Institute for Future Energy Consumer Needs and Behavior

Flexible Elektrische Netze

E.ON Energy Research Center

Modelling the Economic Viability of Grid Expansion, Energy Storage, and Demand Side Management Using Real Options and Welfare Analysis

Henning Krings and Reinhard Madlener

Institute for Future Energy Consumer Needs and Behavior (FCN)
School of Business and Economics / E.ON ERC
RWTH Aachen University,
Aachen, Germany

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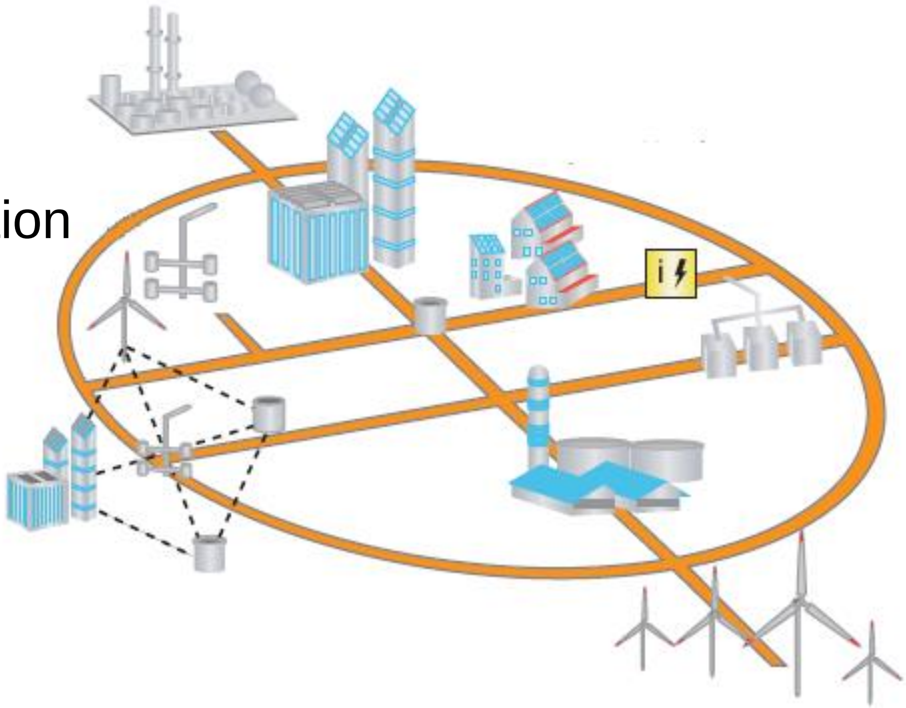
Structure of the presentation

1. Fundamentals
2. Market characteristics & Motivation
3. Model specifics
4. Simulation results
5. Conclusion & Summary



Source: elektroniknet.de

1. Fundamentals – Cost benefit analysis

Cost benefit analysis uses a one-dimensional decision variable

$$NPV = \sum_{t=0}^{T} \frac{E(B_t) - E(C_t)}{(1+r)^t}$$

NPV: Discounted difference between the present values of its benefits and costs

where:

r : Market-specific discount rate

B_t : Benefits in time period *t*

C_t : Costs in time period *t*

T: Lifetime of the asset

1. Fundamentals – Real options analysis

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Managerial flexibility is represented by the adjusted present value:

$$APV = NPV(Investment) + Option\ Value$$

The option type used here is the call option which is computed using the Black-Scholes formula

$$\begin{aligned}&\text{Value of call option} := Call(P, t, r_{\mathrm{f}}, \sigma, EX)\\&= [delta * share\ price] - [bank\ loan]\\&= [N(d_1) * P] - [N(d_2) * PV(EX)]\end{aligned}$$

where:

$$d_2 = d_1 - \sigma\sqrt{t}$$

$$d_1 = \frac{\ln[P/PV(EX)]}{\sigma\sqrt{t}} + \frac{\sigma\sqrt{t}}{2}$$

P : Current price of stock
t : Number of periods till maturity
r_{f} : Risk free interest rate
σ : Standard deviation per period
EX : Exercise price

2. Market characteristics & Motivation

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Source: dena.de

- Increase in renewable electricity production (25% in 2014 → 80% in 2050)
- Higher variability of production

→ Reduced grid stability

- Merit order system and priority dispatch penalize conventionals

→ Reduced electricity production by conventional power plants

→ Reduced supply security

Source: brd.nrw.de

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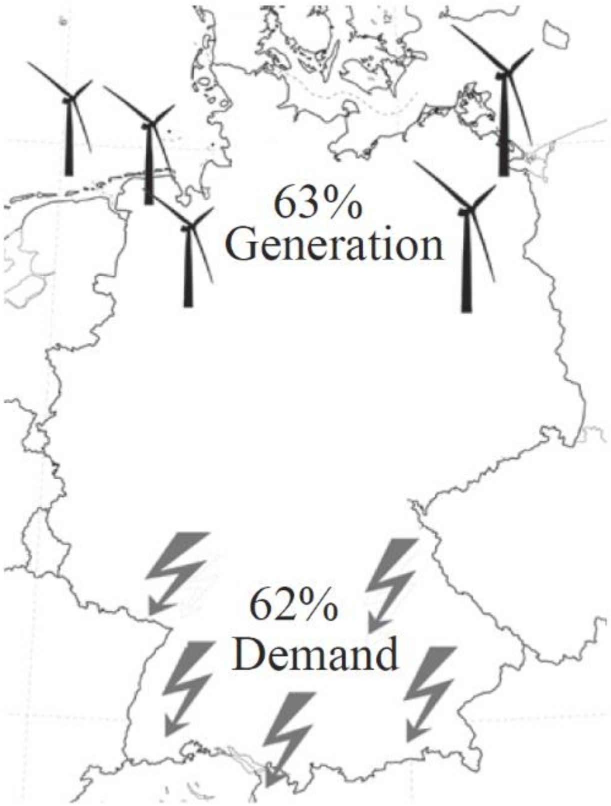
2. Market characteristics & Motivation



Source: Schröder et al. (2012)

- Local clustering of renewable production in northern Germany
- High electricity demand in southern Germany
- Shut-down of conventional power plants mainly in southern Germany

→ High locational disparity of supply and demand

3. Model specification: General characteristics

- The model consists of three parts
- One part for each respective investment opportunity (Grid, Storage, DSM)
- The resulting option values and NPVs are computed and then compared
- Stochastic processes are modeled using a geometric Brownian motion (GBM)

with Ito's lemma: $p_t = p_0 \cdot e^{\left(\left(\alpha - \frac{\sigma^2}{2}\right)t + \sigma\sqrt{t}z\right)}$

3. Model specification: Fundamental real model equations

$$V_{j,t} = \max\left[PV_{j,t} - I_j + \text{Variable } j, Q_{j,t}\right]$$

$V_{j,t}$: Option value at time *t*

$$Q_{j,t} = \frac{E\left[V_{j,t+1}\right]}{1 + r_j}$$

$Q_{j,t}$: Expected discounted option Value at time *t*+1

$$Q_{j,T} = 0$$

$Q_{j,T}$: Value of waiting at the expiration date of the option

$$PV_{j,t} = \sum_{\tau=t+T_{C,j}}^{t+T_{C,j}+L_j} \frac{(R_{j,\tau} - C_{j,\tau})}{(1 + r_j)^{\tau-t}}$$

$PV_{j,t}$: Present value of the investment consisting of the sum of (discounted) revenues and costs

3. Model specification: Real options model specifics, components

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Variable	Grid expansion	Energy storage	DSM
Variable *j*	$-C_{\mathrm{Prep,Grid}}$	$\mathrm{Call}_{\mathrm{ESS,i+1,t}}$	0
Modularity	No	j $= ESS, i$ for $i = 1, \dots, n$ & $\mathrm{Call}_{\mathrm{ESS},i+1,t}$	No
Lumpiness	$I_{\mathrm{Grid}} = Lump_{\mathrm{Grid}} \cdot I_{\mathrm{Grid,km}}$	No	No
Discount factor	r_{f}	r_{ESS}	r_{DSM}
Learning-by-using	No	No	Simple model

- Grid expansion: Additional investment costs, changed discount factor
- Energy storage: Modularity
- DSM: Learning-by-using, large number of stochastic variables

3. Model specification: Real options model specifics, Grid expansion

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Grid expansion model equations

$$V_{Grid,t} = \max\left[PV_{Grid,t} - I_{Grid} - C_{Prep,Grid}, Q_{Grid,t}\right]$$

$$Q_{Grid,t} = \frac{E\left[V_{Grid,t+1}\right]}{1 + r_{Grid}} \qquad Q_{Grid,T} = 0$$

$$PV_{Grid,t} = \sum_{\tau=t+T_{C,Grid}}^{t+T_{C,Grid}+L_{Grid}} \frac{p_{Grid,\tau} \cdot U_{Grid,\tau} - OC_{Grid,\tau}}{(1 + r_f)^{\tau-t}}$$

3. Model specification: Real options specifics, DSM

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Demand side management model equations

$$V_{DSM,t} = \max\left[PV_{DSM,t} - I_{DSM}, Q_{DSM,t}\right]$$

$$Q_{DSM,t} = \frac{E\left[V_{DSM,t+1}\right]}{1 + r_{DSM}} \qquad Q_{DSM,T} = 0$$

$$PV_{DSM,t} = \sum_{\tau=t+T_{C,DSM}}^{t+T_{C,DSM}+L_{DSM}} \frac{LBU_{\tau} \cdot (R_{DSM.\tau} - C_{DSM,\tau})}{(1 + r_{DSM})^{\tau-t}}$$

3. Model specification: Real options specifics, Energy storage

Energy storage model equations

$$V_{ESS,i,t} = \max\left[PV_{ESS,i,t} - I_{ESS,i} + Call_{ESS,i+1,t}, Q_{ESS,i,t}\right]$$

$$Q_{ESS,i,t} = \frac{E\left[V_{ESS,i,t+1}\right]}{1 + r_{ESS}} \qquad Q_{ESS,i,T-(n-i)t} = 0$$

$$PV_{ESS,i,t} = \sum_{\tau=t+T_{C,ESS,i}}^{t+T_{C,ESS,i}+L_{ESS}} \frac{(R_{ESS,i.\tau} - C_{ESS,i,\tau})}{(1 + r_{ESS})^{\tau-t}}$$

3. Model specification: Parameterization

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Parameter	Value	Parameter	Value
r_f	0.015	U_{High}	60,000 MWh/Month
i	0.015	RI	57,500,000
β	0.779	$\eta_{HF} = \eta_{LF}$	0.33
r_m	0.05	η_{ESS}	0.7
$r_{Grid} = r_{DSM} = r_{ESS}$	0.039	OC_{High}	€ 4,750
$p_{HF,0}$	27.007 €/MWh	OC_{Low}	€ 5,650
$p_{LF,0}$	9.232 €/MWh	SK_{High}	€ 2,200
$p_{Grid,0}$	17.9 €/MWh	SK_{Low}	€ 7,750
$p_{E,High,0}$	55 €/MWh		
$\Delta p_{E,0}$	25 €/MWh	$L_{Grid} = L_{DSM} = L_{ESS}$	15 years
$\alpha_{P,Grid}$	0.011/year	$Lump_{Grid}$	100
α_{Grid}	0/year	OC_{Grid}	€ 5,000
α_{PE}	0.067/year	$C_{Prep,Grid}$	€ 100,000
α_{HF}	0.059/year	$I_{Grid,km}$	7924.53 €/km
α_{LF}	0.022/year	$T_{C,Grid}$	4 years
α_{Δ}	0.020		
σ_{Grid}	0.172	OC_{DSM}	€ 1,000
σ_{PE}	0.120	I_{DSM}	€ 8,000,000
σ_{HF}	0.540	$T_{C,DSM}$	1 year
σ_{LF}	0.405		
σ_{Δ}	0.496	OC_{ESS}	€ 5,500
σ_{ESS}	0.355	$I_{ESS,i}$	€ 33.9 million
$\bar{U}_{Grid}$	6,000 MWh/Day	$T_{C,ESS,1}$	2 years
U_{Low}	60,000 MWh/Month	$T_{C,ESS,i>1}$	0.5 years

Sources: Frontier Economics (2010), European Energy Exchange AG (2014), BAFA (2014), Swider (2007); own compilation.

3. Model specification: Parameter sources

- The Parameters and numbers for computation are typical values found in (Swider, 2007) or real values provides by official institutions (See www.bundesregierung.de)
- Linear growth factors and standard deviations are computed using historical values
- The beta factor of RWE is taken for parameterizing the CAPM
  - Good representation of this industry branch

3. Model specification: Fundamental cost benefit model equations

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$$B_{j,t} = NPV_{Inv,j,t} + NPV_{Non-Inv,j,t}$$

$B_{j,t}$: Overall benefit for the investor and non-investor group

$$NPV_{Inv,j,t} = \sum_{\tau=t+T_{C,j}}^{t+T_{C,j}+L_j} \frac{(R_{j,\tau} - C_{j,\tau})}{(1 + r_{ESS})^{\tau-t}} - I_j$$

$NPV_{Investor,j,t}$: NPV of the investor group consisting of discounted cash flows minus investment costs

$$SSE_j = RI \cdot SSEF_j$$

SSE_j : Supply security factor

RI : Cost of alternative (replacement) investment (CHP plant)

$SSEF_j$: Investment-specific supply security factor

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3. Model specification: Cost benefit model, specifics

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Variable	Grid expansion	Energy storage	DSM
$NPV_{Non-Inv,j,t}$	SSE_{Grid}	SSE_{ESS}	$\sum_{\tau=t+T_{C,DSM}}^{t+T_{C,DSM}+L_{DSM}} \frac{LBU_{\tau} \cdot (\Delta p_{E.\tau} \cdot U_{Low})}{(1+r_{DSM})^{\tau-t}} + SSE_{DSM}$
$SSEF_j$	6.0	0.75	0.5

- Grid expansion: Supply security factor is significantly higher than in the energy storage and DSM cases
- Energy storage: No modularity for the cost benefit model
- DSM: Supply security impact low by comparison, Non-investor group benefits from lower electricity prices

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3. Model specification: Supply security factors

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- The supply security factors are different for each investment opportunity
  - Different technologies have a different impact on supply security
  - The investment is compared to an alternative (replacement) investment (RI) that provides the same amount electricity at a specified location
- Grid expansion: SSEF of 6
  - Has a considerably higher capacity than what the RI could provide
  - Connects two areas of potential supply and demand
  - Hence has a high SSEF
- Energy storage systems: SSEF of 0.75
  - Can store energy but also needs to have energy stored to supply
  - Supply and demand can be offset temporarily
  - Hence lower than 1 but still high
- Demand side management: SSEF of 0.5
  - Demand has to be managed short-term
  - Not always available
  - Lower availability than ESS hence lower SSEF

4. Results – Real options analysis

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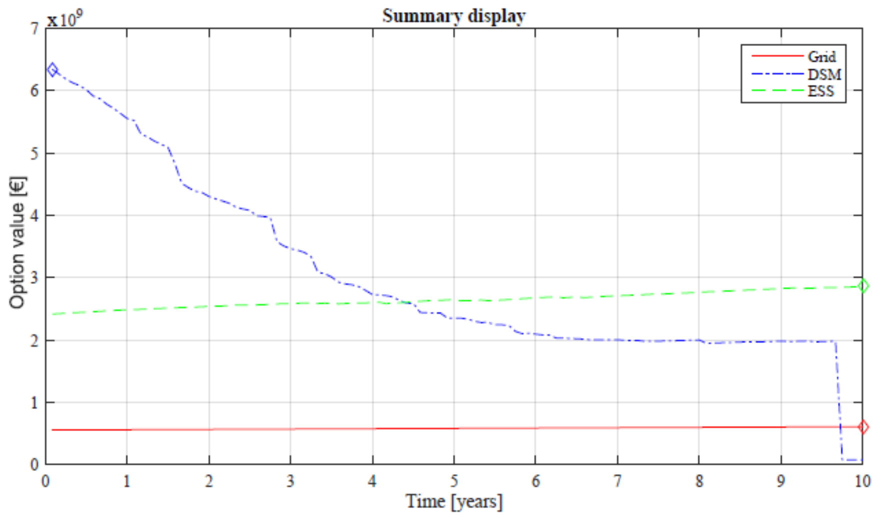

Figure 4.6: Summary display of the real options analysis for a finite time horizon.

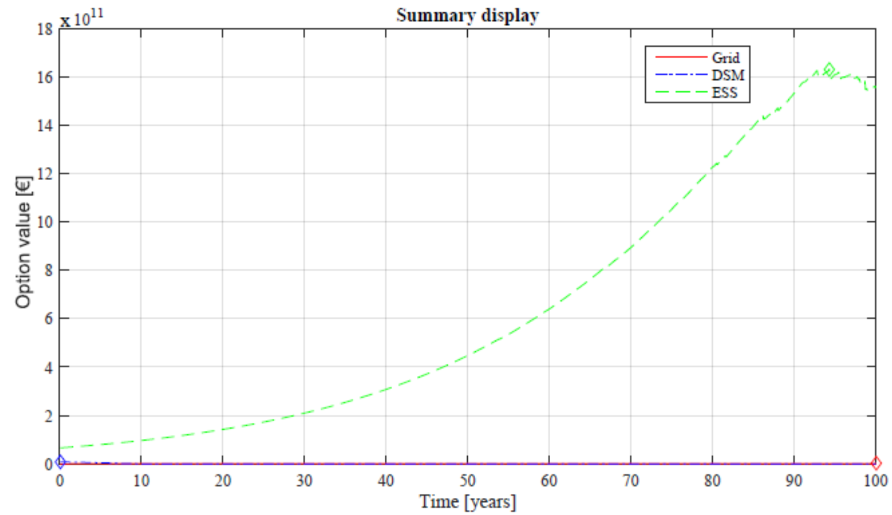

Figure 4.7: Summary display of the real options analysis for an infinite time horizon.

- DSM investment has high volatility caused by stochastic variables but the highest overall option value
- Energy storage investment is the best for an infinite time horizon
- Grid expansion investments have the highest stability
- All investments show positive option values

4. Results – Cost benefit analysis

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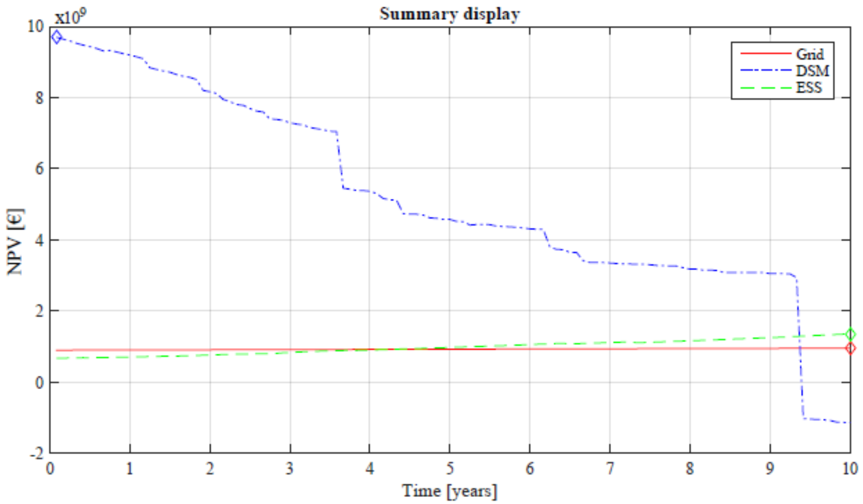

Figure 5.4: Summary display of investment NPVs.

Source: Own figure.

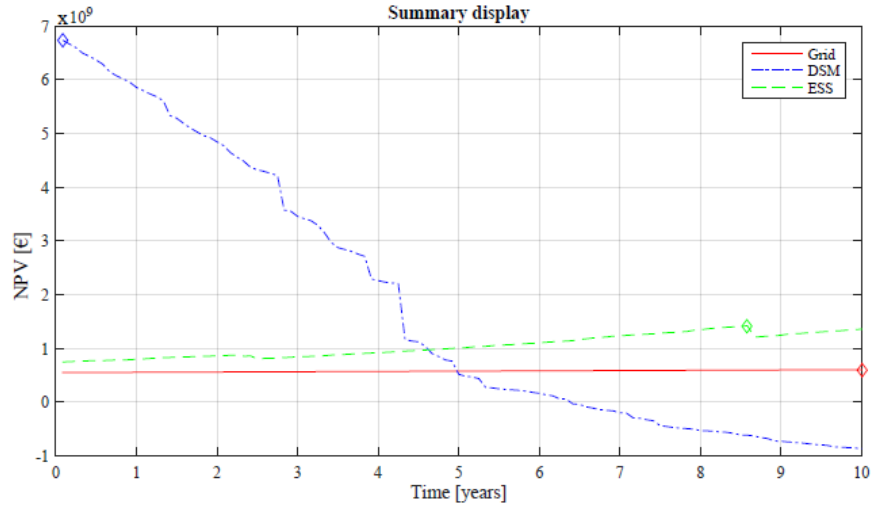

Figure 5.6: Summary display of NPVs without consideration for the value of supply security.

Source: Own figure.

- Supply security → Grid expansion has higher benefit than energy storage
- DSM investment stays volatile for the welfare analysis cases
- Comparison to ROA results show the value of modular investment options for the energy storage case

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5. Summary & Conclusion

- The models presented are all heavily simplified representations of reality
  - Show principal value of model specifics considered
  - Can be extended at will
- All possible investment opportunities considered show positive results
  - With the data used
  - Option value & Overall benefit
- The demand side investment is prone to high volatility due to many stochastically changing price vectors
  - Has the potential for the highest benefit
- The real options analysis demonstrates the value of modular investments for the energy storage investment case
  - Option value increases significantly with the expiration time of the option
- The value of supply security should not be neglected in a cost benefit analysis of an energy investment
  - Grid expansion > Energy storage

Image Source: finance-magazin.de

Many thanks for your kind attention – any questions?

Contact: Prof. Dr. Reinhard Madlener
Tel. 0241-80 49 820, -822
RMadlener@eonerc.rwth-aachen.de

www.fen.rwth-aachen.de

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