Integrating demand response into an agent-based simulation model of the German power sector

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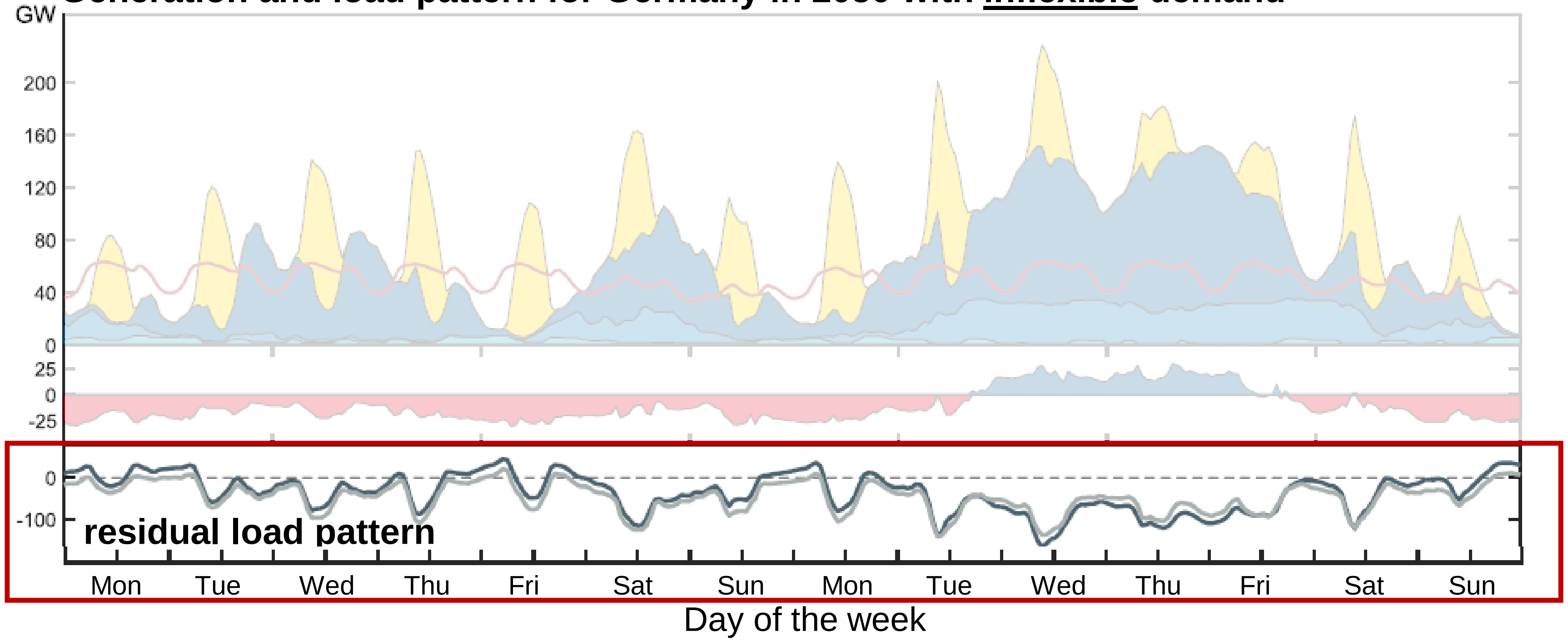
Agenda

1. **Introduction**
2. Methods
3. Case study
4. Conclusion and Outlook

Motivation: Demand response as one option for balancing VRES*

Generation and load pattern for Germany in 2050 with inflexible demand



- Strong fluctuations of residual load
- situations with positive and negative residual loads

➡ **Demand Response as one option to balance some fluctuations**

but …

… (How) Would it's dispatch be scheduled (from a microeconomic point of view)?

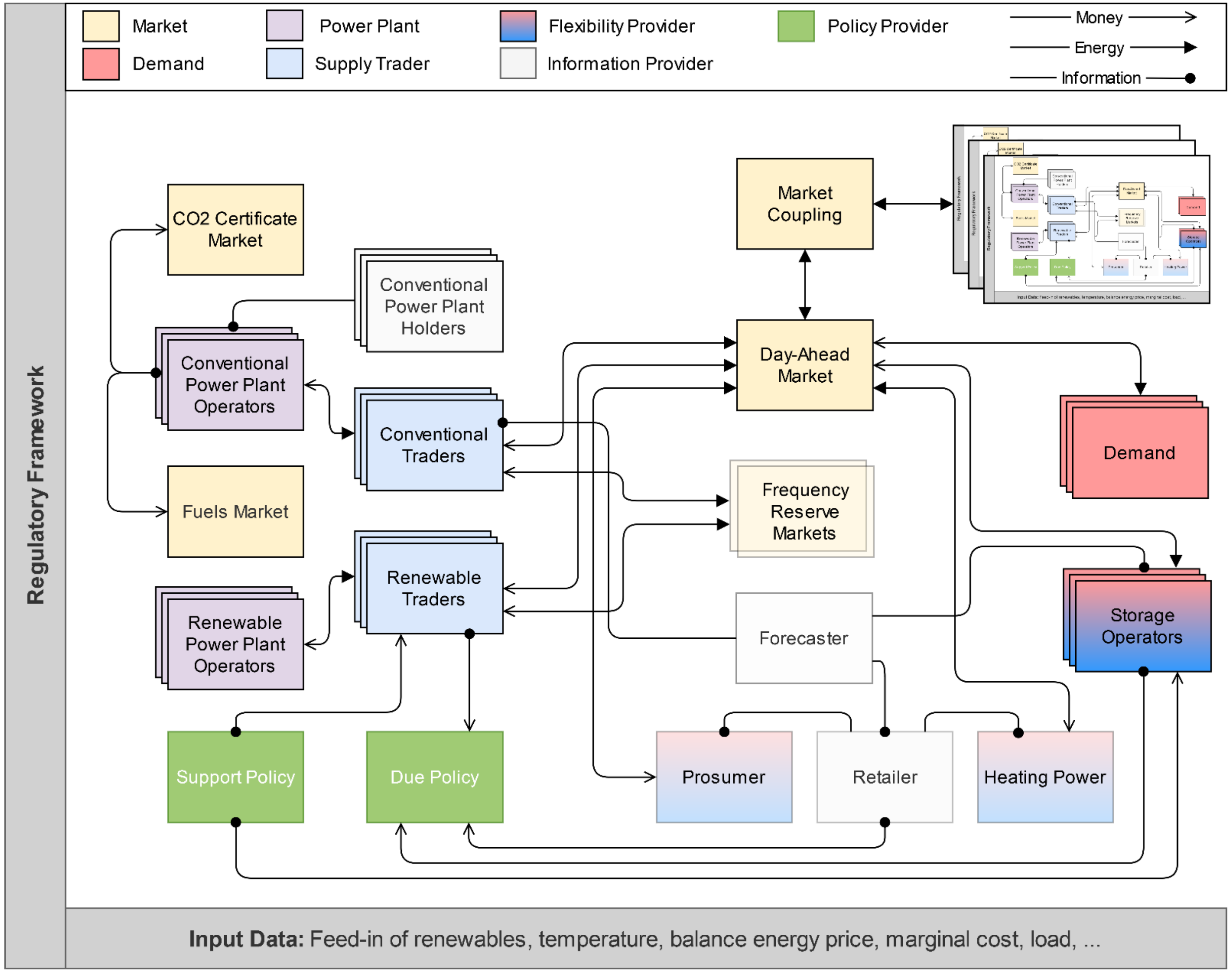
… What are the effects of different scheduling strategies and varying tariff designs?

*VRES: variable renewable energy sources

source: Gerhardt et al. (2017), p. 31; modified

The model AMIRIS* at a glance

- **agent-based simulation** of power markets (focusing on the Day-ahead market)
- Each agent: **bidding strategy** for offering supply / demand bids to EnergyExchange
- EnergyExchange clears market by **intersecting demand and supply curves**
- we may include policy measures and can easily vary strategies



A*gent-based* **M***arket model for the* **I***nvestigation of* **R***enewable and* **I***ntegrated energy* **S***ystems*

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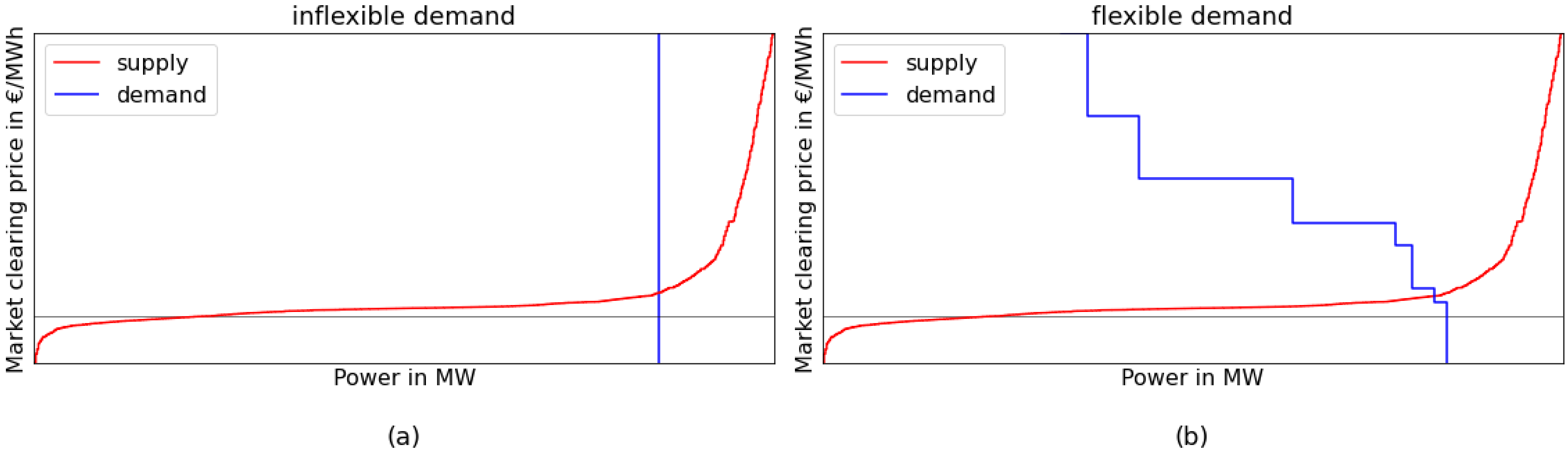
Load shedding



- Starting basis is a completely inelastic demand (a)
- Sheddable demand is provided with a **time series** and offered at respective **variable costs** (value of lost load - VOLL)
- Overall demand time series is decreased by demand eligible for shedding
- Result: more granular demand curve (b)

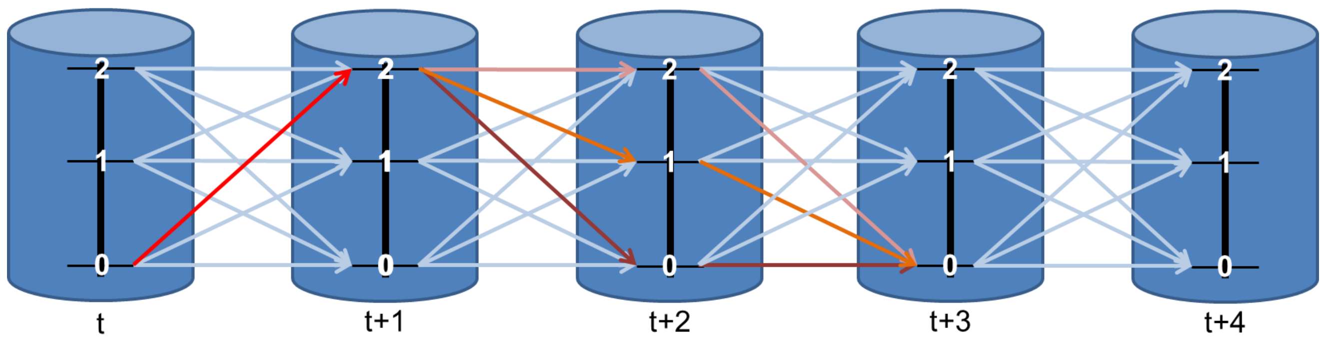
Load shifting – Overview

- Basic **logics**
  - storage-alike
  - *dynamic programming*
  - load shift **energy state** is **discretized**

- **Conditions** which may not be violated
  - **shift time** limit → track it
  - **power** limits → constrain transition between hours
  - **energy** limits → constrain energy state grid

- A ***Strategist*** controls the strategy used; alternatives
  - minimize system costs
  - maximize agent's profits

- Example pattern for energy states
  - maximum shift time = 4
  - initial shift to energy state 2 (red arrow)



⇨ *Different options for compensation*

Load shifting – State definition & Management

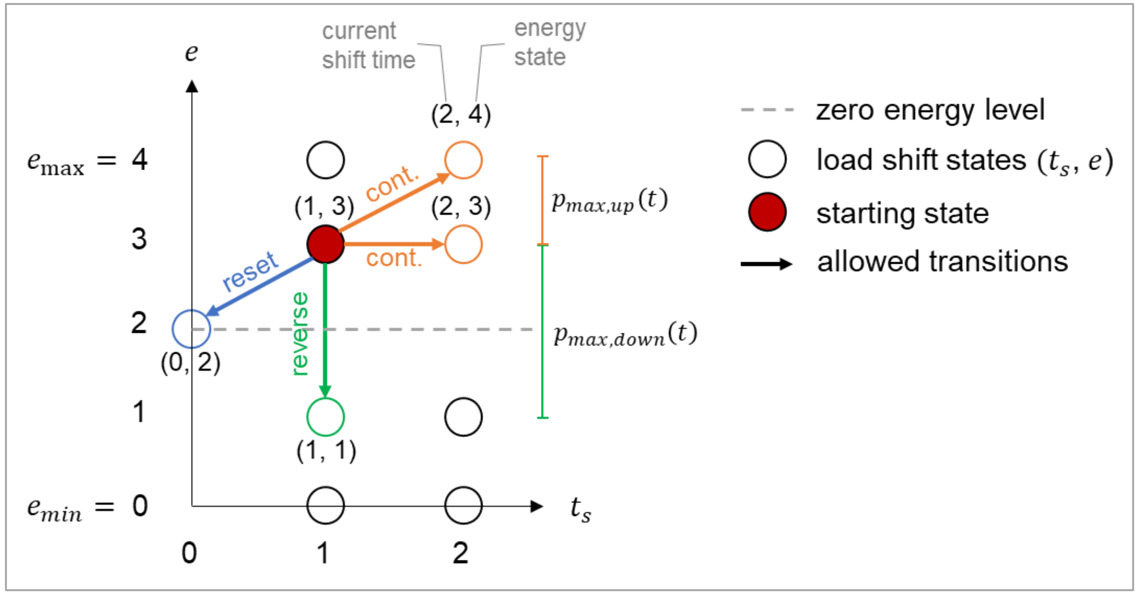
- State definition
  - state: **tuple of current shift time and energy state**
  - map energy states back to real world energy levels

- Choice of **next feasible states**
  - do not violate *energy* limits (*grid*)
  - do not violate *power* limits (*transition*)

- Rules for **shift time**
  - shift continues in the same direction? → increase shift time
  - resetted to zero energy state? → set shift time to 0
  - shift in the other direction? → initialize shift time with 1

- Rules for **energy level**
  - maximum shift time reached? → get back to zero energy state or shift in opposite direction
  - offer choice to prolong shift if feasible within power bounds

allowed state transitions



e:	energy state
e_{min}:	minimum energy state
e_{max}:	maximum energy state
t_{shift}:	shift time
p:	power steps

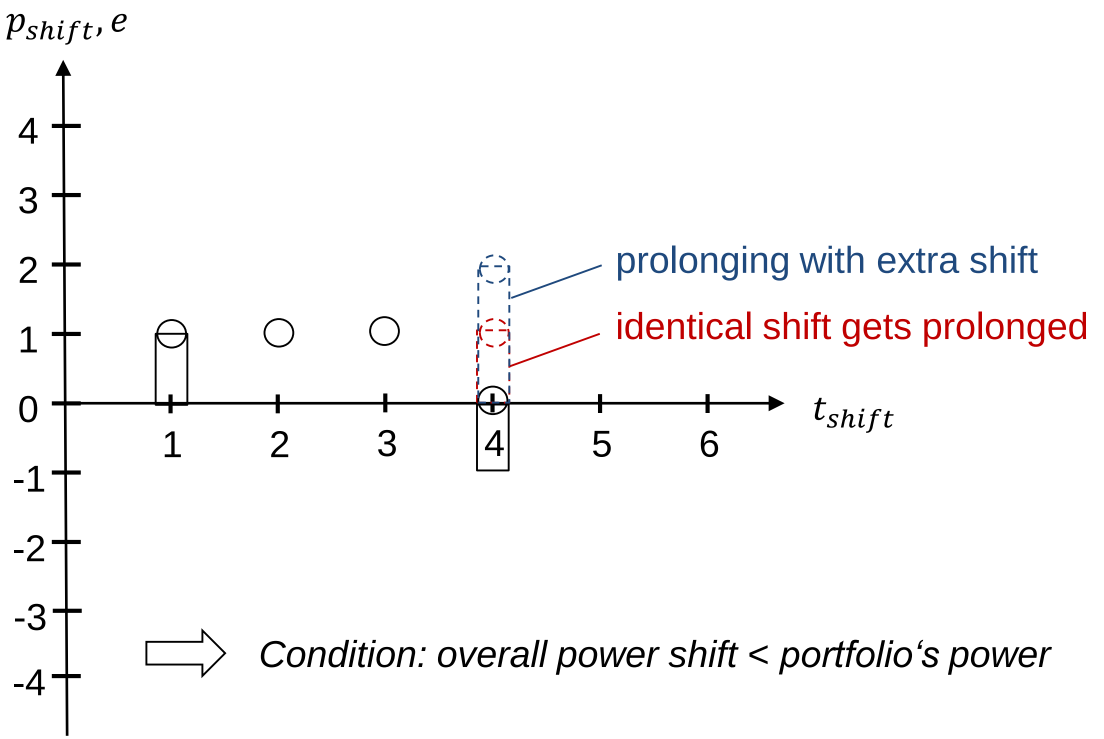
Load shifting – Allow prolonging of shifts

- **Starting point**
  - maximum shift time already reached
  - energy state „rather small“
- **Logic**
  - check: resetting shift plus additional shift in the same direction is an option (in terms of power)?

    - add state to the set of next feasible states
    - add the additional variable costs for the reset

p_{shift}:	power shifted (in steps)
e:	energy state
t_{shift}:	current shift time

Example
- maximum shift time = 4
- power split into 9 power steps
- energy split into 9 (or more) energy steps



Condition: overall power shift < portfolio‘s power

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Case Study Design

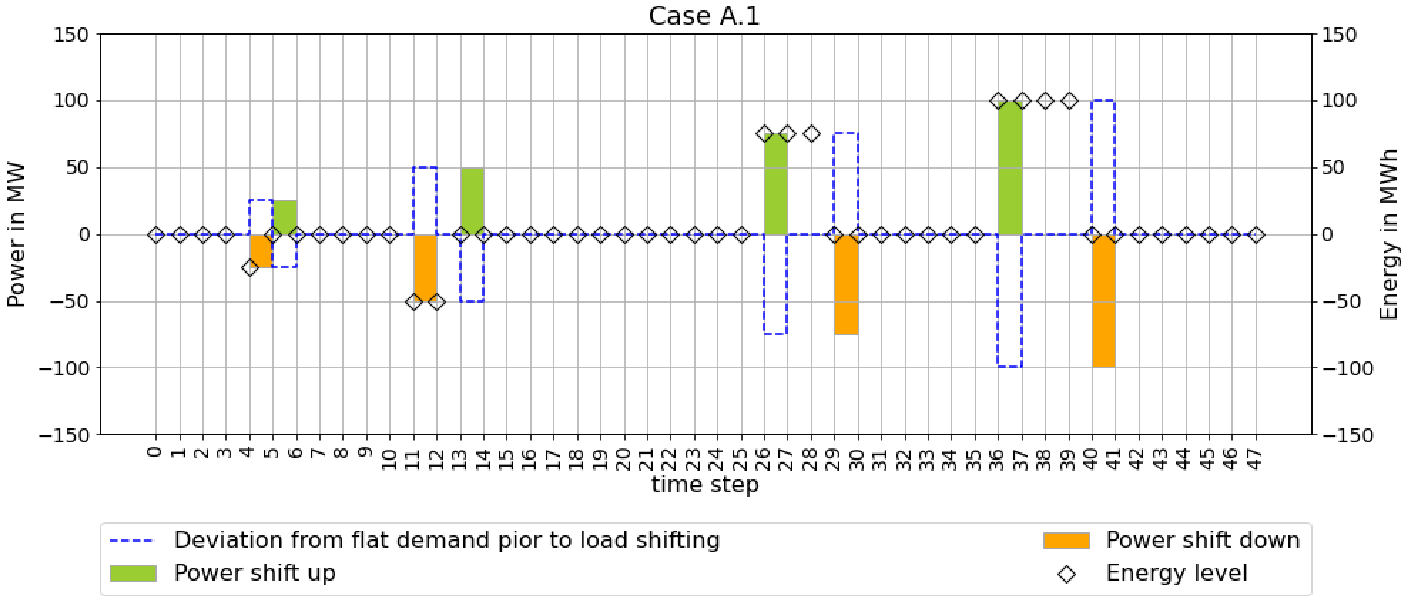
3 Sub-cases considered

	A: Stylized test power system	B: Comparing strategies	C: Comparing tariff designs
Intention	• Proof functionality • Analyze (portfolio) behaviour	• Analyze the behaviour of different dispatch strategies: system cost minimization vs. profit maximization	• Analyze different tariff design options: static vs. dynamic (to some extend)
Setting & Anaysis	• Very simplistic test system • Show modeling effects & limitations • Compare to fundamental modeling behaviour	• Use a power system setting for Germany • Analyse differences in dispatch behaviour, costs & profits	• Use a power system setting for Germany • Analyse differences in dispatch behaviour, costs & profits

Case study A: Stylized test power system – proof of concept

Our approach is functional

- **Situation**
  - some single hour demand variations
  - expectation: level them out with load shifting (cheapest option)

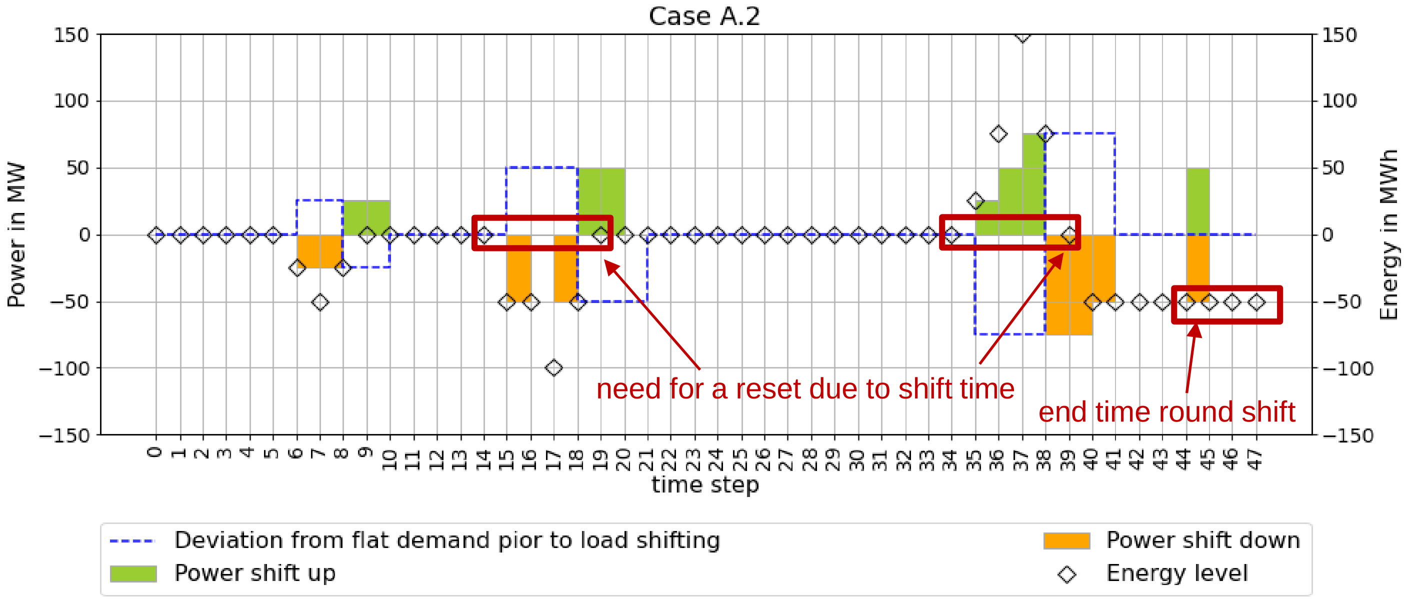


- **Resulting behaviour as expected**
  - demand variations leveled out
  - behaviour of fundamental models replicated

Case study A: Stylized test power system – duration limitiations

Our load shifting portfolio cannot arbitrarily be sliced

- **Situation**
  - some multi hour demand variations
  - expectation: level them out with load shifting (cheapest option)



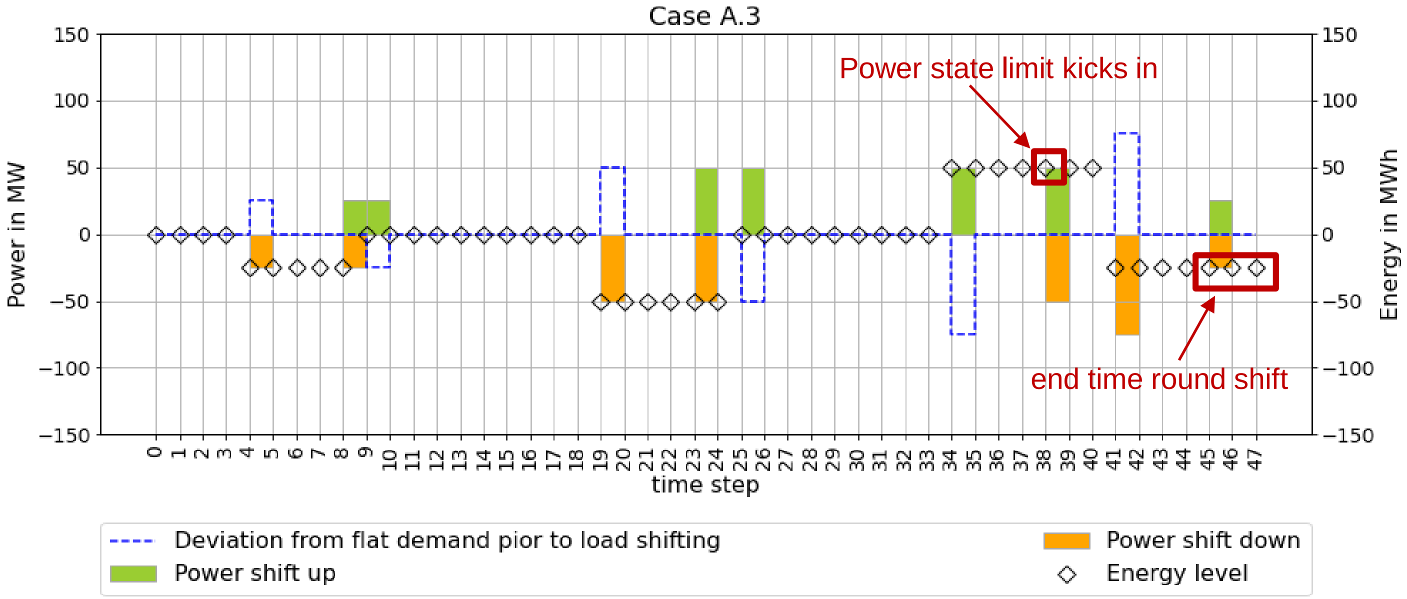
- **Resulting behavior: limitations on portfolio representation**
  - need for a reset after maximum shift time
  - portfolio not sliced into arbitrary parts
  - fringe effects at the end

Case study A: Stylized test power system – prolonged shift time limitiations

Our load shifting portfolio cannot arbitrarily be sliced

- **Situation**
  - some single hour demand variations with long times in between > maximum shift time
  - expectation: level them out with load shifting (cheapest option) by prolonged shifts

- **Resulting behavior again reveals limits**
  - **Prolongation** allowed, but to a limited extend → power limit binding



Case study B: Strategies – system costs minimization vs. profit maximization

More activations with growing portfolio size

Load shifting portfolio capacity in MW	System cost minimizing agent		Profit maximizing agent	
	Activations	Full shift cycles	Activations	Full shift cycles
10	783	537	800	545
100	790	524	813	530
1,000	868	441	929	409
10,000	1,380	179	1,483	143

increasing number of activations with increasing portfolio sizes

larger portfolio size
→ more price deviations levelled out / profits realized

Load shifting portfolio capacity in MW	System cost minimizing agent	Profit maximizing agent		Difference in system costs between the strategies in %	Number of deviating dispatch decisions in h
	Average energy delta / acti-vation in MW	Average energy delta / acti-vation in MW	Profit / installed capacity in €/MW		
10	27	27	26,009	0.0004	137
100	265	261	25,075	0.0041	271
1,000	2,032	1,761	17,533	0.0504	1,233
10,000	5,180	3,856	1,818	0.1742	3,184

Activation: process with up- and downshift, independent of length

Full shift cycle: activation with maximum power / energy shifted and shift not prolonged

Case study B: Strategies – system costs minimization vs. profit maximization

Profit maximizer withholds capacities

Load shifting portfolio capacity in MW	System cost minimizing agent		Profit maximizing agent	
	Activations	Full shift cycles	Activations	Full shift cycles
10	783	537	800	545
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≥

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≥

profit maximizing agent:

- more activations, but fewer full shift cycles
- less of installed capacity shifted

- system cost minimizing agent: reduce price spikes
- profit maximizing agent: balance profits vs. smaller price deviations (activations)

Activation: process with up- and downshift, independent of length

Full shift cycle: activation with maximum power / energy shifted and shift not prolonged

Case study B: Strategies – system costs minimization vs. profit maximization

Deviations increase with portfolio size

Load shifting portfolio capacity in MW	System cost minimizing agent		Profit maximizing agent	
	Activations	Full shift cycles	Activations	Full shift cycles
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100	790	524	813	530
1,000	868	441	929	409
10,000	1,380	179	1,483	143

- system costs deviations low
- deviations increase with growing portfolio sizes

Load shifting portfolio capacity in MW	System cost minimizing agent	Profit maximizing agent		Difference in system costs between the strategies in %	Number of deviating dispatch decisions in h
	Average energy delta / activation in MW	Average energy delta / activation in MW	Profit / installed capacity in €/MW		
10	27	27	26,009	0.0004	137
100	265	261	25,075	0.0041	271
1,000	2,032	1,761	17,533	0.0504	1,233
10,000	5,180	3,856	1,818	0.1742	3,184

- no large influence on overall system costs
- profit maximizing agent: increasing portfolio size → activate smaller (relative) shares of portfolio

Activation: process with up- and downshift, independent of length

Full shift cycle: activation with maximum power / energy shifted and shift not prolonged

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Case study B: Strategies – system costs minimization vs. profit maximization

Profit maximizer suffers from self-cannibalization

Load shifting portfolio capacity in MW	System cost minimizing agent		Profit maximizing agent	
	Activations	Full shift cycles	Activations	Full shift cycles
10	783	537	800	545
100	790	524	813	530
1,000	868	441	929	409
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Load shifting portfolio capacity in MW	System cost minimizing agent	Profit maximizing agent		Difference in system costs between the strategies in %	Number of deviating dispatch decisions in h
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100	265	261	25,075	0.0041	271
1,000	2,032	1,761	17,533	0.0504	1,233
10,000	5,180	3,856	1,818	0.1742	3,184

profit maximizing agent: profits / MW decline with growing portfolio sizes

self-cannibalization effect

Activation: process with up- and downshift, independent of length

Full shift cycle: activation with maximum power / energy shifted and shift not prolonged

Case study C: Tariff designs – static vs. dynamic prices

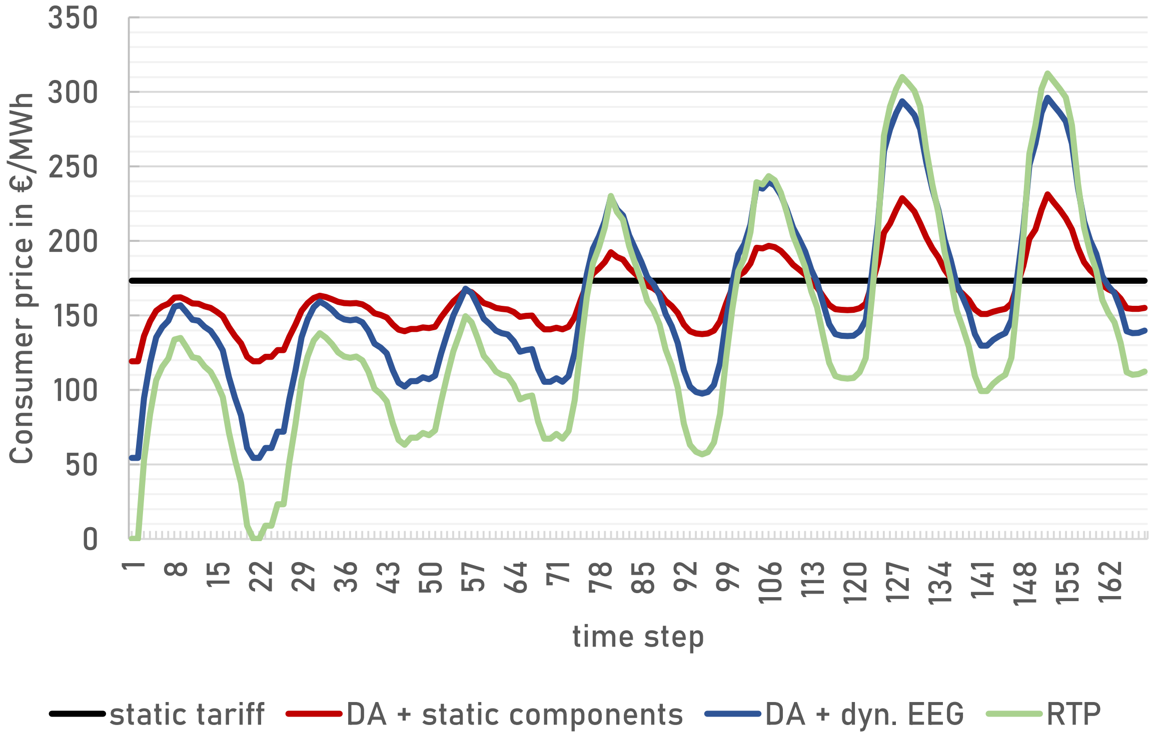
Different simple price models considered

- **Price models**
  1) Static tariff
  2) Day-ahead (DA) price + static add. price components
  3) DA price + dynamic EEG levy + static add. price components
  4) Real-time pricing (RTP)

- **Consumer**
  - 10 MW constant load
  - Medium voltage connection

- **Price components**

Tariff component	Static value in €/MWh	Multiplicator	Cap / Floor in €/MWh
EEG surcharge	**65**	**1.39**	**0 / 130.0**
Volumetric network charge	**11.7**	**1.49**	**0 / 139.2**
Electricity tax	**15.37**	**1.18**	**0 / 110.6**
Other surcharges (sum)	**8.18**		
Wholesale price (base)	**54.0**	**1.00**	**0 / 200.0**
SUM (gross electricity price; VAT 19%)	**173.3**		



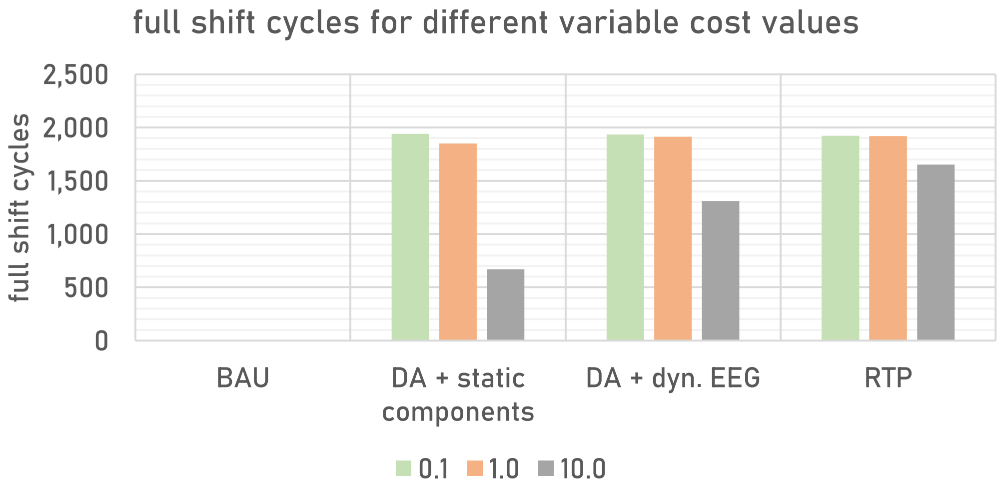
Sources for tariff design: ÜNB (2021a-e); Stuttgart Netze (2021); BDEW (2021); StromStG; KAV

Case study C: Tariff designs – static vs. dynamic prices

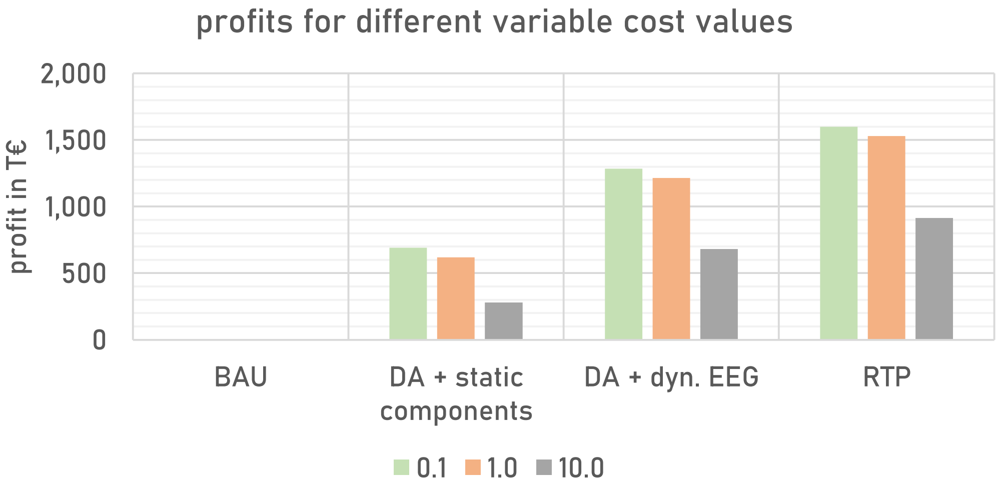
Preliminary findings: increase in profit, but be aware of strong limitations

Findings

- Load shift activations
  - … on a high and similar level for all dynamic variants for low variable costs (tariff models 2-4)
  - … increasing with dynamic share for higher variable costs



- Profits (incl. cost savings) increase with higher dynamic tariff share



Limitations

- Preliminary results
- Very simplistic approach for parameterization
- No capacity-related price components included yet
  → (one of the) major economic incentives for demand response

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Conclusion

Our novel modeling approach enables understanding effects of strategies and tariffs

Method

- **Advantages**
  - computational performance: fast
  - scope: modeling of individual units or portfolios
    → esp. suited to model individual units
  - flexible: support for different strategies & tariffs
- **Disadvantages**
  - some sacrifices on portfolio granularity
  - no continuous resolution
  - no multi-agent strategy (yet!)

Case Studies

- **Case A: Stylized test power system**
  - Proof of concept
  - Limitations in portfolio representation
- **Case B: Comparison of strategies**
  - Increasing discrepancies with growing portfolio sizes
  - (self-)cannibalization of profit maximizing agent
- **Case C: Comparison of tariff designs**
  - dynamic tariff components incentivize load shifting

Outlook

- **Model enhancements**
  - introduce imperfect foresights
  - establish a multi-agent strategy

- **Parameterization updates**
  - extend and update data collection from Kochems (2020a)
  - run a German case study

- **Application: Model comparison**
  - compare to fundamental model potential estimate for demand response potentials
  - study effects of more sophisticated tariff design schemes, esp. including capacity-related charges

Thank you!

Contact information

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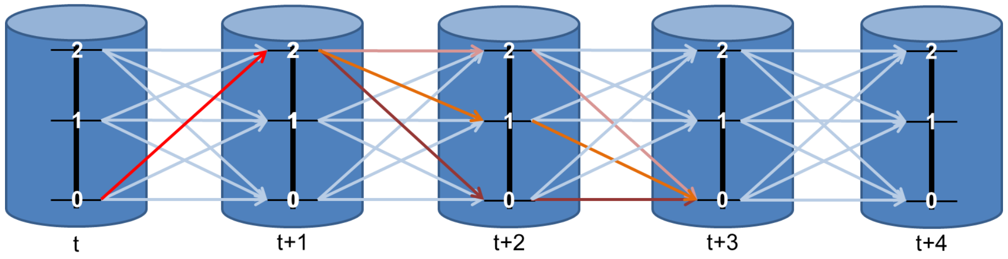

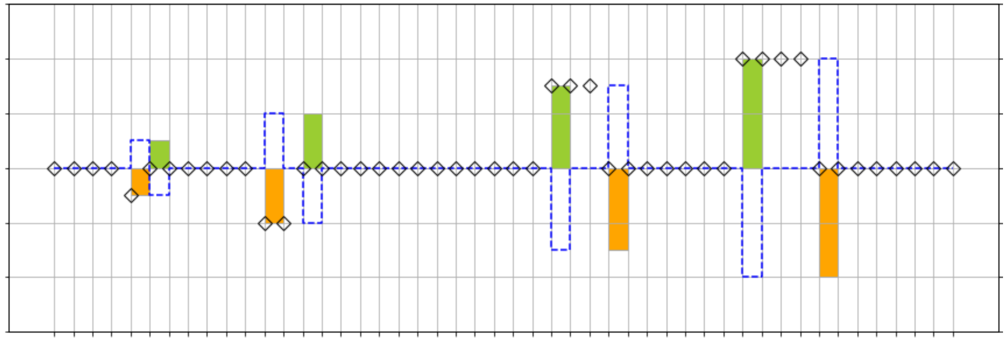

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Integrating demand response into an agent-based simulation model of the German power sector – BACKUP slides

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Comparison with fundamental modeling approaches

Type	Modeling approach	Process description								Solution characteristics		
		Combining up- and downshifts	Load shift storage level(s)	Capacity limit	Interference time considered	Energy limit(s)	Fixed shifting cycles	Portfolio consideration	Microeconomic costs and revenues	Solution method	Solution runtimes	Strategy
Fundamental modeling approaches	Zerrahn & Schill (2015) DIW	Map		X		(ST)		X		LP	sec	Min SC
Fundamental modeling approaches	Gils (2015) DLR	Sym, Bal	X	X	X	(ST, LT)		X		LP	sec	Min SC
Fundamental modeling approaches	Steurer (2017) IER	Sym		X	X			X		LP	sec	Min SC
Fundamental modeling approaches	Ladwig (2018) TUD	Sym	X	X	X	ST, LT	X	X		LP	sec	Min SC
ABM	Kochems and Schimeczek (2021) AMIRIS	En	X	X	(X)	ST		(X)	X	DP	msec	Min SC, Max P

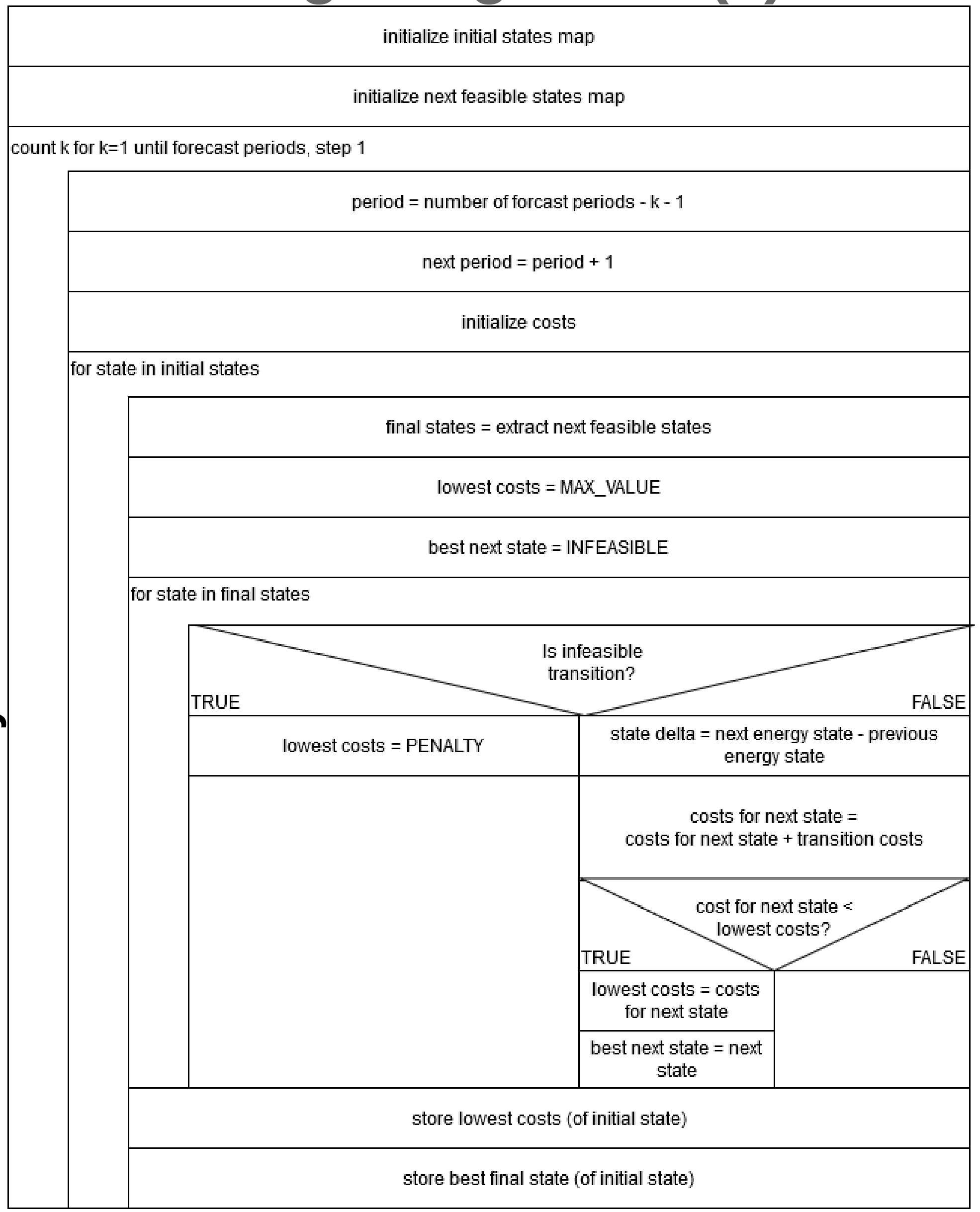
Abbreviations:

- Map: mapping of processes
- Sym: symmetric constraints (one for upshifts and one for downshifts each)
- Bal: Balancing variables used
- En: controlling time-restrictions for unbalanced energy level
- ST: short-term
- LT: long-term
- LP: linear programming
- DP: dynamic programming
- Min SC: minimization of system costs
- Max P: maximization of profit

source: Zerrahn & Schill (2015); Gils (2015); Steurer (2017); Ladwig (2018); own analysis

LoadShifting – Algorithm(s)

SystemCostMinimiser



ProfitMaximiser