***Swarm demand response: virtual storage by small consumers***

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## Overview

Energy storage and load shifting (demand response, DR) are options for coping with the rising share of intermittent renewable generation to reduce environmental damage from electricity. So far DR is interpreted as a technology applicable to heavy industry which can shift a few large loads. Beyond these firms, the potential is expected to be limited as market prices will hardly motivate smaller companies or households to dispense with immediate electricity consumption. But Swarm DR, shifting a lot of small loads by only few minutes apiece, smartly coordinated, could have significant potential.

sDR might be implemented by electrical devices that have been enabled to delay or interrupt operation according to user preferences and highly resolved price signals. In this case it can be expected that a high share of load could be shifted by a short time of 5-10 minutes while a small share might be shifted for longer (e.g. 30-60 minutes) without any costs or inconveniences. If, after this indifference time has elapsed, a price signal succeeds in finding a large enough second wave of electricity consumers who are also willing to shift load (the “successor loads”), a chain of short load shifts can be built up that is equivalent to long term storage.

As enabling sDR entails only a simple extension of the controlling logic of many devices, this “storage equivalent” will be cheap compared to conventional storage. But is sDR really technically equivalent to conventional storage? Even if the ideal technological, market design and communication conditions were met there is still the question of whether sufficient successor loads can be found at any time to avoid an interruption of the chain of shifts. In the best case this might result in an inability to shift load but it could also cause large jumps in required generation that would endanger system stability. The inability to find successors might require additional generation capacity that would not be needed with conventional storage, limiting the economic potential of sDR.

## Methods

We analyse the efficiency and continuity in a model. sDR is modeled as a kind of storage with dynamic capacity constraints for each interval considered. The capacity constraint is dynamic as a small share of the load can be expected to be shiftable for longer periods while a larger share might be shifted for only short periods – depending on the aplliance shifted.

The storage model is quantified with usage data of household appliances suitable for load shifting (Table 1). Based on these data it can e.g. be concluded that per household by delaying the start of a 30-degree washing program by ten minutes (possible once a week) 48 Wh of electrical energy could be shifted from one end of the expected operating period to the other. In contrast to conventional storage, storing energy from the future for present use (by postponing consumption until the energy is available) is also possible.

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| **Device** | **Mode** | **Duration** | **Energy per run [Wh]** | **Usage Density** | **Average Consumption [Wh]** |
| Refrigerator |  | 24 h | 782 | All time | 23,469 |
| Washing machine | 30 Degrees | 1 h | 286 | 1 per week | 8,005 |
| 40 Degrees | 1 h | 650 | 1 per week |
| 40 Degrees Synth | 2 h | 1,064 | 1 per week |
| Dishwasher | 55 Degrees Econ. | 3 h | 871 | 6 per month | 5,231 |
| 65 Degrees Power | 56 min | 1,125 | 2 per month | 2,250 |
|  |  | Total shiftable electricity consumption 38,955 |
|  |  | Total electricity consumption 99,422 |
| Table 1: Usage density and power consumption of household appliances for November 2016, Issi and Kaplan, 2018. |

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This sDR model is then integrated into a highly resolved (10 Minutes) total cost minimizing energy system model including a set of generation technologies with operation costs and investment. In detail, one of the multi-period storages is defined for every 10 minute interval. So a large set of overlapping storages is available.

This model is quantified with looping 24 hour average solar generation in the winter and the summer (for the UK 2040, National Grid scenario) and load profiles generated with DESSTINEE (Bossmann and Staffell, 2016). sDR has then been applied to the residential sector differentiated by end use categories separately (Figure 1 and 2).

For comparison, virtual storage levels have been derived as the aggregated difference between generation and load. This virtual storage is compared to a conventional storage with capacity calibrated to the maximum of the virtual DR.

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| Figure 1: 24-hour winter profiles of shiftable and notshiftable load, and solar generation (10GW Peak). | Figure 2: 24-hour summer profiles of shiftable and notshiftable load, and solar generation (10GW Peak). |

## Results

The analysis shows that under ideal conditions virtual sDR storage is equivalent to conventional storage in terms of generation outputs - in particular a storage of 2 GWh on a British summer weekday summer and 9 GWh on a weekday in winter. So sDR can be considered as a reasonable substitute for conventional storage at lower costs.

Even though the equivalence strongly depends on load profiles and renewable capacities, there is no evidence of sudden sDR-spikes. Prices are in principle able to ‘find’ sufficient shifters. Thus the analysis justifies modelling of sDR as conventional storage and provides a rule of thumb for its storage capacity. This simplifies modelling sDR in large models.

## Conclusions

We have shown how to interpret Swarm Demand Response in the residential sector, how to model and quantify it. Under realistic conditions DR is equivalent to a conventional storage with seasonally variable storage capacity between 2 and 9 GWh. Thus, sDR might replace expensive conventional storage (batteries) or enable countries without a natural storage potential (hydro) to store energy. DR enabled by information and communication technology could provide flexibility for the power system with high shares of renewables.

However, there are still challenges to tackle. For example, from the engineering perspective the reliability of this kind of control system might be questioned as the demand elasticity of consumers is difficult to quantify in price-based DR and relies on real-time communication. This means that sDR may be perceived as “unreliable” and "failures” may occur.

However, the analysis does not show any evidence that under ideal market coordination a sudden DR-spike might emerge. Thus, a case when all shifted fridges switch on as prices go down is unrealistic. Prices are in principle able to ‘find’ successive shifters to smooth load-shifting in a welfare-enhancing way. In that sense a swarm of imperceptible demand shifts directed by market signals behaves like a gigantic storage unit, unknown to any of the participants.

## References

* T. Bossmann and I. Staffell, 2016. The shape of future electricity demand: Exploring load curves in 2050s Germany and Britain. Energy, 90(20), 1317–1333.
* F. Issi and O. Kaplan, 2018:"The Determination of Load Profiles and Power Consumptions of Home Appliances", Energies 2018, 11, 607.