Valuation of the flexibility of power-to-gas facilities

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Agenda

- "Renewable Methane for Transportation and Mobility"
  (joint SNF project in collaboration with HSR Rapperswil and other groups):
  Study business cases, recommendations to policy makers
- Business case
- Value of the flexibility of a P2G plant
- Realization by trading on short-term power markets
- Investment analysis by real option approach
- Discussion
Power-to-gas as energy storage

- Conversation of electricity to gas (hydrogen, methane)
- Synthetic methane can be stored in natural gas grid
- Links power and gas sector
- Long-term energy storage
  (e.g., excess power from renewable generation in summer)

Steps:
- Electrolysis: $2 \text{H}_2\text{O} (+ \text{electricity}) \rightarrow 2\text{H}_2 + \text{O}_2$
- Methanation: $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$ (exothermic)

- $\text{CO}_2$ sources: Biogas plants, waste incinerators, sewage plants, industry
  (e.g., cement mills), air, …

- Overall efficiency $\approx 50$
- Economic feasibility?
Power-to-gas for mobility
Business case: Rough estimation

- Production of synthetic natural gas (SNG) is only profitable when power prices are sufficiently low.
- Assumption: SNG is sold at the price for biogas, what is the maximum electricity price such that the variable gross margin is positive?
- Assumptions (values assumed fix):
  - Gas price: 8 ct/kWh (biogas)
  - Variable operating costs without electricity: 1 ct/kWh
  - Variable grid fee + fees for ancillary services: 0.65 ct/kWh
  - Capacity price (fix): 41'000 CHF/MW
  - Renewable surcharge ("KEV"): 1.5 ct/kWh
  - Guarantee of origin: ≈ 0.5 EUR/MWh
  - 1 CHF ≈ 1 EUR
  - Efficiency 50%
Business case: Rough estimation

- Critical power price (only with variable grid fees):

\[ 80 \text{ EUR MWh} \times 0.5 - 16.5 \text{ EUR MWh} - 0.5 \text{ EUR MWh} \approx 23 \text{ EUR MWh} \]

- Critical power price (with variable grid fees and renewable surcharge):

\[ 80 \text{ EUR MWh} \times 0.5 - 16.5 \text{ EUR MWh} - 0.5 \text{ EUR MWh} - 15 \text{ EUR MWh} \approx 8 \text{ EUR MWh} \]
Average power prices Swissix (day-ahead)
Critical electricity price for SNG production

- To realize an average electricity price of 23 (8) EUR/MWh, one would accept prices up to 30 (13) EUR/MWh on the day-ahead market (profit contribution zero)
- The electrolysis could run approx. 2100 (130) hours per year
- Capital costs, fix grid fees, costs for gas distribution, taxes etc. are still not taken into account
- Conclusion: The electricity price at the day-ahead market (plus fees) is too high for a profitable production of SNG

- Under current market conditions, also pumped-storage hydropower plants can only be operated profitably by
  - provision of ancillary services and/or
  - participation in the intraday market
- Would short-term power trading also have an added value for a P2G plant?
Timeline power trading

Remarks:

- Offers for day-ahead auction submitted by 12 noon (D/A) or 11 a.m. (CH)
- Continuous trading at the intraday market starts at 3 p.m. for hourly products
- Since July 2015 time between gate closure and start of delivery 30 min (D)
- Cross border trading D, A, CH and F possible (implicit allocation of capacity remaining after daily, monthly and annual auctions)
Intraday market: Price variation hourly products
Optionality of P2G plant

- Price fluctuations on the intraday (ID) market are significant, therefore prices can be more favorable than on the day-ahead (DA) market
- The P2G plant is a flexible consumer
- Does this flexibility have a value?
- Earnings profile of P2G plant:

  - The earnings profile corresponds to the payoff of a put option
  - Therefore, we can "price" the flexibility analogously to a financial option
Example: Value of flexibility in Black/Scholes world

- Assume for simplicity that the "flexibility" corresponds to a European option (in fact there are early exercise opportunities as well)
- Option value can be calculated with Black/Scholes
- Example for one hour use:
  - Capacity (electric input): 1 MW
  - Strike = trigger price: 23 EUR/MWh
  - Volatility 100% or 200% (typical values, depending on delivery hour)
  - Time to expiration: $T = 1$, interest rate 0% (can be ignored)
  - Current power price (day-ahead market): $S_0 = 40$ EUR/MWh
  - Option value according to BS for volatility 100%: $P = 5.17$ EUR
  - Option value according to BS for volatility 200%: $P = 13.57$ EUR
- Observe that power is too expensive on the DA market, so we would not buy at this price for production (intrinsic value = 0)
- The flexibility option is not traded, so how can the option value be realized?
Trading strategy: Delta hedging (1)

- In the BS world, the value of an option can be realized by replication
- Here we "replicate" the option by buying or selling electricity on the ID market
- The current position must equal the $\Delta \ (= \frac{\partial P}{\partial S})$ of the option (delta hedging)
- Example for 100% vola: At gate closure power price is below trigger (case 1)

<table>
<thead>
<tr>
<th>remining time [h]</th>
<th>power price</th>
<th>$\Delta$</th>
<th>transaction</th>
<th>cash flows</th>
<th>cash flows (cumulated)</th>
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<tr>
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<td>1.00</td>
<td>0.41</td>
<td>-4.55</td>
<td>-16.19</td>
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</table>

- At the end, 1 MWh SNG is generated
- Profit: 23 EUR (trigger) – 16.19 EUR (power trading) = 6.81 EUR
Trading strategy: Delta hedging (2)

- In the BS world, the value of an option can be realized by replication
- Here we "replicate" the option by buying or selling electricity on the ID market
- The current position must equal the $\Delta = \frac{\partial P}{\partial S}$ of the option (delta hedging)
- Example for 100% vola: At gate closure power price is above trigger (case 2)

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<tr>
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<tr>
<td>0</td>
<td>26.39</td>
<td>0.00</td>
<td>-0.75</td>
<td>19.74</td>
<td>6.11</td>
</tr>
</tbody>
</table>

- All power has been sold by the time of the gate closure, no SNG is generated
- Profit: 6.11 EUR
Practical application

- Note: In both cases – with or without generation – profits (6.81 vs. 6.11 EUR) are close to the theoretical option value (5.17 EUR)
- This results from option replication by trading the underlying (power)

- Application to Swissix prices 2014 & 2015 (strike = 23 EUR/MWh)
- Empirically estimated ID volatilities and a hypothetical value were used (100%)
- The resulting "option values" correspond to the cumulated profit contribution over 2 years:

<table>
<thead>
<tr>
<th>Volatility</th>
<th>empirical</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum option values over 2 years (EUR):</td>
<td>232414.10</td>
<td>104885.64</td>
</tr>
<tr>
<td>Average option value (EUR):</td>
<td>13.24</td>
<td>5.99</td>
</tr>
<tr>
<td>Percentage exercise (production):</td>
<td>88.4%</td>
<td>74.7%</td>
</tr>
<tr>
<td>#production hours p.a.:</td>
<td>7740</td>
<td>6547</td>
</tr>
<tr>
<td>Percentage power purchase day ahead:</td>
<td>10.8%</td>
<td>18.8%</td>
</tr>
</tbody>
</table>
Application of delta hedging 2014 & 2015

prices vs. purchased percentage on day-ahead market

- price DA (EUR/MWh)
- purchased percentage

- price day-ahead market
- purchased percentage on day-ahead market

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Real option analysis

- What is "value" of an investment in a P2G plant?
- Application of real option analysis (approach as in Bakke et al., CMS, 2016)
- Model components overview:

- Price model day-ahead: $m$ scenarios
- Price model intraday: scenarios for profits per hour
- Aggregation: $m$ scenarios yearly earnings
- Investment costs model: $m$ scenarios
- Valuation as real option:
  - Project value
  - Timing
Model components

- Model for day-ahead market prices (similar to Paraschiv et al., 2015):
  - Markov regime switching model
  - Prices may jump to extremely high or low values for some hours and return then to their original level
  - Separation into deterministic and stochastic component with different intra-day seasonality and distribution parameters in summer vs. winter

- Model for intraday market prices:
  - In following examples still Black/Scholes assumptions (GBM), pricing as American option with binomial method
  - Investigation of appropriate price models ongoing

- Investment costs model (following page)

- Not (yet) stochastic: Gas price, exchange rates, fees, …
Model for investment costs

- Highly critical for resulting option values and timing decision (probability of investment)
- Wide range of assumptions in literature (over-optimistic?)
- Current price $\approx 2$ Mio. EUR/MW$_{el}$ (electrolysis + methanation + auxiliary units)
- CO$_2$ from biogas plant
- Expert opinion: Number of P2G plants likely to triple within 10 years
- Schoots et al. (2008): Investment costs for electrolyzers $C_t$ at time $t$ depend on installed capacity $P_t$:

$$C_t = C_0 \left( \frac{P_t}{P_0} \right)^{-\alpha}$$

where $\alpha$ is the "learning index", which is related to the learning rate by

$$lr = 1 - 2^{-\alpha}$$

- The literature reports values $lr \approx 0.2$, which implies $\alpha \approx 0.32$ so that

$$\frac{C_t}{C_0} \approx 3^{-0.32} = 0.7$$
Calculation of option value

- We assume a geometric Brownian motion for the growth of installed plants with parameters $\mu = 0.1$, $\sigma = 0.1$ in the first 10 years.
- After 10 years, the drift parameter decreases linearly to 0 over 20 years.

- Lifetime of option: $T = 30$ years
- Lifetime of plant: 30 years
- Yearly average power price: 38 EUR/MWh (constant over complete horizon)
- Gas price and other parameters constant
- Yearly decision on realization of project
- Calculation of real option value (see Bakke et al., 2016):
  \[ ROV = \max_{\tau \in [0,T]} \left( E_{\tau} \left[ e^{-r\tau} (F(\tau) - I(\tau)) \right], 0 \right) \]
  where $F(\tau)$ is the annual profit flow from the P2G plant
- Numerical valuation of real option with Longstaff/Schwartz (50'000 paths)
Probabilities of investment (w/o grid usage)
Probabilities of investment (with capacity price)
Probabilities of investment (with grid fees + KEV)
Preliminary results: Option values
First implications for assessment of P2G

- Profitability depends highly on legislation (exclusion from grid fees and/or renewable surcharge "KEV")
- Alternative business cases: Power generated by "must run" plants like run-of-river plants, waste incinerators etc. to
  - avoid grid fees
  - generate "green" electricity
- Potentially positive business case for car manufacturer (importer) to avoid penalties for exceeding CO2 emission limit (95 g/km)
  - The Swiss parliament has recently decided that renewable methane qualifies as "CO2-free" fuel
Discussion

- **Ongoing extensions:**
  - Realistic intraday price models
  - Limitations of market liquidity, transmission capacity D/CH
  - Stochastic gas price
  - Other cost/profit factors
  - More realistic values of relevant parameters

- **Open issues:**
  - Long-term evolution of spot market prices
  - Impact of renewable energies on price formation (seasonality shape, …)
  - Provision of ancillary services

- Results may still change, too early for final assessment of P2G investment
- Concept may also be applied to other energy storages (pumped-storage hydropower, batteries), possibly with reduced modelling uncertainties