Impact of Tariff Signals on Storage Operation and Investment

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Agenda

1. **Context and research question**
2. **Modelling approach**
3. **Tariff designs**
4. **Next steps**

1. Context and Research Question

Context:

- Long lead-times and low acceptance for transmission investment
- Weak grid and frequent outages in Burkina Faso
- Storage could provide quick and efficient alternative to grid expansion

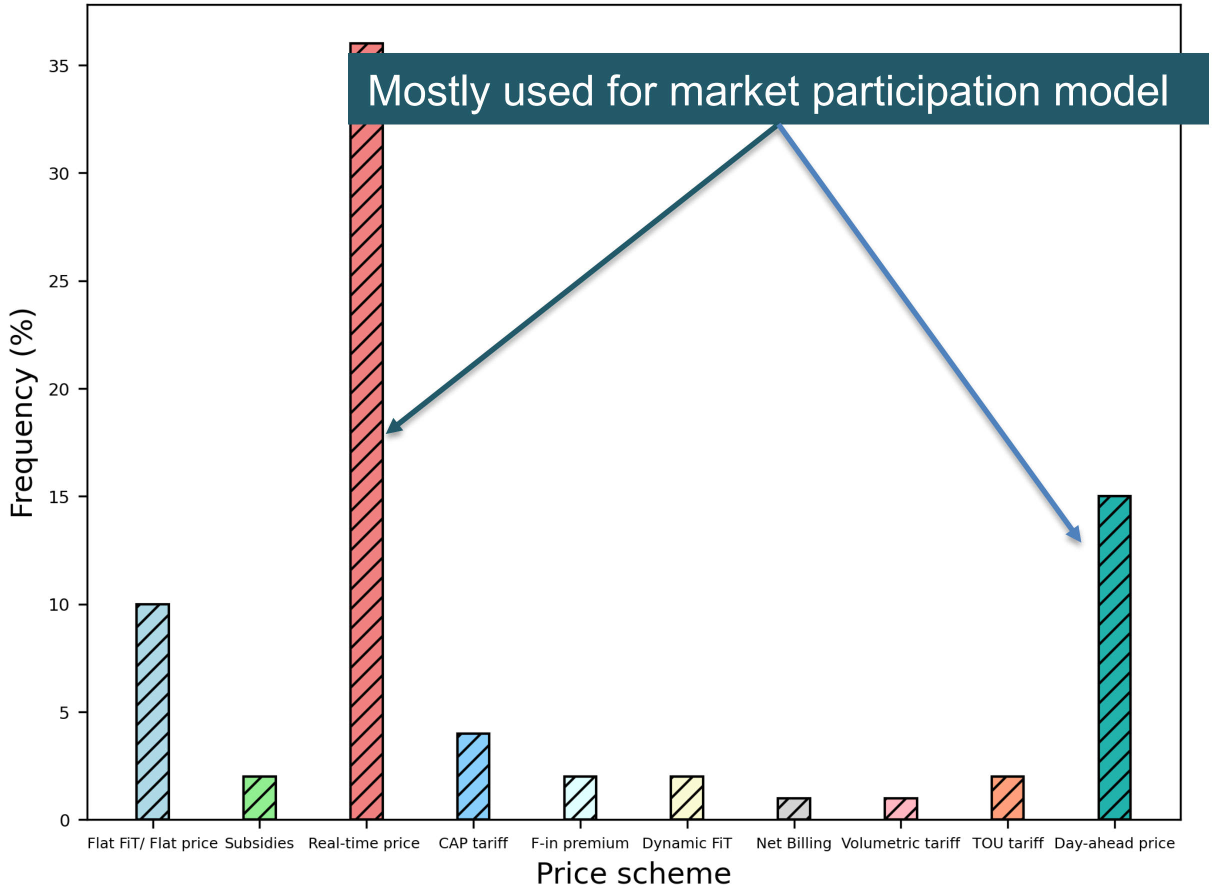
Research question:

- To what extent can cost-reflective tariff signals incentivize optimal storage investment and operation by private investors?

1. Context and Research Question

Literature:

- Energy arbitrage is the main profitable service (Bradbury et al., 2014; Sioshansi et al., 2009; Kelly & Leahy, 2020)
- Investment risk analysis for grid-connected battery storage has received little attention
- No papers simulate investment impact of tariffs depending on gridload



2. Modelling approach

Topology: 2-node debugging system

	Technologies				
Nodes	**Gas**	**Oil**	**Storage**	**PV**	**Load**
N_1	GB_1	GP_1	-	-	
N_2	-	-	ST_2	PV_2	L_2

Time horizon: 10 weather years

2. Modelling approach

Calculation steps

Step1
Central optimization with grid constraints

- Use optimum capacity for generation and storage in subsequent steps
- Save optimum storage capacity for comparison

Step 2
Generation dispatch without grid constraints

- Use optimum dispatch of generation and shadow prices for subsequent steps

Step 3
Storage dispatch based on price signals

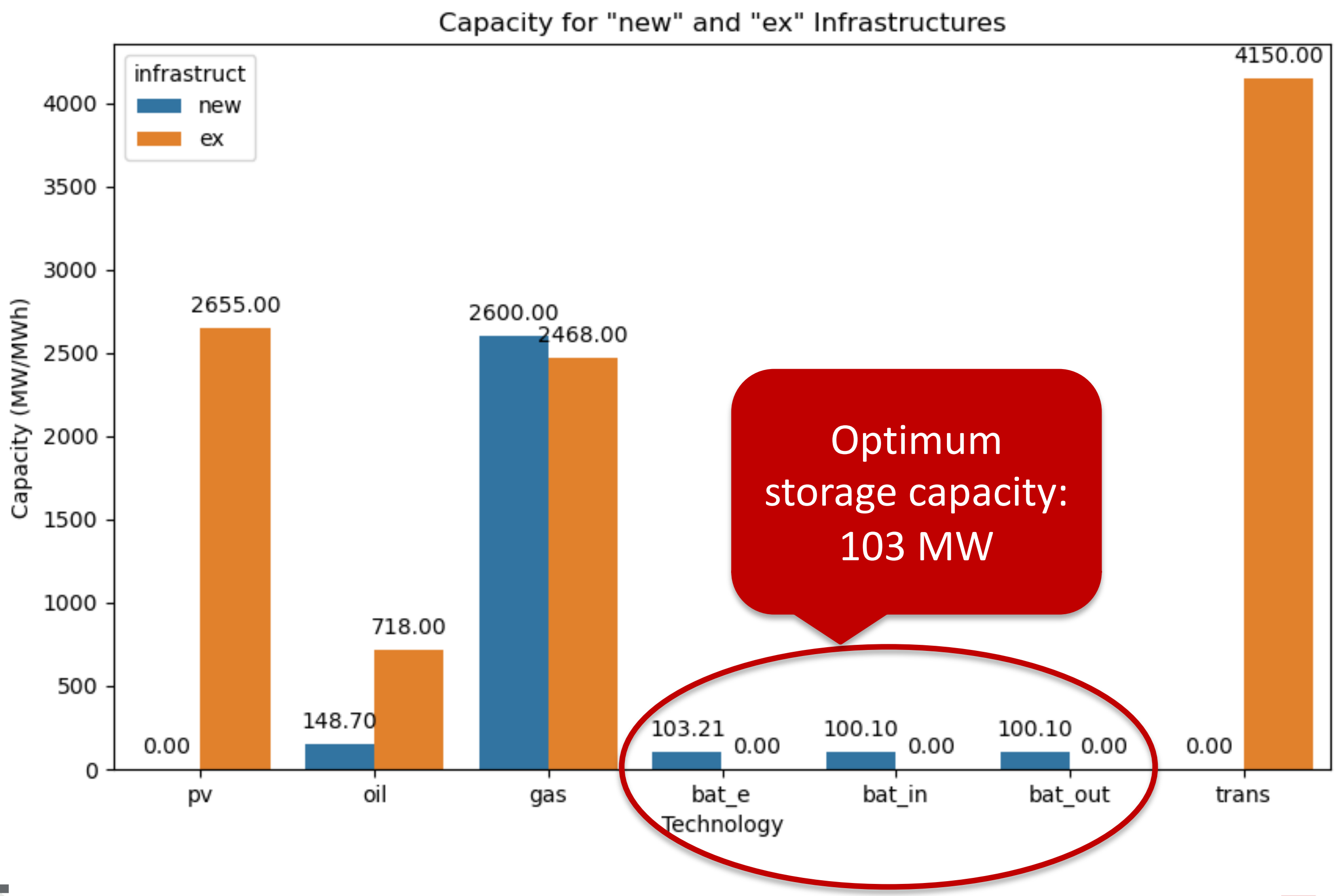
- Profit maximizing dispatch of storage
- Account for impact on tariff and shadow prices (Price-maker model)

Step 4
Storage investment

- Invest while risk / return across weather years is above hurdle rate
- Compare final investment with optimal capacity of step 1
- *?recalculate prices & tariffs (step2)?*

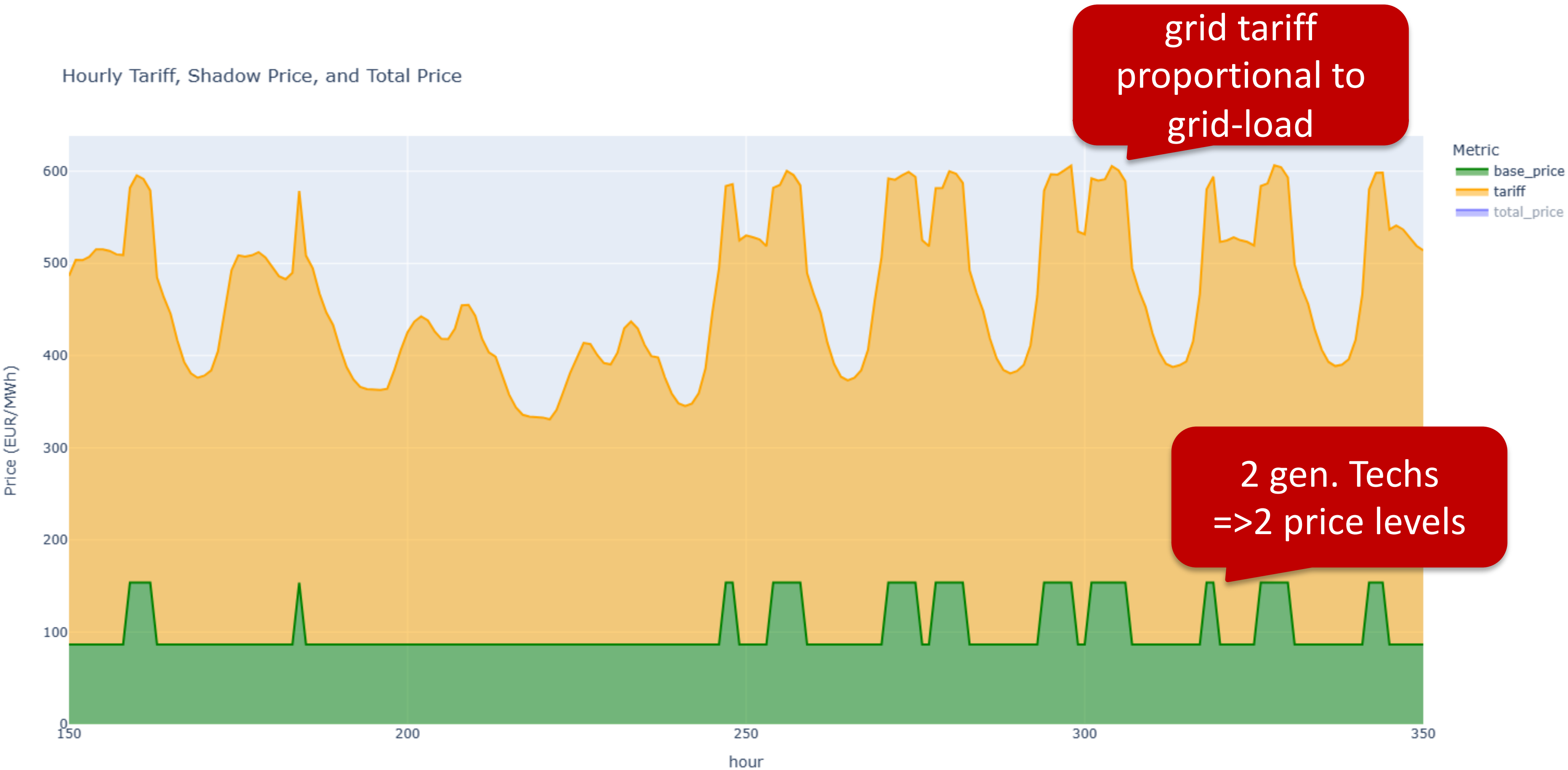
2. Modelling approach

Step1 – Central optimization with grid constraints



2. Modelling approach

Step2 – Generation dispatch without grid constraints



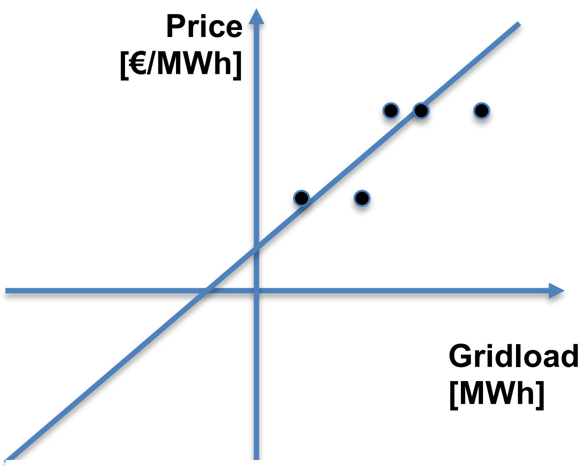
2. Modelling approach

Step 3 – Storage dispatch

Work In progress

Profit maximizing dispatch accounting for impact on wholesale price and grid tariff.

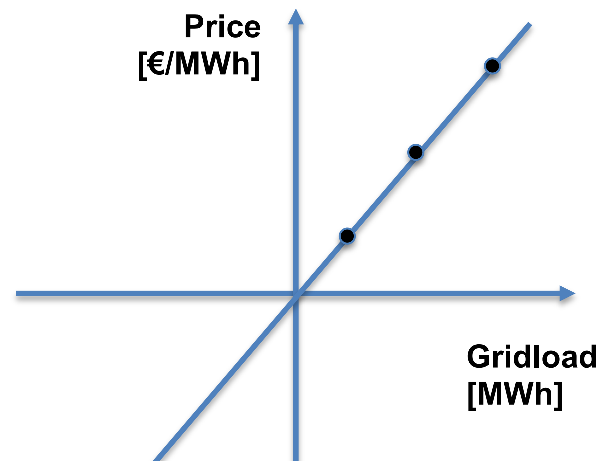
Wholesale price



=> inferred from shadow-price time-series of step 2

TODO: based on Ikechi (2022)

Grid Tariff



=> specified as a function of gridload

2. Modelling approach

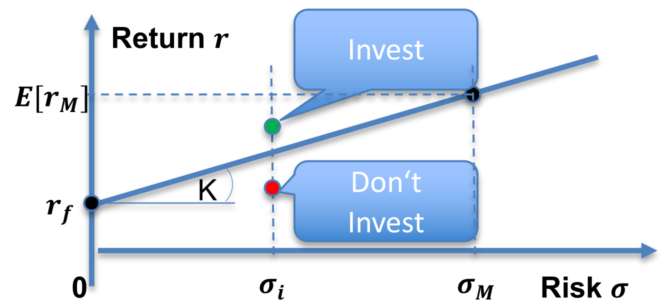
Step 4 – Storage investment

Stepwise increase of storage capacity, as long as average return is above the return that would be expected given the standard-deviation of storage revenues.

Process:

Stepwise increase of storage capacity while profitable:			
1 MW	2 MW	3 MW	…
Calculate profits for 10 weather years:			
Year 1: $r_{i,1}$	Year 1: $r_{2,1}$	Year 1: $r_{3,1}$	
…	…	…	
Year 10: $r_{1,10}$	Year 10: $r_{2,10}$	Year 10: $r_{3,1}$	
Verify whether storage is still profitable:			
$Avg(r_1) > r_f + \sigma_1 K?$	$Avg(r_2) > r_f + \sigma_2 K?$	$Avg(r_3) > r_f + \sigma_3 K?$	

Profitability: CAPM model



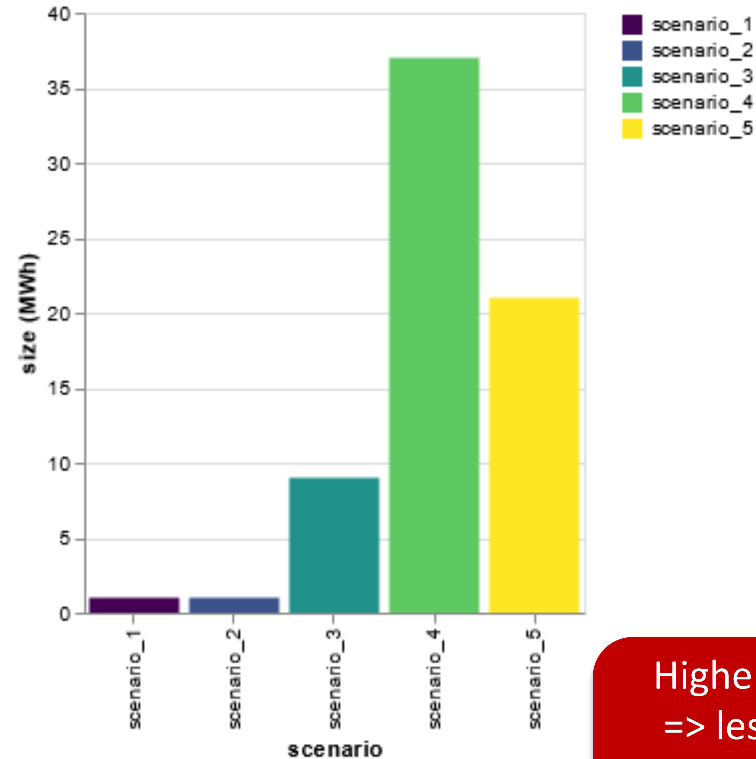
$$E(r_i) = r_f + \sigma_i \times K \tag{3}$$

$$K = \frac{(E[r_M] - r_f)}{\sigma_M} \cdot \rho_{i,M}$$

2. Modelling approach

Step 4 – Storage investment

Work In progress



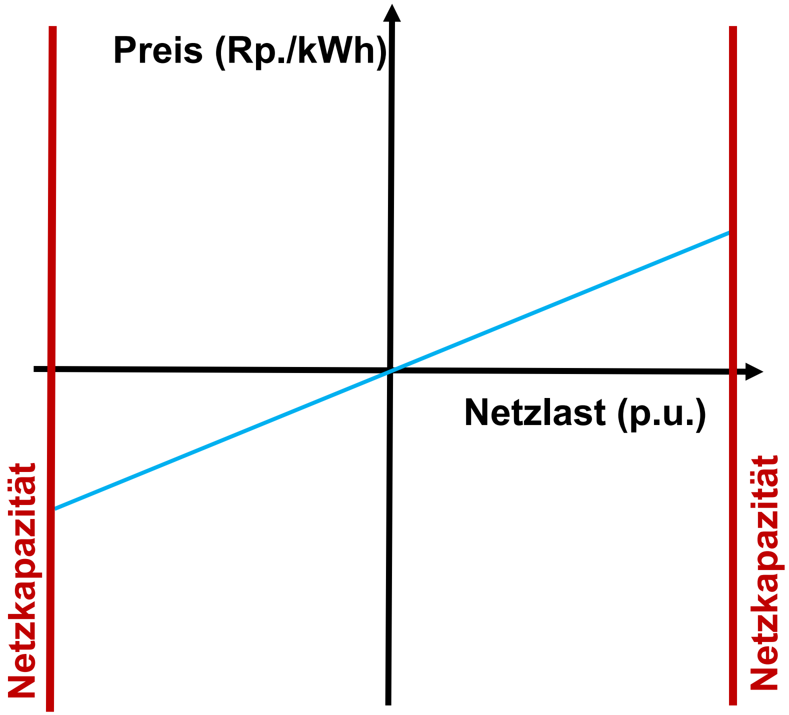
Parameter	1	2	3	4	5
K	0.5	0.5	0.5	1	1.5
tariff:EUR_base	0.1	0.2	0.35	0.4	0.4

Higher risk aversion
=> less investment
(but impact less strong
than impact of tariff)

Higher Tariff
=> more investment

3. Tariff approaches

Design 1 – Proportional grid tariff



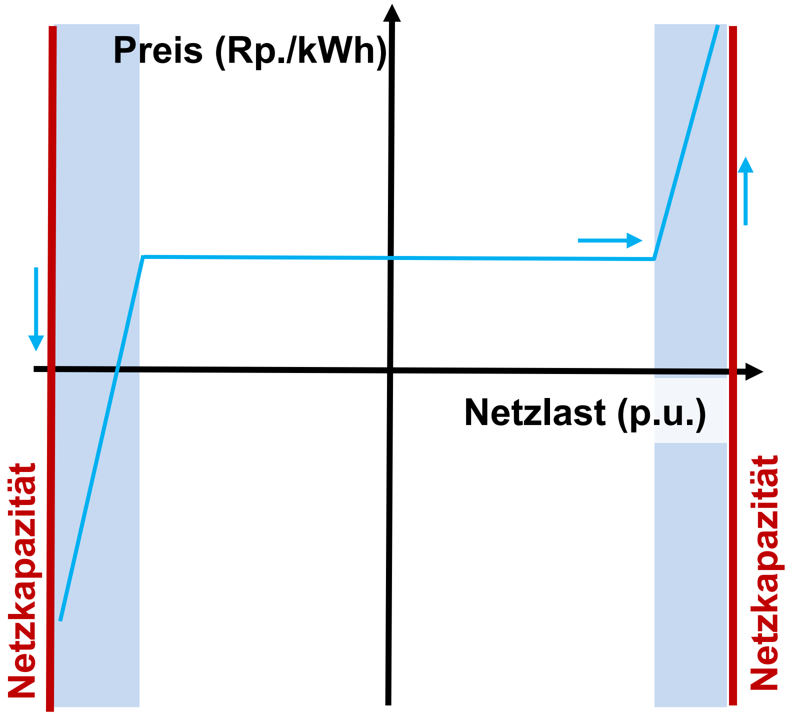
Tarifgestaltung **Wirkung**

1. **Tarif abhängig von gemessener Netzlast** ▶ Vermeidung Rebound Effekt, Kurative Lastsenkung bei Ausfällen

3. Tariff approaches

Design 1 – Step function for grid tariff

Work In progress



	Tarifgestaltung	Wirkung
1	**Tarif abhängig von gemessener Netzlast**	Vermeidung Rebound Effekt, Kurative Lastsenkung bei Ausfällen
2	**Konstanter Preis (Normalfall)**	Effizienter Flexibilitätseinsatz (z.B. Regelenergie, Spotmarkt)
	Steiler Preisanstieg (bei Engpass)	Zuverlässige Engpassbeseitigung

Problem: Non-linear objective function leads to explosion of calculation times

Next steps

- Estimate feedback on wholesale price (following Ikechi (2022))
- Test impact of different tariff designs (non-linear price)
- Expand to multi-node testcase (e.g. 6 nodes? IEEE test system?)

Thank you for your attention!

Questions for discussion

1. Model parameters

Are current battery parameter values realistic?

Technical parameters	Unit	Value
Step size	kW	3000
Round trip efficiency	%	93
Lifetime	Y	10

Cost parameters	Unit	Value
Capital cost (battery)	EUR/kWh	310
Capital cost (inverter)	EUR/kW	140
O&M cost	EUR/kW y	7.2

Investment Decision	Unit	Value
rf	%	2
rM	%	8
σM	%	12
k		0.5

Grid tariff:		
average tariff level	EUR/kWh	0.1

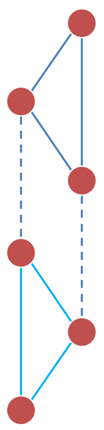
2. Optimisation Problem

How could problem specification & solution time be improved?

- Decision Variable:
  x_t= storage (dis)charge
- Objective function:
  $$Min(\sum_t (x_t \cdot p(x_t))$$
- Market price:
  $$p(x_t) = s_1 x_t\, i + s_2\, x_t(1-i)$$
- Indicator variable:
  $$i := \begin{cases} 0, if\ x_t \geq 100 \\ 1, if\ x_t < 100 \end{cases}$$

Alternative infrastructure scenario

Topology: 6-node test system

		Technologies				Load scenarios	
Topology	**Nodes**	**GasBase**	**GasPeak**	**Storage**	**PV**	**LS1**	**LS2**
	N_1	GB_1	GP_1	-	-		
	N_2	GB_2	GP_2	-	-	L_2=49%	-
	N_3	-	-	-	-	L_2=49%	-
	N_4			ST_4	PV_4		
	N_5			ST_5	PV_5	L_5=1%	L_5=50%
	N_6					L_6=1%	L_6=50%

Time horizon: 10 weather years