Demand side management in industry – necessary for a sustainable energy system or a backward step in terms of improving efficiency?

Karin Arnold
Wuppertal Institute for Climate, Environment and Energy gGmbH
Döppersberg 19
42103 Wuppertal
Germany
Karin.arnold@wupperinst.org

Tomke Janssen
Wuppertal Institute for Climate, Environment and Energy gGmbH
Döppersberg 19
42103 Wuppertal
Germany
tomke.janssen@wupperinst.org

Keywords

demand side management (DSM), energy supply and demand, effectiveness, flexibility, energy-intensive industry

Abstract

Renewable energy plays a key role in the sustainable pathway towards a low carbon future and, despite new supply capacities, the transformation of the energy system also requires the adoption of a method which allows for the integration of increasing amounts of renewable energy. This requires a transition to more flexible processes at an industrial level and demand side management (DSM) is one possible way of achieving this transition. Currently, increased shares of variable renewable energy can cause the electricity supply to become more volatile and result in changes to the electricity market. In order to develop a new dynamic equilibrium to balance supply and demand, sufficient flexibility in demand is required. As adequate storage systems are not available in the short to medium term, the potential for large electricity consumers to operate flexibly is an attractive, pragmatic and feasible option.

Recent studies in Germany suggest that there is significant potential for DSM in so-called "energy-intensive industries". However, the figures (which fall in the approximate range of 1,250–2,750 MW positive and 400–1,300 MW negative shiftable load) should be interpreted with caution. The range of industrial processes considered are diverse and vary from plant to plant, with the result that it is difficult to provide accurate calculations of the accumulated potential for Germany or the EU as a whole.

Based on extensive surveys and panel discussions with representatives from energy-intensive industries (aluminum, cement, chemicals, iron & steel, pulp & paper), which together account for approximately one third of the industrial electricity demand in Germany, our paper provides an overview of both the opportunities and the barriers faced by DSM. One of the key findings is the possible loss in energy efficiency due to DSM: in order to decrease or increase production depending on the stability needs of the electricity system, plants and processes may no longer operate at their optimum levels. The effects on downstream production must also be taken into account in order to gain a more complete understanding of the overall effects of industrial DSM.

Introduction

Renewable energy plays a central role in the pathway towards a decarbonised future. In addition to new supply capacities, the transformation of the energy system also requires a means of integrating increasing shares of renewables. This paper focuses on demand side management (DSM) as a means of addressing this aim within the industrial sector.

Currently, increased shares of variable renewable energy can cause the electricity supply to become more volatile and result in changes to the electricity market. One option for overcoming this is to develop a new dynamic equilibrium to balance supply and demand, with sufficient flexibility in demand. As appropriate storage systems are not available in the short to medium term, the potential for large electricity consumers to operate flexibly appears to be an attractive, pragmatic and feasible option. However, the impact of such a change on energy efficiency must also be considered. In recent years, industry has, in general, become more efficient and is moving towards the 20 % increase in efficiency as proposed in the EU 2020 target (ref). However, major challenges need to be addressed in all industry sectors if this target is to be achieved. The potential for flexible DSM to have a detrimental effect on energy efficiency gains has been highlighted in recent times. As (Kupzog, Roesener, and Palensky 2007) state, in many cases when DSM strategies are put into operation, conflicts between flexibility and efficiency arise.

The following effects have been identified as possible causes of decreased efficiency: processes operating at non-optimal levels in terms of load and extent of use; fewer full-load operating hours; more frequent modification of cycles; and less capacity planning in terms of the plant and plant dimensions. Efficiency losses must be monitored carefully in the case of a shift in focus of industrial processes from optimising efficiency to allowing for a certain amount of flexibility.

While measures linked with enhanced flexibility, such as those listed above, are presumed to be in conflict with an increase in efficiency and vice versa, there are currently no in-depth studies examining the effect. The only evidence of actual efficiency losses comes from limited experience and R&D data, which are based on specific plants and processes. Generally, the assumption is made that these losses do occur in response to flexibility measures, as demonstrated in single plants and processes. However, there is still no definite evidence or accurate data quantifying the losses for individual companies or industry sectors. It may be necessary to accept that negative efficiency in industrial production processes will be inevitable, but will be counterbalanced by the greater efficiency of the overall electricity system. However, further analysis is necessary to examine whether the overall efficiency gains are sufficiently high to justify possible efficiency losses at company level. Despite the lack of data, this conflict between flexibility and efficiency has been highlighted by many experts from different industry sectors as a significant challenge to exploring DSM potential. It is unclear whether this challenge is a technical one, or whether it reflects low acceptance of DSM due to limited and partial knowledge and understanding.

This paper aims to clarify some uncertainties with respect to terminology and definitions of DSM in order to obtain a clearer picture of what it means for different industrial sites. An explanation of the existing types of load management will be given first, followed by a meta-analysis of recent studies evaluating the potential of DSM in Germany. After a new proposal for the classification of potential, a qualitative discussion of the possible effects on energy efficiency and the general suitability of plants for DSM conclude this paper.

Many industry players do not fully agree with the results of diverse studies on DSM potential, as they do not feel their own industry sector and its potential is adequately represented. This is partly due to an inconsistent use of terms and definitions. A further cause is that, due to reasons of data security, the results of the studies are rather vague. This lack of clarity is not intentional by the authors of the individual studies, but is caused by the lack of knowledge and experience of their interview partners in the specific industry sectors. This problem also demonstrates that the acceptance issues surrounding DSM is an important research topic.

Different terms and types of load management

As mentioned above, load management is becoming increasingly important in the context of the transformation of the energy system. Consequently, there is a lot of research into this field. As load management is not a new idea, different types of load management and their definitions are outlined here, providing a brief overview of its historic and current relevance.

In recent decades, **operational load management** has been of particular relevance. Operational load management can be regarded as a means of optimising energy costs by producing higher volumes of goods in times of lower energy prices and producing lower volumes of goods in times of higher energy prices. Individual plant operators contribute to the decision making process relating to production volume/energy consumption, particularly in the case of power plant operators who regularly practice operational load management. Following the German Energy Agency "dena" ("Deutsche Energie Agentur") industrial companies use this measure to reduce cost-intensive peak loads in electricity purchase, which arise from the load-related share of the electricity price (Deutsche Energie-Agentur GmbH (dena) 2012, 9).

In contrast to operational load management, **superordinated load management** is managed by the TSO (transmission system operator). In the second half of the 20th century, programmes were introduced in Germany to prevent peak loads and to enable the better utilisation of base load power plants (Krüger 2011, 1). In a short historical classification of load management, Klobasa uses the term "Least Cost Planning", which refers to insights and knowledge regarding resource-saving and efficient power supply gained in the 1990s (Klobasa 2007a, 9). This focuses on reducing peak load for a particular grid territory in order to minimise costs.

In recent years, the relevance of superordinated load management has risen significantly due to the demand to integrate increasing volumes of variable renewable energies, such as wind power and solar energy. In the literature examined, different terms are used to describe superordinated load management, namely **Demand Side Management (DSM), Demand (Side) Response (DR)** and **Demand Side Integration (DSI)**, all of which are explained in greater detail below.

In general, **Demand Side Management (DSM)** refers to activities that alter the magnitude and/or the time of power demand in order to enhance the overall economic benefits (Charles River Associates 2005a, 6). This is usually carried out by plant operators or by the intervention of the TSO. According to this classic definition, DSM includes a number of strategies designed to influence consumer load. These are illustrated in Figure 1.

The common definitions of these strategies include three different types of **load management** (*Peak Clipping, Valley Filling* and *Load Shifting*), which can be used to achieve short-term effects, but also include **energy efficiency**, which leads to a decreased load within the grid, and **electrification**, which leads to an increased load with the potential to deliver control power if applicable. The two latter strategies have longer-term effects. *Peak Clipping* describes the reduction in consumer load, e.g. in times of peak loads.

In several studies, **Demand Side Response (DR)** is defined as a subset of DSM, characterised by a specific control type. It is used to describe all the activities that alter consumer load which are controlled *indirectly* by the transmission system operator. As a reaction (or response) of a customer to an incentive (mostly monetary), the power use is economically optimised (VDE – Verband der Elektrotechnik Elektronik In-

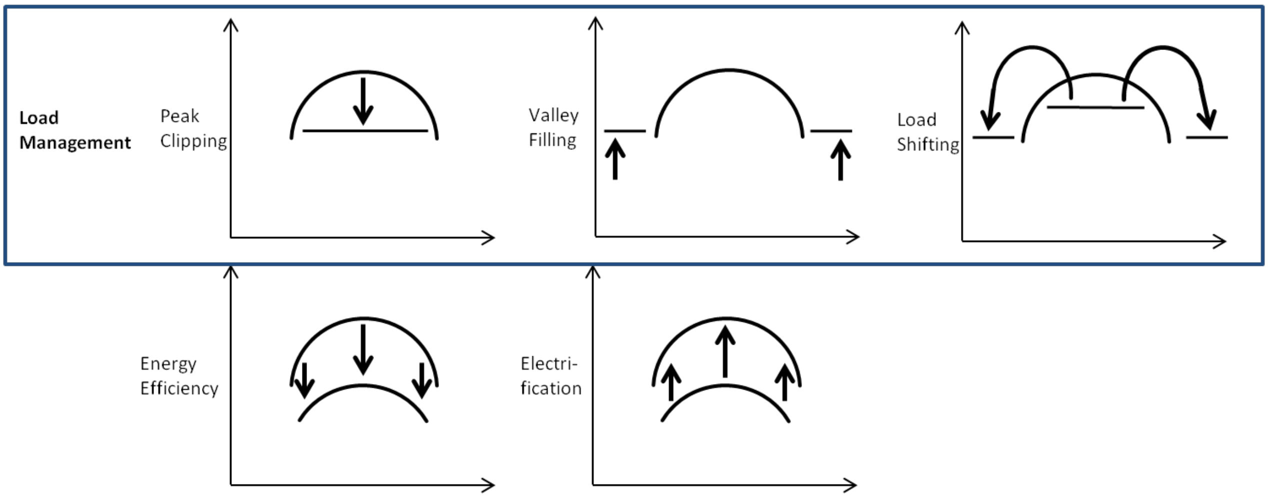

Figure 1. DSM strategies based on (Barakat & Chamberlin. 1993; Charles River Associates 2005b).

formationstechnik e.V. 2012). In other current studies, DR is not considered as a subset of DSM but is used as an independent term (see for example (VDE – Verband der Elektrotechnik Elektronik Informationstechnik e.V. 2012) (von Roon und Gobmaier 2010 p. 3)). In these studies, DSM is not seen as a superordinate measure for direct and indirect control by the TSO but is only used for those measures that influence electricity consumption *directly*. **Demand Side Integration (DSI)** is an additional term often used in these studies and serves as the umbrella term for both direct and indirect measures. To avoid confusion due to these different usages of terms, we use the following definition within this paper: **DSM** is defined as every activity, including both direct and indirect measures, that leads to an adaption of the power demand to the conditions of power generation and the power grid**.** Therefore, it also includes activities that are indirectly controlled by the transmission system operator. The terms **"**Load management" and "Demand Side Management" are understood and used as synonyms.

When discussing the implications of DSM for industrial processes, two other terms are also important. If load reduction is not compensated at a later or an earlier time, the overall energy consumption is lowered. This is called **load shedding**. From the point of view of a producing company, this means that productivity is reduced. In cases where load reduction is compensated by, for example, *Valley Filling* in off-peak times, the combination of the strategies is called **load shifting**. In this case, over a longer time period, the cumulated energy consumption does not change from a theoretical point of view (Kupzog, Roesener, and Palensky 2007, 2). Keeping in mind that there is a specific working point for each production technology where it operates optimally in terms of energy consumption, providing flexibility will inevitably lead to a reduction in the energy efficiency of the process. From a national economic point of view (as opposed to from an individual company perspective), load shedding leads to acceptable costs based on the service it delivers to the electricity system (Schwill 2016).

Meta-Analysis of DSM potential

A LITERATURE REVIEW – APPROACH

This chapter provides the overview of a detailed literature review to assess the technical potential of DSM in the industrial sector. A variety of studies are considered in order to compare their potential; these are briefly presented in the following chapter. Afterwards, the selected sectors and applications are compiled and the different parameters characterising the DSM potential which are considered as relevant and are included in the literature review are described, although many of these are not considered in a number of the studies examined.

RESEARCH LITERATURE

The research literature examined for the meta-analysis mainly focuses on the studies in Table 1.

Most of the studies refer to the five sectors analysed in this paper (aluminum, cement, chemicals, iron & steel, pulp & paper), apart from (Buber u. a. 2013) who does not include aluminum. The current BET study on load balancing potential (Langrock u. a. 2015) aggregates the industrial sectors of aluminum and air separation as well as cement and glass for reasons of data protection. (Hauck 2015), an industrial representative from Trimet, brings into focus the potential in the aluminum industry.

Studies cited frequently in the discussion are (Stadler 2006), (Klobasa 2007a) (Dena 2010) and (VDE – Verband der Elektrotechnik Elektronik Informationstechnik e.V. 2012).

SELECTED SECTORS AND APPLICATIONS

In most studies, the DSM potential of the same six processes (aluminum electrolysis, cement and raw mills, chlorine electrolysis, air separation, electric arc furnace and pulp production) is evaluated. These are regarded as the most promising options due to their high share of electricity costs in gross value added and their technical possibilities of load shedding or shifting. Which aspect is more relevant (cost or energy consumption) depends on the position of actors and can vary, considering the motivation for DSM (optimization of companies revenues or contribution to energy transformation). The motivation to disrupt the production process is higher for

Table 1. Examined research literature.

Abbreviated title	Description of the study (author, year of publication, title …)
Agora 2013	Klobasa et al. 2013. “Lastmanagement als Beitrag zur Deckung des Spitzenlastbedarfs in Süddeutschland”. Auftragsstudie Endbericht. Berlin: Agora Energiewende.
BET 2015	Langrock, Thomas, Siggi Achner, Bastian Baumgart, Christian Jungbluth, Constanze Marambio, Armin Michels, Achim Otto, und Paul Weinhard. 2015. “Regelleistungsbereitstellung mit regelbaren Lasten in einem Energieversorgungssystem mit wachsendem Anteil Erneuerbarer Energien”. Im Auftrag des Umweltbundesamtes.
Buber 2013	Buber, Tim, Anna Gruber, Marian Klobasa, und Serafin von Roon. 2013. “Lastmanagement für Systemdienstleistungen und zur Reduktion der Spitzenlast”. *Vierteljahrshefte zur Wirtschaftsforschung* 82 (3): 89–106.
DENA 2010	Deutsche Energie-Agentur GmbH (dena). 2010. “dena-Netzstudie II. Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015 – 2020 mit Ausblick 2025”.
D.-Franke 2012	Droste-Franke, Bert, Ruth Klüser, und Theresa Noll. 2012. “Balancing renewable electricity energy storage, demand side management, and network extension from an interdisciplinary perspective”. Heidelberg; New York: Springer. http://dx.doi.org/10.1007/978-3-642-25157-3.
Gils 2014	Gils, Hans Christian. 2014. “Assessment of the theoretical demand response potential in Europe”. Energy 67: 1–18.
Gruber 2014	Gruber, Anna, Franziska Biedermann, Serafin von Roon, und Luis Carr. 2014. “Regionale Lastmanagement-Potenziale stromintensiver Prozesse”. In . Graz: Forschungsgesellschaft für Energiewirtschaft mbH. http://portal.tugraz.at/portal/page/portal/Files/i4340/eninnov2014/files/lf/LF_Gruber.pdf.
Hauck 2014	Hauck, Heribert. 2014. “Aluminiumelektrolyse als virtueller Stromspeicher – ein Beitrag zum Gelingen der Energiewende”. Trimet Aluminium SE gehalten auf der Plattform Klimaschutz und Industrie – Branchendialog Alu-/NE-Industrie, Düsseldorf, November 25.
Klobasa 2007	Klobasa, Marian. 2007. “Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz”. Stuttgart: Fraunhofer-IRB-Verl.
Paulus Bogreffe 2009/2011	Paulus, Moritz, und Frieder Borggrefe. 2009. “Economic Potential of Demand Side Management in an Industrialized Country – the Case of Germany” . In Conference Proceedings. Vienna. Paulus, Moritz, und Frieder Borggrefe. 2011. “The potential of demand-side management in energy-intensive industries for electricity markets in Germany”. Applied Energy, The 5th Dubrovnik Conference on Sustainable Development of Energy, Water and Environment Systems.
Praktiknjo 2013	Praktiknjo, Aaron. 2013. “Sicherheit der Elektrizitätsversorgung: Das Spannungsfeld von Wirtschaftlichkeit und Umweltverträglichkeit”. Springer-Verlag.
VDE 2012	VDE – Verband der Elektrotechnik Elektronik Informationstechnik e.V. 2012. “Demand Side Integration – Lastverschiebungspotenziale in Deutschland”. Frankfurt a.M.
Wille-Hausmann 2009	Klobasa, Marian, Thomas Erge, und Bernhard Wille-Haussmann. 2009. “Integration von Windenergie in ein zukünftiges Energiesystem unterstützt durch Lastmanagement”. Fraunhofer – Institut für System-und Innovationsforschung, Karlsruhe.

Table 2. Suitable application for each sector based on the literature review.

Sector	Application
Aluminum	Electrolysis
Chlorine	Electrolysis
Air separation	Air separation
Cement	Cement or raw mills
Steel	Electric arc furnace
Paper	Mechanical pulp production
Cross-sectional technologies	Mills, pumps, compressors, air conditioning…

these sectors than for sectors with a smaller share of electricity costs because the opportunity costs are higher (Paulus und Borggrefe 2009).

The sectors and applications for load management are shown in Table 2. In most cases, different types of load management have been considered, with load shedding the most common followed by load shifting. For many applications, load can be reduced or increased.

Various publications on DSM have included cross-sectional technologies in their analyses. Despite this, a quantitative comparison is not feasible because the studies include different processes under cross-sectional technologies and examine different infrastructures. These variations influence the capability of delivering DSM. Therefore, the discussion of these findings will be solely qualitative due to the lack of comparable quantitative data.

PARAMETERS CHARACTERISING DSM POTENTIAL

A variety of parameters characterise the extent of DSM potential, but typically only a few are assessed in the majority of studies and these generally estimate the overall national potential for industrial sectors based on single appliances.

The average shiftable load available for flexibilisation represents the most important parameter for describing the extent of DSM potential. Additionally, the maximum amount of DSM, referred to as per time unit, and the maximum time a potential can be used continuously are frequently examined. On occasion, the maximum shiftable amount of energy during a certain period of time is used to indicate DSM potential. The latter can be calculated by multiplying the average shiftable load by the maximum duration of the DSM activation and the maximum number of DSM calls in a certain time period.

For clarity in this study, a detailed set of parameters was compiled in order to be able to include any information given in the literature characterising the potential. This is described in the following and provides the basis for the literature review.

Production capacity and electricity demand

As mentioned previously, energy-intensive processes (where the energy used is electricity) offer the highest potential. Consequently, annual production capacities, including electricity demand of the overall sector and of specific processes, are relevant. Additionally, the specific electricity demand per unit output was considered.

Electricity use in energy-intensive production processes is dependent on the production plan. Production is typically planned for the following month or an even longer time span. The resultant electricity demand can be estimated on a detailed daily plan in time units of 15 minutes. The factory owner constantly updates this plan but submits his plan on a monthly basis one month before the monthly production starts. This information is provided to the supplier. This demonstrates that electricity supply in practice is flexible and the actual amounts required can be calculated on the energy market. However, long-term contracts may limit economic flexibility.

Production characteristics/load pattern

There are a variety of production conditions restricting the extent and the availability of DSM potential. Many are reflected in the load patterns used; i.e. the requirements in parameters attached to load pattern. Interviews with the industrial partners in this project highlighted several aspects of key importance in the context of the load pattern which could be used to quantify DSM potential. In order to draw a realistic picture of feasible potential, the following questions should be answered in detail:

- What share of the load is available for load reduction/increase or relates to the specific production asset and its production plans?
- Is there a minimum load that should be maintained?
- Is the relevant process part of a continuous production process; is it located at the beginning of a production value chain with dependencies following production; are there daily and/or seasonal load profiles that define a varying size of the flexible load over time or is it driven by demand?
- How high is the average load that can be offered for DSM; what is the maximum power consumption when the unit operates at full load; what is the usual utilisation level of the relevant processes?

Questions like these help to evaluate whether there is DSM potential and, if there is, to define its characteristics (e.g. electrical power and work, timespan of reducing or increasing the electrical load, load ramps for reduction and increase of the load) depending on the specific process and its production environment.

If the utilisation level is very high and the production unit operates at full load, the power purchased cannot be further increased. Therefore, only positive balancing power can be offered and it is not possible to make up the reduced output at a later stage, meaning that load shedding is the only possible type of load modification. The differentiation between load shedding and load shifting is one of the most important categorisation parameters, since the opportunity cost for the loss of production is an essential element of DSM assessment. Additional parameters to describe production constraints reflected in requirements of the load pattern are the maximum duration of DSM activation, the minimum time between two DSM calls and the maximum number of DSM calls per year. In addition, the type of balancing power that can be provided by a specific industrial potential and the time needed for a process to react to control signals and adapt to changing production conditions are significant.

Costs

In general, costs relating to achieving DSM potential can be divided into **variable costs**, **fixed costs**, **maintenance costs**, **investment costs** and **opportunity costs**.

Firstly, investment costs are often necessary in order to achieve DSM potential. The purpose of an enterprise is the production of goods. According to market analysis and business plans, certain production volumes and production capacities must be realised. In order to be competitive, investment in overcapacities should generally be avoided. Therefore, in many cases, only load shedding is possible, because production capacities are insufficient. To enable the delivery of DSM, additional capacities, storage systems or developments to the infrastructure must be put in place, all of which incur **investment costs**.

Operational costs are also relevant. Achieving DSM potential necessities an increase in **fixed costs;** for example for the development and purchase of data management systems that enable DSM (management and control systems (Frontier Economics 2014)). Furthermore, engaging new staff to meet DSM potential can involve additional costs. Fixed costs are related to the frequency of use of necessary resources: the more they are used the lower the cost per unit.

Also included in operational costs are **variable costs**. These will be incurred when a DSM call is made, for example when control power is delivered. They are also incurred when energy prizes and auctions for control power are checked, when the DSM potential of the production assets is evaluated, when bids are made and accepted, and when control load is delivered.

Energy-intensive production plants or the assets of energy-intensive industries are usually constructed in a manner designed to minimise energy consumption and the use of raw materials during the continuous operating mode (i.e. large scale continuous production operating with no intermittency) at a defined operating point or in a defined operating window. Legacy requirements do not allow for fluctuating operating modes adapted to the supply of electricity by a power grid fed by renewable energies. Irregular operating modes cause inefficiencies (including production losses and lower production quality) which are part of the variable costs, but also cause increased **maintenance costs** because of increased wear. Due to a lack of experience and limited R&D these additional costs are often unknown and cannot be quantified.

Opportunity costs refer to the business purpose of the company. Depending on the market situation and whether or not a company is producing at full capacity, it may be of advantage to a company to adopt DSM – and perhaps to reduce production. This must be taken into consideration by the company within its decision-making process in respect to new investment. Opportunity costs also contribute to the variable costs that arise when a DSM call resulting in load shedding is made, as outcomes include reduced production or lower product quality.

In general, it can be noted that the costs in all categories vary significantly depending on the industry sector, type of production and the production plant itself, including the specific circumstances at a particular production site of a company (e.g. degree of capacity utilisation).

Impacts on energy use

As previously mentioned, reduced energy, resource and material efficiencies can occur as a side effect of flexibilisation due to deviation from the optimum operating levels. This aspect is, therefore, particularly relevant since it relates to the overall conflict between efficiency and flexibilisation strategies. However, none of the studies examined provide quantitative data for the increase in energy demand caused by DSM in the different industry sectors. This is mainly due to the complexity of the issue: the impacts of DSM on energy use may vary significantly between production technologies, as well as between different production settings, even when comparing the same technology. The age of the plant can also impact on the potential of DSM, as can the operating mode and the value chains that cause different operating modes (the latter is of particular relevance for chemical sites).

FINDINGS AND OVERVIEW FROM THE LITERATURE REVIEW RELATED TO THE SELECTED SECTORS

As mentioned above, a variety of parameters is needed to describe DSM potential. In the literature, the potential is described in different levels of detail. Most studies present only an average value for the flexible load available in specific processes (compare for example (Dena 2010), (Droste-Franke, Klüser, und Noll 2012) and (VDE – Verband der Elektrotechnik Elektronik Informationstechnik e.V. 2012)). Some differentiate between maximum, minimum and average flexible load (see for example (Gils 2013a)). (Klobasa 2007b) differentiates between the flexible load for single appliances according to changing seasonal load patterns (e.g. different values for summer and winter). A study conducted by Agora (Klobasa et al. 2013) identifies flexible loads for various management timeframes (in contrast to most of the studies which only mention constant (maximum) management timeframes). Overall, only one study adopts a very detailed approach. (Stadler 2006) assesses three-dimensional potential curves for the flexible load available for some appliances – depending not only on the management timeframe but also on the temperature, which is an important exogenous parameter for appliances e.g. cold stores or heat pumps. However, this study was published approximately ten years ago and applies solely to industries for which the potential of compressed air applications is assessed. Therefore, no quantitative data from this study is used in the following comparison.

The study published by (Langrock u. a. 2015) was funded by the Umwelt Bundesamt (UBA), the German Federal Environment Agency, and it differs from previous studies in the way it depicts the flexibility potential. The study assesses the socio-technical potential and classifies the potential according to the specific forms of use of the available products on the electricity market. The socio-technical potential is defined as a subset of the technical potential, which takes into account the individual perspective of the company's economic and logistical conditions in addition to technical restrictions. It is not part of the quantitative comparison in this overview.

This overview highlights and compares two parameters from the studies: annual electricity demand by sector and the average shiftable (and partly shedable) load available. The reason for concentrating on these parameters is because these are the ones examined in most of the studies.

As mentioned above, in the industry sectors examined a company's electricity demand is an important criterion for its DSM potential. The higher the electricity demand – and hence the load – in a particular sector, the higher the possible impact on grid stability. Therefore, electricity demand is a subject examined by all the studies considered in the literature review. The range of given values for annual electricity demand by sector is presented in Figure 2.

The lowest values presented in the studies are shown in grey, the highest values in black and the average represented by the red dot. It is clear that the range is comparatively wide for sectors such as steel or chlorine. This may result from an issue outlined earlier in this paper (see section above on "parameters"): that different processes, companies and plant settings are included under a single sector and, therefore, different categories of potential have been estimated. Individual plant availability and plant settings are not necessarily reflected. According to the studies, the paper industry has the highest annual electricity demand based on the average value, followed by chlorine and steel production. Since this parameter plays an important role in the assessment of DSM potential, this compilation highlights the fact that different studies make significantly different assessments about DSM potential.

An overview of the range of the maximum load increase and load reduction as the main parameters for depicting the flexibility potential for the abovementioned sectors given in the different studies can be found in Figure 3.

For the purpose of this report, the term "positive" will be taken to describe a load reduction. This is necessary when demand

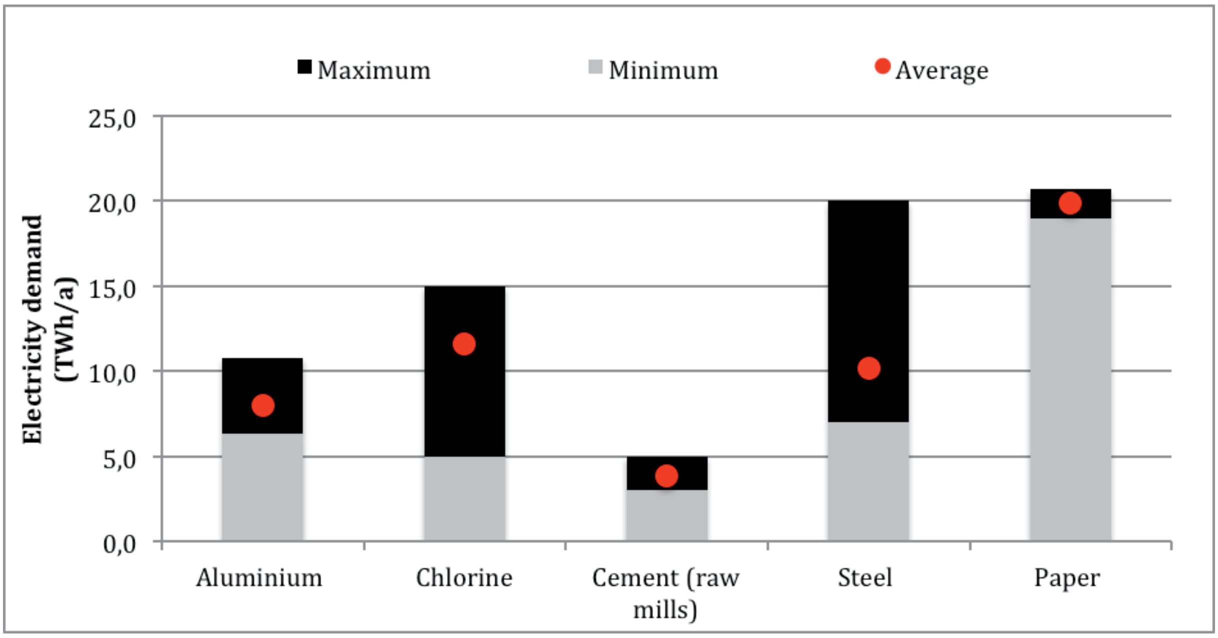

Figure 2. Annual electricity demand by sector.

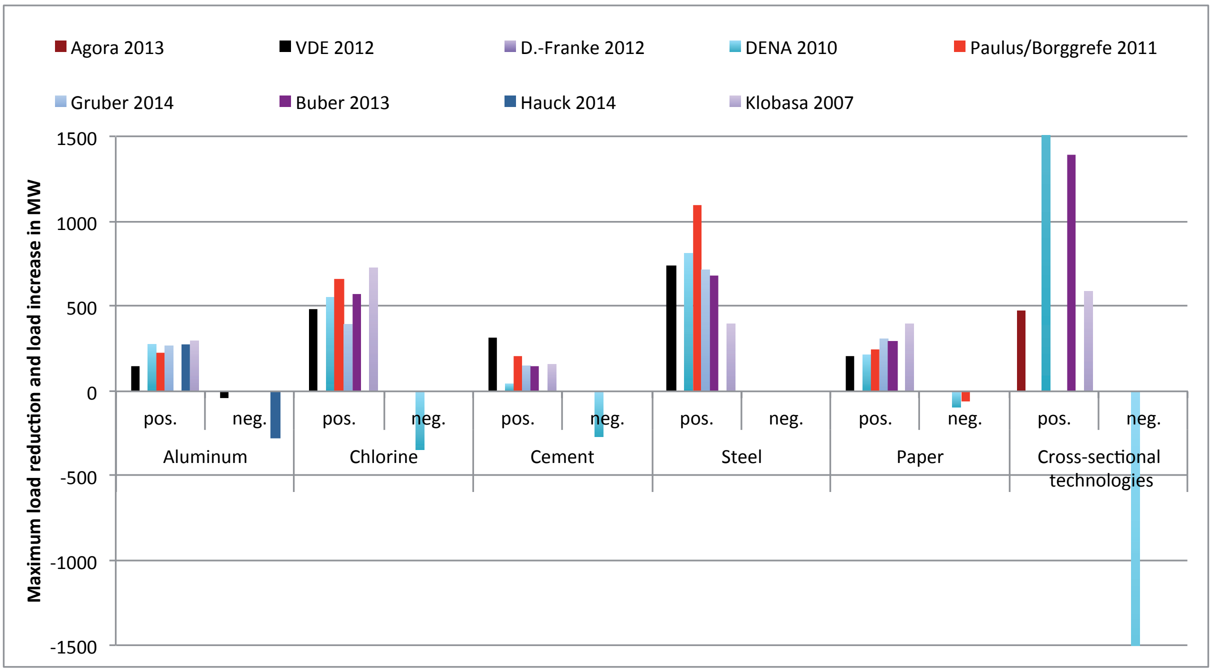

Figure 3. DSM potential by sector and by study ("technical potential").

exceeds supply. The term "negative" refers to a load increase. This definition applies to the balancing energy market.
In some studies, quantitative values do not differentiate between shiftable and shedable load. In such cases, the shedable load is commonly assessed as the maximum available capacity of a process available for DSM.

However, the industrial experts consulted in this study state that this is a theoretical and not a technical potential (see the following section: "Proposal for new definition of potential terms"). Consequently, the figures for shiftable loads (as opposed to shedable loads) are used for the comparison below. However, due to the fact that in some of the studies no differentiation is made between shedable and shiftable load in the figures given, there is a risk that some of the positive load reduction potential below might refer to the load shedding potential.

The highest positive potential can be found in the steel industry due to its high specific electricity demand, while the chemical industry has the highest negative potential due to its good storage options. The negative shiftable load potential of the industrial electricity-intensive processes is generally significantly smaller than the positive potential, due to the very high utilisation levels of the production processes.

Where the capacity to make up for lost production units is not possible, a company has to choose between producing goods and delivering DSM. This has a direct impact on the company's willingness to offer flexibility and the "availability" of the potential (techno-economic and economic potential).

As indicated above, the range of estimated potential is comparatively wide. Aside from the varying electricity demand used as a parameter for assessing the potential, various uncertainties and different basic assumptions in the studies contribute to the large differences evident in the shiftable load. As mentioned above, differing basic assumptions are one important reason for the variations in the study results; for example those relating to electricity consumption. Klobasa (10.5 TWh in 2005) and the DENA study (9.8 TW in 2008) use similar values to each other; this contrasts with the VDE study which bases its estimations on nearly half of those values (5.6 TWh in 2010).

The following section proposes a new classification of DSM potential, as existing definitions of the potential are not always consistent and the definition of the term "technical potential" is not sufficiently clear.

Proposal for enhanced definition of potential terms

DIFFERENT TERMS AND TYPES OF POTENTIALS

When considering different terms and types of load management it is important to examine the different types of load management potential. Generally, a distinction can be made between theoretical, technical, economic and feasible potential, and other categories also exist. The definitions of these terms and the delimitations between them are not, however, always clear and are even less likely to be consistently applied.

(Gils 2013b) differentiates between theoretical, technical and economic potential and, in addition, refers to "accepted utilisation" and "feasible potential". In doing so, he provides a solid base for discussion. In his terms, the theoretical potential is defined as the sum of all appliances suitable for load management, with the technical potential differing from the theoretical potential based on the limits to necessary information and communication technologies and infrastructure (ICT). A subset of the technical potential is the economic potential, which is the feasibility from an economic point of view under the current market conditions. In addition to the economic feasibility, the acceptance of the consumer (i.e. willingness to offer flexibility) is required to unlock the feasible potential. This aspect seems to be more important at household and small company level, rather than for large-scale energy-intensive industries. The same definitions are provided by (Grein und Pehnt 2011).

While these definitions provide a solid base for first approaches to analyse potential, there is great debate between industry actors about their needs and requirements when assessing the possibilities for DSM. This indicates that further detail must be included in the definitions. For industry actors, the economic potential is the most relevant aspect to consider when taking decisions about whether or not to adopt DSM. However, the economic potential cannot be quantified without in-depth knowledge of the technical potential. In order to accurately assess the technical potential, concise information about the respective process in question is mandatory, as every plant and every process must be considered on a case-by-case basis. It is, therefore, overly-simplified to consider the theoretical (defined as the sum of all appliances suitable for load management, see below) and technical potential on the same level, as suggested by (Gils 2013b) and others.

Therefore, within the framework of this project, this study presents our own categorisation of DSM potential. This is based on and further develops the work of (Gils 2013b; Grein und Pehnt 2011) and others. The categories are illustrated in Figure 4.

The starting point is the same: the theoretical potential. This potential reduces as each additional category is included, but the reduction is not expected to be in equal steps. This is also shown in Figure 4, which provides a qualitative (not quantitative) depiction.

The categories can be described as follows:

- The **theoretical potential** is defined as the sum of all appliances suitable for load management. For example, a production facility of 50 MW has a theoretical potential of 50 MW of electrical capacity.
- The **technical potential** includes all appliances that are basically usable due to the existing necessary information and communication infrastructure (Gils 2013b) – minus the electricity required for the basic maintenance of the plant, e.g. electricity for pumps, electric fans and base voltage that cannot be shut down (not even for a period of time) without closing the site completely. Taking the example of a production facility of 50 MW, the plant could suffer damage if it delivers the full theoretical potential of 50 MW. The technical potential in this definition is expected to be only slightly lower than the theoretical potential.
- The **techno-economic potential** follows the same logic: it describes the case where (1) a certain base load needs to be maintained in order to be able to deliver the same quality of products as would be possible without DSM (2) the plant is not "damaged" nor will it age more rapidly under DSM (risks include, for example, the increased ageing of membranes of membrane electrolysis to produce chlorine caused by frequent load changes). Both are relevant aspects that will influence the decision of the operators to participate in DSM and could also be included in the category of "accepted utilisation" according to (Gils 2013b). They could, on the other hand, fall into the category of economic potential, as reductions in product quality or increases in plant maintenance are economic aspects to take into consideration. The questions addressed by these factors are crucial for plant operators, which is why they are given a more prominent position in our definition. It unreasonable to focus on technical potential that will never be realised because it requires major curtailments in production or in revenue (as in the case of early ageing and increased maintenance). The expectation is that the step between the described technical and techno-economic potential will be larger than the one between the theoretical and technical potential.
- The **economic potential** is a subset of the techno-economic potential. It has been defined as that which is feasible from an economic point of view under current market conditions, which generally means what costs (both variable and fixed) are incurred when applying the flexibilisation options and what possible revenue will be generated from the balancing power markets. However, in order to make an accurate calculation of costs incurred by the plant operator, a variety

of factors must be taken into account. Downstream effects should be identified and quantified: in the case of load shifting, additional storage facilities should be accounted for; for load shedding, the decrease in production may have to be compensated for further down the line. In the plant itself, efficiency losses might occur, further increasing the operating costs. Additional increases to operating costs can arise from reduced product quality, which can be caused by unfavorable production modes introduced alongside DSM.

- The **socio-economic potential** includes the effects on human resources: flexible operation may require multi-shift operations; more staff could be needed; or existing staff may need to be trained in different ways. Regulatory framework aspects are also included here; for example the question of the deployment of further storage facilities, which may be subject to regulatory approval. Acceptance by staff and the local community is also part of the evaluation of the socio-economic potential.
- Last but not least, it must be assumed that only part of the socio-economic potential will be harnessed, even if all the conditions are fulfilled and the framework is established in the right way. Therefore, predictions about the **practical potential** should be viewed with caution. Experience in other fields of potential analysis demonstrates that a multitude of aspects can hinder the implementation of socio-economic potential. These aspects only become clear and can only be understood on a case-by-case basis. Initial evaluations of DSM potential in Bavaria and Baden-Wuertemberg in southern Germany by DENA show that the "accepted potential", as they have evaluated it, is significantly lower than the technical potential – but not proportional and with high deviations from case to case (Seidel 2016).

Qualitative discussion of the effects and challenges

From discussions with many industry experts, it has been determined that the willingness of industry players to participate in DSM is low. Areas of concern include the practicability or otherwise of DSM, and its possible negative effects on the plant and the overall production process. One of the main fears surrounds the potential loss of efficiency of the given process. This must be considered in the context of the EU 20-20-20 goals (ref); one of these goals is for the further increase of (industrial) efficiency by 2020 by 20 % in comparison to 1990 levels. This is regarded as a very challenging goal even without the added complication of demand flexibility.

However, some scientific studies seem to overestimate the DSM potential of industrial plants, as indicated in the meta-analysis in this study, while simultaneously underestimating the difficulties and challenges that industry actors face in introducing DSM into their processes. It is important to remember that industrial plants have to operate in an economic manner. Many industrial processes do not produce final products but are intermediates in a chain and are, therefore, part of a network of downstream processes, all of whom are dependent on the others to keep their own production processes running. Contracts for the provision of products within these chains must be fulfilled and may even be subject to trade regulations.

In the following section, some of the effects and challenges will be qualitatively discussed, based on the expert discussions which have contributed to this study. The issue of the impact on efficiency is once again the focus of consideration. Overall, some processes can expect a greater loss of efficiency than others. It should be stated, however, that some of the "low hanging fruits" (offering low efficiency losses) have already been exploited – if not for superordinated load management for greater grid stability then for internal optimisation of production costs. This raises the following questions: what processes lend themselves to DSM and what impacts on efficiency have to be taken into account?

Low efficiency losses are likely to occur when energy can only be "relocated" and requested at an alternative point of time. An example is the application of pumps to maintain a certain water levels – for example, to balance the equilibrium between basins or at an embankment. Usually the pumps are automatically activated if the level in one basin rises above or drops below a certain mark. In many cases it should be possible to extend these boundaries in both directions (rise and fall) in order to take into account the developments and dynamics of

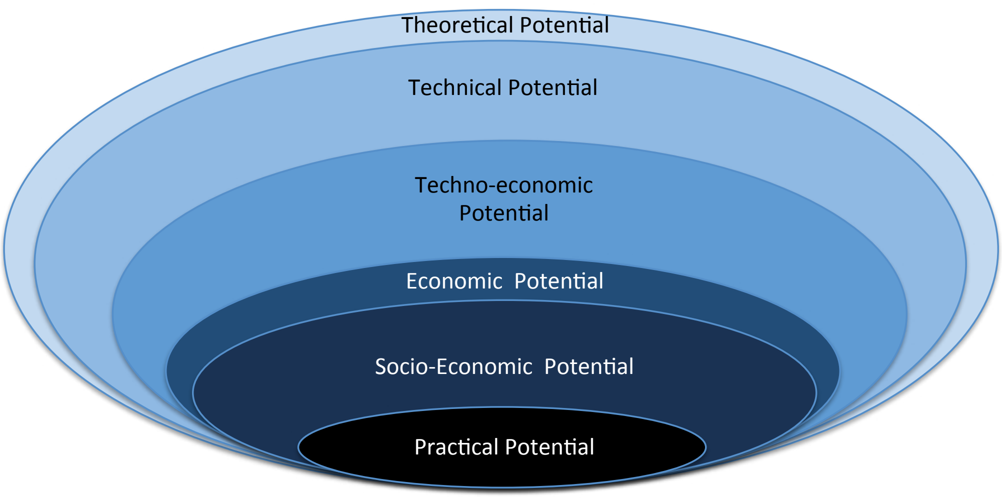

Figure 4. Categories of potential for industrial DSM (own definition and illustration).

the energy market. In such instances, critical values must be respected and safety, of course, takes priority over low energy prices. There are known examples of these types of DSM applications, but they do not relate specifically to energy-intensive industries.

In theory, energy can also be shifted easily in pure thermal processes operating in temperature ranges that do not include extremes of cold or heat. The temperature devices generally work in cycles and are not in continuous operation, so minor adjustments to the operating mode to meet the requirements of the energy market are comparably straightforward. Cold storage is a good example: many food products have a temperature tolerance to some degree and a certain timeframe exists where the temperature can be held in this "field of tolerance". Therefore, the cooling machinery does not have to react automatically if the temperature deviates from the set reference value; it may be possible to delay the cooling until a time of surplus electricity. On the other hand, cooling could be activated in times of surplus electricity before the reference value is reached, by cooling products to a lower temperature before allowing them to warm up to the given temperature limit. This is, however, an inefficient way of operating as the unwritten "law of refrigeration technology" states that lower temperatures than necessary should not be generated because this uses more energy.

The situation for higher temperatures in heat applications is similar. Generally, it is possible to expand the temperature range of boiling or melting processes and allow for a broader tolerance than usual in order to make use of a certain timeframe when the electricity prices are lower. The specific characteristics of the process and critical limits (melting and solidification points, for example) must, of course, be respected. It is generally possible to heat a certain process to a somewhat higher degree than required or to let it cool down a bit more and heat it up again. Theoretically, the energy required for this change is only relocated and, in total, no more energy is required than for the usual regulation of the process. However, closer examination of the overall impact on energy use is needed, because the temperature losses related to a given process increase with rising temperatures. The size of the losses in practice depend mainly on the deviation in the temperature and the level of temperature reached, the isolation of the process, and the products and intermediates entering and leaving the process etc.

However, if the process is not purely thermal, but also contains for example a chemical component, it becomes more complex and difficult to quantify. This is the case for chlorine/aluminium electrolysis, where electricity and heat trigger the chemical reaction in an electro-chemical process. In the case of aluminium, the reduction of oxide to aluminium serves as an example. In theory, the molten mass of the fused-salt in the electrolysis could provide, to a limited extent, heat storage and could, therefore, de-couple the heating of the process from a very certain reference temperature. However, the acceptable temperature range in this process is very small – due, among other reasons, to the chemical efficiency of the reaction. Below the lower boundary, the conductivity of the molten mass is no longer sufficient to keep the process alive. So if the temperature drops too far, the whole reaction ends and the process comes to a standstill. This is irreversible due to the loss of conductivity at lower temperatures and will have significant economic consequences for the plant. If the temperature rises too much, on the other hand, the crust of the molten mass, which is maintained for safety reasons, begins to melt and the process is also ruined. The fact that the temperature range between the lowest and the highest boundary is 6 K within an operating temperature of about 1,000 °C, underlines how critical the correct management of the process is. From the plant's economic point of view, the margin for experiments is very tight – although there is limited potential in terms of DSM that could be exploited.

The processes outlined above make use of the internal storage within a process, either in the form of fluid in a basin, or in the form of temperature stored in the given process. A different approach to load management is the shifting of the operating point of a plant. Most plants and processes have a very specific optimal operating point and most plant operators try to adhere precisely to this point. The internal optimisation is a function of capacity, utilisation rate and the operating point. To achieve load shifting it is necessary to maintain these optimal conditions (for example at an 80 % utilisation rate) and operate the plant at a rate of only 60 % in order to realise a positive load for the grid operator (load reduction). This means that the plant is less efficient than it would be at an 80 % utilisation rate. This is, however, not the only effect: in order to compensate for the reduced production, the plant must be operated for a certain timeframe at a higher utilisation rate, for example at 100 %, because normal production levels cannot simply be reduced as trade contracts and downstream processes must be fulfilled. If this load reduction is to be assessed as economically feasible, the discontinuous production will necessitate the provision of storage. The impact on energy efficiency has not been measured by many operators and there is very little data in this area. Therefore, accurate judgements with regard to the energy system cannot currently be made and further R&D is crucial. As part of this research, it must be taken into account that start-up and shutdown procedures normally require more energy than normal operations. In this context it should be mentioned that large-scale plants, which can only be operated between zero and full capacity ("on or off"), are not a popular option for load management among transmission system operators and aggregators. If the task is to follow a curved line of electricity demand, switching 50 MW "on or off" is not always helpful. This situation has the potential to be solved if, over time, more plants of different capacities are in the DSM pool and if the DSM products offered by grid operators become better adapted to industrial needs.

Having a site with a modular structure can offer additional degrees of freedom appropriate for DSM use. Take as an example a site comprising five comparable plants. If the utilisation rate is below the maximum, a conceivable solution could be to maintain four of the plants at their optimal operating level and to reduce the fifth as far as needed to fulfil the required demand – and vice versa in the case of increased utilisation rates. The four plants would operate at their highest levels and efficiency losses would only occur at the fifth plant. From an economic (rather than an energy) perspective, storage devices would be necessary to allow for discontinuous production (this may also be necessary from a regulatory viewpoint). The four plants would operate at their optimal level, while the fifth would only be needed on the rare occasions when more capacity was needed. This is, however, a kind of "stranded investment" because the fifth plant will barely be able to repay the investment made in it, or will have to be funded from the revenue generated by DSM.

Redundant installations can be used for DSM in a similar way to a modular site. For security and safety, many installations have redundant devices that could be used for load shifting. The many emergency generators and emergency power supplies fall into this category. As their engines have to be tested on a regular basis in order to ensure their functionality, these test drives could also be used to provide shiftable load to the grid.

Conclusions

Making a process flexible in order to harness DSM potential often requires adaptations that result in decreased efficiency or increased effort (e.g. additional storage devices etc.). Conversely, implementing DSM management can trigger the development of new and innovative processes and strategies that can lead to enhanced efficiency. The installation of heat exchangers is an example. Without the requirement to de-couple some of the process heat from the automatic and process-oriented supply in order to react to the energy market, industry players may not have considered the benefits that heat exchangers could have for thermal efficiency – even for processes not (often) required to operate flexibly.

The most cost effective period for implementing innovative DSM strategies occurs during the construction phase of a new industrial site because it is easier to include innovations during the planning phase rather than later in upgrading and retrofitting phases. However, there are limited opportunities to put this approach into practice as few "green field" sites remain in Germany for new construction. In contrast, the continual retrofitting and upgrading of industrial plants is common practice. Therefore, the major opportunities for DSM adoption lie within the upgrading cycles of large-scale plants and these should be realised. However, in practice, intensive evaluation and monitoring of possible efficiency losses should be undertaken before the widespread implementation of DSM in any industry branch. Even if efficiency losses are small, the sum of many small losses over time may have a negative impact on the industry and/or the energy system. The impact of flexibility on efficiency is, therefore, an important issue requiring further research and analysis.

Simultaneously, the fears and concerns voiced by industry players must be taken seriously and need to be addressed. These concerns are not only on an economic level. This concluding anecdote illustrates the insecurities that exist with regard to the overall topic of grid stability: a site operator refuses the use of his emergency power generator for DSM, because he fears the device would then not be available for his own use in the case of an emergency. This fear is clearly irrational. The emergency generator would only be needed if there was a power outage and the site lost connection to the grid. In that case, the grid operator would not be able to access the generator for its own purposes, so it would still, of course, be at the demand of the site operator.

The fear may be irrational, but the example shows that many concerns still need to be addressed and challenges overcome in the broad field of demand side and load management.

References

Barakat & Chamberlin. 1993. "Principles and Practice of Demand-Side Management". TR-102556. Palo Alto, California: EPRI. http://www.epri.com/search/Pages/results.aspx?k=Principles+and+Practice+of+Demand-Side+Management.

Buber, Tim, Anna Gruber, Marian Klobasa, und Serafin von Roon. 2013. "Lastmanagement für Systemdienstleistungen und zur Reduktion der Spitzenlast". *Vierteljahrshefte zur Wirtschaftsforschung* 82 (3): 89–106.

Charles River Associates. 2005a. "Primer on Demand-Side Management with an emphasis on price-responsive programs". CRA No. D06090. Oakland, California: The World Bank. http://siteresources.worldbank.org/INTENERGY/Resources/PrimeronDemand-SideManagement.pdf.

—. 2005b. "Primer on Demand-Side Management with an emphasis on price-responsive programs". CRA No. D06090. Oakland, California: The World Bank. http://siteresources.worldbank.org/INTENERGY/Resources/PrimeronDemand-SideManagement.pdf.

Dena. 2010. "Dena-Netzstudie II: Integration erneuerbarer Energien in die deutsche Stromversorgung im Zeitraum 2015 – 2020 mit Ausblick 2025". Berlin: Deutsche Energie Agentur GmbH. http://www.dena.de/fileadmin/user_upload/Download/Dokumente/Studien___Umfragen/Endbericht_dena-Netzstudie_II.PDF.

Deutsche Energie-Agentur GmbH (dena). 2012. *Handbuch Lastmanagement. Vermarktung flexibler Lasten: Erlöse erwirtschaften – zur Energiewende beitragen.* Berlin.

Droste-Franke, Bert, Ruth Klüser, und Theresa Noll. 2012. *Balancing renewable electricity energy storage, demand side management, and network extension from an interdisciplinary perspective*. Heidelberg; New York: Springer. http://dx.doi.org/10.1007/978-3-642-25157-3.

Frontier Economics, Formaet. 2014. "Strommarkt in Deutschland – Gewährleistet das derzeitige Marktdesign Versorgungssicherheit". *Bericht für das Bundesministerium für Wirtschaft und Energie, London, Aachen*.

Gils, Hans Christian. 2013a. "Abschätzung des möglichen Lastmanagementeinsatzes in Europa". In . Wien: Deutsches Zentrum für Luft- und Raumfahrt, Institut für Technische Thermodynamik. http://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/events/iewt/iewt2013/uploads/fullpaper/P_189_Gils_Hans_Christian_31-Jan-2013_12:22.pdf.

—. 2013b. "Abschätzung des möglichen Lastmanagementeinsatzes in Europa". In Wien: Deutsches Zentrum für Luft- und Raumfahrt, Institut für Technische Thermodynamik. http://www.eeg.tuwien.ac.at/eeg.tuwien.ac.at_pages/events/iewt/iewt2013/uploads/fullpaper/P_189_Gils_Hans_Christian_31-Jan-2013_12:22.pdf.

Grein, Arne, und Martin Pehnt. 2011. "Load management for refrigeration systems: Potentials and barriers". *Energy Policy* 39 (9): 5598–5608.

Hauck, Heribert. 2015. "Herausforderungen und chancen der Energiewende für die Aluminiumerzeugung in Deutschland". gehalten auf der Sitzung Lunkungsausschuss, Düsseldorf, Februar 19.

Klobasa et al. 2013. “Lastmanagement als Beitrag zur Deckung des Spitzenlastbedarfs in Süddeutschland”. Auftragsstudie endbericht. Berlin: Agora Energiewende.

Klobasa, Marian. 2007a. *Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz*. Stuttgart: Fraunhofer-IRB-Verl.

—. 2007b. *Dynamische Simulation eines Lastmanagements und Integration von Windenergie in ein Elektrizitätsnetz*. Stuttgart: Fraunhofer-IRB-Verl.

Krüger, Christine. 2011. “Lastmanagement – Neue Anforderungen und Einsatzfelder durch den Ausbau regenerativer Energien”. Technologiebrief. Wuppertal: Institut für Gründungs- und Innovationsforschung/Wuppertal Institut für Klima, Umwelt, Energie GmbH.

Kupzog, Friederich, Charlotte Roesener, und Peter Palensky. 2007. “Konzepte zur koordinierten Nutzung verteilter Energiespeicher”. *Internationale Energiewirtschaftstagung an der TU Wien*, 219–30.

Langrock, Thomas, Siggi Achner, Bastian Baumgart, Christian Jungbluth, Constanze Marambio, Armin Michels, Achim Otto, und Paul Weinhard. 2015. “Regelleistungsbereitstellung mit regelbaren Lasten in einem Energieversorgungssystem mit wachsendem Anteil Erneuerbarer Energien”. Im Auftrag des Umweltbundesamtes.

Paulus, M., und F. Borggrefe. 2009. “Economic potential of demand side management in an industrialized country– the case of Germany”. In *10th IAEE European conference, energy, policies and technologies for sustainable economies, Vienna*, 7–10. http://www.aaee.at/2009-IAEE/uploads/fullpaper_iaee09/P_488_Paulus_Moritz_31-Aug-2009,%2019:08.pdf.

Schwill, Jochen. 2016. “Flexibilität statt Grundlast! Gewinn- und Optimierungspotenziale in der Industrie”. gehalten auf der Treffen der Arbeitsgruppe 2: “Flexibilitätsoptionen für die Industrie in NRW”, Lünen, März 14.

Seidel, Hannes. 2016. “Die Identifizierung und Erschließung von Flexibilitäten – Handlungsoptionen und Strategien für die Industrie”. gehalten auf der Treffen der Arbeitsgruppe 2: “Flexibilitätsoptionen für die Industrie in NRW“, Lünen.

Stadler, Ingo. 2006. *Demand response: nichtelektrische Speicher für Elektrizitätsversorgungssysteme mit hohem Anteil erneuerbarer Energien*. dissertation. de.

VDE – Verband der Elektrotechnik Elektronik Informationstechnik e.V. 2012. “Demand Side Integration – Lastverschiebungspotenziale in Deutschland”. Frankfurt a.M.