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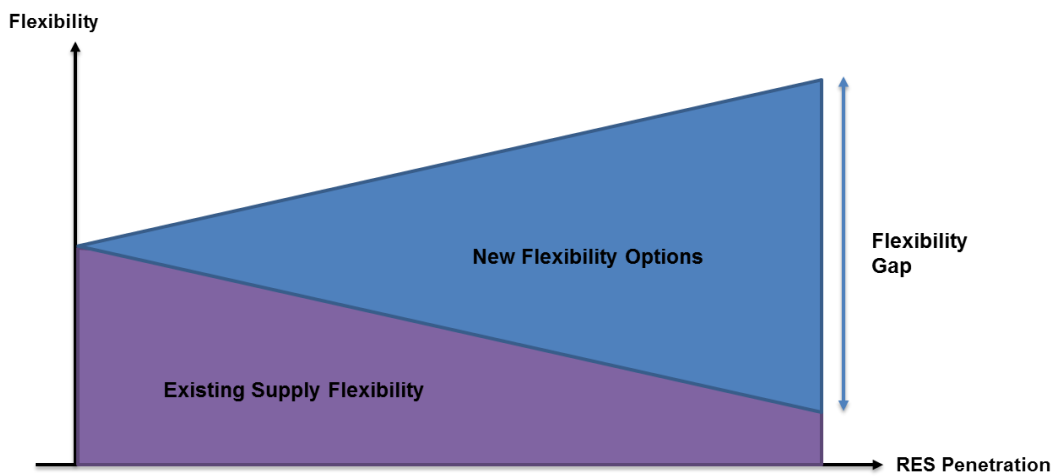
Quantification of demand response actions in a block of residential buildings

With a simulation-based approach

Flexibility gap in the power system

In previous times when an electrical system was only supplied by centralized power plants, such power plants provided all the flexibility for the system (rotating masses, ramping, etc.). They cover the variability and uncertainty from the demand side.

The increasing use of RES and distributed generation is challenging the systems by requiring more flexibility, for the supply side must follow the net-load (demand minus variable RES generation).



New flexibility options

- **From the network side,** to improve the power grid, which enables the sharing of flexibility resources over larger geographic areas
- **From the market side,** improvement of the market operation principles, such as lower the market mimumum biding size, or expanding the market zones
- **From the demand side,** demand side is no longer defined as the consumer but seen as prosumer.

  Thermal storage in buildings' structures

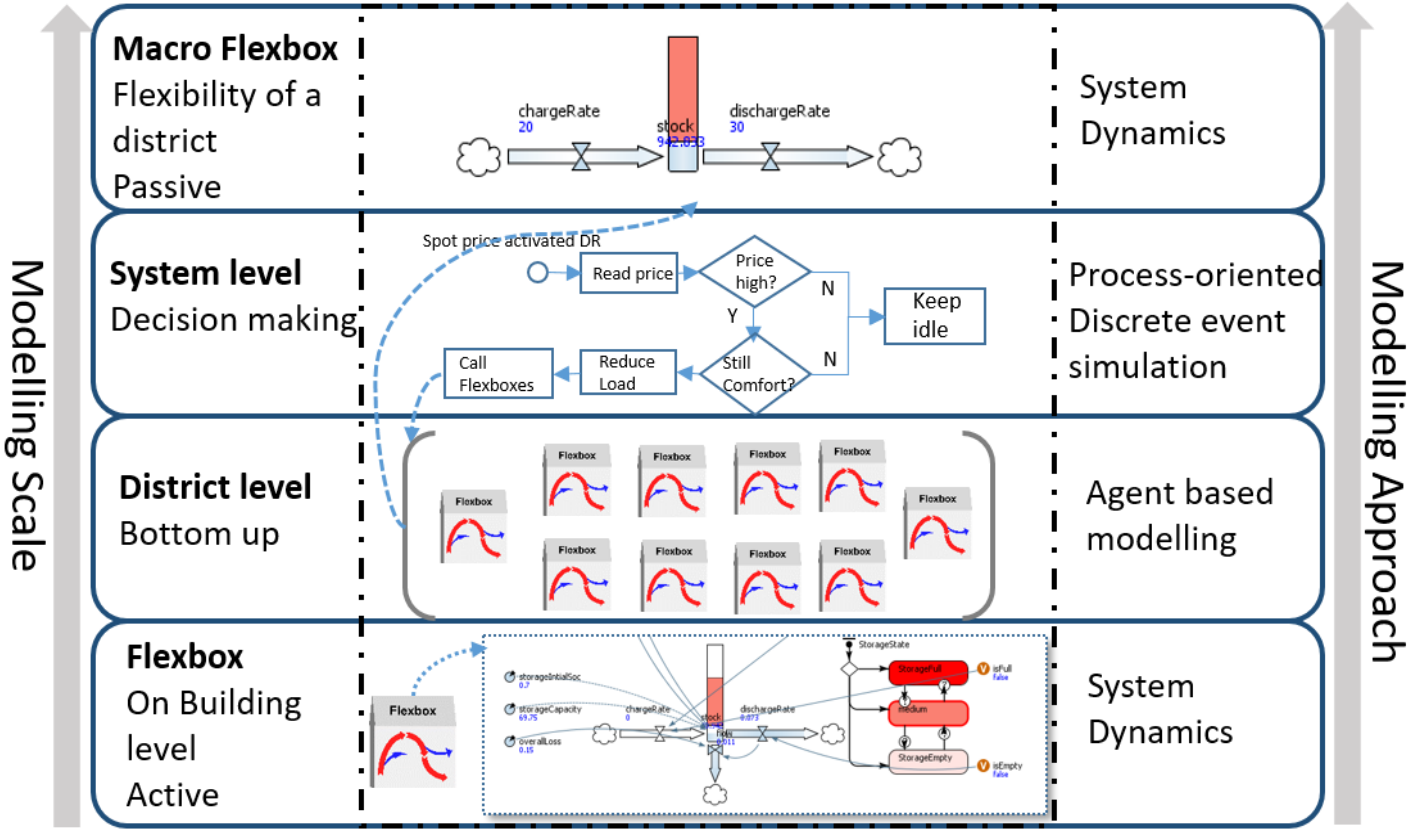
  Electrical loads and storages

  Distributed generation units

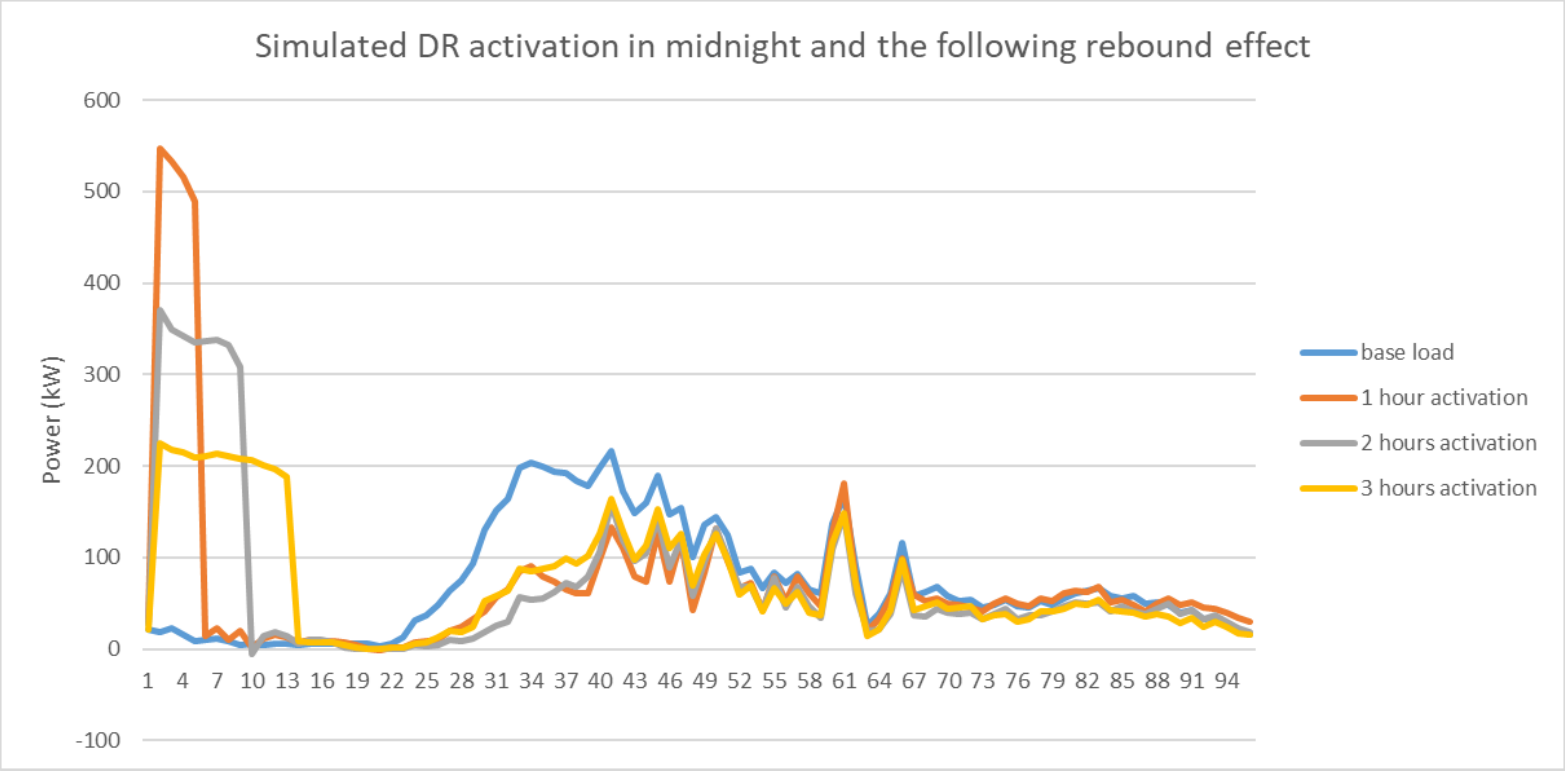
In this work, we study a simulation-based method for quantifying demand response actions of large clusters of small electrical loads and storages.

A simulation model to simulate demand response actions

The energy system of 100 single-family buildings are modelled with heat pumps, electric boilers, heat storages, PV and batteries, based on a block of residential buildings located in Wüstenrot, Germany.

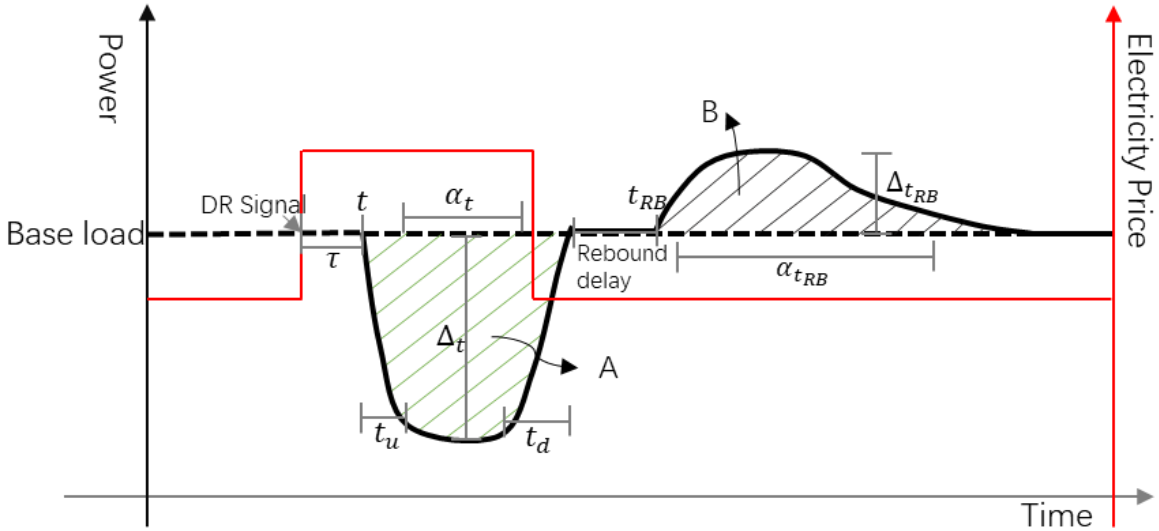


Simulated load traces with and without DR actions



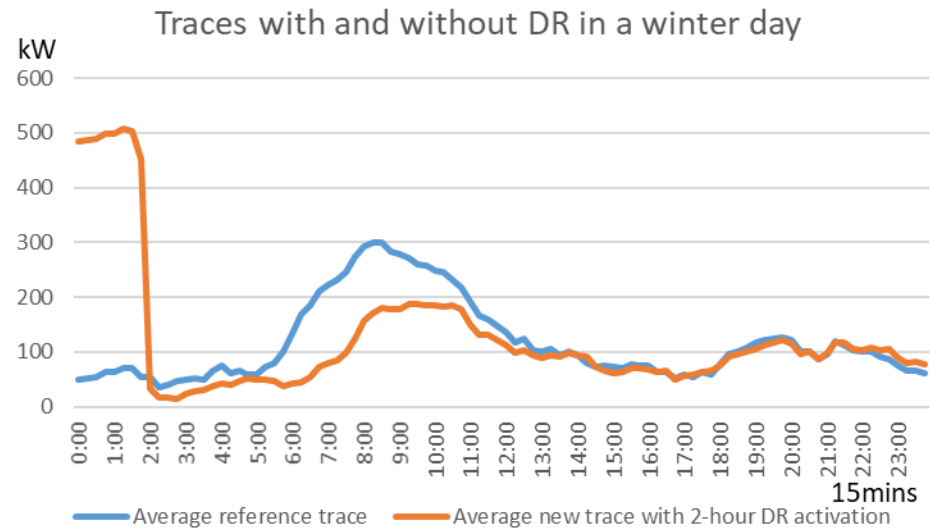
- The affordable DR capacity differs depending on the activated duration, however, shifted energy has a similar quantify.
- Similar behaviour of rebound effects can be observed after DR activations, which have different activation durations.

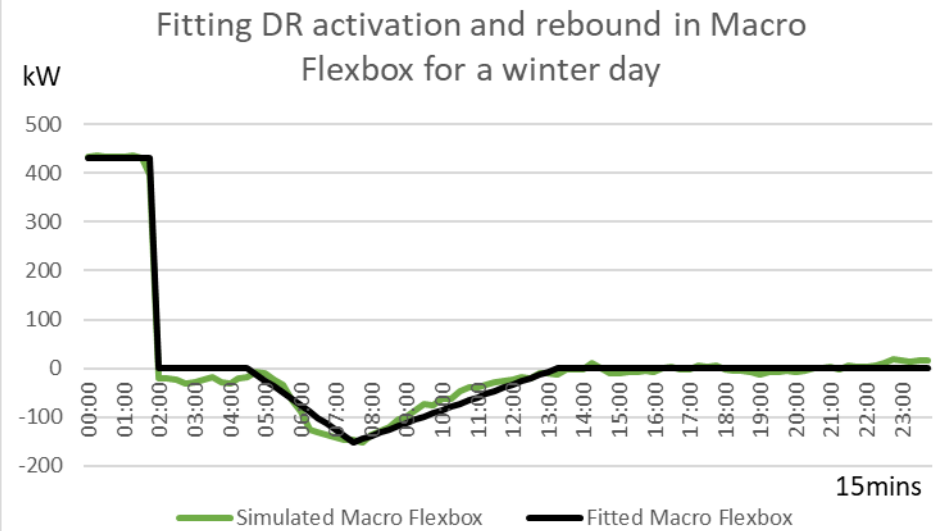
Macro Flexbox - DR activation of a cluster of small loads and its rebound effect



Parameter	Symbol	Data type	Example Value
Response delay	$\tau(t)$	Static	30 sec
Ramp-up time	$t_u(t)$	Static	5 mins
Ramp down time	$t_d(t)$	Static	5 mins
Flexible capacity	$\Delta P(t)$	Dynamic[1]	+100 kW
DR activation starting time	t	Dynamic	3 am
DR activation duration	$\alpha(t)$	Dynamic	1 hour
Rebound Capacity	$\Delta P_{RB}(t)$	Dynamic	-20 kW
Rebound Duration	$\alpha_{RB}(t)$	Dynamic	5 hours
Rebound Delay after DR	$\tau_{RB}(t)$	Dynamic	1 hour
Energy Losses / Gains	$\vartheta(t)$	Static	+2%

DR happens in the night in winter

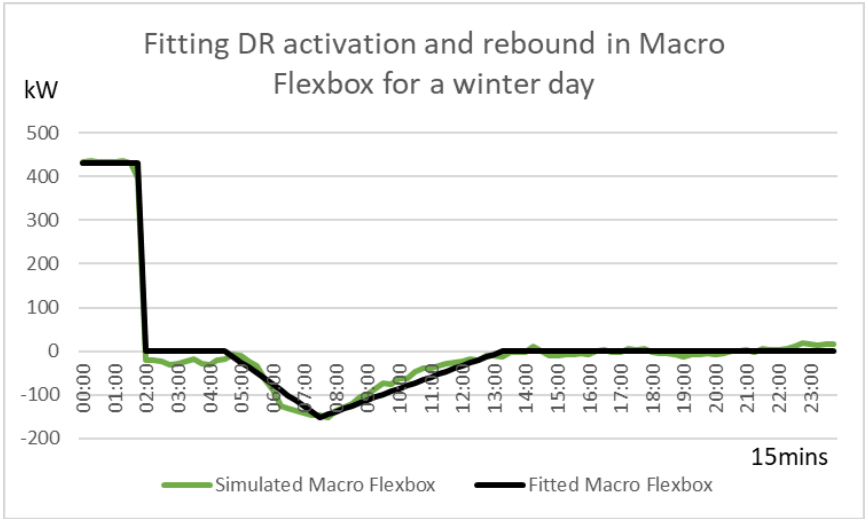


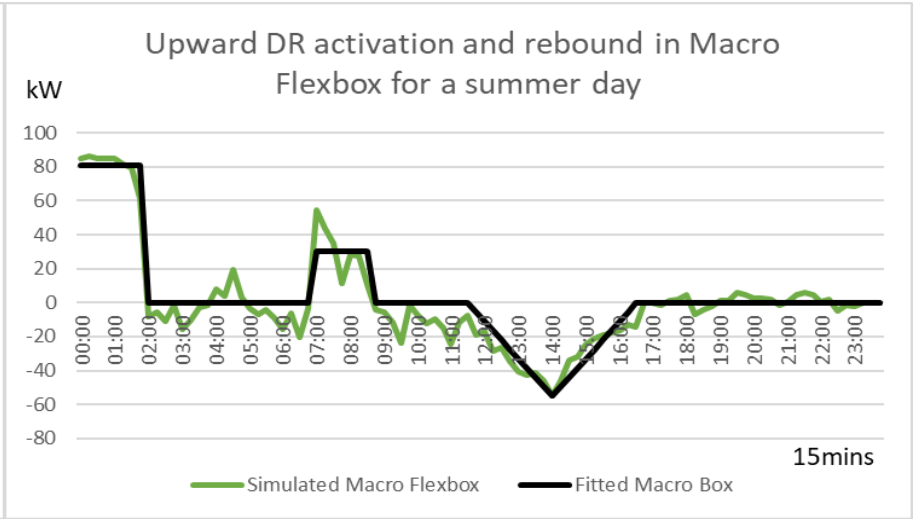


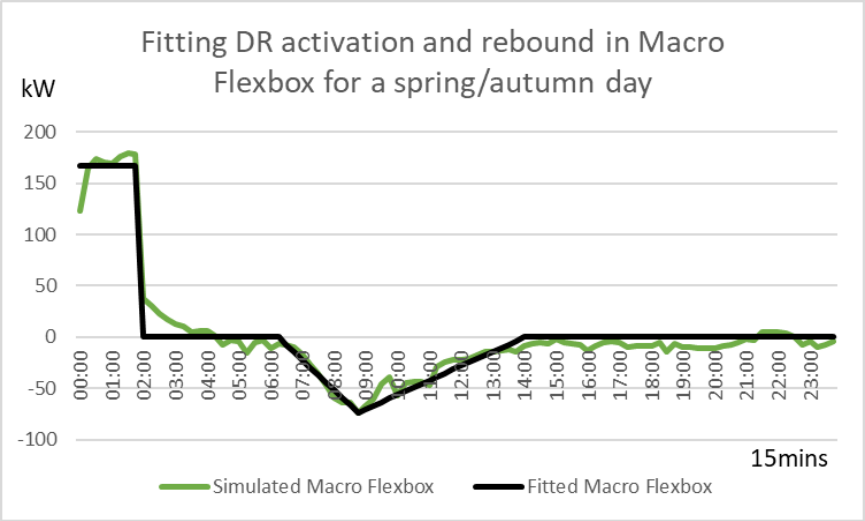
Fitted parameters of the Macro Flexbox

Parameter	Average value
Flexible capacity	+430 kW
DR activation starting time	0:00 O'clock
DR activation duration	2 hours
Rebound Capacity	<=151kW
Rebound Duration	8.5 hours
Rebound Delay after DR	2.5 hours
Energy Losses	+5.2%

Seasonal change of DR actions







We compare the activations that happen in the midnight for 2 hours in all the season.

- From winter to summer, both the DR activation capacity and rebound capacity decrease.
- The rebound happens later in warm seasons than in winter.
- The visible increased PV injection to the grid happens in summer due to DR.

Summary and outlooks

1. The resulting parametric description varies significantly for each use case, which differs according to the energy system carrying out the DR action and according to the applied system operation strategy.
2. The time at which the DR happens, the duration and capacity of DR and the seasonal effect influence the parameters significantly.
3. Next steps of the study:

- the participation of demand response applied on small residential loads in day-ahead market and intraday market, with assumed preferable market conditions
- Quantification of the affordable demand response capacity of small residential loads to participate in balancing markets.

Thank you…

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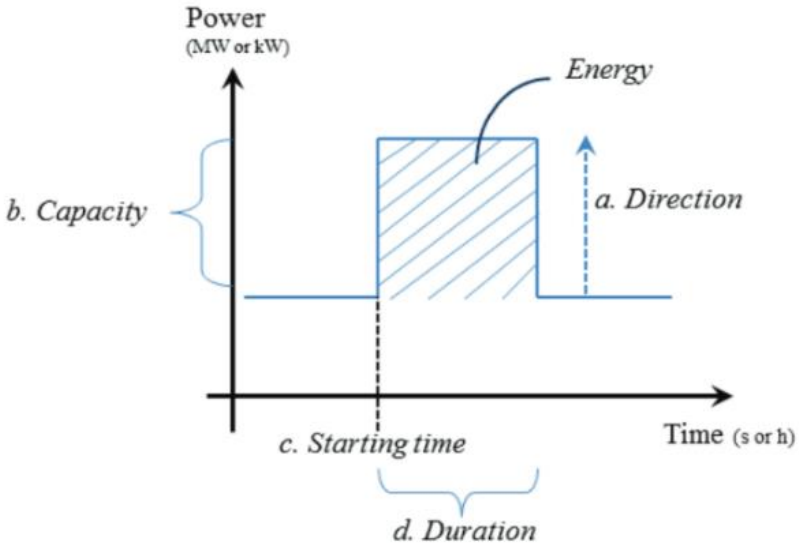
Appendix
Flexibility quantification: individual flexibility



Taking a heat pump and thermal storage system as an example, at the moment t, judging from the current running state of the heat pump $S_{HP,t}$, we let flexibility capacity of the $P^{t}_{\overline{HP},}$ in direction of decreasing its load:

$$P_{\overline{HP},\,t} = \begin{cases} 0, & \text{if } S_{HP,\,t} = \text{off} \\ P_{HP,\,installed}, & \text{if } S_{HP,\,t} = \text{on} \end{cases} \quad (1)$$

Where $P_{HP,installed}$ refers to the installed power of the heat pump.

To ensure the comfort level is not disturbed, we determine the duration $T_{\overline{HP},t}$ that the regulated capacity can be kept, based on the predicted thermal demand $\overline{D}_t$, and thermal energy stored in the linked storage $E_{storage,\,t}$:

$$T_{\overline{HP},\,t} = \begin{cases} 0, & \text{if } P_{\overline{HP},\,t} = 0 \\ \dfrac{E_{storage,\,t}}{\overline{D}_t}, & \text{if } P_{\overline{HP},\,t} \neq 0 \end{cases} \quad (2)$$

Thus, the flexible energy $E_{\overline{HP},t}$ for the system to decrease is resulted:

$$E_{\overline{HP},\,t} = P_{\overline{HP},\,t} * T_{\overline{HP},\,t} \quad (3)$$