Pumped Hydro Storage in the Iberian Electricity Market

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Pumped Hydro Storage
Baixo Sabor, March 2011

Source: EDP website
Background and Motivation

• EU’s 20-20-20 targets by 2020:
  – Reduce GHG emissions to 20% below 1990 levels
  – **Increase renewable energy consumption to 20%**
  – Increase energy efficiency by 20%

• Portugal has enacted its own targets for 2020
  – 31% total energy consumption from renewables
  – 60% electricity consumption from renewables
  – **Double hydro capacity (4500 MW in 2010 --> 9500 MW in 2020)**
    • 636 MW of new pumped hydro storage (PHS) capacity (60% increase)
636 MW New Pumped Hydro

<table>
<thead>
<tr>
<th>New Dam</th>
<th>Owner</th>
<th>Optimal power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baixo Sabor</td>
<td>EDP</td>
<td>170</td>
</tr>
<tr>
<td>Foz Tua</td>
<td>EDP</td>
<td>234</td>
</tr>
<tr>
<td>Alvito</td>
<td>EDP</td>
<td>48</td>
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<td>Gouvães</td>
<td>Iberdrola</td>
<td>112</td>
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<tr>
<td>Girabolhos</td>
<td>Endesa</td>
<td>72</td>
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</tbody>
</table>

- Three different companies bought rights to build storage
- Each of these companies has other generation assets
- Big enough to influence market price
Research Questions for Non-Price Taker Pumped Hydro Storage

1. How does new PHS affect consumers? Thermal generators? CO$_2$ emissions?
2. How do results change depending on the objectives of different stakeholders?
3. Is investment in pumped hydro storage (compared to conventional hydro) cost effective?
Pumped Hydro Storage Optimization Model

Objective Functions (Depend on who owns the storage: three scenarios)

- Maximize profit of electricity arbitrage
- Maximize profit of electricity arbitrage PLUS profit from thermal generators
- Maximize profit of electricity arbitrage MINUS consumer expenditure on electricity
Pumped Hydro Storage Optimization Model

Objective Functions (Depend on who owns the storage: three scenarios)

Maximize profit of electricity arbitrage

Maximize profit of electricity arbitrage PLUS profit from thermal generators

Maximize profit of electricity arbitrage MINUS consumer expenditure on electricity

Decision Variables:

- Storage level
- Power output and input
- Market price
- Thermal power output (for thermal-storage owner)
Pumped Hydro Storage Optimization Model

Objective Functions (Depend on who owns the storage: three scenarios)

Maximize profit of electricity arbitrage
Maximize profit of electricity arbitrage PLUS profit from thermal generators
Maximize profit of electricity arbitrage MINUS consumer expenditure on electricity

Decision Variables: Storage level, storage/thermal power output and input, market price

Subject to constraints:

Technical constraints of storage (power output, reservoir capacity)

Market demand and price relationship

[Graph showing the relationship between price (€ per MWh) and market volume (GWh)]
Arbitrage Profits: Degradation due to Crowded Market

Profit in Euros per MW capacity per day

- EDP
- Endesa
- Iberdrola

Legend:
- Individual firm
- All three firms
Consumer Expenditure and Storage Operations under Different Ownership Conditions

![Graph showing change in consumer expenditure and reservoir level over hours in winter case.](image)

- **Change in Consumer Expenditure**
  - Winter: Blue bar for PHS, red for PHS+thermals, yellow for PHS+consumer
  - Spring: Blue for PHS, red for PHS+thermals, yellow for PHS+consumer
  - Summer: Blue for PHS, red for PHS+thermals, yellow for PHS+consumer
  - Fall: Blue for PHS, red for PHS+thermals, yellow for PHS+consumer

- **Reservoir Level (hm³)**
  - Hours (Winter case): 1 to 289
  - Levels range from 1110 to 1160
Generator Profits and CO$_2$ Emissions under Different Ownership Conditions

- **Change in Thermal Generator Profits**
  - Winter: Positive increase
  - Spring: Small increase
  - Summer: Slight decrease
  - Fall: Slight decrease

- **Change in CO$_2$ Emissions**
  - Winter: Slight decrease
  - Spring: Increase
  - Summer: Slight increase
  - Fall: Increase
Annual arbitrage profits trend with market price spreads

Market Price Spread

Arbitrage profit
In California, larger price spreads mean higher profits.
Capital Costs of PHS €510-800/kW

- Arbitrage in Portugal does not create positive ROI, but prices in California likely will
Conclusions

• Pumped hydro can affect market prices if new capacity is big enough
  – Effects on consumers, thermal generators, and CO₂ emissions depend on ownership of storage
• New pumped hydro in Portugal will not recover its capital costs with arbitrage
  – But the same dams in another market could (CAISO)
• Other reasons for Portugal’s investment:
  – Integration of renewables and distributed generation
  – Energy independence
  – Ancillary services/grid reliability
Support

• Fellowship from the Portuguese Foundation for Science and Technology (Fundação para a Ciência e a Tecnologia)
• Grants from the Alfred P. Sloan Foundation and EPRI to the Carnegie Mellon Electricity Industry Center
• Doris Duke Charitable Foundation
• Department of Energy National Energy Technology Laboratory
• Heinz Endowments to the RenewElec program at Carnegie Mellon University
• US National Science Foundation
Questions?

![Graph showing profit in Euros per MW capacity per day for EDP, Endesa, and Iberdrola.]

- **EDP**
- **Endesa**
- **Iberdrola**

![Graph showing arbitrage profit over a two-week period.]

![Graph showing change in consumer expenditure by season.]

- **Winter**
- **Spring**
- **Summer**
- **Fall**

Legend:
- **PHS**
- **PHS+thermals**
- **PHS+consumer**
Backup Slides
Arbitrage Profits with Forecast vs. Perfect Information

![Graph showing Arbitrage Profits per MW storage per week with different seasons and price spreads.]

- **Winter**: Perfect Information = €1,800, Forecast = €800, Max Price Spread
- **Spring**: Perfect Information = €140, Forecast = €60, Max Price Spread
- **Summer**: Perfect Information = €20, Forecast = €20, Max Price Spread

Electricity price spread (Euros/MWh)
Objective Functions

Independent:
\[
\max \sum_{i=1}^{n} \left( \sum_{k=1}^{5} \frac{-p_i gh_{i,k} q_{i,k}^{up}}{1000 \eta_{k}^{up}} + \eta_{k}^{dn} p_i gh_{i,k} q_{i,k}^{dn} / 1000 \right)
\]

Thermal:
\[
\max \sum_{i=1}^{n} \left[ \left( \sum_{k=1}^{5} \frac{-p_i gh_{i,k} q_{i,k}^{up}}{1000 \eta_{k}^{up}} + \eta_{k}^{dn} p_i gh_{i,k} q_{i,k}^{dn} / 1000 \right) + \left( \sum_{j=1}^{j} \left( p_i - r_j \right) w_{i,j} \right) \right]
\]

Consumer:
\[
\min \sum_{i=1}^{n} \left[ p_i d_i + \sum_{k=1}^{5} \frac{p_i gh_{i,k} q_{i,k}^{up}}{1000 \eta_{k}^{up}} - \eta_{k}^{dn} p_i gh_{i,k} q_{i,k}^{dn} / 1000 \right]
\]