Energy flexibility in German industry

An economic model-based analysis of parallel revenue streams from batteries

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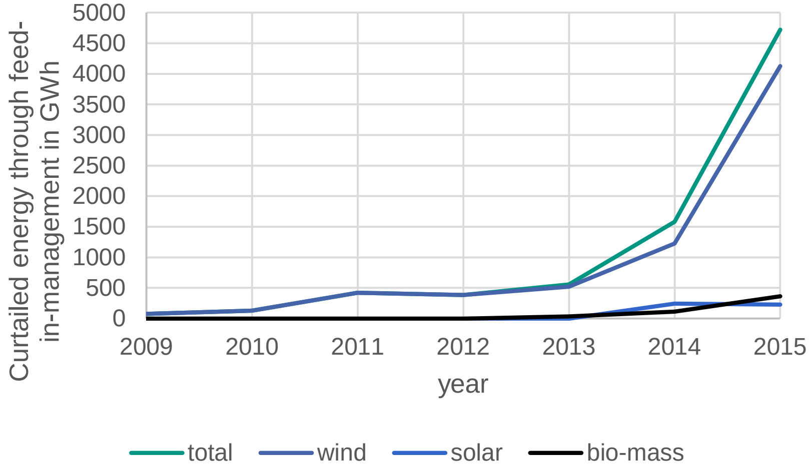
Agenda

- Why energy flexibility?
- Battery revenue streams
- Research question
- The flex-model
- Results
- Conclusion/Outlook

Why energy flexibility?

- Integration of growing amount of renewable energy (International Electrotechnical Commission (2011))
- Avoid grid extension (Reid und Julve (2016); Bolay et al. (2016))
- Prices for battery storage systems (BSS) have dropped (Kairies et al. (2016))



Curtailed energy through feed-in-management in Germany (Bundesnetzagentur (2016))

Why energy flexibility?

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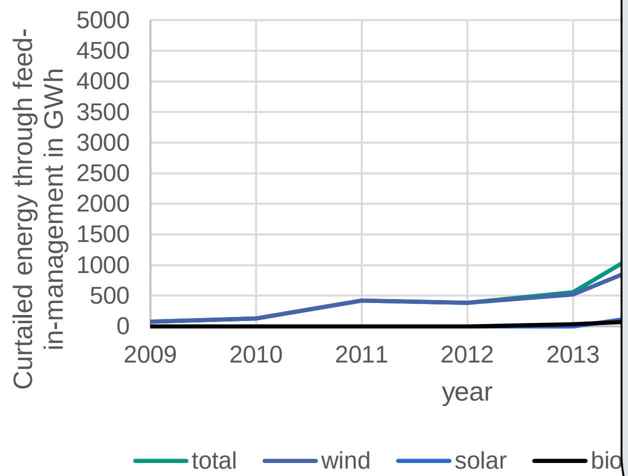

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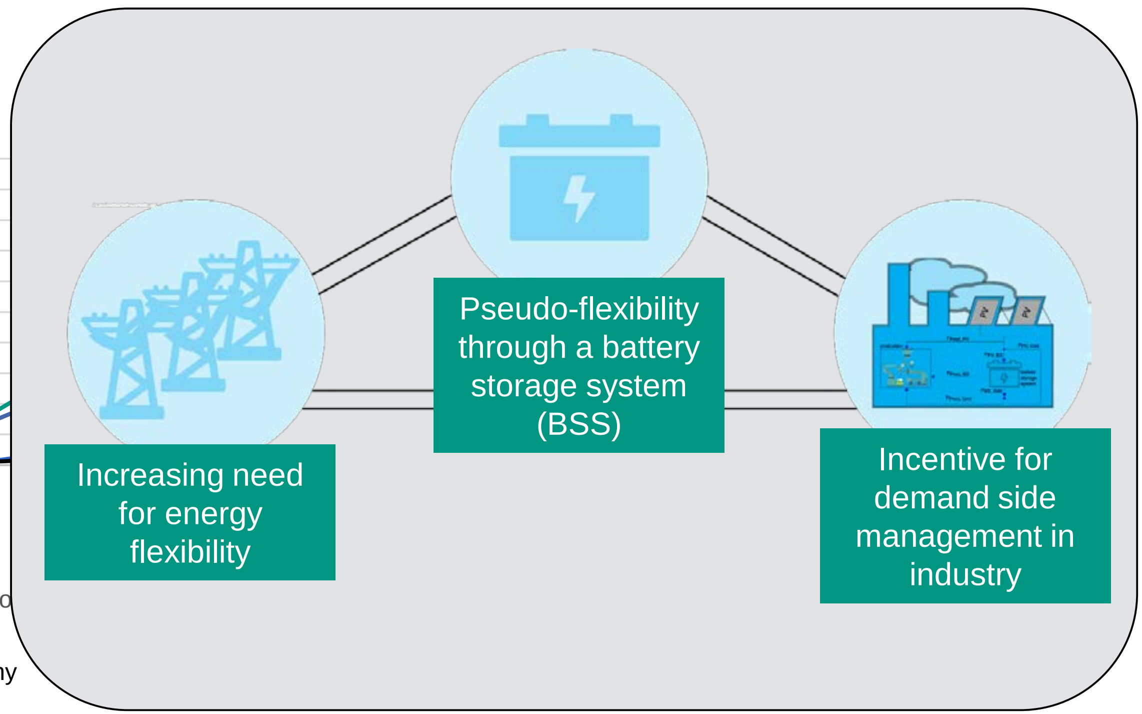

Battery revenue streams

Balancing control power

- Primary Balancing Control
- Secondary Balancing Control

Arbitrage trading

- Day-ahead market
- Intraday market

Peak shaving

- Capacity prices for grid connection
- Individual grid prices

Increasing self-consumption

- Utilizing own energy production
- PV, Wind or CHP

Battery revenue streams

Reserve power

- Primary balancing control
- Secondary balancing control
- Back-up power

Arbitrage Ttading

- Day-ahead market
- Intraday market

Peak shaving

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Battery revenue stream

Arghandeh, R. et al. 2014

Reserve power

- Primary balancing control
- Secondary balancing control
- Back-up power

Arbitrage Ttading

- y-ahead market
- aday market

Cho, J. and Kleit, A. 2015;

Dowling, A. et al. 2017

Moreno, R. et al. 2015

Stephan, A. et al. 2016

Peak shaving

- Capacity prices for grid connection
- Individual grid prices

Increasing self-consumption

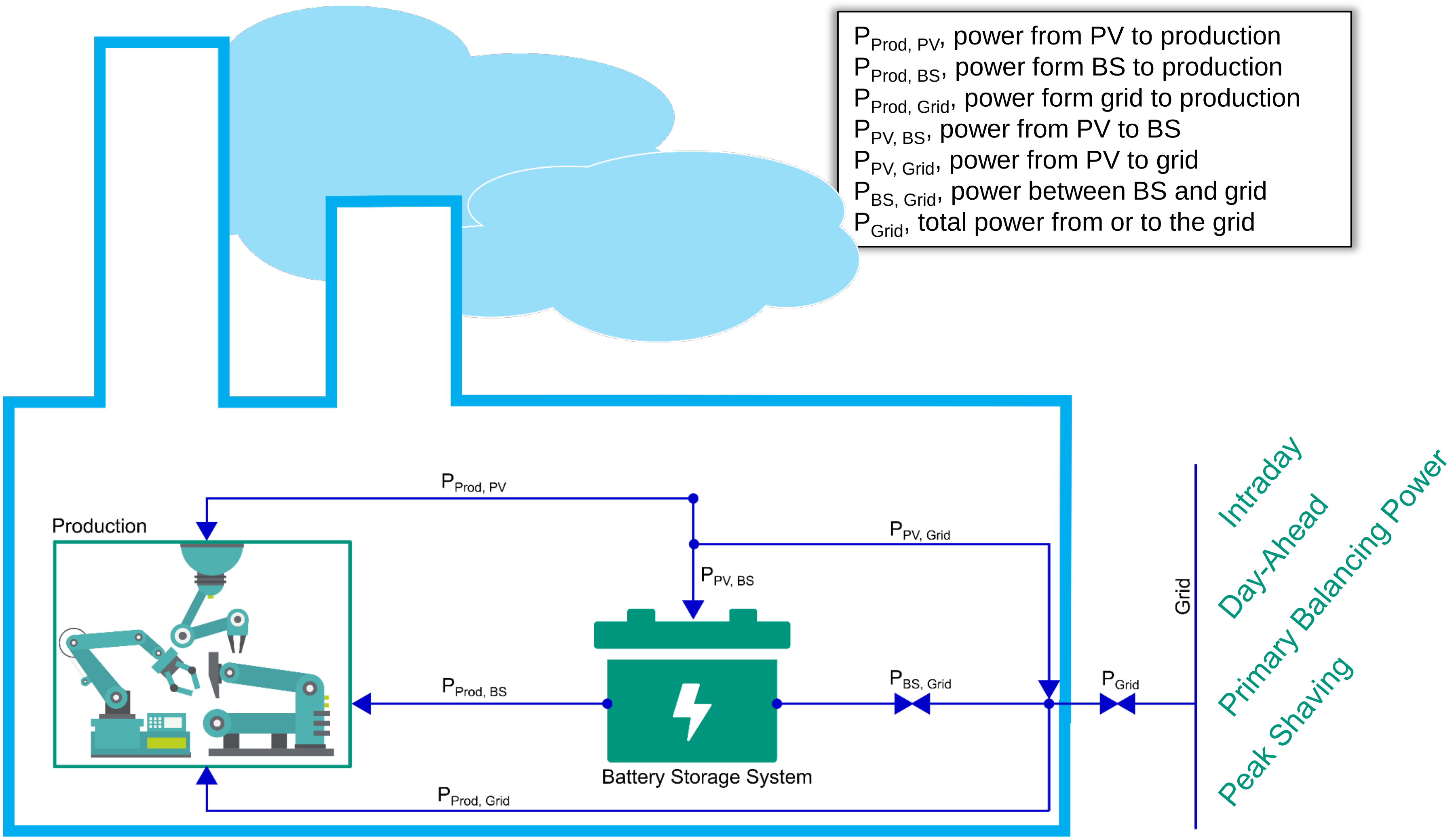
- Utilizing own energy production
- PV, Wind or CHP

Research question

- By following different revenue streams in parallel, can we increase the profitability of a battery storage system (BSS)?

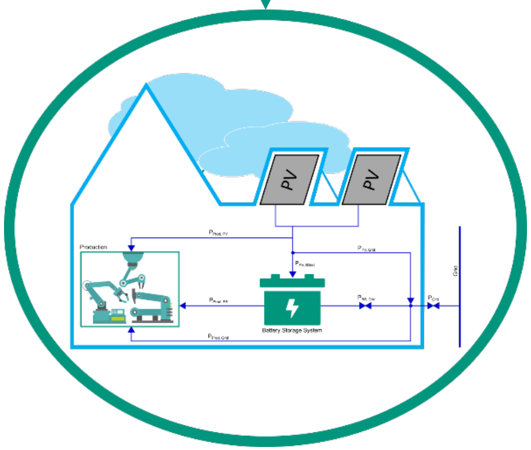
The flex-model

$P_{Prod,\ PV}$, power from PV to production
$P_{Prod,\ BS}$, power form BS to production
$P_{Prod,\ Grid}$, power form grid to production
$P_{PV,\ BS}$, power from PV to BS
$P_{PV,\ Grid}$, power from PV to grid
$P_{BS,\ Grid}$, power between BS and grid
P_{Grid}, total power from or to the grid



Model explanation

Energy demand and
supply profiles



Battery dispatch schedule

Model explanation

$$\min cost_{var} = \sum_{q=1}^{4} x_{q,h,w}^{intra} \cdot c_{q,h,w}^{intra}$$

$$\min cost_{var} = \sum_{h=1}^{168} \left(\sum_{q=1}^{4} x_{q,h,w}^{intra} \cdot c_{q,h,w}^{intra} \right) + x_{h,w}^{hour} \cdot c_{h,w}^{hour}$$

} Arbitrage

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} Arbitrage

$$\min cost_{var} = \sum_{w=1}^{50} \left(\sum_{h=1}^{168} \left(\sum_{q=1}^{4} x_{q,h,w}^{intra} \cdot c_{q,h,w}^{intra} \right) + x_{h,w}^{hour} \cdot c_{h,w}^{hour} \right) + P_{w}^{PRL} \cdot c_{w}^{PRL}$$

} Primary balancing power (PBP)

Model explanation

Arbitrage:

$$\min cost_{var} = \sum_{q=1}^{4} x_{q,h,w}^{intra} \cdot c_{q,h,w}^{intra}$$

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Peak shaving:

$$\min cost_{var} = \left(\sum_{w=1}^{50} \left(\sum_{h=1}^{168} \left(\sum_{q=1}^{4} x_{q,h,w}^{intra} \cdot c_{q,h,w}^{intra} \right) + x_{h,w}^{hour} \cdot c_{h,w}^{hour} \right) + P_{w}^{PRL} \cdot c_{w}^{PRL} \right) + P^{Peak} \cdot c^{Peak}$$

Model explanation

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Arbitrage

$$\min cost_{var} = \sum_{w=1}^{50} \left(\sum_{h=1}^{168} \left(\sum_{q=1}^{4} x_{q,h,w}^{intra} \cdot c_{q,h,w}^{intra} \right) + x_{h,w}^{hour} \cdot c_{h,w}^{hour} \right) + P_{w}^{PRL} \cdot c_{w}^{PRL}$$

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Peak shaving

Investment annuity:

$$\min cost = cost_{var} + Inv_{BSS} \cdot Ann_{i,T}$$

Model explanation

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} Peak shaving

- MILP
- **30** blocks of variables - **848,552** single variables
- **41** blocks of equations – **798,053** single equations
- **50** discrete variables
- Implemented in GAMS
- CPLEX solver

Investment annuity:

$$\min cost = cost_{var} + Inv_{BSS} \cdot Ann_{i,T}$$

Input data

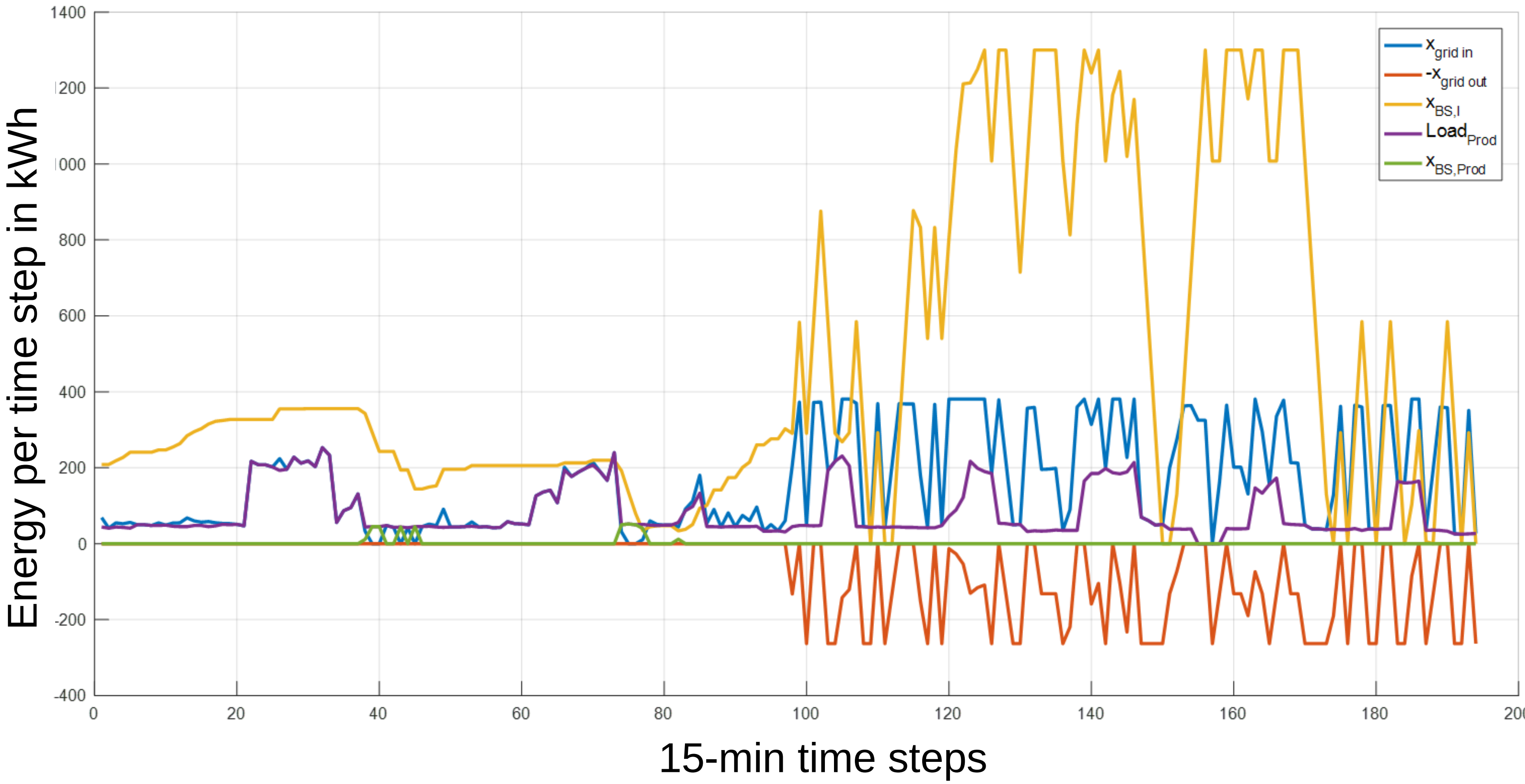
- Base year 2016
- 5 industrial load profiles

Company	1	2	3	4	5
Peak load in kW	391	1793.5	362.9	2797.6	120.3
Yearly demand in MWh	2345	25312	810	67518	1532

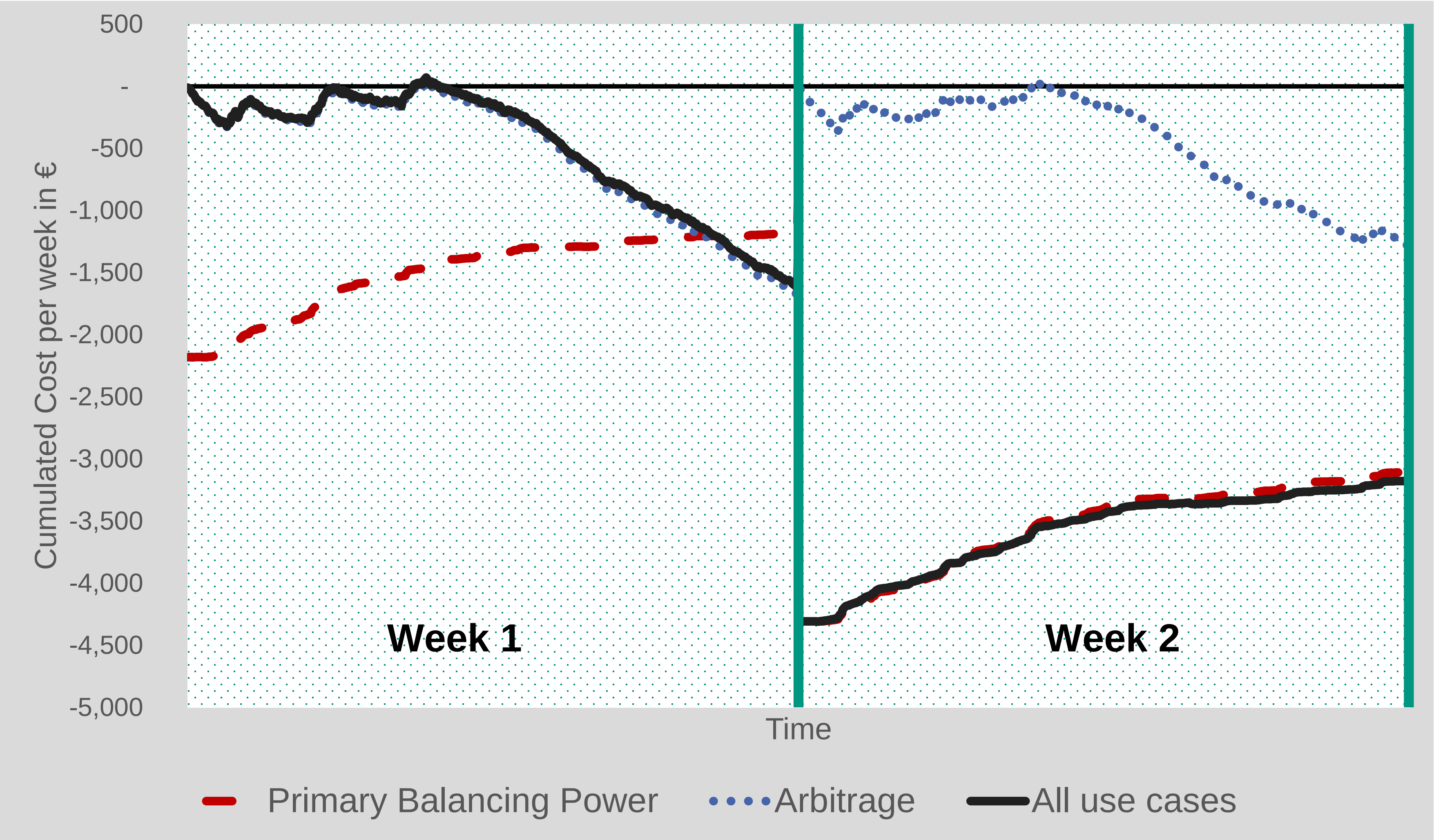
- EPEX prices
  - day-ahead hourly
  - intraday quarterly continuous trading
- Prices for primary balancing power
- Frequency data in seconds
- Fixed capacity prices
  - 10,000 €/MW*a

Battery parameter	
Capacity	1300 kWh
Power capability	1300 kW
Lifetime	11 years
Investment	1100 €/kWh

Exemplary two days



Cumulated cost of energy per week



Annual cost in €

Use Case	Company				
	1	2	3	4	5
Peak shaving	497,687	3,842,551	288,310	10,371,557	347,934
Primary Balancing Power	52,273	462,190	28,736	1,200,949	26,111
Arbitrage	39,254	449,947	14,473	1,189,446	11,200
Primary + Arbitrage	33,415	444,073	8,700	1,183,572	5,404
All use cases	23,676	428,517	- 3,070	1,166,897	3,874
Peak load in kW	391	1,793	363	2,797	120
Reference case (0.15 €/kWh)	355,660	3,814,735	125,129	10,155,676	231,003

Annual cost in €

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Conclusion

- Parallel revenue streams increase profitability of a BSS
- Strongly depends on:
  - Production profile
  - Production size vs. battery size
- Either primary balancing power or arbitrage trading
- Extreme electricity price spreads diminish the advantage of an industrial load combined with a BSS

Outlook

- Battery **degradation** and **sizing** need to be considered
- **Grid cost** need to be considered
- **Bid sizes** need to be considered
- **Uncertainties** need to be considered
- **Aggregating** industry loads need to be considered
- **PV-Self-Production** needs to be integrated
- **Balancing power** demand in more detail

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Appendix