjected to a quantitative and qualitative economic evaluation of the investment.

A. Investment Planning

The payments/receipts are distributed by the construction phase (August/2008 - July/2014) and operation phase (August/2014 - July 2054), Plot 2. During the operation phase the values are subjected to an inflation rate of 2.6%.

B. Payments

The accounted payments are execution, O&M and personnel costs and costs with the Baixo Sabor Fund.

Execution

The costs regarding the execution of the project are presented in the following Table 2:

<table>
<thead>
<tr>
<th>Payments</th>
<th>Upstream Dam [k€]</th>
<th>Downstream Dam [k€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Natural Resources, Expropriations, Compensations</td>
<td>21 491</td>
<td>3 305</td>
</tr>
<tr>
<td>2 Auxiliary Civil Structures</td>
<td>19 447</td>
<td>4 813</td>
</tr>
<tr>
<td>3 Principal Civil Structures</td>
<td>101 317</td>
<td>36 178</td>
</tr>
<tr>
<td>4 Equipments</td>
<td>58 270</td>
<td>36 650</td>
</tr>
<tr>
<td>5 Studies and Project</td>
<td>10 284</td>
<td>5 087</td>
</tr>
<tr>
<td>6 Management and Supervision</td>
<td>16 194</td>
<td>6 208</td>
</tr>
<tr>
<td>7 Unforseen</td>
<td>8 861</td>
<td>3 313</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>253 864</strong></td>
<td><strong>95 554</strong></td>
</tr>
</tbody>
</table>

Table 2 – Execution costs

O&M and Personnel

The O&M and personnel costs were estimated from the previous table, according to the methodology applied in the National Plan of Dams with Significant Hydroelectric Potential (NPDSHP). In the reference year, annual costs with O&M (0.5% of [3] and 1.5% of [4]) amount to 2111 k€, while annual costs regarding personnel (0.2% of [8]) are 663 k€.

Baixo Sabor Fund

As a compensation for the Baixo Sabor infrastructure construction indicated in the Environmental Impact Statement, the tenderer, EDP, is obligated to annually contribute to the constitution of a financing fund named Baixo Sabor Fund. [11]

In the building phase, EDP is in charge of financing a total of 1340 k€ to the Investment and Development Triennial Plan, between 2011 and 2013. In each year during the operation phase, the value which EDP has to contribute to the Baixo Sabor Fund is based on 3% of the net revenue estimate generated by the two Baixo Sabor dams in Electricity Markets.

C. Receipts

The Baixo Sabor will be paid in electricity markets through the sale of electric energy, the supply of ancillary services and the power guarantee.

C.1. Electricity Markets

The computer program developed in the Master’s Thesis of Eng. José Carlos Sousa has allowed estimating remuneration of hydroelectric plants, in a market environment, of a stream similar to the National Douro for the year of 2020. The program strategy accounts for the generation of electricity during the peak price hours and the pumping, in the dams that have this function, in off-peak hours, if the operating restrictions of the plant allow this. [13]

The program presents the following essential principles:

- Market prices are price-takers;
- Cascade interconnection;
- Non-linear relation between power, drop and flow.
- Respecting operation restrictions;

The inputs are the real characteristics of the several hydroelectric plants for the National Douro Adapted (NDA) cascade (Figure 9), the flows and the market prices.

Figure 9 - National Douro Adapted cascade

The flows data were kindly supplied by EDP Produção and refer to the dams in the figure, based in historic monthly results of hydrologic regimes of 40 years (1966-2005) and not in predictions. The monthly flows were converted to hours, because the program is hourly.

The automatic calculation model of EDP Produção, called VALORAGUA, has simulated for the year of 2020 the
MIBEL (Iberian Electricity Market) expectable behavior in spot market, through the interaction and competitiveness between the various technologies existing in that market environment. From the simulation resulted 40 annual price scenarios, agreeing with each year of the flows history. Each price scenario is presented in hours.

The average annual market price that resulted from that simulation was 72.68 €/MWh and will be used as reference data to obtain the appreciation of the hydroelectric plants.

**Simulation Methodology**

The simulation was performed for the National Douro Adapted cascade and for two cases: with and without the two Baixo Sabor dams.

The simulation developed, for each hour of the 40 years of simulation (350 400 hours), the average producible and consumable (by pumping) energies, the average water volumes used in energy generation and pumping, average discharged volumes, and the corresponding appreciation for each dam of the National Douro Adapted cascade. The following Figure 10 represents this methodology.

**Output Data Handling**

For the simulation “with the Baixo Sabor”, in relation to the produced and consumed energy by the upstream dam, the Plot 3 presents 48 hours of simulation, Plot 3.

The annual results from the simulation show that, in a year considered normal, the Baixo Sabor [B] and [C], Foz Tua [E] and Torrão [H] plants, as they have reservoirs with the biggest storage capacity, can manage better the water resources they deal with. These plants focus their production in peak hours, where prices are most rewarding (preferably above average market price), optimizing volumes of water to be used in generation, aiming on profit maximization. On the other hand, the other plants in the Douro cascade, being out-of-the-river type, present a very limited storage capacity so that the option of storing water, although desirable, is not always possible, which forces them to operate during more hours but not always on those that match the best market prices.

The inclusion of Baixo Sabor allows for a better regularization of flows in the cascade and causes a positive impact in the dams situated downstream in the main Douro river course (Valeira, Régua, Carrapatelo and Crestuma-Lever).
The Foz Tua and Torrão plants, being located in Douro tributaries, aren’t positively affected by the Baixo Sabor.

Regarding the pumping, the upstream Baixo Sabor dam is the one that can better manage it. Due to the great storage capacity, a bigger water volume can be pumped.

Summing up, in a year considered normal, the construction of Baixo Sabor will impact the NDA cascade in average, in 2020, the value of 4 627 k€. Since the complete cascade is operated by EDP, the total revenue from both Baixo Sabor dams plus additional revenue from the remaining dams are, in average, 28 502 k€.

C.2. Ancillary services

The generating sets in the Baixo Sabor upstream dam will be able to work under the secondary and tertiary regulation system through the remote real power regulation system centralized in REN. This is not planned for the downstream dam.

The adopted strategy for the calculation of Baixo Sabor revenues for ancillary services was the same used in the NPDSHP. So, it was assumed that the upstream Baixo Sabor dam can reach, in average, a value for ancillary services matching 15% of its net profits obtained in electricity markets. The estimated value for the year of 2020 is 2 158 k€. [14]

C.3. Power Guarantee

The Portuguese State forecasts the assignment of remuneration to the hydroelectric plants in Ordinary Regime situated in Portugal for providing power guarantee services to the national electric system in terms of availability service and investment encouragement. [15]

The BSHP remuneration which could be obtained with the availability service will be ignored, due to the uncertainty of this portion’s remuneration. Regarding the investment encouragement, as the BSHP already has an operating license emitted by the DGEG and the power to be installed is 171 MW, the annual value to be paid to EDP will be 3 420 k€. The power guarantee remuneration will be updated over 10 years according to the inflation rate in use.

D. Economic evaluation

The Baixo Sabor investment needs a quantitative economic evaluation, through economic indicators, and qualitative, so that the investment may be understood from the investor point of view.

D.1. Quantitative Analysis

After the payments/receipts were determined, it was necessary to do a financial evaluation to determine the Total Cash Flow for a project period of 47 years. From that Total Cash Flow it was possible to calculate the following economic indicators: Net Present Value (NPV) and the Internal Rate of Return (IRR). [16]

\[ NPV = \sum_{i=1}^{n} \frac{CF_i}{(1 + DR)^j} \]  \hspace{1cm} (2)

- \( CF_i \) – Cash Flow in year i [€];
- \( DR \) – Discount rate [%];
- \( n \) – Period [year];

The discount rate (DR) used in the NPV calculation can be interpreted as the return rate demanded by the company as a whole to make a certain investment viable. In that case, it can be called Weighted Average Cost of Capital (WACC). In short the WACC is the weighted average of the third-party capital costs (demanded by the creditors to loan financial resources to the company, normally associated to banking institutions and loan interest) and the company’s equity (return demanded by the company’s shareholders to accept the investment).

\[ WACC = \frac{MVe}{MVe + Mvd} \cdot Re + \frac{Mvd}{MVe + Mvd} \cdot Rd(1 - t) \]  \hspace{1cm} (3)

- \( MVe \) – type of shares (market value);
- \( Mvd \) – type of bonds (market value);
- \( Re \) – cost of equity;
- \( Rd \) – cost of debt;
- \( t \) – corporate tax rate

The results of Net Present Value for 6%, 8%, 10% and 12% discount rates are shown in the following Table 4.

<table>
<thead>
<tr>
<th>DR[%]</th>
<th>NPV [k€]</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>34,711</td>
</tr>
<tr>
<td>8</td>
<td>-43,550</td>
</tr>
<tr>
<td>10</td>
<td>-86,216</td>
</tr>
<tr>
<td>12</td>
<td>-109,371</td>
</tr>
</tbody>
</table>

**Table 4 – NPV results to different Discount Rates**

If the discount rate is equal to 8%, 10% or 12%, the NPV is negative, which means that the project is economically unviable. For the rates of 6%, the NPV is positive. This means that the investment is economically viable. It covers not only the initial investment and the minimum remuneration demanded by the DR but it also has the capability to generate financial surplus.

**Internal Rate of Return (IRR)**

The IRR (NPV=0) that resulted from the application of the formula is 6,74%. Under this economic indicator’s point of view, the project will only be viable if the IRR is equal or more than the WACC (so that profit can be generated), that is, the company’s structure should only accept this project if the WACC is less than the IRR.

The IRR calculated for the BSHP (6,74%) can be compared with other projects, namely with the hydroelectric plants selected in the NPDSHP. From the 7 plants that received positive proposals, EDP is the company executing 3: Fridão (IRR:13,0), Foz Tua (IRR:14,4) and Alvito (IRR:5,7). As can be seen, Fridão and Foz Tua are two very attractive projects comparing with the BSHP in terms of profitability. Alvito, although having an IRR inferior to BSHP, was one of the projects selected by both the NPDSHP (Assureira presented a IRR of 12,4 and
wasn’t chosen) and the EDP (may have based its choice in an IRR different from the one calculated in the NPDSHP, even because, for example, the predicted power to be installed is now more), which proves that there are other relevant criteria that should be evaluated, mainly for the company’s shareholder structure. [14]

D.2. Qualitative analysis

The BSHP is presently under construction which means that, after the previous economic indicators in the phase of project were calculated, the WACC has allowed the beginning of construction. Even if the actual IRR is not as high as desired, the investment in this hydroelectric plant has revealed appealing to investors.

The WACC value depends essentially in the credibility, dimension, culture, strategic vision, maturity that the company has before the shareholders and creditors so that they finance the investment at reduced risk. The rating agencies consider EDP as a company with a stable outlook, due to its Portuguese electricity market dominance, its growing projection in the Iberian market and for the reduced risk of the business units that most contribute to the cash flow.

Banking Institutions

The WACC portion which refers to third-party capital costs is associated with banking institutions and bonds.

In relation to banking institutions, EDP can get co-financing from European banking institutions at low interest rates and longer terms, granted by the European Investment Bank (EIB) to the refurbishment of Alqueva and Venda Nova or yet from the European Bank for Reconstruction and Development (EBRD).

In a strategy of diversification of financing sources, EDP has done the first bond issue in the Swiss market, in February 2011, amounting 230M Swiss francs, with a maturity of 3 years (February 2014) and a coupon of 3.5%. Equally in February, EDP has issued bonds worth 750 M€ maturing in 5 years (January 2016) and with a coupon of 5.875%. [17]

The previous demonstrations show that if the Baixo Sabor can get foreign financing through the EIB or EBRD and/or through the issue of bonds at lower interest, the third-party capital costs portion of the WACC can be influenced to be smaller.

ShareHolders

The WACC portion related to the company equity, represented by the shareholder structure, was positively influenced, not only by economic indicators and external evaluations, but also by qualitative aspects that reflect policies, the mission and the lines of strategic orientation of the EDP Group. EDP has the objective of being the most competitive and efficient electricity and gas operator in the Iberian Peninsula.

Through the years, the policies sustained by EDP allowed to strengthen the solid position in the rankings of high international prestige, standing out the world leadership in the electrical sector on the Dow Jones Sustainability Index in 2011. Good practices being developed by EDP intend to be continued in the future and the Baixo Sabor will be an important foundation for the environment policies, biodiversity and climatic changes. [6]

In accordance to its energy policy targets, EDP has a goal of reducing 70% of CO2 specific emissions by 2020 in relation to 2008, by diversifying energy sources, namely by the increase of renewable generation CO2 emission-free like the Baixo Sabor plant. [6]

The BSHP consolidates the Portuguese hydroelectric domination by EDP. Through this strategic reserve of water in the high Douro, EDP has total control of the national Douro course, helping the regularization of streams and maximizing production in its dams downstream from Baixo Sabor. Not tendering this project would mean a direct dependence from the competition in the regularization of streams in the rest of the EDP cascade. It is also worth mentioning that this project replaces the Foz Côa dam, which was attributed to EDP.

This plant, being pumped-storage type, will complement the increase of renewable generation technology like wind power, currently in great expansion in Portugal.

The socially responsible attitudes being developed by EDP and its international recognition give credibility and trust from its shareholders and attract new investors, for a leading and thriving company. The Baixo Sabor meets the company strategy in various aspects and is appealing from the sustainability point of view.

V. CONCLUSIONS

The BSHP is a project of national interest that goes beyond electric energy generation, due to its location in the High Douro region and for its significant storage capacity. The pump-storage allows for a smaller dependence from natural flows for supply and generation.

An investment is only viable if the Weighted Average Cost of Capital (WACC) is lower than the Internal Rate of Return (IRR). According to the assumptions and estimates taken during the planning and calculation of payments/receipts, the calculated IRR value was 6.74%. As the BSHP project is currently in execution and assuming that the investors (banking institutions and shareholders) would only accept this investment if it was economically viable, it can be concluded
that the calculated IRR value is bigger than the classified WACC.

The EDP Group has understood that this investment constitutes an opportunity for the company, a reason that led the company structure to accept the challenge of its implementation. For the shareholders, besides the economic indicators, the potential business in a comprehensive view concluded that this is an attractive investment.

REFERENCES

[1] REN, Dados Técnicos do REN, 2010