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An increased flexibility of the electricity demand side through demand response (DR) is an opportunity to support the integration of renewable energies. By optimising the use of the generation, transmission and distribution infrastructure, DR reduces the need for costly investments and contributes to system security. There is a significant technical DR potential for load reduction from industrial production processes in Germany, as well as from cross-cutting technologies in industry and the tertiary sector.

The availability of demand response as a system resource depends on the underlying type of demand. Already today energy-intensive industries market significant demand capacity in the German minute reserve. The DR literature reveals that there is a potential of several gigawatts of additional capacity available for at least one hour in Germany. Demand can also cover longer periods, but this often requires investment, for example in storage capacity for intermediate products.

To enable the effective use and full remuneration of demand response, further improvements in power market design are discussed: (i) Enabling third parties (referred to as Demand Side Management Companies) to help business customers realise their flexibility potential; (ii) creating robust intraday and balancing prices in auction platforms as reference prices for longer-term contracts to stabilise revenue streams of flexibility providers; (iii) it needs to be further assessed whether additional catalysing instruments are necessary to initiate investment in new business processes or storage capacity.

Demand response delivers several benefits associated with a more flexible electricity system

The integration of renewables will require an increasingly flexible electricity system. Demand response is one flexibility option discussed in the portfolio with more flexible generation resources (supply side) or electric storage (e.g. batteries). In its 'State of the Energy Union' report, the European Commission names DR as a strategic priority in future legislation (EC 2015).

Demand response (DR) refers to "voluntary changes by end-consumers of their usual electricity use pattern", either in response to changes in the price of electricity over time, or to incentive payments (EC 2013). This change in energy consumption takes on one of two forms, namely load shifting (load decrease or increase, shifting energy consumption to a later or earlier point in time) or load reduction (without a corresponding load increase at a later point in time). In the German discourse, the term 'demand side management' (DSM) usually only refers to 'demand response'.

However, in addition to demand response, in the international debate DSM also includes energy efficiency measures (Hurley et al. 2013), as companies that manage energy use more actively are likely to both unlock flexibility and efficiency potentials. For the remainder of the paper we focus on demand response only. Demand response can provide the following key functions:

Generation adequacy: DR can reduce peak demand and thus the amount of generation and storage capacity otherwise required to meet this demand. This may lead to substantial investment cost savings (Bradley et al. 2013; Gils 2016). Moreover, the price level at which many of the demand side options can be made available – several 100 Euros/MWh – reduces the steepness of the demand curve. This improves the functioning of power markets and strengthens the investment framework.

Flexibility provision: Demand response contributes to flexibility by providing quick reserves and ramping capacity to balance generation and load, as well as by enhancing the system reserve to network congestion. Reserves are necessary in the case of either contingency events or large variations in system load and generator outputs, e.g. due to variable renewable feed-in. Provided an adequate control infrastructure is installed, DR can provide ramping capacity within seconds (Hurley et al. 2013). The amount of part-loaded generation scheduled to operate for the provision of reserves is thus reduced, increasing the amount of renewable electricity that can be absorbed into the system (Strbac 2008). A load increase at times of a high feed-in by renewable energies helps to integrate renewables into the system by increasing the market value of renewable electricity and preventing a curtailment of feed-in due to low energy prices (Connect 2015). Finally, demand response can help to solve network constraints (BNetzA 2015). This is true both in power markets with locational differentiated prices, as well as for less market oriented administrative redispatch mechanisms.

Significant and cost-competitive DR potential in the German industry and tertiary sector

While the European Commission (2013) estimates that only around a tenth of the European Union's demand response potential is used today, some EU countries like Italy, Spain and the UK already utilise up to 6% of their peak load as demand response capacity (BET 2015). Experience from the United States' ISO New England, Midcontinent ISO and PJM markets shows that demand response rates of 10% are possible (Jahn and Gottstein 2013; FERC 2015).

Although there may be a role for demand response in the household sector in the future, demand response in the industrial and tertiary sectors is widely considered more cost effective due to lower transaction costs of engaging larger loads. Hence most studies focus on production process technologies, such as paper and cardboard production, electric steel plants, chlorine electrolysis, aluminium electrolysis, air separation and the container glass industry, as well as cross-cutting technologies in these sectors. BET (2015) identify a technical DR potential of 6.4 GW in Germany, available for at least one hour. Under current regulatory and market conditions 3.5 GW of this potential is estimated to be viable. BET (2015) exclude response capacity from sectors like cement because of its daily and seasonal demand variations. These potentials may be realised with improved power market design that provides additional response options at times of high power demand.

Buber et al. (2013) extrapolate the results from Fraunhofer ISI and FfE (2013) on the load reduction potential in Southern Germany to the whole of Germany. The authors identify 1.7 GW of shiftable loads, available for at least two hours. In addition, industrial cross-cutting technologies could provide another 1.4 GW, available for at

least one hour on working days at daytime. This potential reduces to 0.8 GW on a Sunday afternoon.

Gils (2014) assesses the theoretical load shifting and load shedding potential in the European industry, tertiary sector and household sector. The analysis couples technical characteristics of processes with statistical load data. Gils (2014) finds an average potential (i.e. the fraction of the maximum potential that is available on average throughout the year) of 3.5 GW in industry, of which 0.4 GW are cross-cutting technologies. DR potentials in the tertiary sector are of the same magnitude (around 3.8 GW). However, more than half of the average potential in the tertiary sector stems from commercial ventilation. The energy consumption of this process is highly variable, depending on the time of the day and the day of the week. Moreover, the potential available in the tertiary sector may be further reduced due to negative impacts on comfort levels (Gils 2016).

The following table summarises the demand reduction potentials identified in the German industrial and tertiary sector (in GW).

Sector/Source	**Industrial processes**	**Industrial cross-cutting technologies**	**Tertiary sector**
BET (2015)	6.4 / 3.5 *	-	-
Buber et al. (2013)	1.7	0.8-1.4	-
Gils (2014)	3.1	0.4	Up to 3.8

* Technical potential / sociotechnical potential

The economics of industrial process technologies are fundamentally different from those of cross-cutting technologies. DR in industry has relatively low investment costs (between 200 and 8,000 €/MW on average, up to 21,000 €/MW), but high variable costs (usually below 500 €/MWh, cf. BET 2015). Thus **investment costs** are less than a tenth of the cheapest flexibility options at the generation side (open cycle gas turbines, see Schröder et al. 2013) and is competitive with other flexibility options such as batteries, even taking future cost reductions of these technologies into account (Zerrahn and Schill 2015; Brouwer et al. 2016). Cross-cutting technologies in the tertiary sector, on the other hand, have comparatively high investment costs (largely between 200,000 and 900,000 €/MW, see Frontier and Formaet 2014), but only marginal variable costs (Buber et al. 2013).

The **variable costs** of demand response from process technologies are highly process-dependent and may differ significantly even within one industrial sector (BET 2015). For voluntary load reductions without a subsequent load increase, the variable costs correspond to the value of lost load and are thus much larger than those for load shifting (Paulus and Borggrefe 2011). However, the main DR potentials lie in load shifting.

Steurer et al. (2015) estimate **fixed annual costs** for the infrastructure enabling DR in different sectors. There are conflicting views on the existence of such fixed costs for industrial processes. While Paulus and Borggrefe (2011) assume no fixed costs in industrial processes, BET (2015) report fixed annual costs of up to 6,000 €/MW in the same industries.

Towards a further deployment of demand response in Germany

Demand response is already happening in the German energy market. Large German energy-intensive industrial companies market flexible loads from their production processes, e.g. in the balancing market (dena 2015). Moreover, around 1.2 GW of loads are prequalified under a demand response programme called “Abschaltbare

Lasten" (AbLaV 2012; cf. dena 2015). Under current market conditions, however, loads are often shifted solely in order to reduce network charges (Connect 2015). The challenge is putting DR resources to a more productive use from an energy system perspective.

DSM Service Companies (or aggregators) – utilities or independent specialised third parties – can help identify and market DR potentials at the company level. These actors operate pools of demand facilities, selling electric loads of smaller businesses as single units in electricity markets (SEDC 2015). Aggregators have been responsible for a major share of the increase of DR capacity in the US in the last decade (Taylor and Taylor 2015; SEDC 2015). Aggregation increases the reliability of demand response, as it diversifies the risk of individual customers failing to curtail (Taylor and Taylor 2015). It is, however, more valuable at the system level, including other demand and supply side resources (Neuhoff 2015). DSM Service Companies use their industry knowledge and experience to identify flexible load potentials at the company level that many end-users are unaware of (dena 2013). This process also gives rise to economies of scale (Neuhoff 2015).

Worries about technical risks of a disruption of production and a reduced product quality are major barriers that prevent companies from making use of their demand response potentials (Olsthoorn et al. 2015). These concerns need to be taken seriously and possibilities to avoid negative impacts of DR on production processes should be discussed.

There is a consensus in the literature that all energy markets should be opened to the demand side. The goal is creating a level playing field between the supply side, demand response and other flexibility options. Moreover, price signals that reveal the value of flexibility for the energy system are needed (see e.g. ENTSO-E 2015). In the US, clear instructions from the national energy market regulator FERC to treat demand response equally to supply side resources have set the basis for a marked increase of DR capacity (Jahn and Gottstein 2013). An open question is whether additional incentives are needed to catalyse the realization of demand response. Such policies could include specific products tailored for DR (ENTSO-E 2014) or broader programmes such as capacity markets. Capacity mechanisms have been the source of significant revenue streams to support this development in New England and PJM (BET 2015; Hurley et al. 2013). Higher performance requirements for demand resources introduced recently have led to a moderate decrease of contracted capacity in the PJM market, yet its availability as a system resource has increased significantly (PJM 2014, 2015, 2016).

The current regulatory framework in Germany offers only limited revenue possibilities for demand response (dena 2015; SEDC 2015). Consequently, the German Federal Ministry for Economic Affairs and Energy has announced a series of measures that will facilitate the access of demand-side resources to wholesale and balancing markets in its electricity market white paper (BMWi 2015). Among other measures, the proposals aim to facilitate the access of DR resources to the German balancing market and standardise the interaction of DSM Service Companies, utilities and balance responsible parties.

Conclusion

Demand response can potentially be a valuable system resource in the transition towards a low-carbon electricity system. Some DR capacity is already marketed in Germany today. However, significant additional untapped potential exists. Drawing from international experience and considering the technical potential in industry and the tertiary sector, a DR capacity in the order of 10% of German peak load (around 7 GW) in these sectors alone seems possible.

In order to deploy this potential, smaller loads – e.g. cross-cutting technologies such as cooling and ventilation – will have to be aggregated and marketed, either on the system level or on the firm level by DSM Service Companies (utilities, aggregators). It remains to be seen whether creating a level playing field on all energy markets will suffice to incentivise demand response. Additional payments may become necessary to finance costly investments into additional storage capacity (e.g. product storage or compressed air storage), unlocking DR potentials that are available for several hours (Fraunhofer ISI and FfE 2013).

The costs of marketing larger potentials of flexible demand are uncertain from today's point of view. Investment costs are lower in industry compared to the tertiary sector, while variable costs are much higher. On the other hand, incentivising demand response may offer synergies with energy efficiency policies. In the process of identifying DR potentials, for example, DSM Service Companies may also help to identify and realise energy efficiency potentials at the company level.

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