Assessing the impact of power tariff design on demand response potentials – A Case study for Germany

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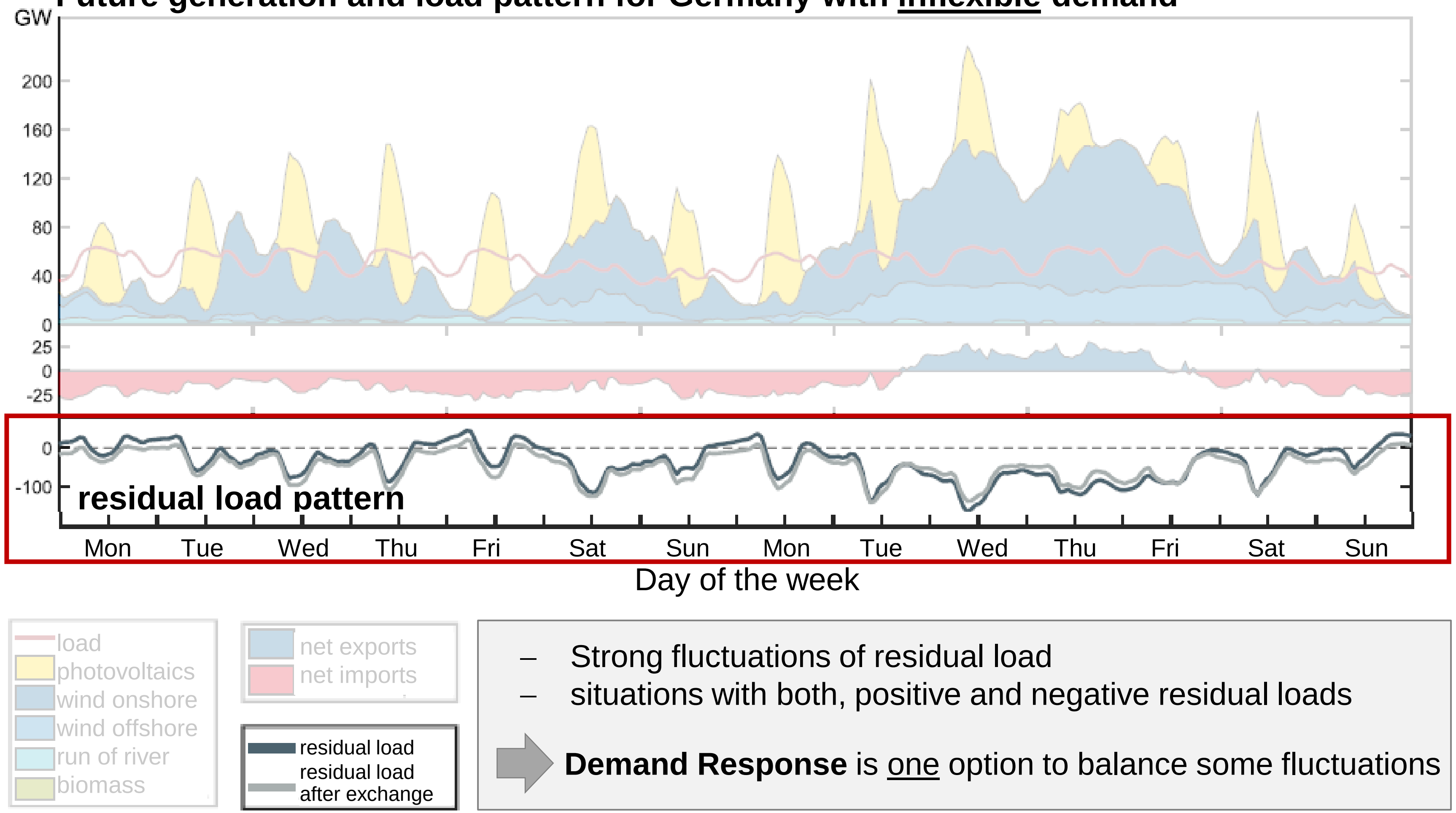
Motivation: Demand response as one option for balancing VRES*

Future generation and load pattern for Germany with inflexible demand



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

➜ **Demand Response** is one option to balance some fluctuations

but …

… *What **potentials** are there?*

… *(How) Would its dispatch be scheduled (from a **microeconomic** point of view)?*

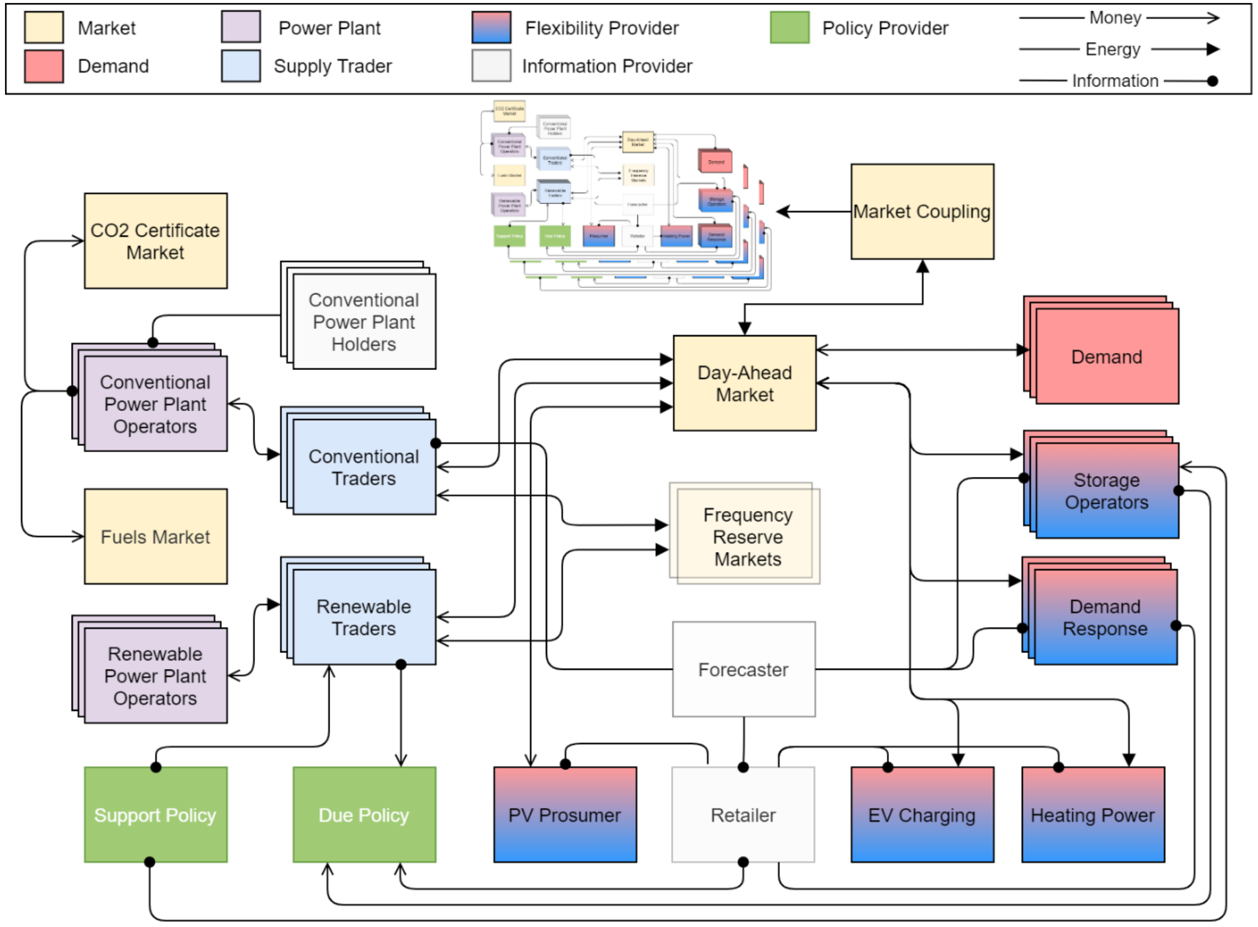
… *What are the effects of different scheduling strategies and varying **power tariff** designs?*

*VRES: variable renewable energy sources

source: [1, p. 31]; modified

AMIRIS at a glance

- **Agent-based simulation** of power markets (focusing on the Day-ahead market)



Input Data: Feed-in of renewables, temperature, balance energy price, marginal cost, load, ...

Agent-based Market model for the Investigation of Renewable and Integrated energy Systems

AMIRIS at a glance

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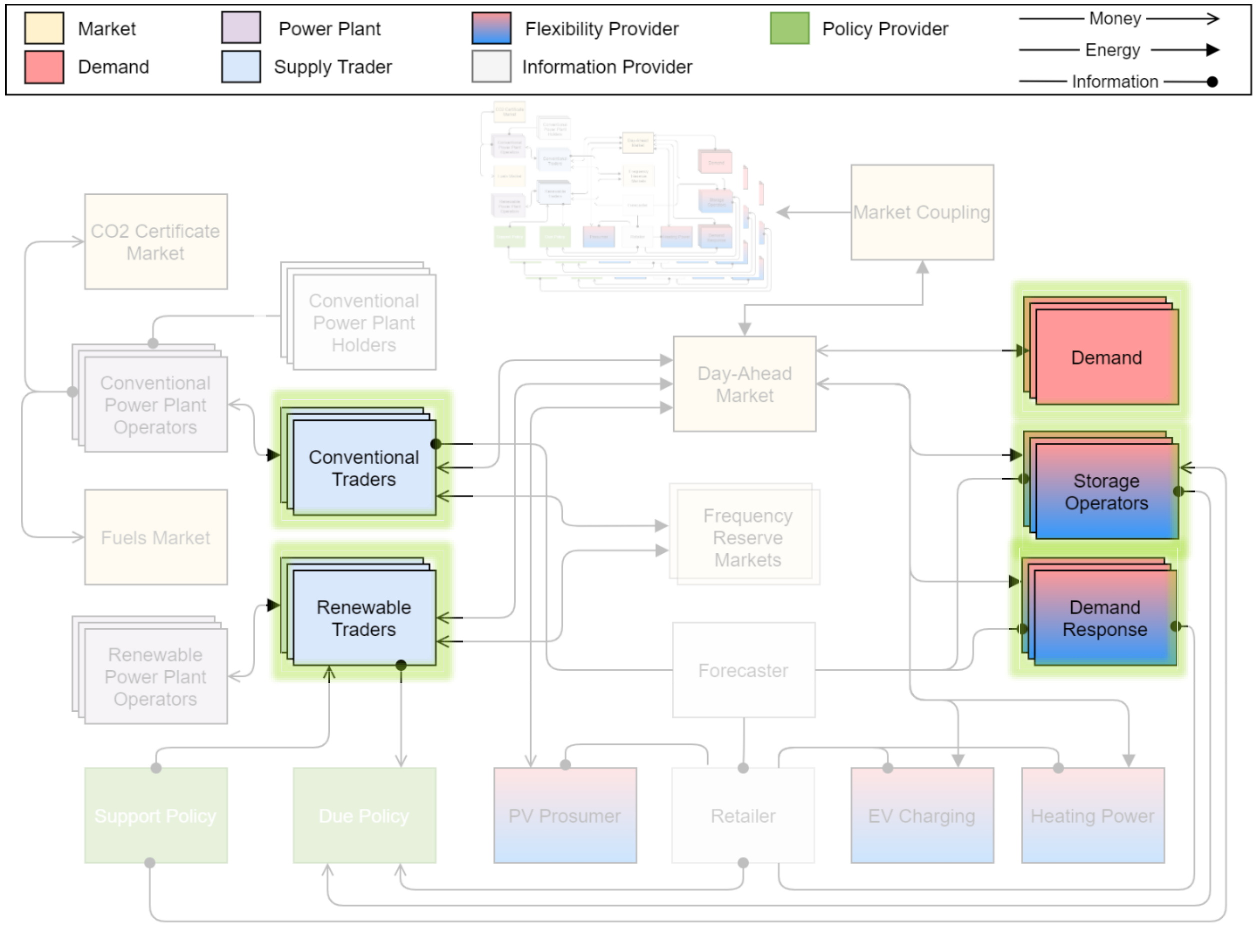
- Each trading agent has a **bidding strategy** for offering supply and/or demand bids to the Day-ahead Market.



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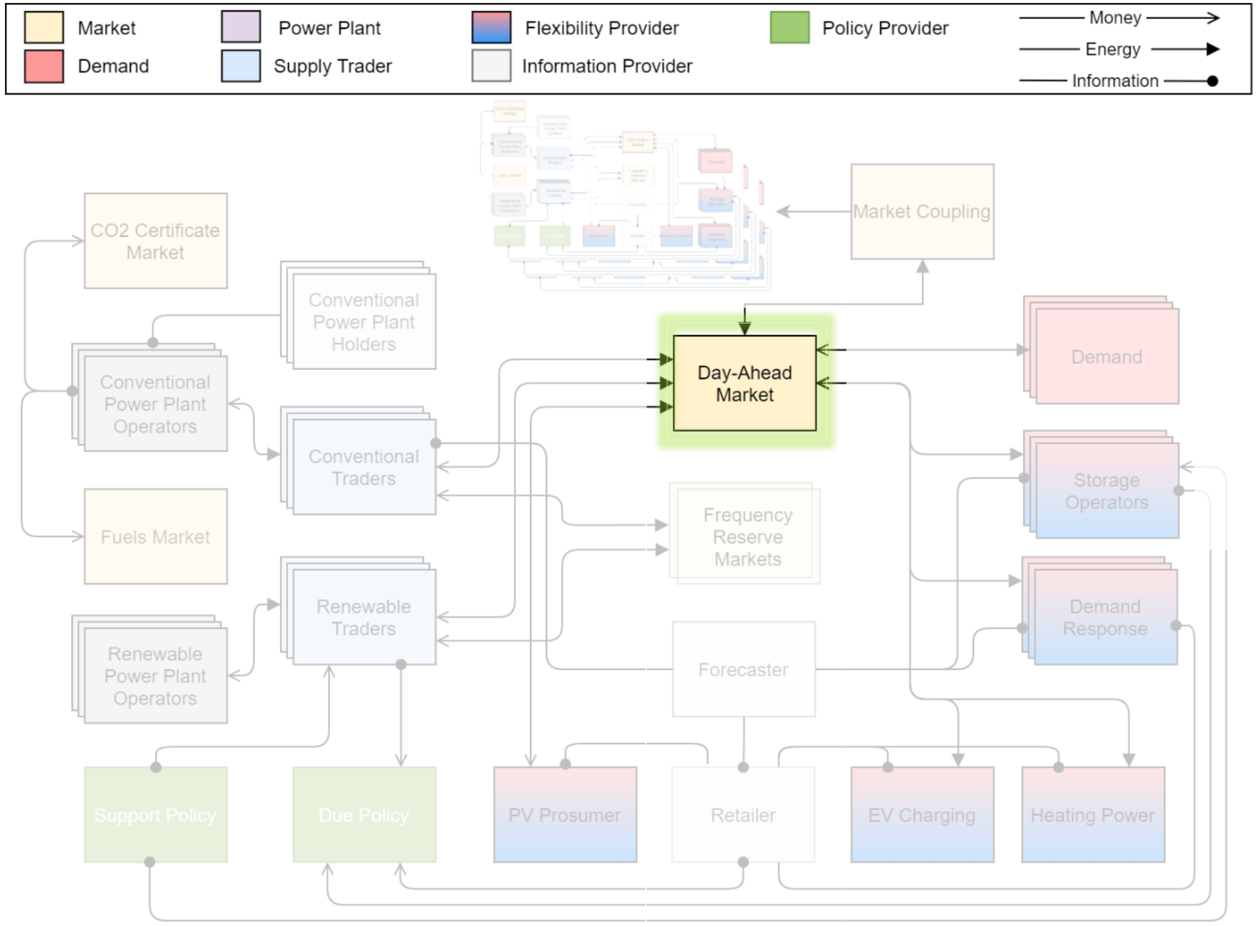
Agent-based Market model for the Investigation of Renewable and Integrated energy Systems

AMIRIS at a glance

- **Agent-based simulation** of power markets (focusing on the Day-ahead market)
- Each trading agent has a **bidding strategy** for offering supply and/or demand bids to the Day-ahead Market.
- Day-ahead Market is cleared by **intersecting aggregated demand and supply curves**.

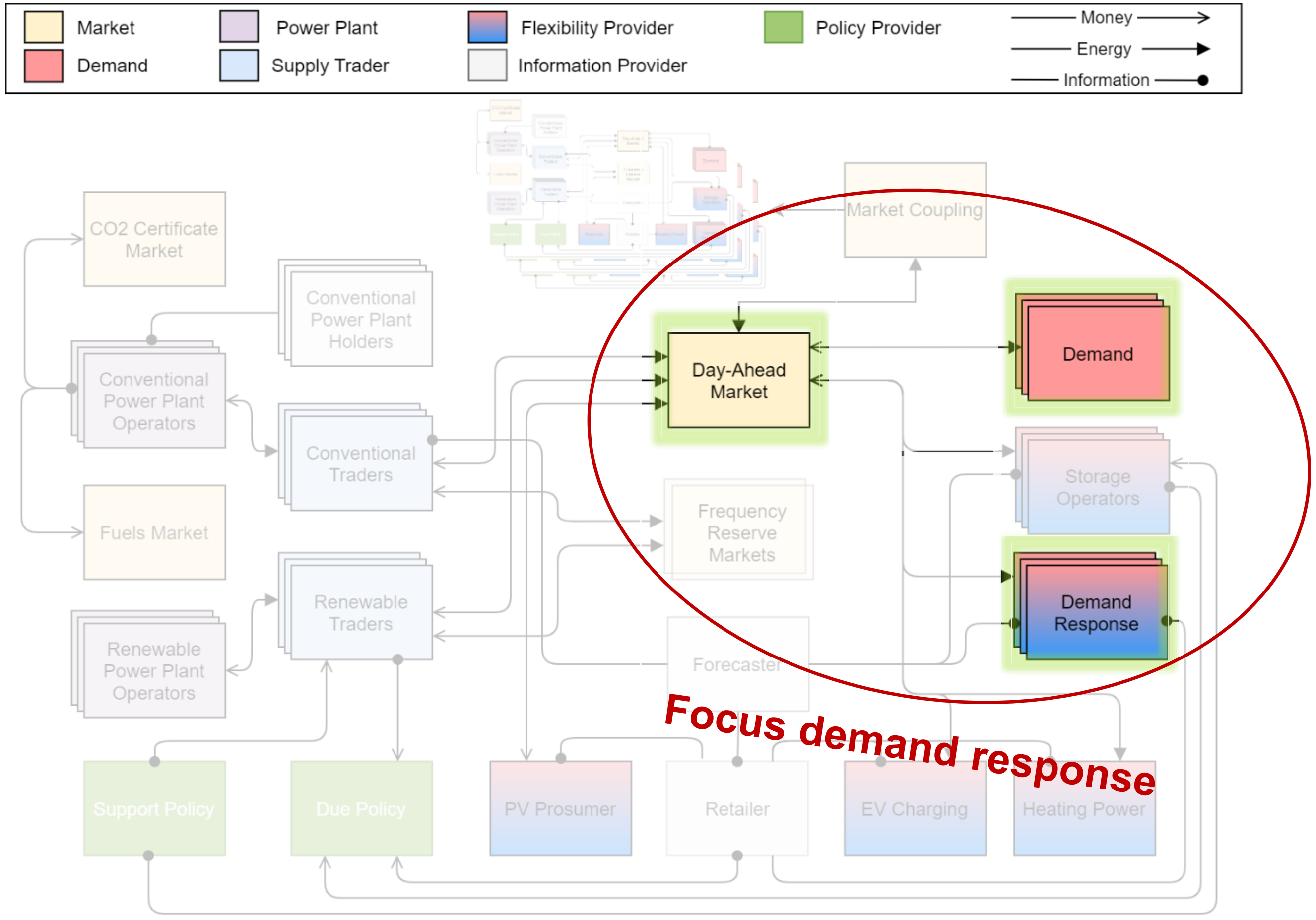


Input Data: Feed-in of renewables, temperature, balance energy price, marginal cost, load, ...

__A__gent-based __M__arket model for the __I__nvestigation of __R__enewable and __I__ntegrated energy __S__ystems

AMIRIS at a glance

- **Agent-based simulation** of power markets (focusing on the Day-ahead market)
- Each trading agent has a **bidding strategy** for offering supply and/or demand bids to the Day-ahead Market.
- Day-ahead Market is cleared by **intersecting aggregated demand and supply curves**.
- For **flexibility options**, we can easily analyse different **marketing strategies** (also responding to tariff design).



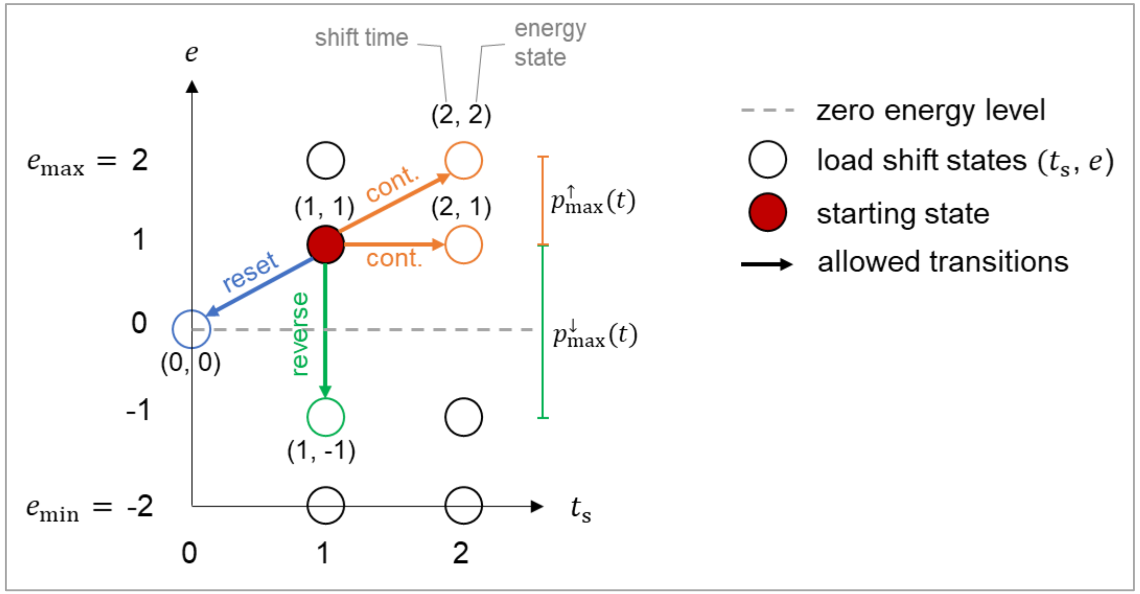
Input Data: Feed-in of renewables, temperature, balance energy price, marginal cost, load, ...

Modelling: Demand Response – load shifting

Load shifting modelled with dynamic programming

- Basic logics
  - dynamic programming
  - load shift **energy state** is **discretized**
- **Limits** which may not be violated
  - **shift time** → track it
  - **power** → constrain transition between hours
  - **energy** → constrain energy state grid
- A **strategist** controls the strategy
  - Used: Profit maximization considering power tariffs

allowed state transitions



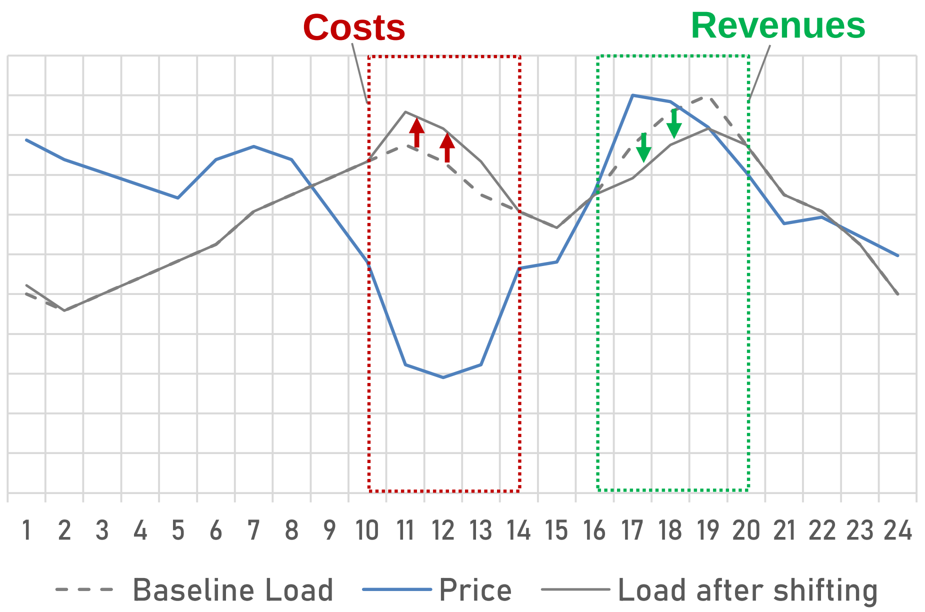
e:	energy state
e_{min}:	minimum energy state
e_{max}:	maximum energy state
t_s:	shift time
p:	power steps

Modelling: Marketing strategy & power tariffs

Maximize profit considering power tariffs and their design (static vs. dynamic)

Marketing strategy – profit maximization

- **Goal:** Maximize **profits** taking into account consumer power tariff



- Consider own price repercussion

Power tariffs design – building block approach

- **Tariff components**
  - Static: fixed payment per MWh or
  - Dynamic: indexed with day-ahead price (multiplier)
- **Parameterization approach**
  - Bounds
    - lower: 0
    - upper: 2x static value
  - Define multipliers such that

payments for static component with baseline demand
=
payments for dynamic component with baseline demand

Case study – Germany 2019

Evaluating microeconomic demand response potentials …

Power system based on open data

- Open power system data for capacities & efficiencies [4]
- Price data from BMWK / DESTATIS / EEX [5-8]
- Time series from SMARD [9]
- Data set publicly available at https://gitlab.com/dlr-ve/esy/amiris/examples

Load shedding options

Clusters	variable costs in $€_{2018}$/MWh
Industry cluster shifting	**194**
Households cluster	300
Industry cluster shedding	574
Industry cluster combined	**864**

No shedding activity → price level too low

Load shifting option analyzed (industry cluster)

Characteristic	Value
processes & applications	processes (e.g. paper industry); cross-cutting technologies (e.g. ventilation)
maximum positive potential (load reduction)	2079 MW
maximum negative potential (load increase)	1627 MW
maximum simultaneous load	5848 MW
maximum shifting duration	6 h
variable costs	160.4 $€_{2018}$/MWh

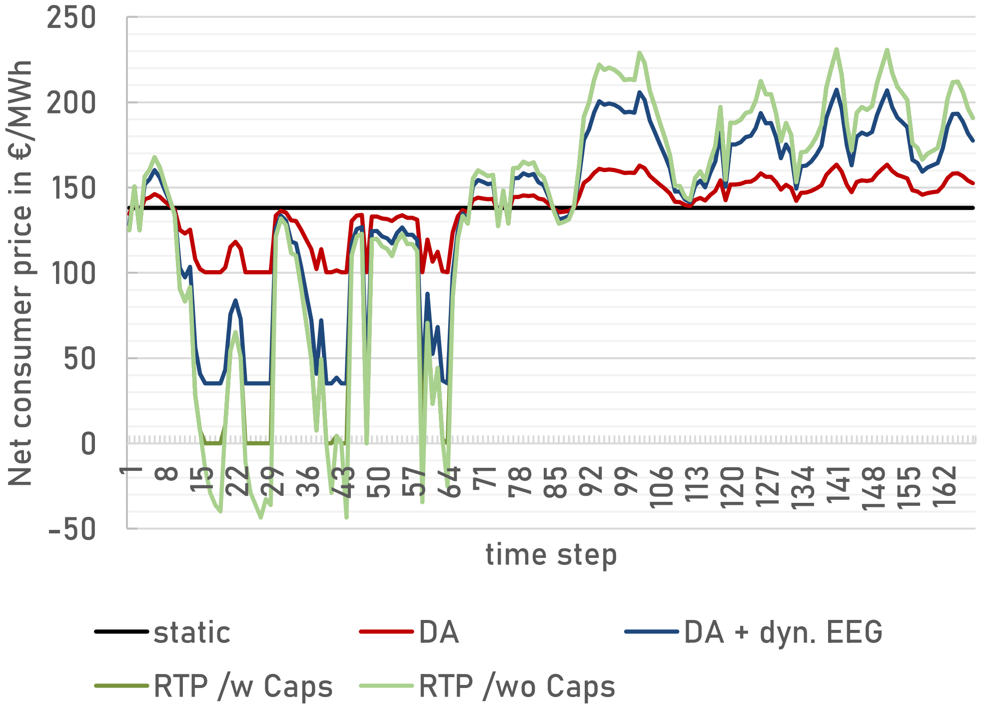
Analyze sensitivities:
1 €/MWh, 10 €/MWh, 20 €/MWh

Sources for demand response parameters: [2; 3]

Case study – Germany 2019

… for five different power tariff models

	Static		DA		DA + dyn. EEG		RTP /w Caps		RTP /wo Caps	
Price component	**Dyn.**	**Caps**	**Dyn.**	**Caps**	**Dyn.**	**Caps**	**Dyn.**	**Caps**	**Dyn.**	**Caps**
Power price (day-ahead)	✗	–	✓	✓	✓	✓	✓	✓	✓	✗
EEG levy	✗	–	✗	–	✓	✓	✓	✓	✓	✗
volumetric network charge	✗	–	✗	–	✗	–	✓	✓	✓	✗
other volumetric price components	✗	–	✗	–	✗	–	✓	✓	✓	✗



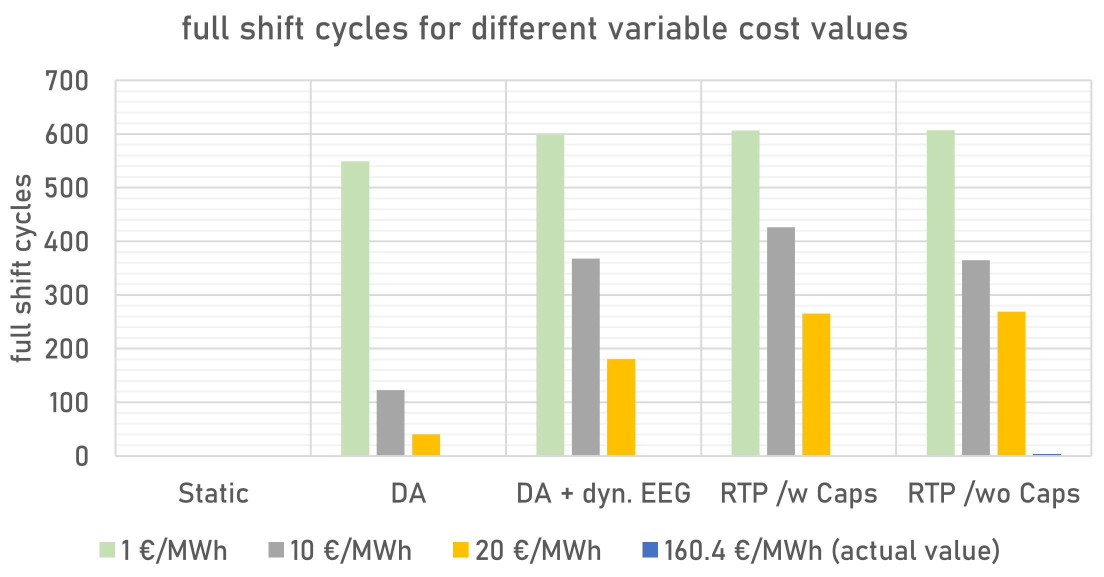
Dyn.: dynamic; Caps: upper and lower bound contained
DA: day-ahead prices passed onto consumers; RTP: real-time pricing

Sources for tariff design: [10-18]

Case study Results: Impact of static vs. dynamic prices

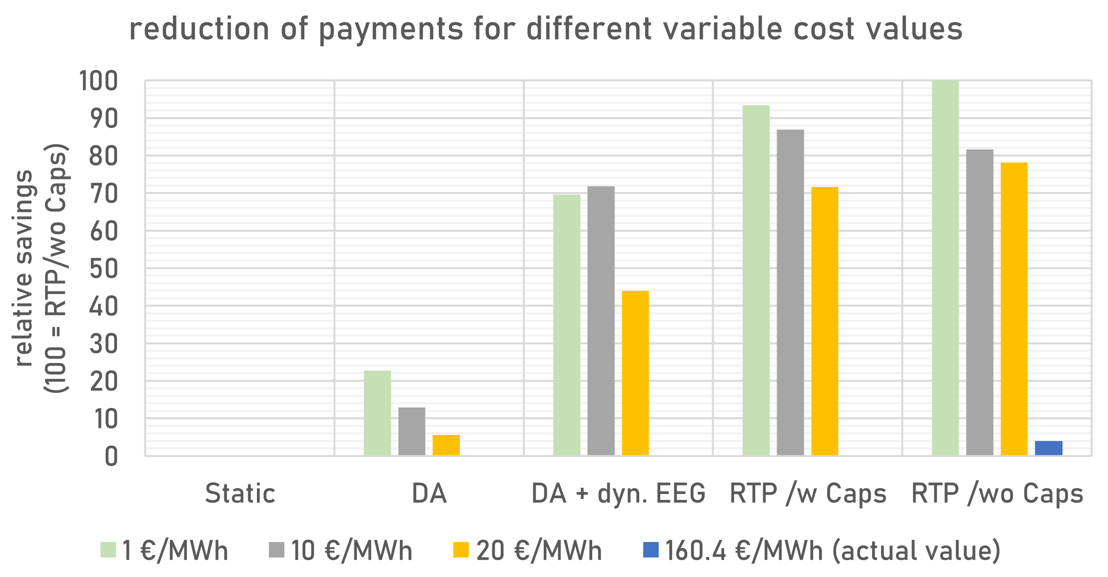
Activations rise with increasing dynamic tariff share. So do achievable savings.

Shift cycles



- Full shift cycle: Activation (upshift & downshift) with maximum energy
- Low starting level for higher variable costs (20 €/MWh)
- Saturation for low variable costs (1 €/MWh)

Achieved savings



- Savings rise with increasing dynamic tariff share
- drastic change, when EEG levy (~ 40 % of consumer tariff) is made dynamic

Conclusion & outlook

We layed the foundation to study impacts of power tariffs on demand response potentials

Conclusion

1. **Higher dynamic tariff shares** incentivize more market-based demand response, but **low variable costs** are a prerequisite.

2. Load shedding is not utilized due to **insufficient price level**.

Limitations

- **(Competing) Flexibility**
  - Other flexibility options not considered
  - Perfect foresight price prognosis
- **Tariffs**
  - Capacity-related tariffs not considered
  - EEG levy to be tax financed at latest from 2023 on
  - Parameterization of dynamic tariffs requires thorough design

Outlook

- Study conflicting incentives with capacity-related components
- Compare system optimization against agent-based potential

Thank you!

Contact information

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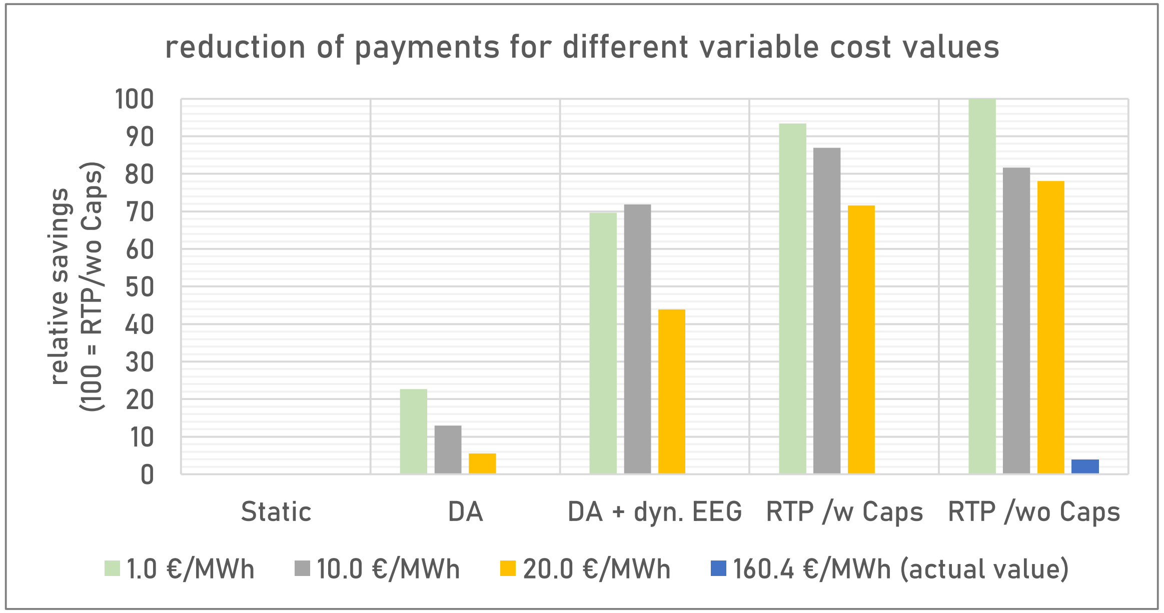

Sources 1/2

[1] N. Gerhardt; D. Böttger; T. Trost; A. Scholz; C. Pape; A.-K. Gerlach; P. Härtel; I. Ganal, Analyse eines europäischen -95%-Klimazielszenarios über mehrere Wetterjahre. Teilbericht im Rahmen des Projektes: Klimawirksamkeit Elektromobilität - Entwicklungsoptionen des Straßenverkehrs unter Berücksichtigung der Rückkopplung des Energieversorgungssystems in Hinblick auf mittel- und langfristige Klimaziele, im Auftrag des BMUB, Fraunhofer IWES, Kassel, 2017.

[2] J. Kochems, Lastflexibilisierungspotenziale in Deutschland - Bestandsaufnahme und Entwicklungsprojektionen. Langfassung, In: IEE TU Graz (Hrsg.): EnInnov 2020 - 16. Symposium Energieinnovation. Energy for Future - Wege zur Klimaneutralität. Graz, 12.-14.02.2020, https://www.tugraz.at/fileadmin/user_upload/tugrazExternal/4778f047-2e50-4e9e-b72d-e5af373f95a4/files/lf/Session_E5/553_LF_Kochems.pdf, accessed 11.05.2020.

[3] J. Kochems, “Demand response potentials for Germany: potential clustering and com-parison of modeling approaches,” in INREC 2020: 9th International Ruhr Energy Conference, Duisburg / online, 2020.

[4] J. Weibezahn, R. Weinhold, C. Gerbaulet, and F. Kunz, “Conventional power plants,” Open Power System Data, 2020, doi: https://doi.org/10.25832/conventional_power_plants/2020-10-01

[5] BMWK, “Zahlen und Fakten: Energiedaten: Nationale und internationale Entwicklung,” Letzte Aktualisierung: 27.09.2021, Berlin, 2021. Accessed: Jan. 29 2022. [Online]. Available: https://www.bmwi.de/Redaktion/DE/Artikel/Energie/energiedaten-gesamtausgabe.html

[6] DESTATIS, “Prices: Data on energy price trends: Prices - Long-time series from January 2005 to December 2021 -,” Statistisches Bundesamt, Wiesbaden, 2022. Accessed: Jan. 29 2022. [Online]. Available: https://www.destatis.de/EN/Themes/Economy/Prices/Publications/Downloads-Energy-Price-Trends/energy-price-trends-pdf-5619002.pdf?__blob=publicationFile

[7] r2b, Consentec, Fraunhofer ISI, and TEP, “Definition und Monitoring der Versorgungssicher- heit an den europäischen Strommärkten: Erster Projektbericht; Projekt Nr. 047/16,” im Auftrag des Bundesministeriums für Wirtschaft und Energie, Köln, Jan. 2019. Accessed: Jan. 29 2022. [Online]. Available: https://www.bmwi.de/Redaktion/DE/Publikationen/Studien/definition-und-monitoring-der-versorgungssicherheit-an-den-europaeischen-strommaerkten.pdf?__blob=publicationFile&v=18

[8] EEX, “Emission Spot Primary Market Auction Report 2019,” Leipzig, 2020. Accessed: Jan. 29 2022. [Online]. Available: https://www.eex.com/de/marktdaten/umweltprodukte/eex-eua-primary-auction-spot-download

Sources 2/2

[9] BNetzA, “SMARD: Marktdaten,” 2022. Accessed: Jan. 29 2022. [Online]. Available: https://www.smard.de/home/downloadcenter/download-marktdaten

[10] ÜNB, “EEG-Umlage: netztransparenz.de,” Accessed: Jan. 29 2022. [Online]. Available: https://www.netztransparenz.de/EEG/EEG-Umlagen-Uebersicht

[11] ÜNB, “KWK-Umlage,” netztransparenz.de. Accessed: Jan. 29 2022. [Online]. Available: https://www.netztransparenz.de/KWKG/KWKG-Umlagen-Uebersicht

[12] ÜNB, “§ 19 StromNEV-Umlage: netztransparenz.de,” Accessed: Jan. 29 2022. [Online]. Available: https://www.netztransparenz.de/EnWG/-19-StromNEV-Umlage/-19-StromNEV-Umlagen-Uebersicht

[13] ÜNB, “Offshore-Netzumlage: netztransparenz.de,” Accessed: Jan. 29 2022. [Online]. Available: https://www.netztransparenz.de/EnWG/Offshore-Netzumlage/Offshore-Netzumlagen-Uebersicht

[14] ÜNB, “Abschaltbare Lasten-Umlage: netztransparenz.de,” Accessed: Jan. 29 2022. [Online]. Available: https://www.netztransparenz.de/EnWG/-19-StromNEV-Umlage/-19-StromNEV-Umlagen-Uebersicht

[15] Stuttgart Netze, “Preise und Regelungen für die Nutzung des Stromverteilnetzes gültig ab 1. Januar 2021: Version 2.0,” Preisblatt der Stuttgart Netze GmbH, Stuttgart, Dec. 2020. Accessed: Jan. 29 2022. [Online]. Available: https://www.stuttgart-netze.de/media//filer_public/27/00/27009045-05ad-4a9b-9d5d-bde1fce4a306/255_20210210_preise_und_regelungen_2021_v20.pdf

[16] BDEW, Strompreisanalyse Juni 2021, https://www.bdew.de/media/documents/BDEW-Strompreisanalyse_no_halbjaehrlich_Ba_online_10062021.pdf, accessed 01.09.2021, 2021.

[17] Stromsteuergesetz vom 24. März 1999 (BGBl. I S. 378; 2000 I S. 147), das zuletzt durch Artikel 6 des Gesetzes vom 30. März 2021 (BGBl. I S. 607) geändert worden ist: StromStG.

[18] Konzessionsabgabenverordnung vom 9. Januar 1992 (BGBl. I S. 12, 407), die zuletzt durch Artikel 3 Absatz 4 der Verordnung vom 1. November 2006 (BGBl. I S. 2477) geändert worden ist: KAV.

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Parameterization

Technical demand response potentials derived from meta-analysis & clustered

Meta-analysis – technical potentials

Kochems (2020a) [2]

- **literature** from 2005-2018*
- 30 publications (24 groups)

	parameters
capacity	eligibility for shifting / shedding
capacity	**positive shifting / shedding potential (load reduction) in MW**
capacity	**negative shifting potential (load increase) in MW**
capacity	average / minimum / maximum load
capacity	installed power / shiftable share
time	activation duration
time	**interference duration**
time	**shifting duration**
time	regeneration duration
time	maximum activations (per year)
costs	**specific investment expenses**
costs	**variable & fixed costs**

**Update ongoing*

… for all
- processes
- years SQ, 2020, 2025, …, 2050
- sectors (ind, tcs, hoho)

Clustering & time series

Kochems (2020b) [3]

- **Clustering**
  - Cluster parameters: positive interference & shifting duration, cost parameters
  - K-Means clustering within sectors
- **Load profiles**
  - profiles per branch (Wirtschaftszweig WZ) from Demand Regio disaggregator
  - derived from downwards shifting availability (no min. load)
- **Availability timeseries up / down**
  - literature-based: data, esp. [19]-[22]; DWD temperature data
  - data lacks filled with assumptions

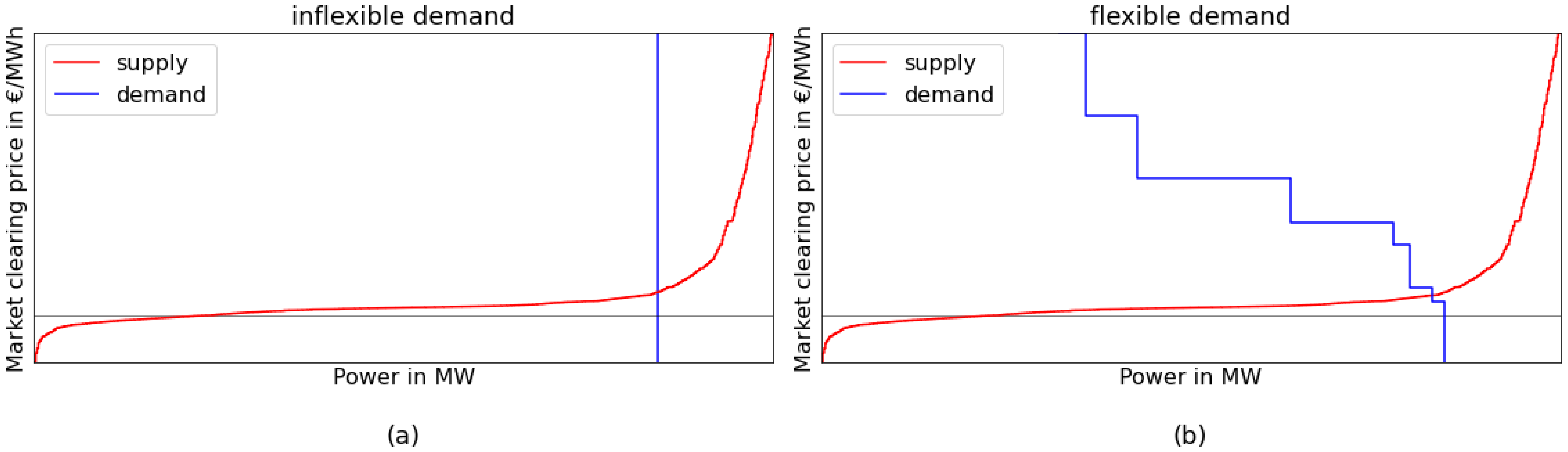
Extensions made

- Stricter distinction between shifting & shedding
- Usage of 5%, 50% and 95% percentiles
- Major code revision & improvement

SQ: status quo; ind: industry; tcs: trade, commerce, services; hoho: households

Modelling: Demand Response – load shedding

Load shedding modelled by introducing segmentation of demand curve



- 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)

Technical demand response potentials – major findings

Potential for industrial processes & cross-cutting technologies; heterogeneous data quality

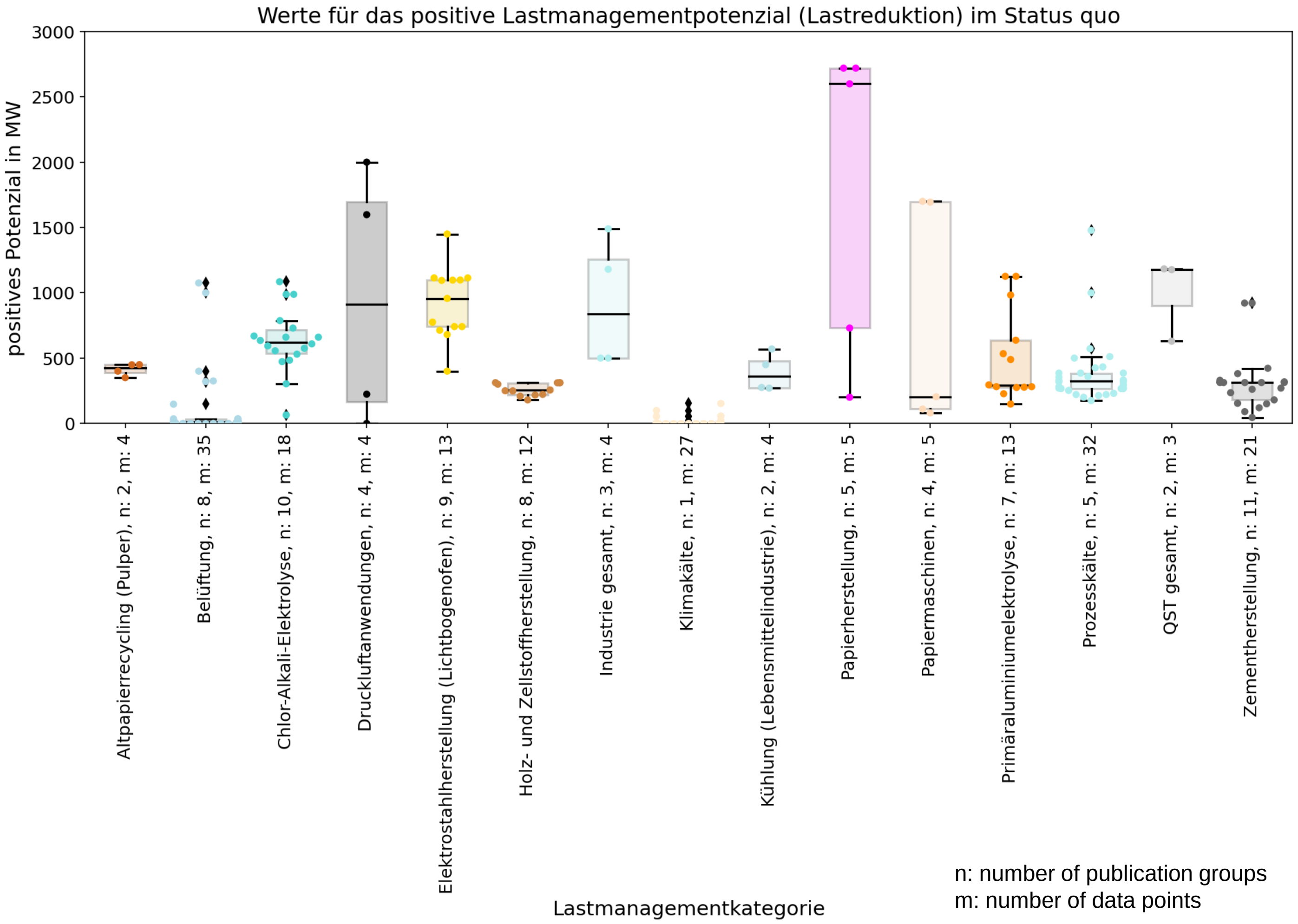
Potentials

Sector	Potentials
Industry	• Energy-intense processes, e.g. primary aluminium, chlorine electrolyses (esp. shedding) • Cross-cutting, e.g. pressurized air
tcs	• Heating & cooling • Cross-cutting, e.g. ventilation
House-holds	• Heating & cooling • White goods • Not (yet) evaluated: electric vehicles

Data quality trends

Parameters	Ind	tcs	hoho
Capacity-related			
Time-related			
Cost-related			

	Good: double-digit data points
	Medium: 1-3 publications; single-digit data points
	Bad: 1-2 publications; 1-3 data points



n: number of publication groups
m: number of data points

source: based on [2]

Technical demand response potentials – clustering results

Seven demand response clusters derived

Industry cluster shifting	Paper industry	mechanical and chemical wood pulp, paper machines, paper recycling
	Processes	air separation units
	Cross-cutting technologies	ventilation, process cold, climate cold, compressed air
Industry cluster shedding	Processes	electric arc steel-making
Industry cluster shifting and shedding	Processes	Chlor-alkali electrolysis, Primary aluminium electrolysis, cement mills, copper and zinc electrolysis, foundries (arc furnace), calcium carbide production (arc furnace)
	Cross-cutting technologies	Cooling (food industry)
Commerce cluster	Cross-cutting technologies in general	Process cold, ventilation, lighting, process heat
	Other	pumps in drinking water supply, crushers (recycling industry), cold stores, process cold (retailing industry)
Household cluster shifting	White Goods	refridgerators, dishwashers, tumble dryers, washing machines, freezers, fridge-and-freezer combination
Household cluster shifting & shedding	Heating	Heat circulation pumps
Commerce & households cluster (heating and cooling)	Heating applications	Heat pumps, night storage heating, hot water supply
	Cooling applications	Climate cold (air conditioning)

source: based on [3]

Tariff components

Assumed payment obligations for an industrial consumer cluster

<table>
<tr><th>Tariff component</th><th>Static value in €/MWh</th><th>Multiplier</th><th>Cap / Floor in €/MWh</th></tr>
<tr><td>EEG surcharge</td><td>65</td><td>1.707</td><td>0 / 130.0</td></tr>
<tr><td>Volumetric network charge</td><td>11.7</td><td>0.306</td><td>0 / 23.4</td></tr>
<tr><td>Electricity tax</td><td>15.37</td><td rowspan="2">0.617</td><td rowspan="2">0 / 47.1</td></tr>
<tr><td>Other surcharges (sum)</td><td>8.18</td></tr>
<tr><td>Wholesale price (base)</td><td>37.84</td><td>0.991</td><td>0 / 200.0</td></tr>
<tr><td>SUM (net electricity price; excl. margin)</td><td>138.9</td><td></td><td></td></tr>
</table>

Sources for tariff design: [10-18]

Backup Sources

[19] M. Steurer, “Analyse von Demand Side Integration im Hinblick auf eine effiziente und umweltfreundliche Energieversorgung,” Dissertation, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universität Stuttgart, Stuttgart, 2017.

[20] C. Pellinger and T. Schmid, “Verbundforschungsvorhaben Merit Order der Energiespeicherung im Jahr 2030: Teil 2: Technoökonomische Analyse Funktionaler Energiespeicher,” FfE, München, May. 2016. Accessed: Mar. 20 2019.

[21] T. Ladwig, “Demand Side Management in Deutschland zur Systemintegration erneuerbarer Energien,” Dissertation, Technische Universität Dresden, Dresden, 2018.

[22] H. C. Gils, “Balancing of Intermittent Renewable Power Generation by Demand Response and Thermal Energy Storage,” Dissertation, Universität Stuttgart, Stuttgart, 2015.