Agent-based modeling of demand response for the German power sector

Johannes Kochems & Christoph Schimeczek

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Institute of Networked Energy Systems

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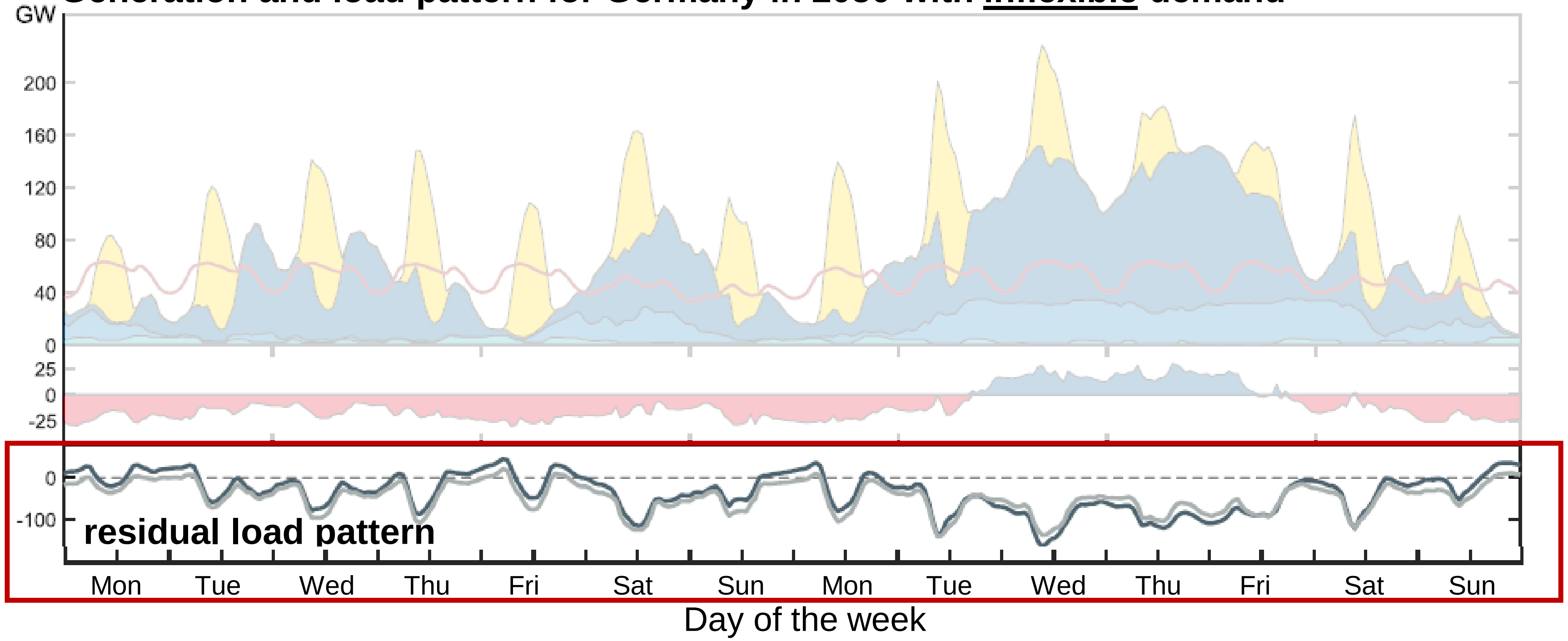
Agenda

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 …

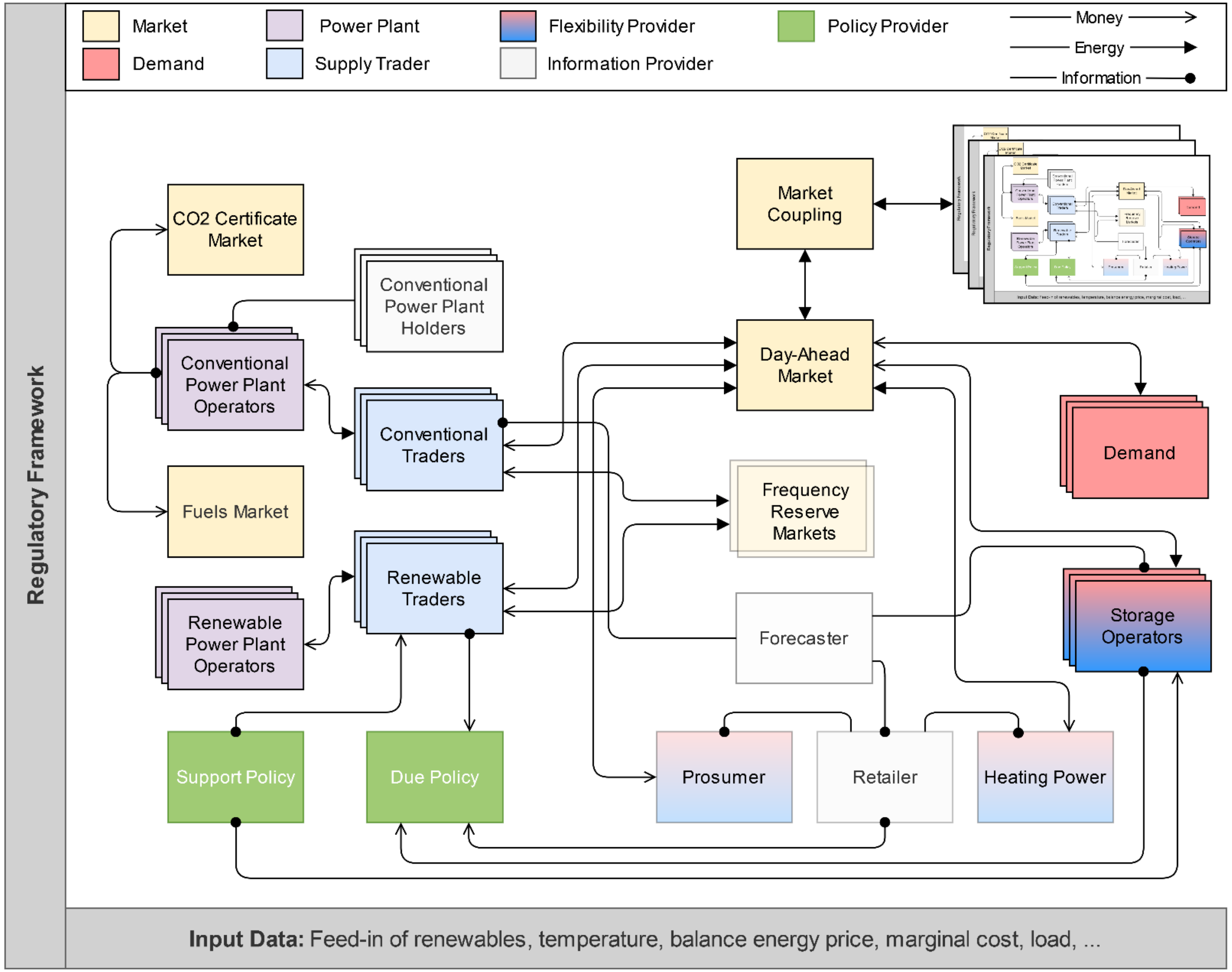
- *Which potentials are there?*
- *(How) Would it's dispatch be scheduled from a microeconomic point of view?*

*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

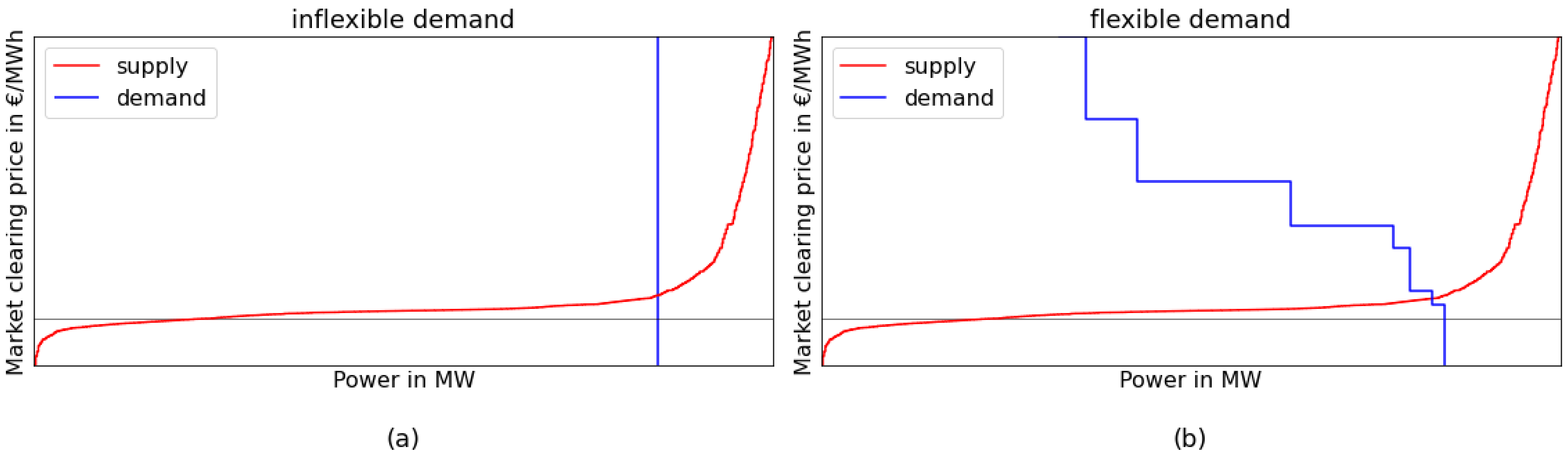


Agent-based **M**arket model for the **I**nvestigation of **R**enewable and **I**ntegrated energy **S**ystems — printed as: **A**gent-based **M**arket model for the **I**nvestigation of **R**enewable and **I**ntegrated energy **S**ystems

Agenda

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

Load shedding



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

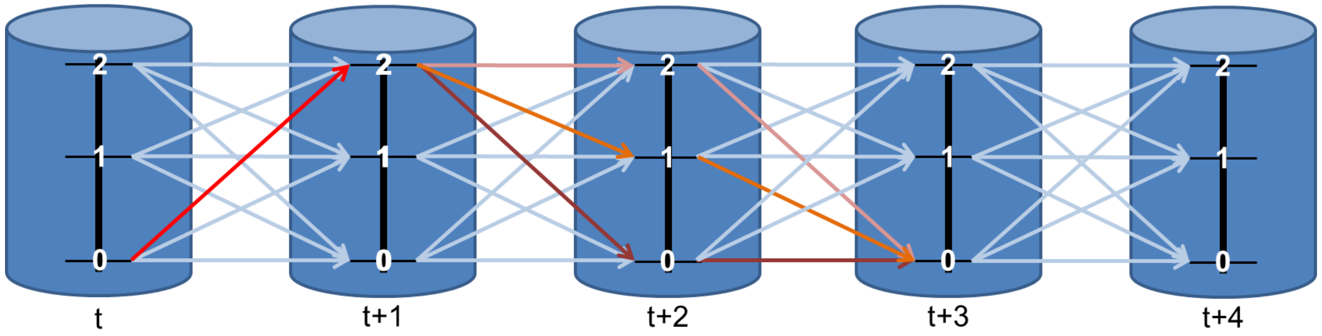
Load shifting – Overview

- 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

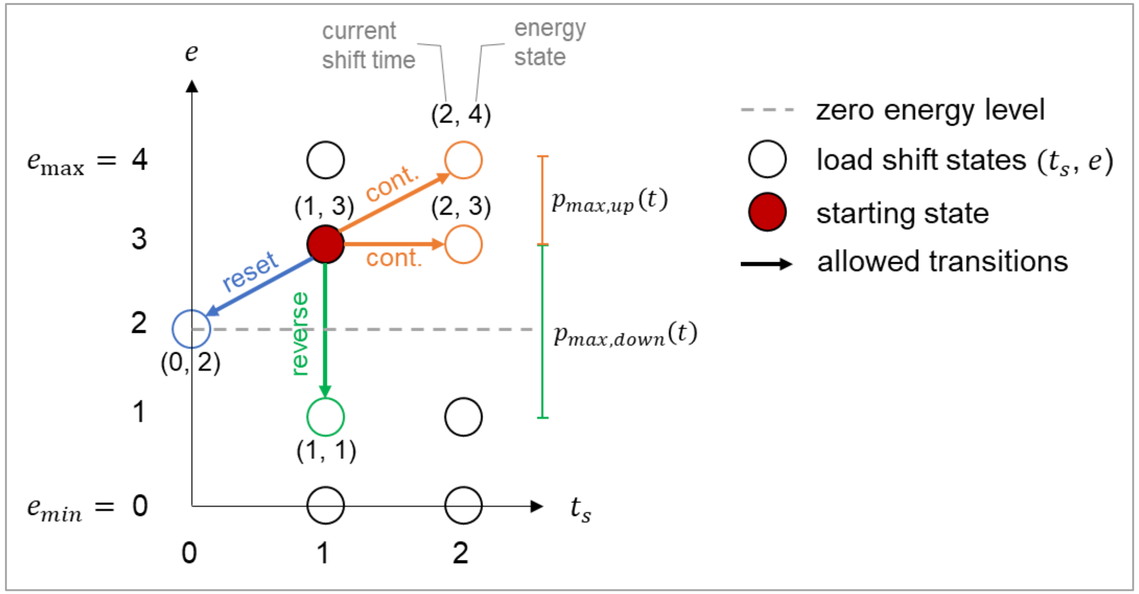
- State definition
  - state: **tuple of current shift time and energy state**
  - map energy states back to real world energy levels

- 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

Stylized test power system – proof of concept

- **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

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Comparing strategies – system costs minimization vs. profit maximization

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 / 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

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

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

Comparing strategies – system costs minimization vs. profit maximization

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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)

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

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

- 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

Comparing strategies – system costs minimization vs. profit maximization

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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

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Conclusion and Outlook

Conclusion

- **Advantages**
  - computational performance: fast
  - flexible: support for different strategies & tariffs
  - scope: modeling of individual units or portfolios
    → esp. suited to model individual units

- **Disadvantages**
  - some sacrifices on portfolio granularity
  - no continuous resolution
  - no multi-agent strategy (yet!)

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 different (more sophisticated) tariff incentive schemes

Thank you!

Contact information

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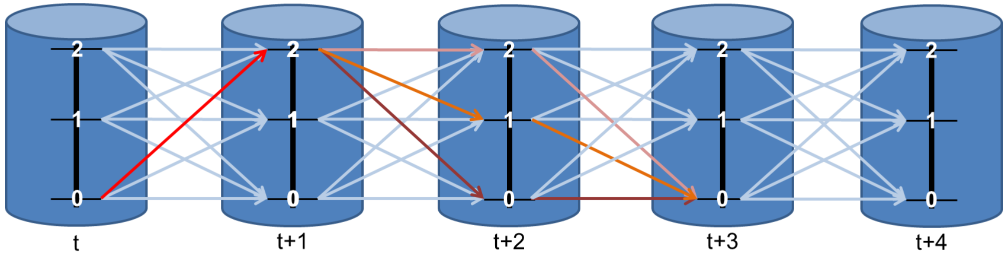

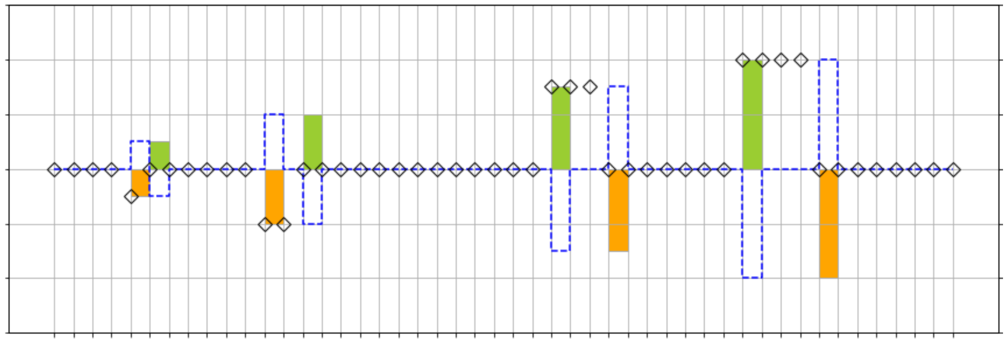

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Integrating demand response into an agent-based simulation model of the German power sector – BACKUP slides

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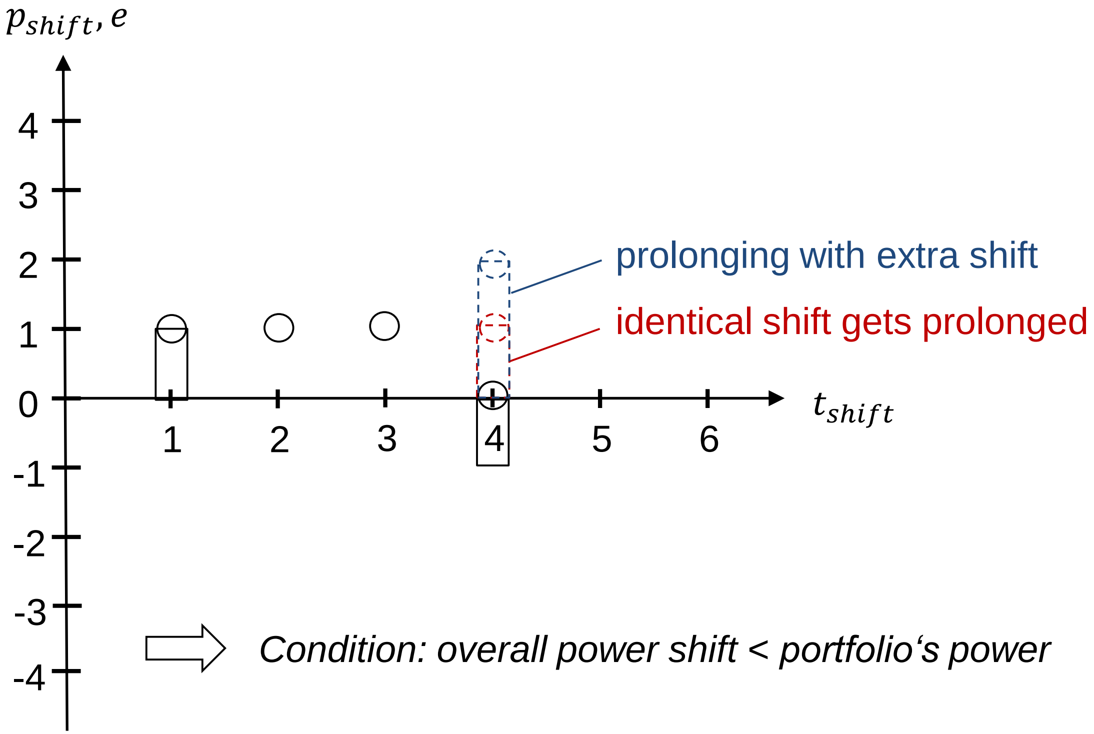
Load Shifting – Allow prolonging of shifts

- **Starting point**
  - Maximum shift time is already reached
  - Energy state is „rather small“

- **Logic**
  - Check whether resetting the shift and a shift in the same direction are an option (in terms of power)
  - If so, add the state to the set of next feasible states
  - Add the additional variable costs for the reset

Example

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

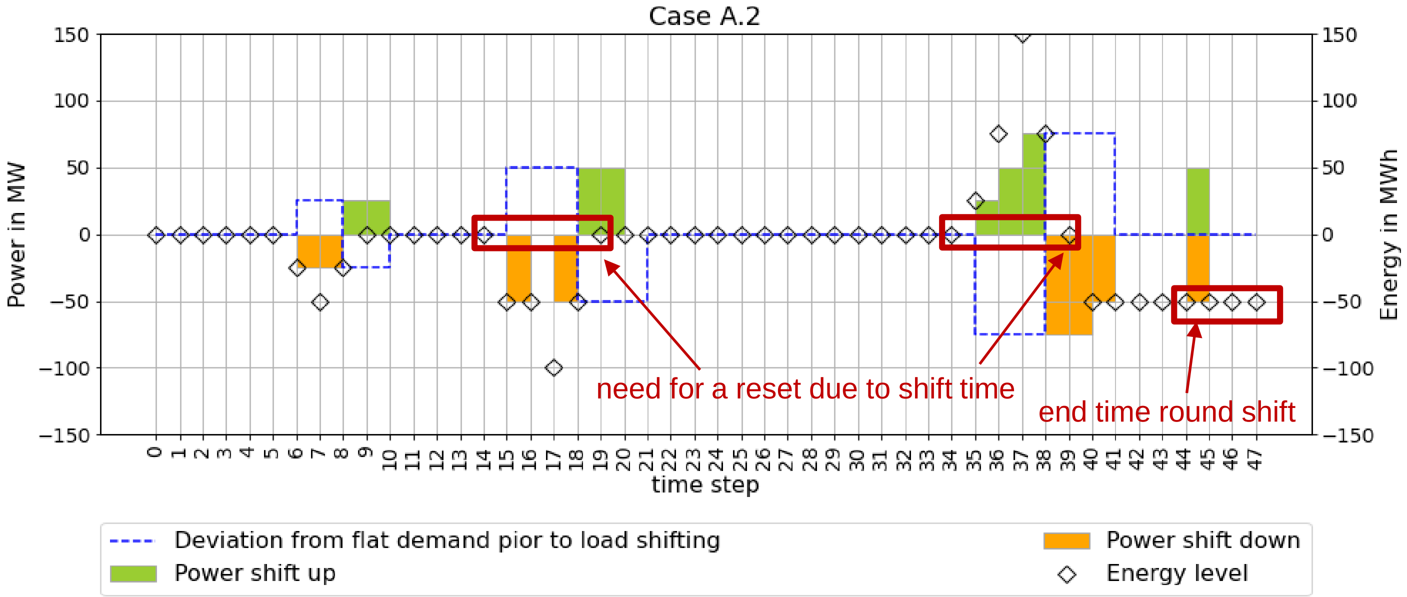


Condition: overall power shift < portfolio‘s power

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

Stylized test power system – duration limitiations (portfolio)

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

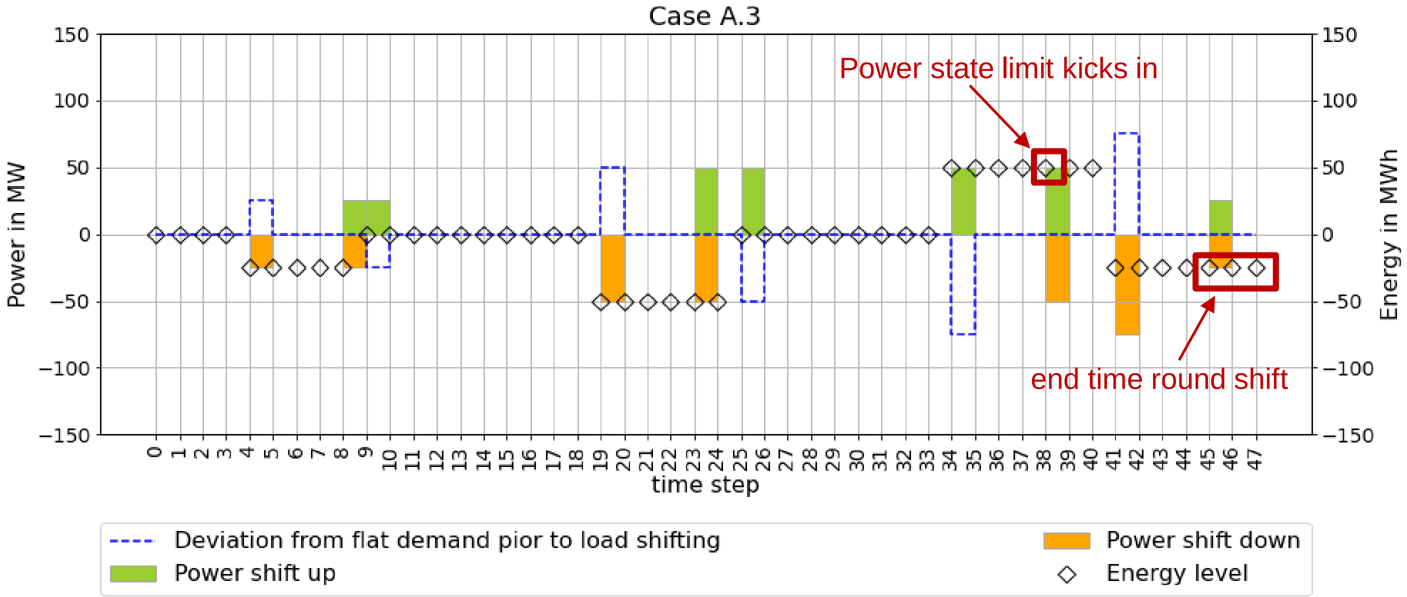


- **Resulting behaviour shows limitation on portfolio representation**
  - need for a reset after the maximum shift time
  - portfolio may not be sliced into arbitrary parts (as for fundamental models)
  - We observe some fringe effects at the end

Stylized test power system – prolonged shift time limitiations

- **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** is allowed, but to a limited extend since power limit may become binding.



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
	Gils (2015) DLR	Sym, Bal	X	X	X	(ST, LT)		X		LP	sec	Min SC
	Steurer (2017) IER	Sym		X	X			X		LP	sec	Min SC
	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

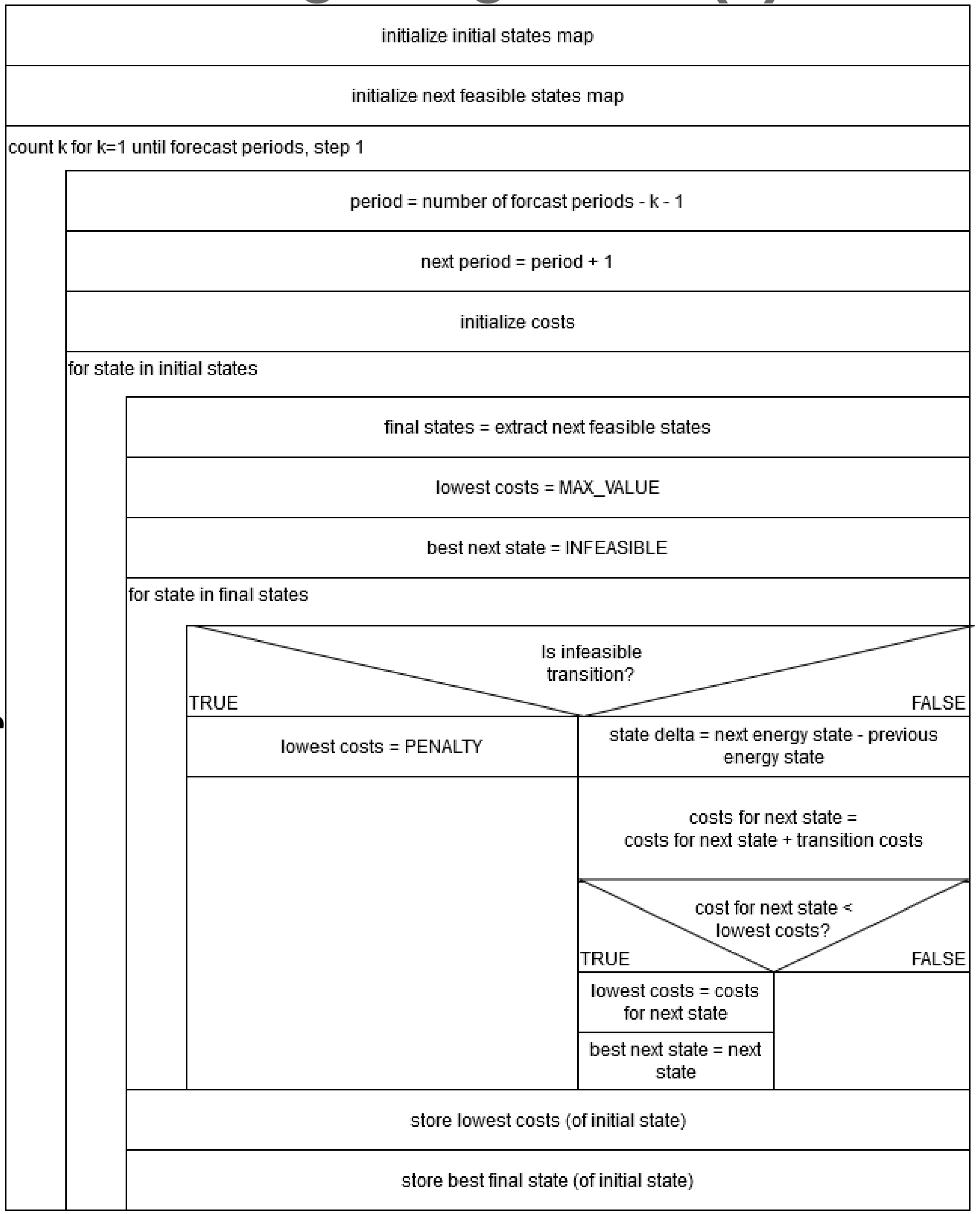
Abbreviations:

- 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