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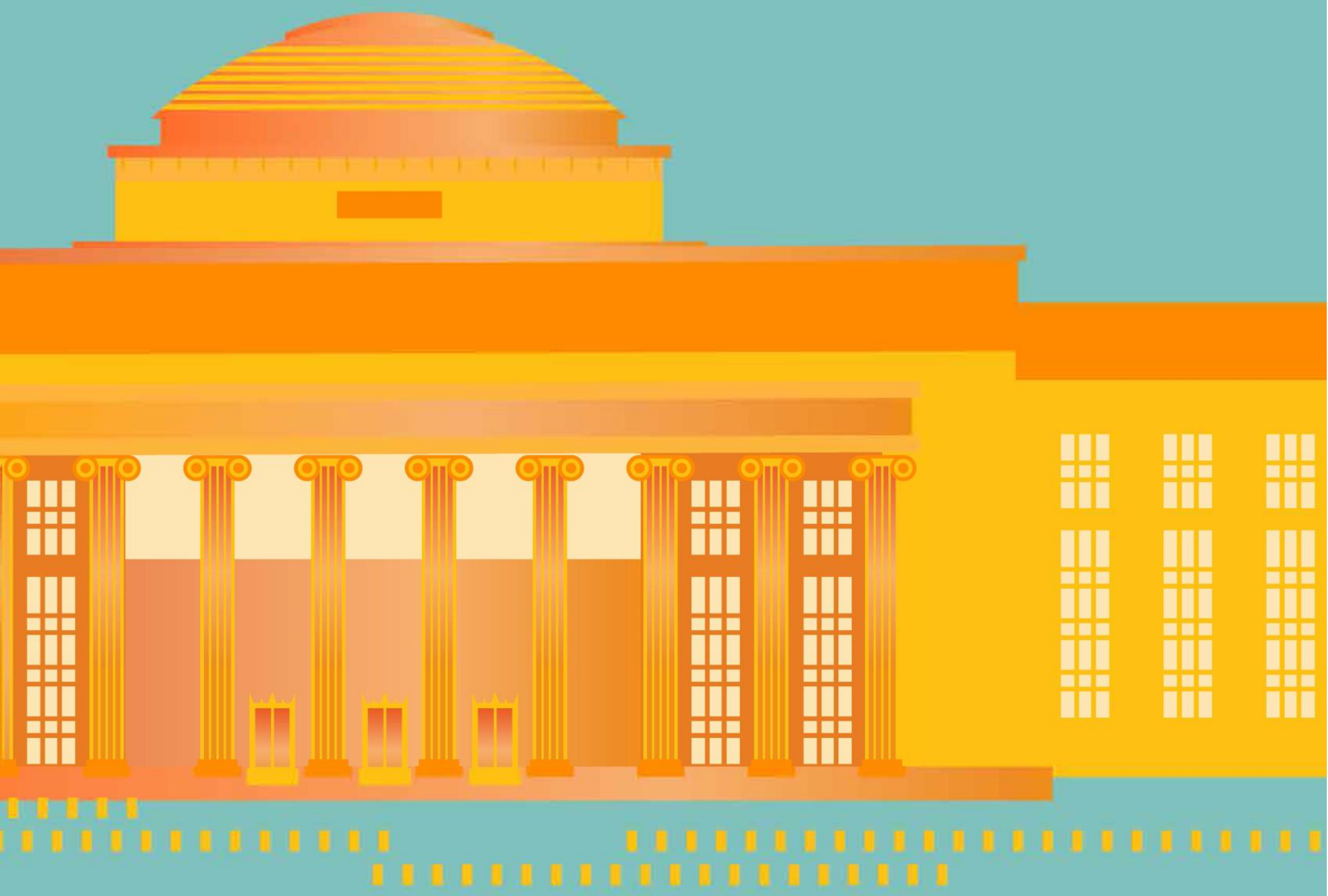

BUSINESS CASES OF FLEXIBILITY PROVISION OF ENERGY AGGREGATORS OPERATING IN MULTIPLE ENERGY MARKETS (EUROPEAN MARKET DESIGN)

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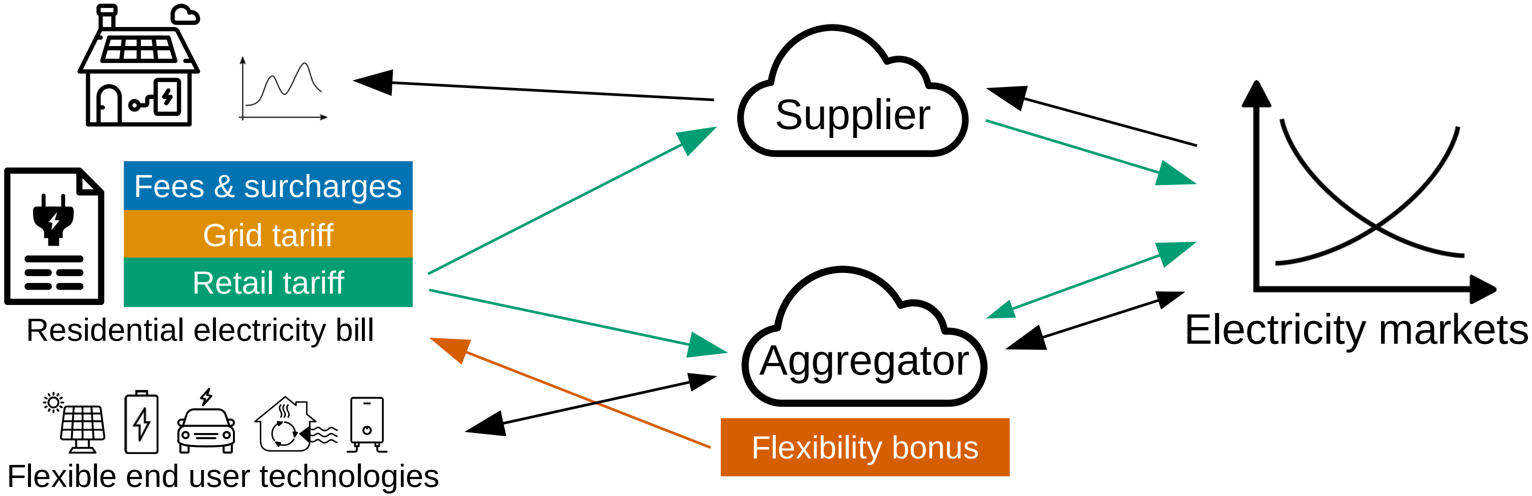
Motivation

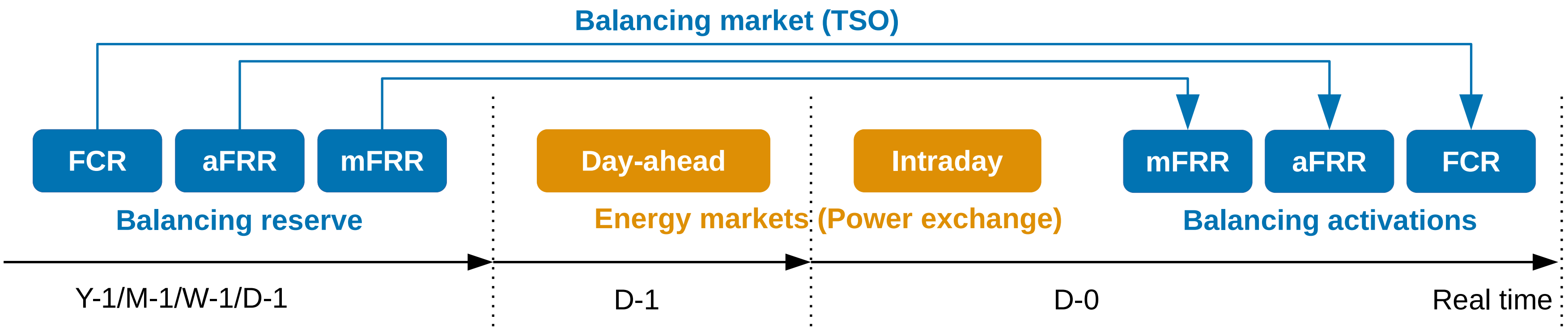
- Electricity systems require flexibility for the integration of variable RES.
- The lack of market access and price signals leaves flexibility potential of residential technologies unused.
- Aggregators can provide market access by optimizing residential flexibility potential on different electricity markets.



European short-term electricity markets

United States	Europe
• Centralized unit commitment model by ISO • Complex bids • Co-optimization of balancing reserve and energy • Locational marginal prices	• Internal unit commitment by generators • Simple bids • Sequential balancing reserve markets (TSO) and energy markets (power exchanges) • Zonal pricing

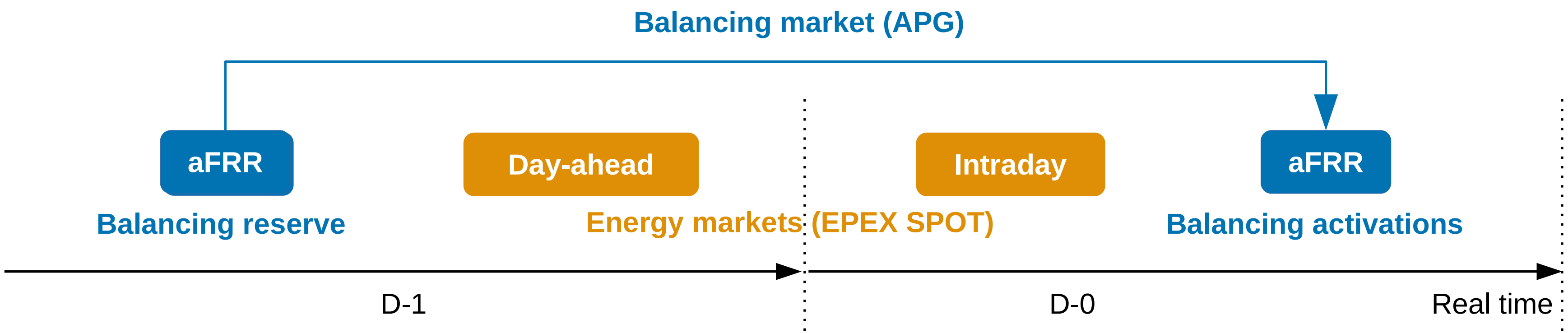
(Source: A. Botterud, H. Auer, Resource Adequacy with Increasing Shares of Wind and Solar Power: A Comparison of European and U.S. Electricity Market Designs, Economics of Energy & Environmental Policy 9 (2) (Apr. 2020), doi:10.5547/2160-5890.9.1.abot, http://www.iaee.org/en/publications/eeeparticle.aspx?id=329)



FCR … Frequency Containment Reserve
aFRR … automatic Frequency Restoration Reserve
mFRR … manual Frequency Restoration Reserve

Own representation based on K. Poplavskaya, Impact of balancing market design on business case for storage, Seminar: Business Models and Regulation for Storage, 11/30/2018, Vlerick Business School, Brussels, Belgium, http://horizon2020-story.eu/wp-content/uploads/Session-III-_-KseniaPoplavskayaK_final.pdf

Markets considered in this work



- Six four-hour products for upward and downward regulation, respectively
- Bids consist of a reserve price and an activation price.
- Bids are accepted based on a mix of reserve and activation price.
- Pay-as-bid pricing

- Hourly products
- Uniform pricing
- Bids only consist of energy price

- Quarter-hourly products
- Uniform pricing
- Bids only consist of energy price

- Reserves are activated based on the activation price.

APG - Austrian Power Grid (https://www.apg.at/en/)
EPEX SPOT (https://www.epexspot.com/en)

Simulation strategy:

1) Daily day-ahead co-optimization of aFRR and day-ahead market bids based on expected prices and balancing activation probabilities (MILP)
2) Quarter-hourly simulation of balancing activations (e.g. historic, random or extreme cases)
3) Quarter-hourly simulation of intraday market trades to react on unexpected balancing activations (respecting the intraday market lead time)

Day-ahead optimization

Daily rolling optimization minimizing expected cost on markets including other end user cost components:

$$\min c_{dayahead} + c_{balancing} + c_{grid} + c_{fees} + c_{component}$$

subject to

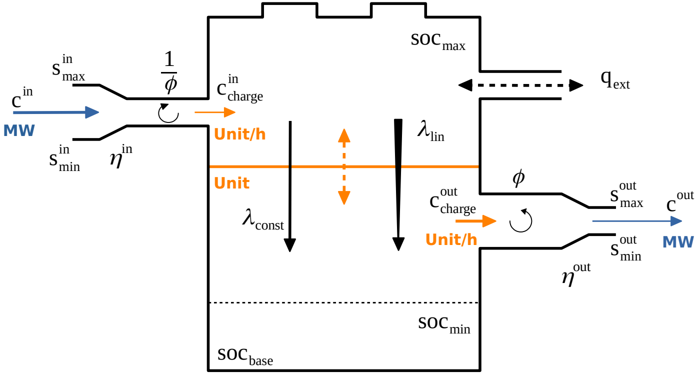
- Balancing bid constraints
- Energy balance between technology operation and market bids
- Component-specific technical constraints
- Component-specific state-of-charge and power reserves for balancing market activations
- Component-specific Power reserves for potential intraday market reactions

Programmatically build optimization models for different technology portfolios:

1) Initialize model and expressions for aggregated market bids and total cost for the considered time frame.
2) For each component
    1) Initialize variables for technical operation, state-of-charge and market schedules.
    2) Add component-specific variables and cost to global model expressions.
    3) Add component-specific constraints.
3) Formulate objective from global model expressions and solve model. (Gurobi)
4) Update schedules for each component

Abstract Component Interface

- All component-specific steps and constraints are implemented generically in terms of 20 functions forming the Abstract Component Interface.
- They define default methods that can be overloaded for specific component types for the implementation of different technologies.



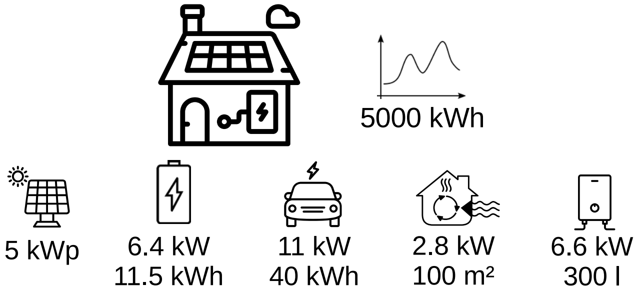
Function	D	Unit	Description
$s^{in}_{max}(t)$	0	MW	Maximal consumption power
$s^{in}_{min}(t)$	0	MW	Minimal consumption power
$s^{out}_{max}(t)$	0	MW	Maximal production power
$s^{out}_{min}(t)$	0	MW	Minimal production power
$\eta^{in}(t)$	1		Charging efficiency
$\eta^{out}(t)$	1		Discharging efficiency
$\phi(t)$	1	$\frac{MWh}{Unit}$	Conversion factor between MWh of electric energy and the energy unit in the storage
$\alpha(t)$	1	Bool	Availability
$soc_{max}(t)$	0	Unit	Maximal state-of-charge
$soc_{min}(t)$	0	Unit	Minimal state-of-charge
$soc_{base}(t)$	0	Unit	Base state-of-charge
$soc_{start}(\vec{t})$	0	Unit	Starting state-of-charge before the time steps in $\vec{t}$
$soc_{stop}(\vec{t})$	0	Unit	Minimal state-of-charge at the end of $\vec{t}$
$q_{ext}(t)$	0	Unit	External storage input or output
$\lambda_{const}(t)$	0	$\frac{Unit}{h}$	Constant storage loss factor
$\lambda_{lin}(t)$	0	$\frac{1}{h}$	Linear storage loss factor
$c^{in}(t)$	0	$\frac{EUR}{MWh}$	Cost associated with consumption excluding market cost and tariffs
$c^{out}(t)$	0	$\frac{EUR}{MWh}$	Cost associated with production excluding market cost and tariffs
$c^{in}_{charge}(t)$	0	$\frac{EUR}{Unit}$	Cost associated with charging
$c^{out}_{charge}(t)$	0	$\frac{EUR}{Unit}$	Cost associated with discharging

Julia's type system, multiple dispatch and generic programming provide a convenient and powerful toolbox to implement such modular generic interfaces.

More information: Stefan Karpinski, The Unreasonable Effectiveness of Multiple Dispatch, JuliaCon 2019, https://www.youtube.com/watch?v=kc9HwsxE1OY

Use case description

Household configuration



Optimization strategies

- *Baseline*
  No price signals, technical optimization
- *Day-Ahead*
  Optimize for day-ahead market prices only
- *Balancing*
  Co-optimization of day-ahead and balancing market

Time periods (market prices)

- *Period 1* Oct 1, 2017 – Sep 30, 2018
- *Period 2* Nov 1, 2018 – Jun 30, 2018

Data for

- market prices,
- balancing market bids and activation probabilities,
- and measured data to calibrate the heat pump parameters

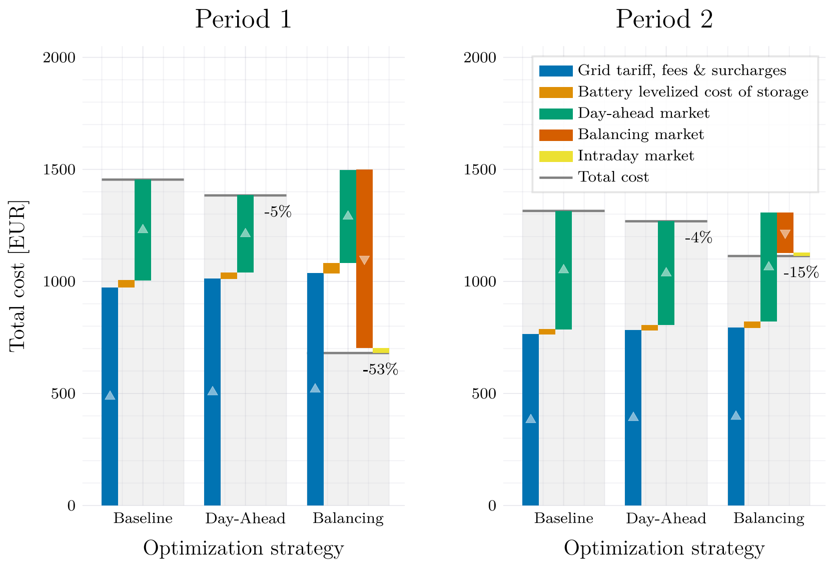
were kindly provided by project partners

- TIWAG (https://www.tiwag.at/en/)
- IDM (https://www.idm-energie.at/en/)

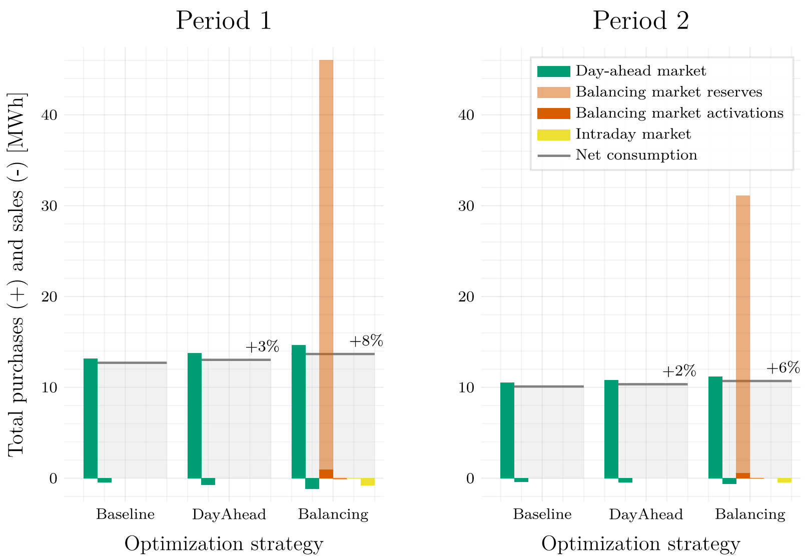
from the Flex+ project (https://www.flexplus.at/) funded by the Austrian Research Promotion Agency (FFG) and the Climate Energy Fund (grant No. 864996)

Single Household Results

Total cost components



Quantities traded on different markets



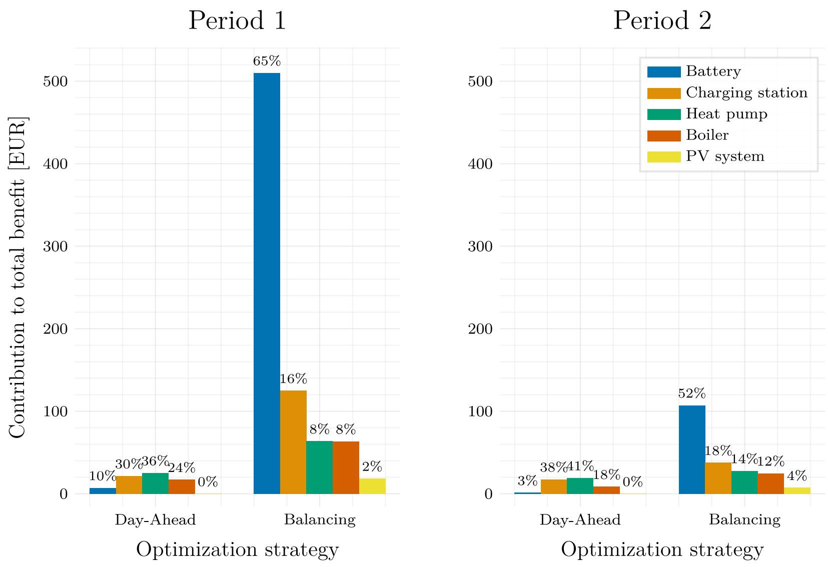
- Significant cost reduction with Balancing optimization strategy
- Period 1 provided more economic potential on balancing markets.

- Increase in net consumption with market optimization
- Mostly negative balancing market products with are chosen.

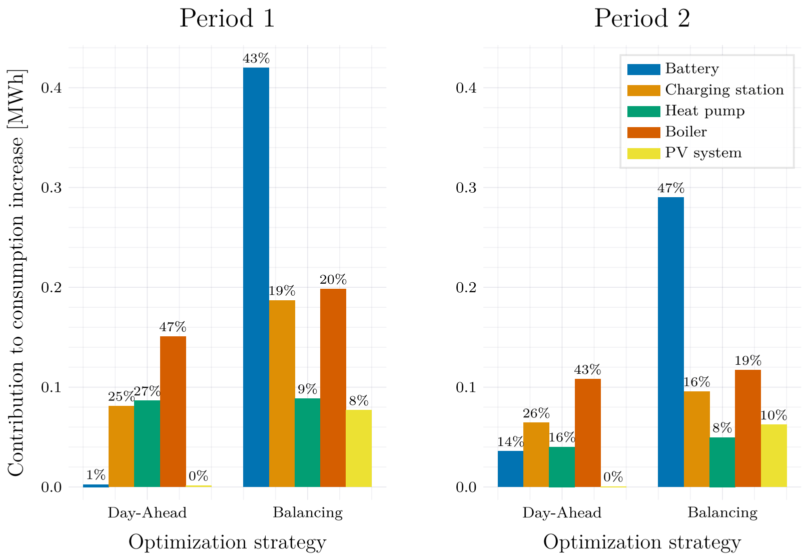
Contribution of different technologies

Simulate all 32 combinations of individual technologies either participating in market optimization or operating in Baseline mode and calculate the Shapley value.

Contribution to total benefits



Contribution to consumption increase



Highest contribution by battery in Balancing optimization strategy

Highest contribution to consumption increase by electric boiler in the Day-Ahead optimization strategy

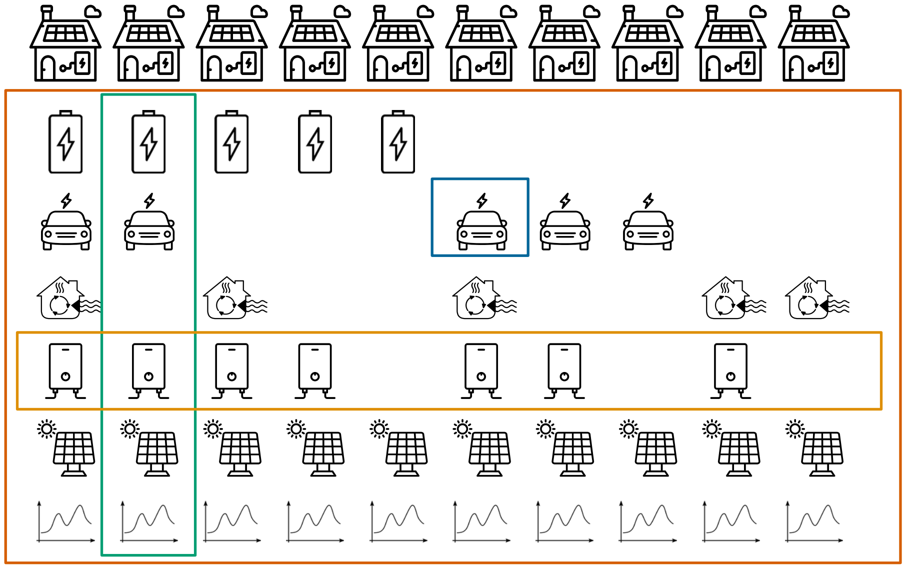
Level of aggregation in the optimization

Single Optimization on component level

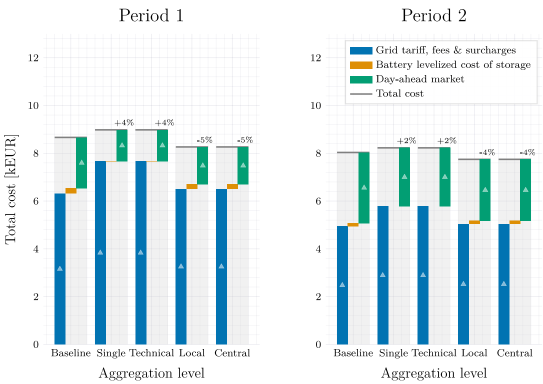
Technical Aggregation to component-specific pools

Local Optimization in local energy management system

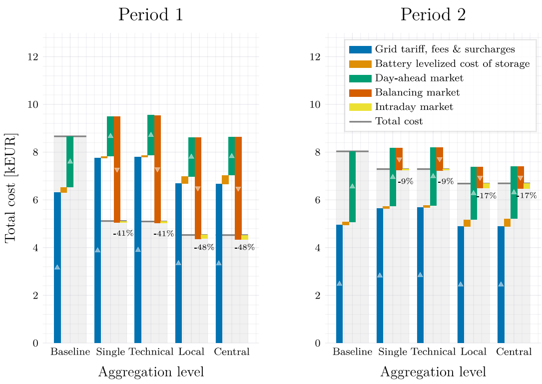
Global Co-optimzation of all technologies



Day-ahead optimization strategy



Balancing optimization strategy



Conclusions

- Market access (especially balancing market and day-ahead market co-optimization) can provide significant benefits for end users and aggregators.
- On balancing markets batteries provide the highest economic potential. Heat pumps and electric vehicles contribute the most to load-shifting on the day-ahead market.
- It is important to consider the total electricity bill including grid tariff cost, fees and surcharges in the market optimization to ensure economic benefits.
- Considering the intraday to balance unexpected balancing activations significantly increases the potential size of balancing market bids.

Future research:

- Analysis of tariff design options for flexibility bonus considering different end user – supplier - aggregator constellations.
- Consider forecast errors and use intraday market to balance them.
- Price-based optimization of intraday market balancing.

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