Valuation of the flexibility of power-to-gas facilities

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Agenda

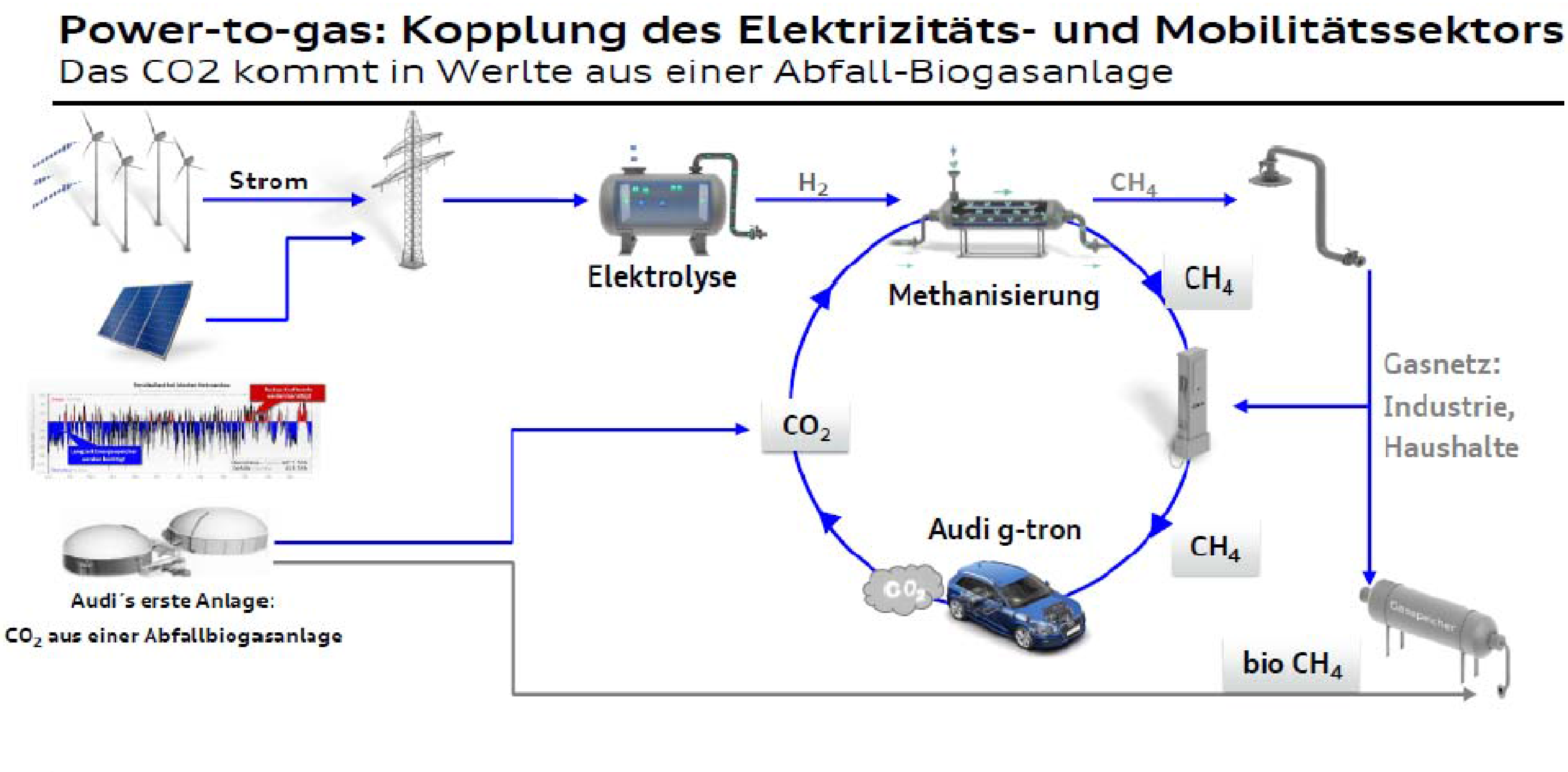
- "Renewable Methane for Transportation and Mobility"
  (joint SNF project in collaboration with HSR Rapperswil and other groups):
  Study business cases, recommendations to policy makers
- Business case
- Value of the flexibility of a P2G plant
- Realization by trading on short-term power markets
- 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: $2H_2O$ (+ electricity) $\rightarrow 2H_2 + O_2$
  - Methanation: $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$ (exothermic)
- 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

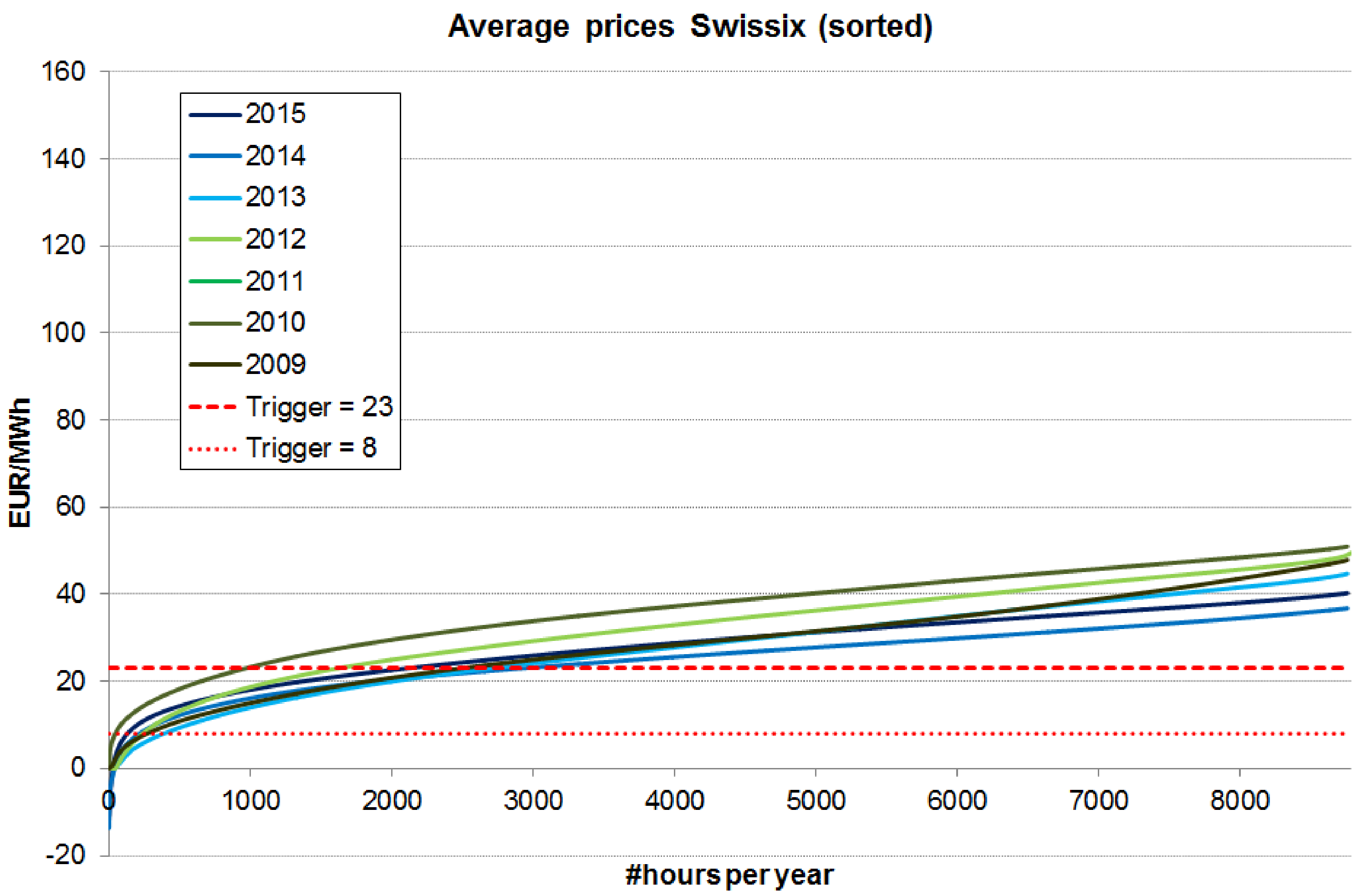
- Critical power price (only with variable grid fees):

$$\underbrace{80\,\frac{\text{EUR}}{\text{MWh}}}_{\text{gas price}} \times \underbrace{0.5}_{\text{efficiency}} - \underbrace{16.5\,\frac{\text{EUR}}{\text{MWh}}}_{\text{op. costs, fees}} - \underbrace{0.5\,\frac{\text{EUR}}{\text{MWh}}}_{\text{GoO}} \approx 23\,\frac{\text{EUR}}{\text{MWh}}$$

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

$$\underbrace{80\,\frac{\text{EUR}}{\text{MWh}}}_{\text{gas price}} \times \underbrace{0.5}_{\text{efficiency}} - \underbrace{16.5\,\frac{\text{EUR}}{\text{MWh}}}_{\text{op. costs, fees}} - \underbrace{0.5\,\frac{\text{EUR}}{\text{MWh}}}_{\text{GoO}} - \underbrace{15\,\frac{\text{EUR}}{\text{MWh}}}_{\text{KEV}} \approx 8\,\frac{\text{EUR}}{\text{MWh}}$$

Average power prices Swissix (day-ahead)

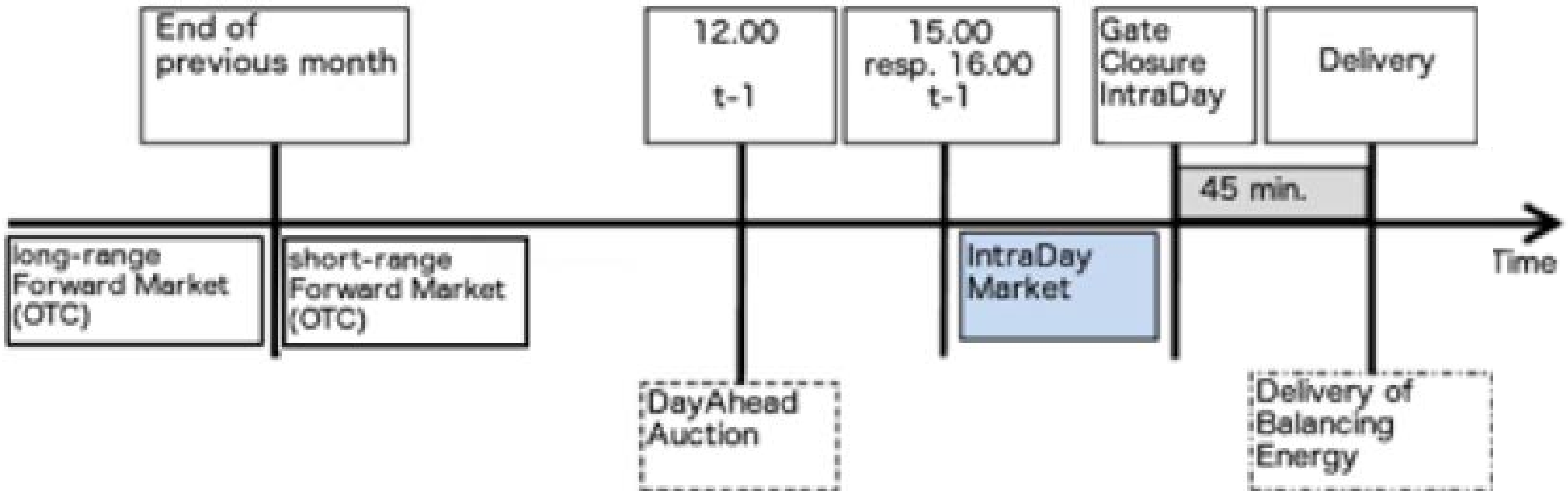


Critical electricity price for SNG production

- 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

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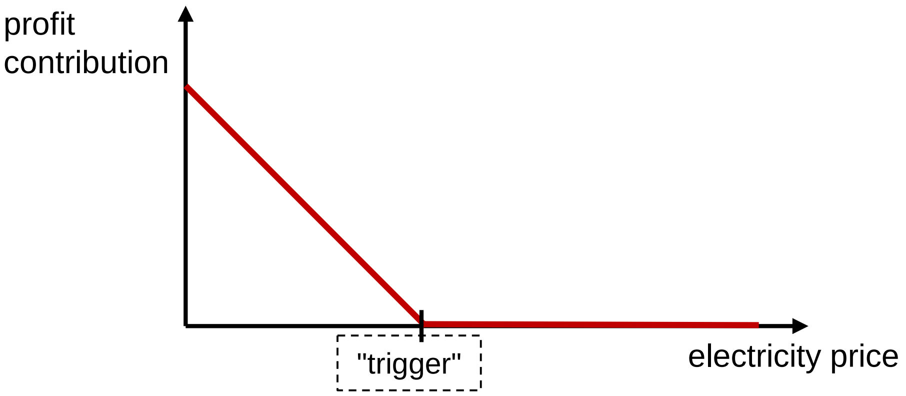
Optionality of P2G plant

- 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 Δ (= $\partial P / \partial S$) of the option (delta hedging)
- Example for 100% vola: At gate closure power price is below trigger (case 1)

remining time [h]	*power price*	*Δ*	*transaction*	*cash flows*	*cash flows (cumulated)*
24	40.00	0.15	0.15	-5.84	-5.84
21	26.47	0.27	0.12	-3.24	-9.08
18	31.11	0.22	-0.05	1.59	-7.49
15	47.02	0.10	-0.12	5.66	-1.83
12	51.63	0.07	-0.03	1.53	-0.30
9	52.11	0.05	-0.02	0.88	0.58
6	48.29	0.04	-0.01	0.43	1.01
4	24.93	0.34	0.30	-7.54	-6.54
2	20.64	0.59	0.25	-5.10	-11.64
0	11.13	1.00	0.41	-4.55	-16.19

- 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 Δ (= $\partial P / \partial S$) of the option (delta hedging)
- Example for 100% vola: At gate closure power price is above trigger (case 2)

remining time [h]	*power price*	*Δ*	*transaction*	*cash flows*	*cash flows (cumulated)*
24	40.00	0.15	0.15	-5.84	-5.84
21	25.91	0.28	0.13	-3.36	-9.21
18	29.36	0.24	-0.04	1.13	-8.07
15	39.55	0.14	-0.10	3.85	-4.22
12	61.31	0.04	-0.10	6.07	1.85
9	59.92	0.03	-0.01	0.61	2.46
6	35.57	0.13	0.10	-3.56	-1.11
4	26.75	0.28	0.15	-4.07	-5.17
2	18.19	0.75	0.47	-8.46	-13.63
0	26.39	0.00	-0.75	19.74	6.11

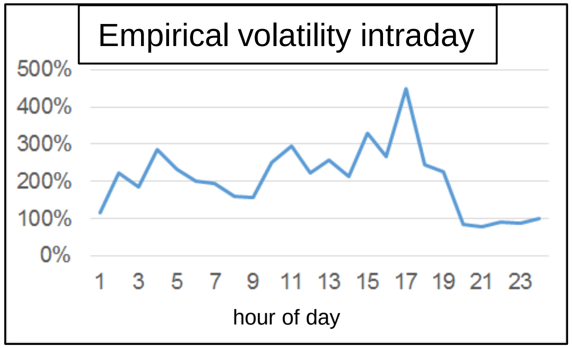
- All power has been sold by the time of the gate closure, no SNG is generated
- Profit: 6.11 EUR

Practical application

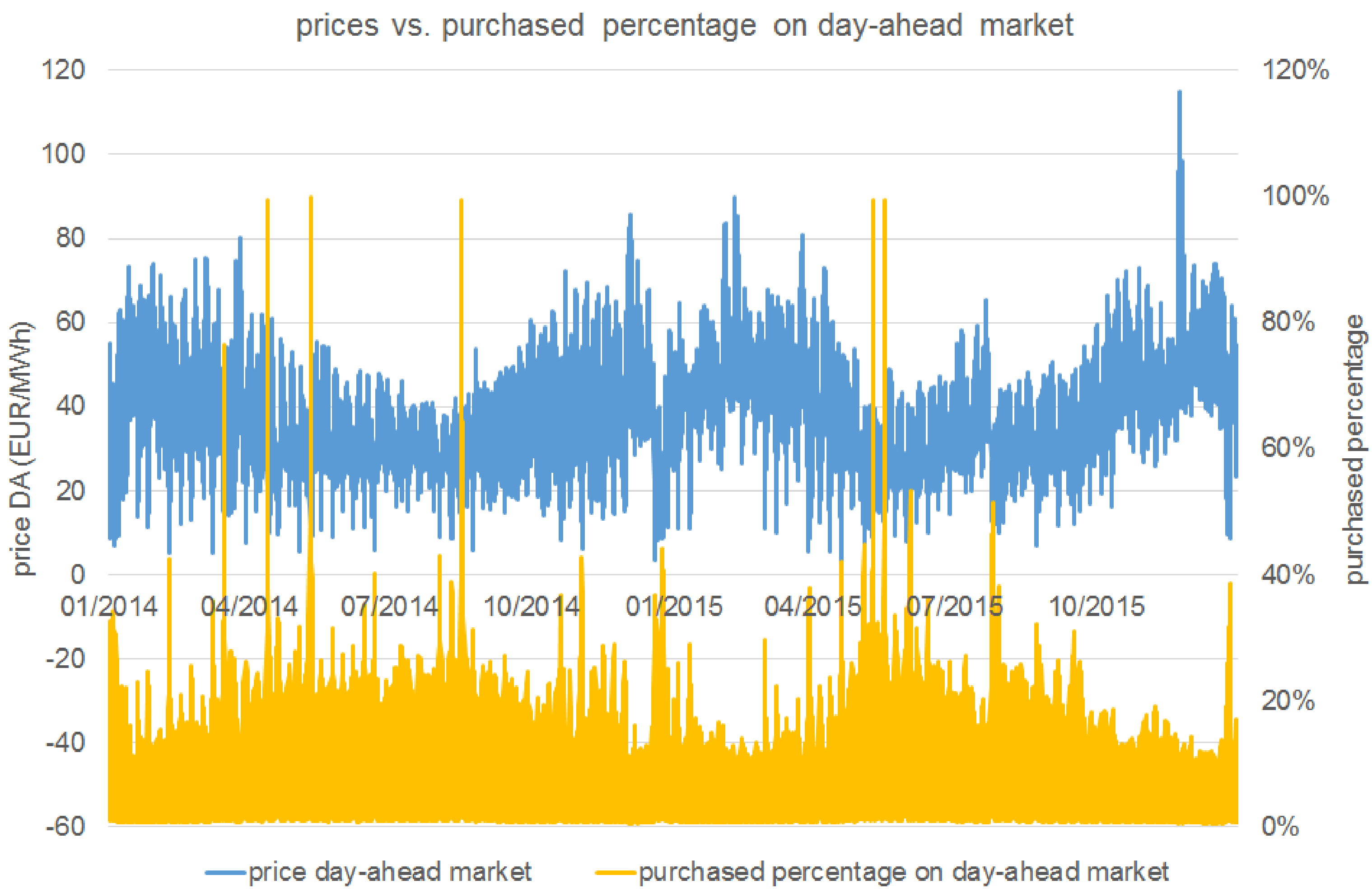
- Note: In both cases – with or without generation – profits (6.81 vs. 6.11 EUR) are close to the theoretical option value (5.17 EUR)
- This results from option replication by trading the underlying (power)

- 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:

Volatility	empirical	100%
Sum option values over 2 years (EUR):	232'014.10	104'885.64
Average option value (EUR):	13.24	5.99
Percentage exercise (production):	88.4%	74.7%
#production hours p.a.:	7740	6547
Percentage power purchase day ahead:	10.8%	18.8%

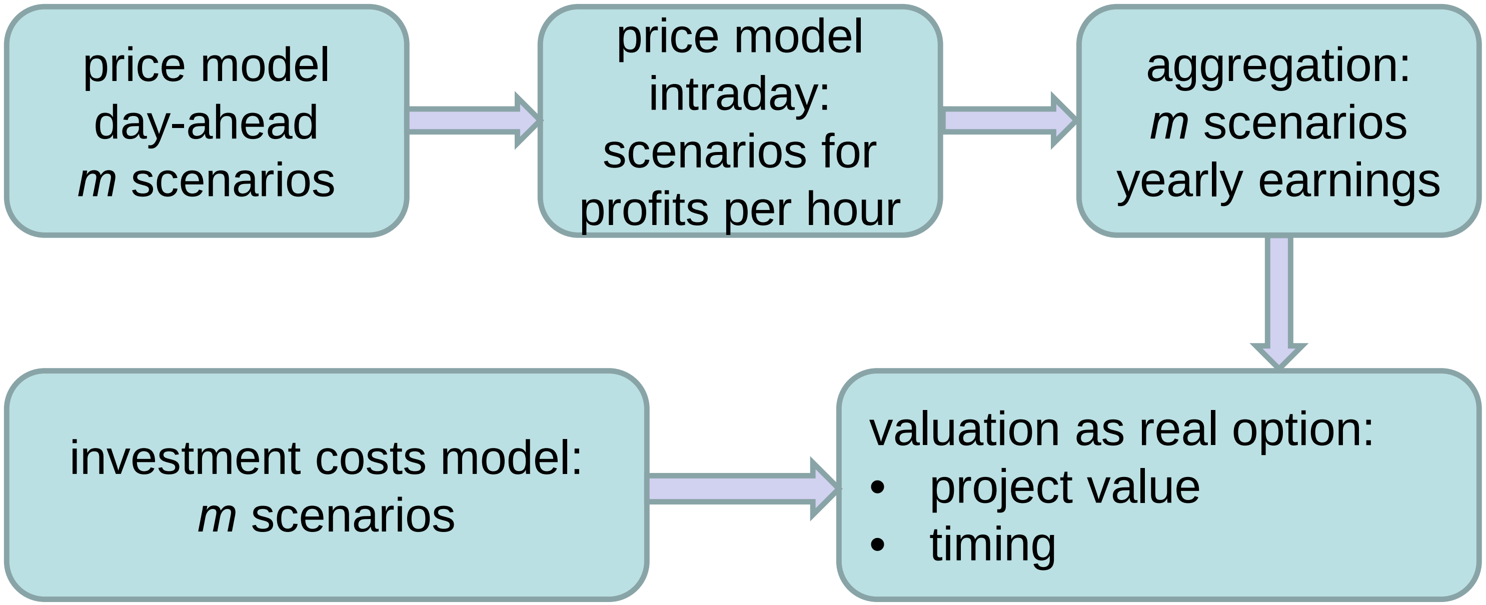


Application of delta hedging 2014 & 2015



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:



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 ≈ 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:

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

where α 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

$$C_t / C_0 \approx 3^{-0.32} = 0.7$$

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

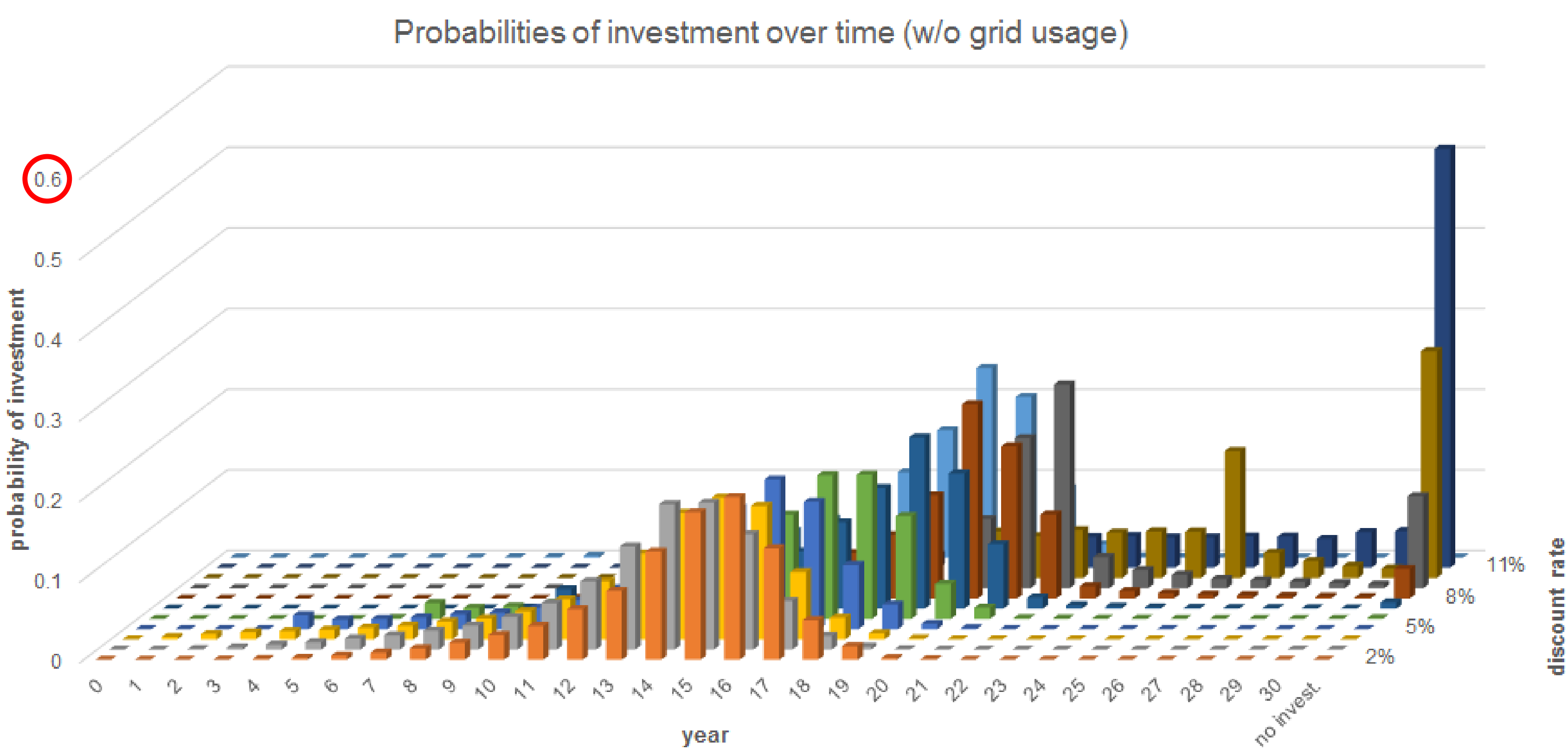
- Lifetime of option: T = 30 years
- Lifetime of plant: 30 years
- Yearly average power price: 38 EUR/MWh (constant over complete horizon)
- Gas price and other parameters constant
- Yearly decision on realization of project
- Calculation of real option value (see Bakke et al., 2016):

$$ROV = \max_{\tau \in [0,T]} \left(\mathrm{E}_\tau \left[e^{-r\tau} (F(\tau) - I(\tau)) \right], 0 \right)$$

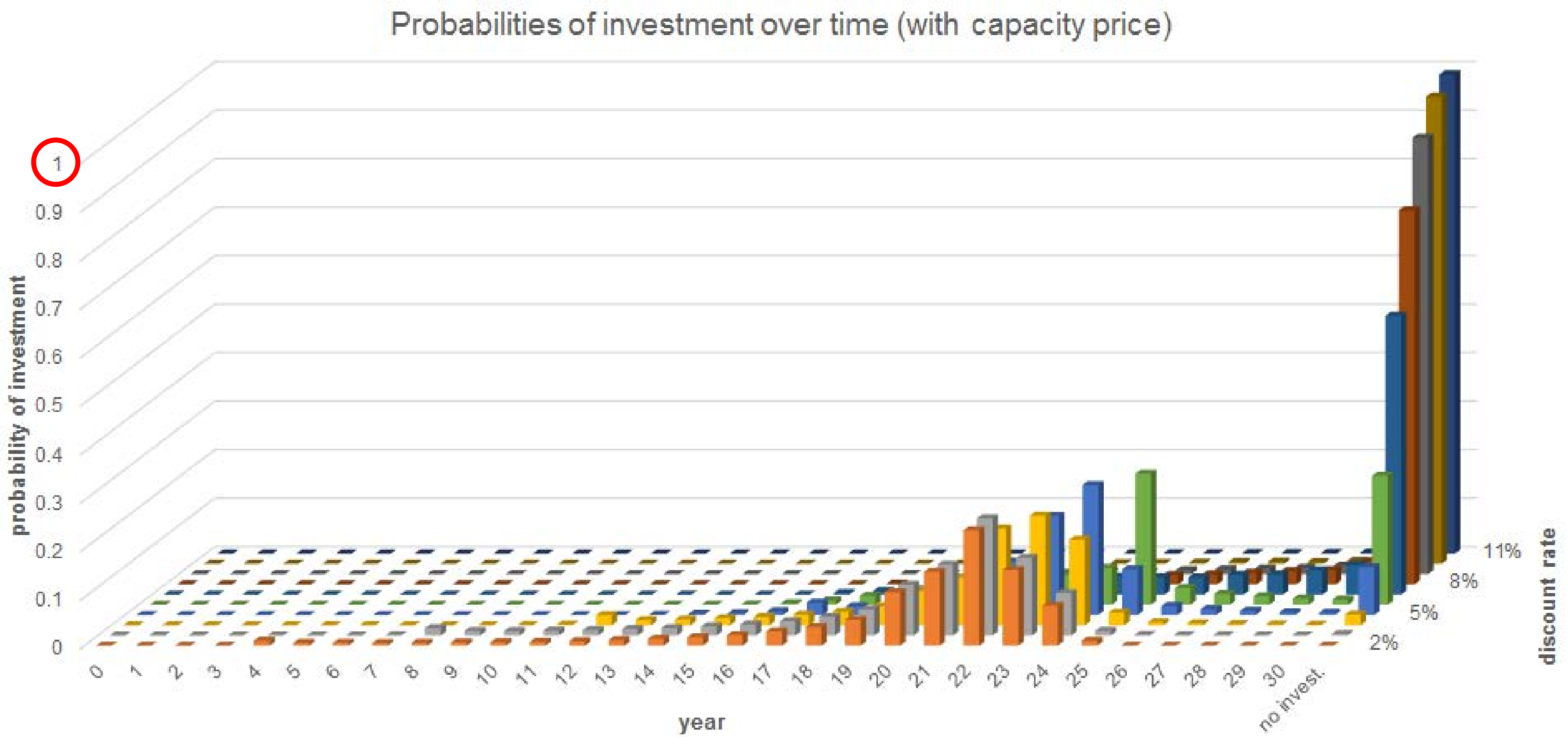
  where $F(\tau)$ is the annual profit flow from the P2G plant

- Numerical valuation of real option with Longstaff/Schwartz (50'000 paths)

Probabilities of investment (w/o grid usage)



Probabilities of investment (with capacity price)



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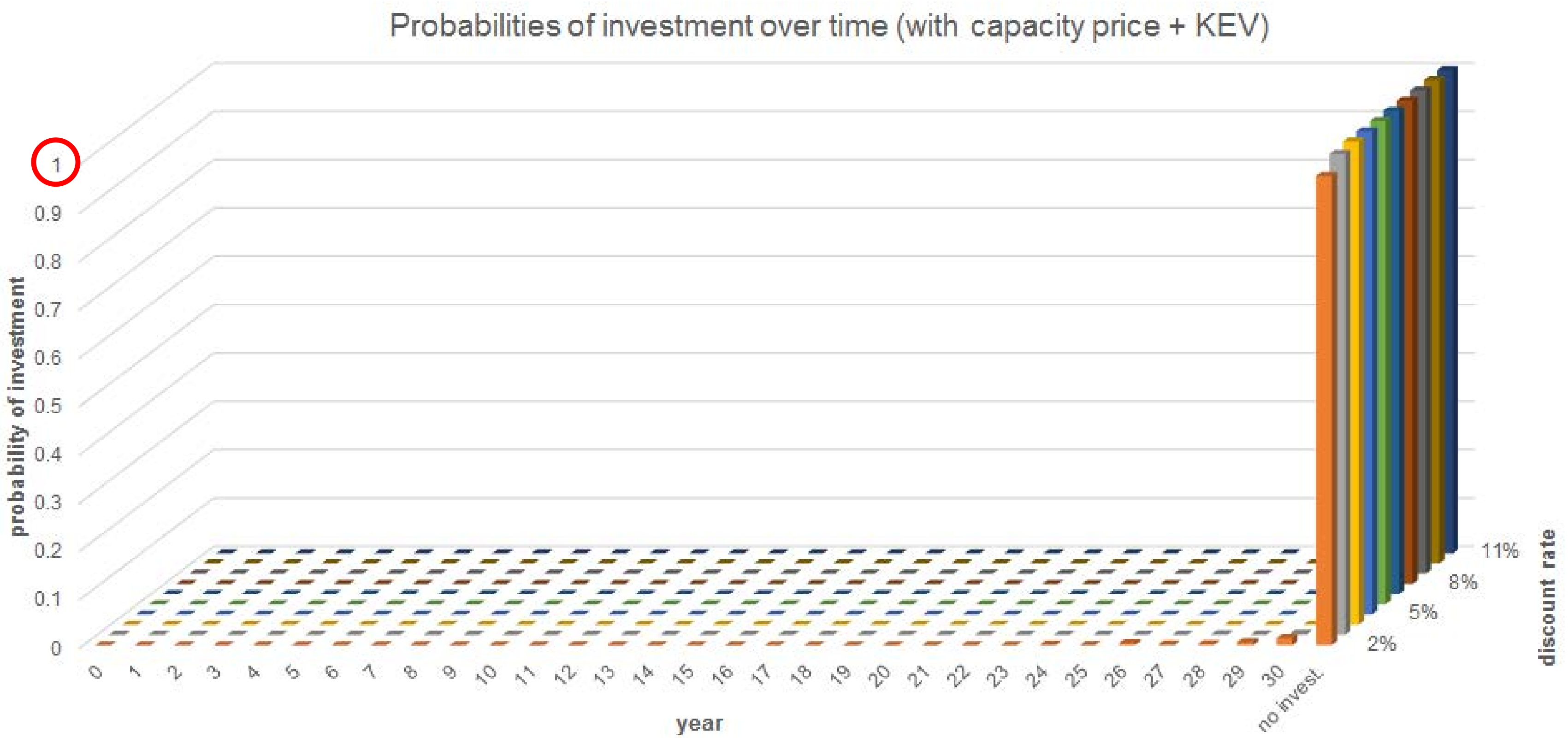
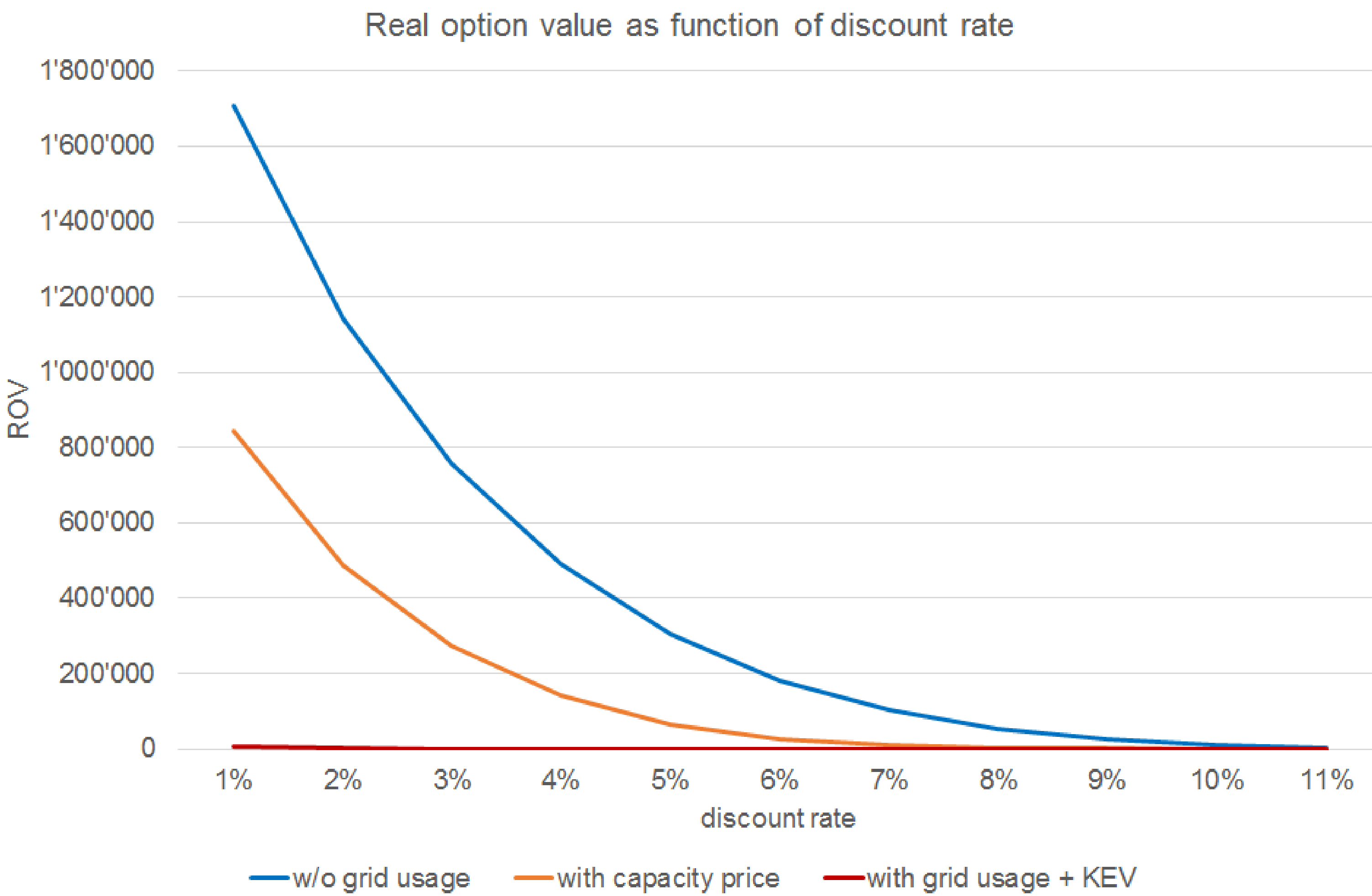
Probabilities of investment (with grid fees + KEV)



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