
Load Management as a Way of Covering Peak Demand in Southern Germany

Final report on a study conducted by Fraunhofer ISI and Forschungsgesellschaft für Energiewirtschaft

STUDY

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Foreword

All of Germany's nuclear power stations are to be decommissioned by 2022. The majority of the energy they generated will be compensated for by means of wind farms and solar arrays. On days when the demand for electricity is high, there could be shortages in the electricity supply overnight and at downtimes in Germany's southern states in particular, if the necessary capacities are not put in place in good time. This is because the majority of Germany's nuclear power stations will be disconnected from the grid in southern Germany and it is open to question as to whether the transmission systems in other regions can be expanded in time.

There will be very few hours and days in the year when peak demand coincides with a lack of electricity generated by means of wind energy and solar power. Building highly flexible power plants to bridge this gap for just a few hours a year could therefore be more expensive than shifting the demand for electricity in time. From an economic perspective, it may be wiser to voluntarily involve the electricity consumers in solving the problem. In southern Germany alone, the output of several large power plants could be saved if active consumption management were implemented. What's more, such measures could be implemented in a relatively short space of time –

and at a cost that would likely be below the cost of building gas-powered peak load power plants. This is brought to bear in this study, which was produced with the assistance of numerous companies in Bavaria and Baden-Württemberg and also the two states' governments.

However, active consumption management can only become a part of the electricity system if the consumers – in particular businesses and industrial enterprises – benefit from temporarily reducing their electricity consumption when asked to do so. And for this to be the case, the current electricity market needs to be changed and expanded. There are already plenty of examples of a time shift in the consumption of electricity being compensated financially, as is the case in the world's biggest electricity market, the USA. If Germany were to take a leaf out of the USA's book, it could not only maintain its high level of security of supply, but could also lower the costs caused by its energy transition.

I hope you find this study interesting.

Best regards,
Patrick Graichen
Executive Director, Agora Energiewende

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1. Abstract

This study stems from the question of what part can be played by electricity consumer load management in guaranteeing security of supply in southern Germany. The aim of the study is to as accurately as possible determine the realizable potential of a region already affected by network shortages and reduced generation capacities. The focus was therefore placed on the potential that can be implemented at short notice – potential that can be expected in particular in relation to industrial applications and to applications that can already be activated today, such as heat pumps. For the purposes of the study, interviews were conducted with companies, energy utilities, and service providers, and an online survey was conducted among approximately 300 companies. Data collection and the calculation of potential were based on the evaluation of existing studies and statistics, and on data from 40 company visits.

In total in southern Germany, there is realizable potential of approximately one gigawatt (GW) that can be made available for a period of one hour. Just under half of this potential can be made available by applications and processes in the energy-intensive industries. This potential is already used for the purposes of optimized electricity procurement and therefore reduces the system-wide peak load. It is also available as additional potential in the balancing energy market and as redispatch potential. The other half of the potential is made available by industrial cross-section technologies. This potential can likewise contribute to a reduction in the peak load and also to the balancing energy market and redispatch. Activatable applications such as heat pumps and electric storage heaters can play a part in security of supply by contributing to the balancing energy market and/or redispatch. However, as is the case with the energy-intensive processes, their contribution to a reduction in the peak load is very limited, because these applications tend not to be connected at peak load times.

There are currently not the appropriate programs and parameters in place for more intensive use of this identified potential. The lion's share of the identified loads therefore do not meet the requirements of Germany's Interruptible Loads Ordinance (AbLaV). For loads to be able to contribute to security of supply, the minimum load requirements, advance notice times, etc. need to take the characteristics of loads into account accordingly. Flexible electricity consumers can then be an affordable alternative to conventional generation capacity.

2. Summary

Background

The expansion of renewable energies has significantly increased the proportion of fluctuating feed-in and is therefore increasing the need for flexibility options and, in the medium term, also system services. With Germany exiting nuclear energy, thereby causing five nuclear power stations to be switched off in southern Germany, the energy supply situation has become tight in this region. There is now already a greater need for redispatching energy due to the delayed process of expanding the grid. A cold reserve of 2.5 GW has already been procured by the transmission system operators as a short-term means of nonetheless being able to guarantee security of supply. Germany's planned reserve power plants regulation introduces other measures, such as the transmission system operators holding tenders for additional power plant capacity in order to increase security of supply.

In general, flexible electricity consumers can play their part here by contributing system services (e.g. redispatch or balancing energy) or a reduction in the peak load. This is where this project comes in, to determine the available potential, the necessary incentives, and the existing obstacles, based on practice and in discussions with the affected stakeholders. The aim is to take into account the specific company structures and production processes in southern Germany. The analysis of potential focuses on the following areas:

- Industrial applications (including cross-section technologies)
- Heat pumps and electric storage heaters

Based on this, the part played by load management in delivering security of supply is to be determined and is to be compared with other options.

Approach and method

The point of departure for this study is an analysis of today's critical supply situations, in order to identify possible flexible load requirements. The realizable potential is then derived on the basis of the analysis of existing studies and statistics. In addition, details of the electricity consumption, power requirements, operation level, and technical facilities of 40 companies were taken from FfE GmbH's Learning Energy Efficiency Networks (LEEN) and were analyzed.

To validate the estimated potential and to identify the necessary incentives and the existing obstacles for the companies, in-depth discussions were held with all the relevant stakeholders. This involved approximately 300 companies being surveyed online and also interviews with ten of the larger enterprises in southern Germany. These were supported by the chambers of commerce and industry and the trade associations in Baden-Württemberg and Bavaria. Talks were also held with various energy utilities and service providers, to find out about implementing load management. Above all, load management is expected to play a part in guaranteeing security of supply by reducing the peak load, by participating in the balancing energy market, and by contributing to redispatch measures.

The potential that is calculated is the realizable potential that is already limited from a technical and economic perspective. The estimation of the economic potential is based on the condition that load management will, at most, lead to very limited value added reductions for the companies and to only a limited reduction in the comfort level provided by heat pumps and electric storage heaters. The compensation paid in accordance with Germany's Interruptible Loads Ordinance (AbLaV) serves as a financial incentive.

Grid requirements for loads

The supply situation in southern Germany is likely to remain tight in the medium term, because expansion of the grid capacities and generation capacities is not expected to happen until in the medium term. The analyses of re-dispatch and of balancing energy needs suggest that there is generally an increase in demand for a limited number of hours. The power needed ranges from one to several gigawatts. There is therefore generally a good fit with the requirements that can also be met by loads.

Results of the online survey on load management conducted among companies

The online survey showed that so far less than four percent of the companies surveyed are involved in the balancing energy market or in bilateral agreements with transmission system operators (see Figure 1). Just un-

der half of the companies surveyed already employ load management as a way of reducing their peak load. A quarter of the companies do not yet have any experience in the area of load management.

On average, the companies estimate their load management potential to be around five to six percent of the average load, with estimates of the potential ranging from less than two percent of the current load to more than 15 percent (see Figure 2). There was no evidence of any dependence on the absolute level of a company's power requirements. To a limited degree, estimates of the load management potential depended on the companies' electricity intensity – the higher the intensity, the more likely a company was to make a higher estimate of its potential. This was also corroborated by the on-site interviews.

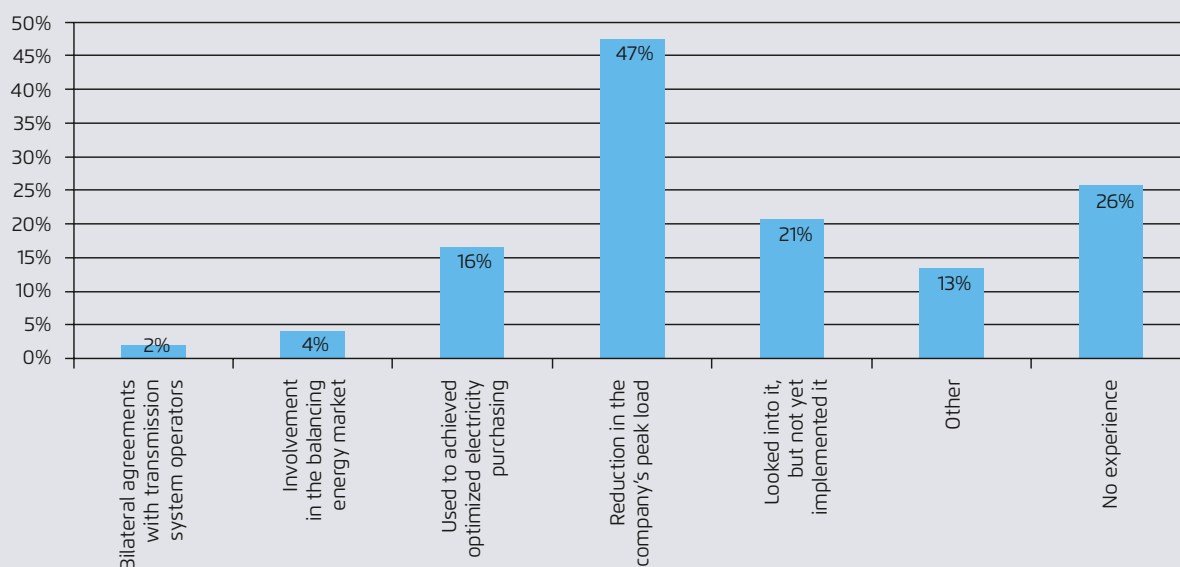
Load management currently implemented by companies

Figure 1

Please state the degree of experience that your individual plant/site has with the topic of load management.

in % of the answers, N = 97

N.B.: The percentage total is greater than 100% because multiple answers were permitted



Created by Fraunhofer ISI

The company survey showed that the available loads are typically in the **power range** of several **hundred kilowatts (kW)** to **several megawatts (MW)**. The **advance notice** needed is **at least 15 minutes**, with approximately 40 percent of the companies surveyed also declaring advance notice times of **at least eight hours**.

81 percent of the companies surveyed stated **shifting periods of less than two hours**. Only 19 percent of the companies surveyed said that shifting periods of four or more hours were possible. The companies with long shifting periods often said that production plants and process heating offered the greatest potential. Other applications with long shifting periods that were mentioned included ventilation and air-conditioning applications.

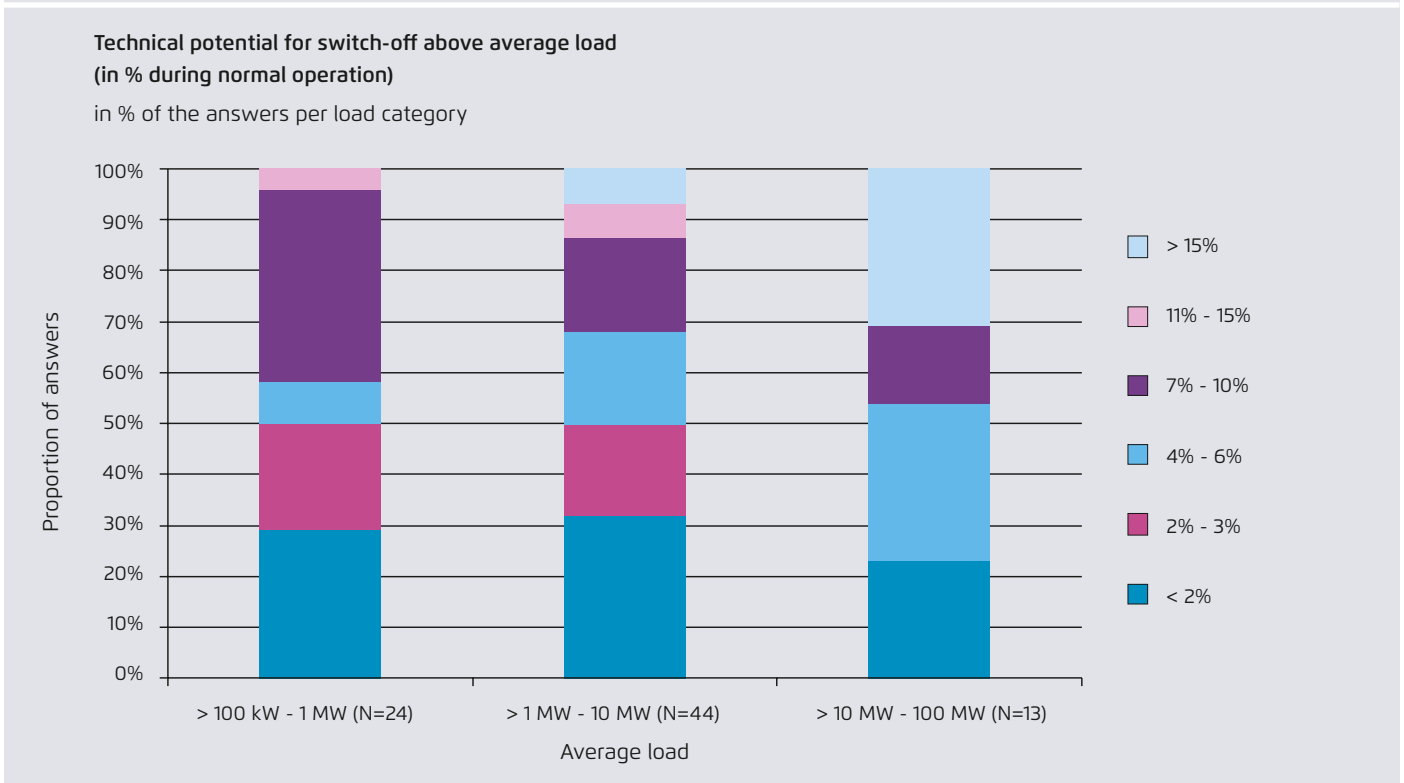
For approximately 45 percent of the companies in the survey, the potential is available to them around the clock. Eight percent said that potential was only available to them between the hours of 18:00 and 08:00, during which time the load could often be shifted for longer than two hours. 70 percent of the companies estimated that the realizable **number of activations** was a **maximum of 50 times a year**. Approximately ten percent considered more than 100 activations a year to be feasible.

Realizable potential in energy-intensive industry

In order to determine the potential, sites were first identified where these processes are used. The available technical potential was calculated on the basis of production and electricity consumption data and also other key technical figures, such as the ability to run on a partial load.

Estimate of technical load management potential within companies

Figure 2



Created by Fraunhofer ISI

Talks were also held with companies in order to validate the calculated potential and to get an estimate of its economic feasibility.

Cement

In the cement industry, cement mills and raw meal mills are particularly suited to load management. These are already primarily used overnight and on weekends. In Bavaria and Baden-Württemberg, the power requirements for these applications at a total of 14 sites were estimated at around 130 MW, of which approximately 50 MW could be used for load management. The applications have shifting periods of up to four hours. The times that can be realized in the case of raw meal mills are, to some extent, much shorter due to the mills' limited storage capacities. Advance notice of at least 30 minutes is needed.

Paper

The application with the greatest potential in terms of load management is wood grinders used to make mechanical pulp. The power requirements of the wood grinders at twelve sites in Bavaria and Baden-Württemberg were estimated to be around 90 MW. The sites had shifting periods of approximately two hours, although advance notice times of less than an hour were considered to be feasible. There is additional potential in the recycling of waste paper and in pulp production.

Chemicals industry and chlorine production

Within the chemicals industry, the production of chlorine is very well suited to load management. The power requirements for chlorine electrolysis in southern Germany are approximately 250 MW, with around 160 MW of this being available for load management during partial load operation. In addition to partial load operation, load shedding is also an option, although this results in higher costs. In this case, 250 MW of power is available. The applications can be switched off for two hours, with longer periods possible in some cases.

Electric steel industry

There are two steel plants in southern Germany with average power requirements of approximately 150 MW for their electric steel furnaces. This potential would also be available for load management. Activating load management would have to be incorporated into production planning because a switch-off in the middle of operations should be avoided. Load management can be realized in this batch process that takes from 30 to 120 minutes by delaying the start of the next batch. In general, switch-off periods of up to two hours are possible.

Summary

In relation to the applications examined, additional load management potential is in particular offered by increasing the level of participation in the balancing energy markets and in grid relief redispatch measures. According to the transmission system operators (TSO's), approximately 76 MW of load in southern Germany already qualifies for the balancing energy market. The calculations therefore show that southern Germany has additional potential for system-supporting load management of 400 to 450 MW in the four applications examined in detail alone (see Table 1). There are also additional applications in the metal, chemicals, and paper industries that could boost this potential even further.

Load management potential realizable with industrial cross-section technologies

In addition to energy-intensive processes, cross-section technologies are also well suited to load management. Cross-section technologies are used interdisciplinarily and are characterized by high time availability and regional distribution. Examples of cross-section technologies include pumps, compressors, and ventilators.

The contributions that can be made per business are usually much lower than in the case of companies with

Load management potential of energy-intensive processes

Table 1

Application	Max. power requirements in MW	Shifting period in h	Frequency	Econ. potential based on AbLaV in MW
Cement (raw meal and cement mills)	130	Up to 4, sometimes longer	20 to 50 times	Approx. 50
Paper (wood grinders)	Min. 90	2, sometimes longer	20 to 50 times	Approx. 90
Chlorine (electrolysis)	250	Approx. 2	20 to 50 times	Approx. 160
Steel (electric steel furnaces)	200	Approx. 2	20 to 50 times	Approx. 150
Total		Approx. 2	20 to 50 times	400 to 450
Already used in the balancing energy market				76
Already used for optimized procurement				300 to 400

Fraunhofer ISI estimates

energy-intensive processes, but there are nonetheless two reasons in particular why cross-section technologies are of interest when it comes to load management. The available load management potential was calculated on the premise that there was no significant impact on the comfort level and on a business’s value added. Following the successful implementation of load management, which entails some investment, the occasional and brief activation of the available loads generates next to no additional costs for the participants. The second aspect is the anticipated low transaction costs due to the ability to apply successful implementations elsewhere, too. Once developed, a load management solution in the area of, for example, ventilation can be applied to a large number of businesses with only minimal modifications needed. In addition, the high time availability and the regional distribution of cross-section technologies make them well suited to inclusion in a load management program.

The load management potential offered by cross-section technologies depends on a number of factors. In the main, it is the business hours (a one-, two-, or three-shift sys-

tem) that determine the loads incurred at different times of the day and on different days of the week. In addition to the condition that production not be restricted, there are other factors that limit flexible operation: facilities not being available (for example due to maintenance, etc.), uninterruptible facilities (for example extraction systems), the size and type of the storage capacity available, and a minimum operation size. The switching on of facilities with no storage capacity (e.g. lighting, ventilation) is not taken into account because this would generate additional electricity consumption that is not offset by any operational benefits.

If we consider the suitable businesses in southern Germany on the basis of the aforementioned limiting factors, the biggest contribution to load management in the area of cross-section technologies is made in the mechanical engineering and automotive sectors.

If we simply consider the loads, and not the duration of load shifting, there is great potential in the areas of compressed air, cooling, and ventilation. Approximately a quarter of the switch-off potential can be realized

simply by reducing the degree of ventilation. Compressed air likewise has very high power requirements, but the loads in this area can only be shifted for a very short time.

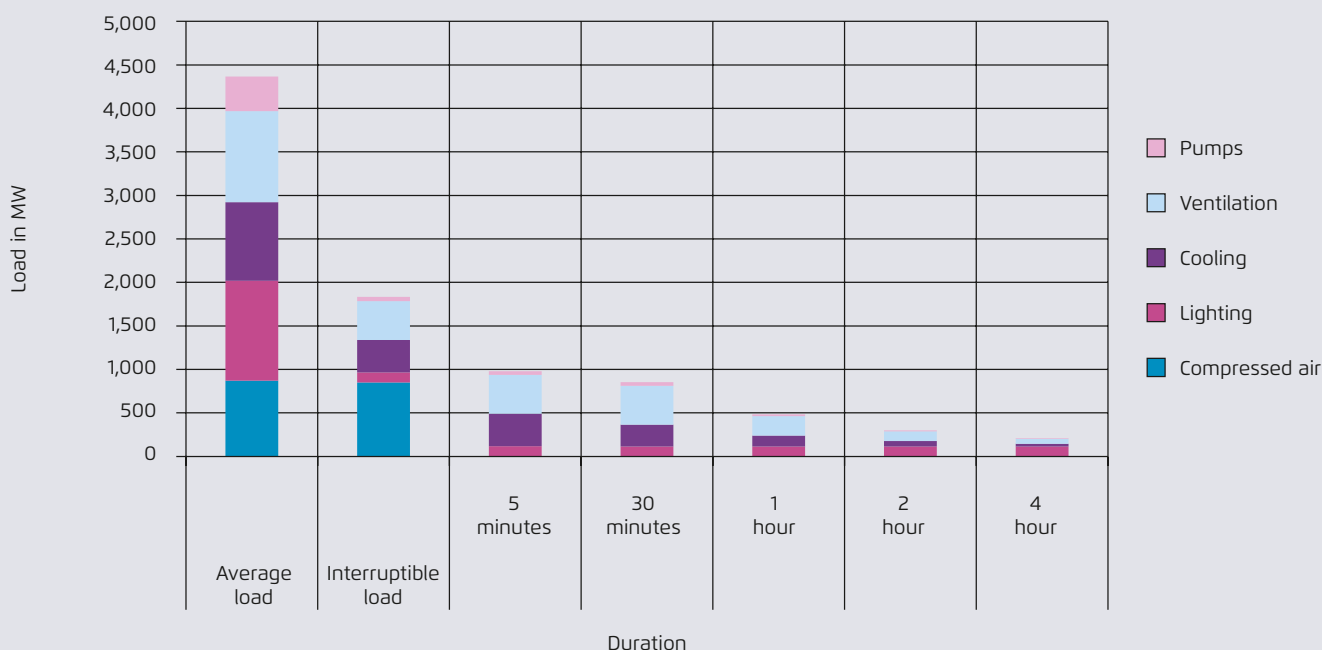
During normal operation, 480 MW could be switched off for a period of one hour (see Figure 3), with the greatest potential being in the area of ventilation systems and cooling systems. In comparison to the average load of the cross-section technologies considered, which is around 4,350 MW, the proportion that can be used flexibly is approximately eleven percent. This proportion is just three percent in comparison to the total average consumption load of 14 GW for industry in southern Germany. The relative contributions to load management of the various cross-section technologies over a period of an hour vary greatly. Depending on the sector in question, the average load during normal operation can be reduced by between 0.4 and a maximum of 4.6 percent.

Figure 3 shows that greater contributions to load management are only available for brief periods. The longer the contribution is needed, the smaller the average contribution from shifting or switching off the consumer's load becomes. Load management is therefore first and foremost suited to providing system services in the short term or covering peak loads.

The functional correlation between the duration and degree of load management could also be the reason behind the difference between the potential as stated in the online survey and the potential calculated mathematically. A large number of the companies stated that they believed there was load flexibilization potential in the area of compressed air. After closer consideration, however, this would appear to be rather optimistic. If compressed air is needed for production processes, a switch-off frequently results in production losses. The tanks tend to only be as big as is needed for the air compressors

Interruptible load achieved by flexibilizing cross-section technologies in southern Germany (normal operation) relative to duration – technical potential for suitable companies without consideration of the cost of implementation (staff and ICT)

Figure 3



Created by FfE

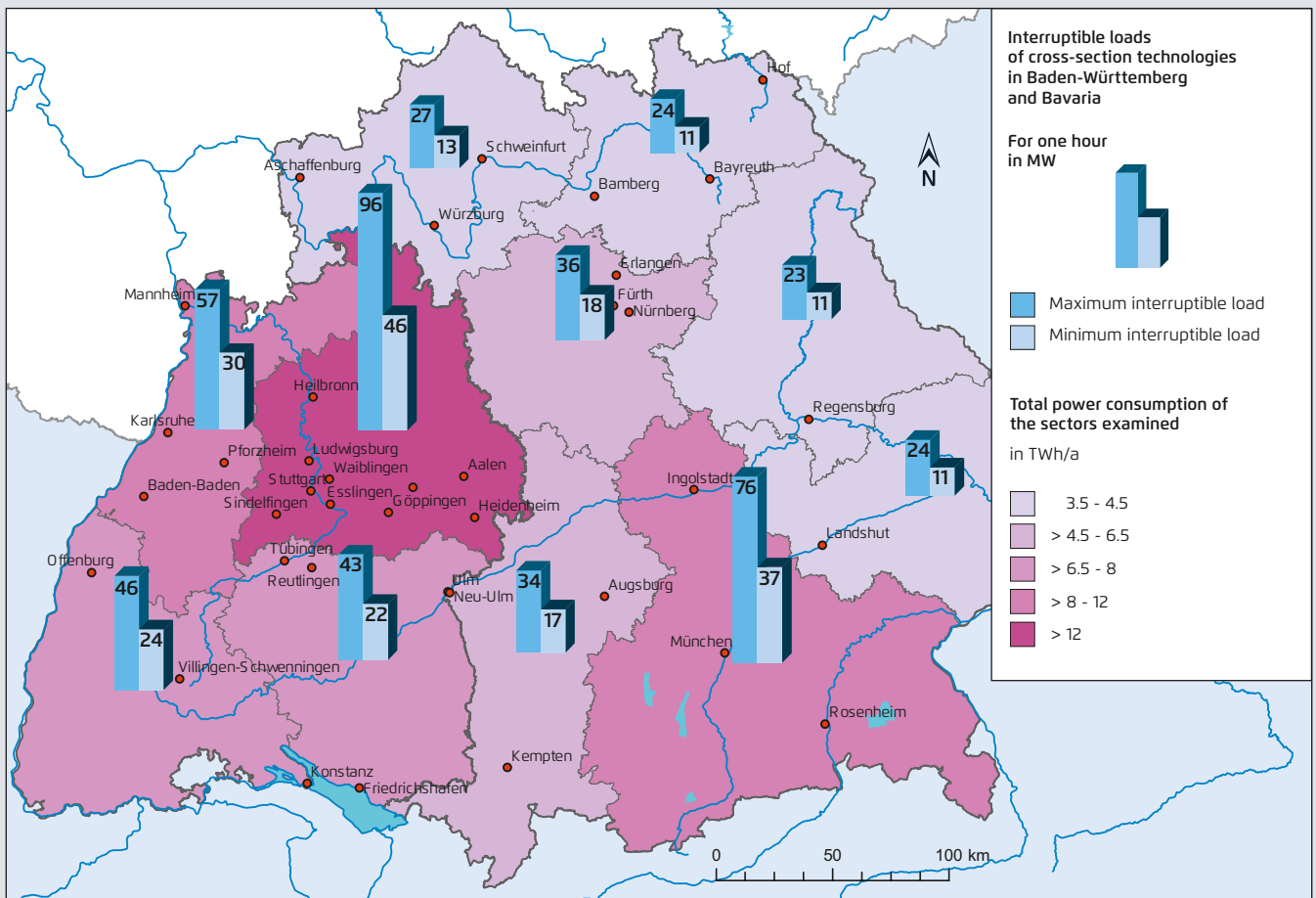
to switch their loads on and off for a matter of seconds. Therefore, only compressed air applications not directly linked to the production process can be used for switch-offs, for example when compressed air is used for cleaning purposes.

Although lighting was frequently mentioned as an option in the online survey, the potential it offers is limited because a reduction in illuminance is generally attributed to an increase in energy efficiency. In exceptional cases, illuminance can be dimmed for an extended period (such as four hours) if it is above what is required by law for the workplace, but the result can impact staff productivity.

As cross-section technologies are used interdisciplinarily, their load management potential is spread in much the same way as their industrial electricity consumption. The regional spread of minimum and maximum load management potential can be seen in Figure 4. The minimum interruptible load for a typical Sunday afternoon was calculated to be around 240 MW, which is approximately half of the potential offered during normal operation on a workday.

Maximum and minimum interruptible load of the cross-section technologies for one hour

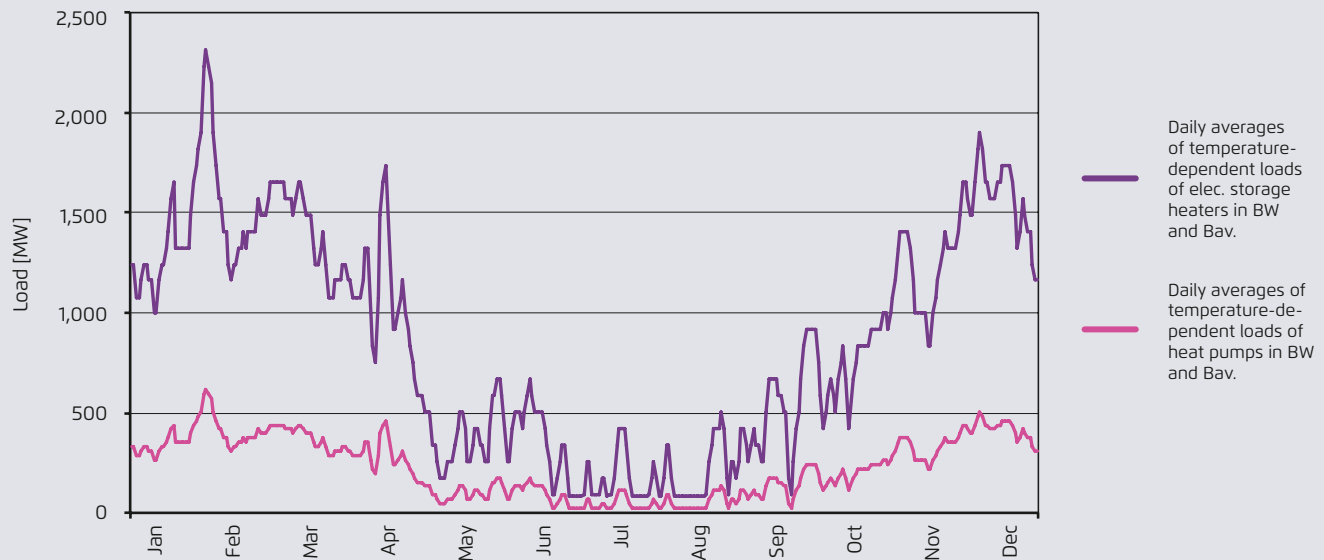
Figure 4



Created by FfE based on data from the German Federal Statistical Office and data collected in-house

Load of electric storage heaters and heat pumps in southern Germany based on the applicable test reference years

Figure 5



Created by FfE

Realizable load management potential of heat pumps and electric storage heaters

The potential here is calculated on the basis of data for electricity-based heating applications provided by distribution system operators and energy utilities. It was possible to account for 67 percent of southern Germany's municipalities on the basis of this data. Once the data had been validated, it was extrapolated to include areas for which no data was available.

The load profiles of electric storage heaters and heat pumps are subject to very strong temperature-dependent fluctuations. There is therefore primarily load management potential overnight on cold days. There tends to be only limited potential during the winter peak load times (18:00 to 20:00). Heat pumps offer greater availability of load-reducing potential because of their relatively constant load profile over the course of a day, meaning that these loads can be reduced briefly anytime. In addition, the load of electric stor-

age heaters can be increased, depending on the time of day and the temperature.

The fluctuation in loads according to the season is shown in Figure 5. The maximum average daily load for electric storage heaters and heat pumps totaled 2,900 MW in the test reference year. The minimum average daily load was around 100 MW in the summer.

The temperatures during the periods examined and the temperature-dependent load profiles of the individual distribution system operators were taken into account when calculating the average load profiles and served as the basis for calculating the potential of flexibilized operation.

With an average outdoor temperature of 0 °C on a reference day in southern Germany, electric storage heaters and heat pumps offered load management potential of almost 3,400 MW for an hour – albeit a specific hour, rather than any hour during the day.

Overview of the load management potential of electric storage heaters and heat pumps Table 2

Equivalent daily average temperature	Elec. storage heaters Version 1		Heat pumps	
	Switch-off 1 hour			
	Minimum in MW	Maximum in MW	Minimum in MW	Maximum in MW
-10 °C	0	4,610	550	630
0 °C	0	3,010	340	400
10 °C	0	1,620	110	180

Created by FfE

Table 2 shows that rising temperatures go hand in hand with lower load management potential. In the worst case, only heat pumps are able to offer load management potential, in the amount of 340 MW. And in the summer, the minimum can drop to 30 MW during the day.

Conclusions

From the perspective of the grid, load management potential can contribute to security of supply if it is available in critical grid situations. A contribution can then be made to security of supply by reducing the system-wide peak load or by providing balancing energy or covering redispatch requirements.

The focus in the search for major application fields is, on the one hand, on energy-intensive processes which are already used for load management within companies, but which could also be used for grid-compliant load management (see Table 3). There is also additional potential in the area of cross-section technologies, especially industrial ventilation and air-conditioning applications, which can often also include loads of several hundred kilowatts. And in the field of electric heat generation (heat pumps and electric storage heaters), the existing potential could be tailored more to the grid. In total, industrial cross-section technologies and energy-intensive processes in southern Germany offer load management potential of more than a gigawatt, which can be activated for periods ranging from 30 minutes to two hours.

Overview of the realizable load management potential in Baden-Württemberg, including potential already exploited Table 3

	Load reduction potential for one hour		Potential already exploited	
	Minimum in MW	Maximum in MW	Contribution to peak load reduction in MW	Balancing energy in MW
Energy-intensive processes	Almost anytime > 400		300 - 400	76
Industrial cross-section technologies	Basic operation, Sunday ≈ 240	Normal operation, workday, daytime ≈ 480	0	0
Heat pumps	Summer ≈ 30	Winter (-10 °C) ≈ 630	Minimal contribution	0
Electric storage heaters	Summer, daytime 0	Winter, nighttime (-10 °C) ≈ 4,610	No contribution, as systems not connected to grid	0

Created by FfE

In particular, this potential is available for the provision of balancing energy or to cover redispatch needs. Industrial cross-section technologies are the prime option in terms of reducing the system-wide peak load. Energy-intensive processes and also electric storage heaters are typically no longer connected to the grid at times when there is a system-wide peak load.

The financial incentives for load management should initially be sufficient to cover the upfront investments (implementation and planning of load management along with the cost of the control technology required). Companies typically expect to have to spend several thousand euros up front before they can participate in a load management program. An investment becomes interesting for companies if it allows them to reduce their electricity costs by more than five percent. Lower incentives may also be sufficient for larger companies.

3. Introduction

The increase in electricity generation using the fluctuating energy sources of the sun and wind is increasing the need for system services such as balancing energy. At the same time, the proportion of fossil fuel power plants, which to a large extent currently provide these system services, is shrinking. In addition, the imminent move into offshore wind power coupled with the phasing out of nuclear power will result in power generation being focused on northern Germany, far away from the consumer hubs in southern and western Germany. With the current delay in grid expansion, redispatch needs are already higher. In addition, Germany's Federal Network Agency (BNetzA) recommended that transmission system operators acquire a cold reserve of 2.5 GW for the 2012/13 winter, to ensure reliable grid operation. So far, procurement of this cold reserve has been non-competitive and is focused entirely on the generation side. Germany's Interruptible Loads Ordinance (AbLaV) was introduced at the beginning of 2013. The Federal Network Agency already states that switching off loads in southern Germany is a fundamental option when it comes to boosting grid stability and security of supply, although no detailed studies of this have been conducted as yet.

The electricity consumers' load management can play a part in supporting the system if it is integrated into the existing system services or is used to reduce the peak load (Hurley 2013). Load shifting can free up balancing energy and redispatch capacity, thereby offsetting some of the demand for conventional system services. It is, however, not yet possible to provide redispatch capacity by means of load shifting. This happens at the request of the transmission system operator, who then compensates the power plant operators affected. In addition, load management can reduce peak demand and therefore also the guaranteed generation capacity requirements needed to cover the electricity demand for a matter of hours.

The load management potential available in industry, and also in households and in the commerce, retail, and service sector has been examined in past studies, which have shown that there is considerable potential in all of these sectors. Industrial applications have already been incorporated in the minute reserve market to a degree, although the proportion of these is likely to have dwindled in recent years due to prices that have been falling since 2007. Recent estimates for Germany peg the available load at around 500 MW throughout the country (Langrock 2013).

This is the point at which the proposed project comes in, in order to gain a detailed estimate of the load management possibilities, in particular in terms of the potential that can actually be exploited and also the economic potential. A key question is whether the existing economic incentives and requirements are sufficient for electricity consumer load management to be able to make a relevant contribution to security of supply in the face of a changing electricity supply system. In addition, there are individual applications (in particular electric storage heaters) which could already be employed to boost grid stability. The project initially involves producing a detailed list of the possible applications in southern Germany and also the necessary incentives, in order to determine the potential contribution of load management to covering peak demand and also to other system services, and therefore to increasing security of supply in general.

3.1 Aim and approach

The primary aim of the project is to calculate the load management potential of a defined region – southern Germany – and to derive from this the potential that can actually be realized. The focus is on the potential that is the most relevant due to size and the speed at which it can be implemented:

- Industrial applications (including cross-section technologies)
- Heat pumps and electric storage heaters

Insofar as is possible, the analysis takes into account the specific company structures and production processes in southern Germany. The contribution that the potential can make to security of supply is determined on the basis of the load shifting potential calculated (load, shifting period) and is also compared with other measures.

The approach is based on the following steps.

The starting point is an analysis of the current critical supply situations that load management would need to respond to. This involves the evaluation of various studies conducted in particular by the Federal Network Agency. This analysis is then used to determine a profile of the requirements made of load management potential.

Ascertainment of the available potential is based on the analysis of existing studies and statistics. In addition, details of the electricity consumption and power requirements of a total of 40 companies are evaluated, these details having been sourced from FfE's Learning Energy Efficiency Networks (LEEN) (FfE GmbH 2012).

To validate the estimated potential and to identify the necessary incentives and the existing obstacles for the companies, in-depth discussions were held with the relevant stakeholders. Transmission system operators, energy utilities, energy management service providers, companies, business associations, and political decision makers were all involved. In addition, approximately 300 companies were surveyed online and interviews were conducted with ten of the larger enterprises in southern Germany. Dialog with the companies was supported by the chambers of commerce and industry and the trade associations in Baden-Württemberg and Bavaria. Talks were also held with various energy utilities and service providers, to find out about implementing load management.

Based on these findings, recommendations for action were deduced regarding how load management potential could play a part in guaranteeing security of supply in the future. In this respect, there is, in particular, discussion of the relevant obstacles and the necessary incentives for implementation. In this study, potential is seen for load management to contribute to security of supply first and foremost in three different areas of application. These are:

- Reduction of the peak load
- Participation in the balancing energy market
- Contribution to redispatch measures

3.2 Definition of load management potential

When determining load management potential, it can be advantageous to define how the calculated potential is characterized and what potential term is at its core. We can make a general distinction here between technical, economic, and realizable potential. Theoretically, all of electricity demand can be used for load management, for example when a plant ceases production. However, this study does not take such extreme cases into account.

We start with **technical potential**. Technical potential is derived from the power requirements of relevant applications and specifically takes into account technical boundary conditions such as partial load operation options, storage options, and availability at different times of the day and during different seasons.

Based on the technical potential, the **economic potential** that can be achieved in view of the given boundary conditions can then be derived by means of a comparison with the economic incentives. However, due to non-monetary obstacles, only a proportion of this economic potential can actually be realized. This then equates to the **realizable or practical potential**. The realizable potential is interpreted in such a way in this study that the companies do not experience **any major obstacles to value added**. In relation to households, the assumption is made that there is **no significant reduction in the level**

of comfort compared to the status quo (for example with heat pumps). Only the concrete conditions and obstacles within a company and also the actual financial incentives are relevant to the implementation of potential. The compensation offered by the Interruptible Loads Ordinance (AbLaV) serves as a reference for economic incentive. This amounts to compensation of €2,500/MW a month and a unit price when load shifting is used in the range of €100 to €400/MWh.

4. Determining the Application Cases for Load Management in Southern Germany

4.1 Suitable compensation measures based on load management

The Federal Network Agency stated in its *Monitoring Report 2012* that reserve capacity of 2.5 GW was needed to successfully operate the system. This figure is based on the analyses of the TSO's. This calculated reserve capacity can serve as a benchmark for evaluating load management potential that can be used as balancing energy or redispatch. A distinction should be made between two functions:

- (1) Redispatch potential to eliminate the overloading of single or multiple grid elements. The position within the grid of the balancing energy involved is an important factor here.
- (2) Balancing the system by means of additional balancing potential. Here it is a question of simply striking a wholesale balance between generation and consumption, which calls for available grid capacities.

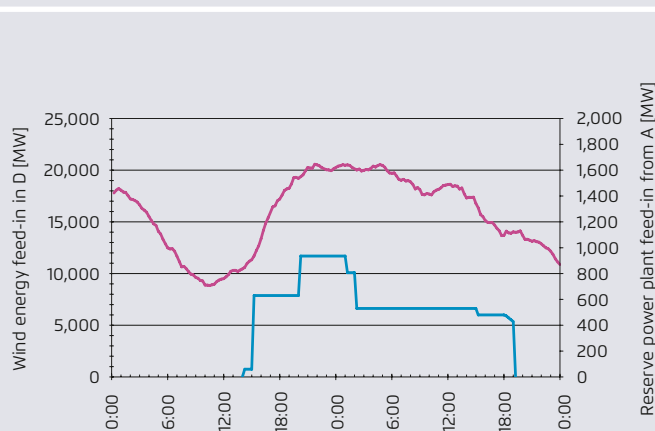
In both cases, the contribution made to stabilizing the system is also dependent on the window in which the switched-off power is then made available. This is particularly significant in the case of the balancing energy made available by means of load management, because the switched-off load is, to some extent, then compensated for at the end of the switch-off period, thereby having the effect of increasing the load.

Achieving system stability calls for other system services in addition to the provision of real power. One of these so-called system services is the provision of reactive power. Using load management to balance energy has an impact first and foremost on the real power balance, while changes in the reactive power needs within the grid are dependent on the type of consumer involved in the load management measure. Systems with a high de-

gree of inductance, such as electric motors, have an influence on the reactive power balance. Load shifting thanks to load management can therefore not always be directly compared with balancing energy from, for example, conventional power plants that are also capable of delivering other system services.

Detailed analyses of the grid situations in conjunction with load management potential broken down on the basis of geographical spread and time availability are needed in order to evaluate the contribution to mitigating critical situations made by load management potential in southern Germany. The project was not able to establish any more specific findings regarding the requirements of load management potential in the talks held with the Federal Network Agency and the TSO's. The feed-in from the Austrian reserve power plants that was needed on December 8 and 9, 2011, in order to clarify the system situation can serve as a rough preliminary guideline regard-

Wind energy feed-in in Germany (pink) and feed-in from reserve power plants in Austria (blue) on December 8 and 9, 2011 Figure 6



Grid report on the situation in winter 2011/12, Federal Network Agency (May 2012)

ing volumes. Taking the feed-in recorded over time (see Figure 6), we see that an energy volume of around 17 GWh was sourced and that the average output was approximately 600 MW. There was a peak feed-in of 935 MW.

To identify the requirements to be met by the loads, on the one hand grid-critical situations are analyzed, these generally going hand in hand with redispatch needs. This is followed by the analysis of the balancing energy used, in order to determine the contribution that load management might make to the balancing energy market.

4.2 Analysis of the relevant grid-critical situations in southern Germany

Comparisons with the moratorium period

Calculations made by the transmission system operators (TSO's) for the Federal Network Agency show that the simultaneous switching off of eight nuclear power stations, thereby reducing generation capacity by five gigawatts in southern Germany, and also the longer-term lack of 8.5 GW of energy have brought the transmission systems to the brink of their power ratings in a number of situations (Federal Network Agency, May 2011). The TSO's have at their disposal various measures to safeguard grid stability, such as redispatch, countertrading, and security-related power sales within a control area (abbrevi-

ated in this study as 'SIV'). Increased use of these forms of intervention was evident year on year during the moratorium period. Table 4 shows the energy volumes used for these measures and clearly demonstrates that the volume used (in MWh) increased more than twofold year on year (Federal Network Agency, May 2011).

In the period after the moratorium (April/May 2011), the volume used to safeguard grid stability was around 280 GWh a month, in comparison to 120 GWh in the previous year (April/May 2010) and was around 55 GWh more than in the previous year's summer (April to September 2010). On average over the whole month, this equates to used power (redispatch, countertrading, and SIV) of 380 MW in spring 2011, in comparison to 160 MW in spring 2010 and 75 MW in the 2010 summer period. However, these measures are actually only implemented for a limited number of hours a month, and as such the used power volumes are much higher. The appendix includes examples in which up to five gigawatts and a volume of up to 80 GWh were used in a day for the measures described here.

The development of the total generation capacity in Germany results in a greater need for transmission capacities from north to south in the transmission system (in particular completion of the Görries-Krümmel, Osterath-Weißenhurm, and Remptendorf-Redwitz grid

Implementation of redispatch, countertrading, and SIV* measures

Table 4

Transmission system operator	Moratorium period March 15 to May 15, 2011		Previous year – spring April 1 to May 31, 2010		Previous year – summer April 1 to September 30, 2010	
	Volume in MWh	MWh/month	Volume in MWh	MWh/month	Volume in MWh	MWh/month
Amprion	0	0	0	0	14,011	2,335
TransnetBW	0	0	0	0	0	0
50Hertz	414,845	207,422	205,763	102,882	276,184	46,031
TenneT	140,264	70,132	33,130	16,565	40,938	6,823
Total	555,108	277,554	238,893	119,447	331,132	55,189

*SIV: security-related power sales within a control area

Moratorium report, Federal Network Agency (May 2011)

expansion projects). There have been delays in grid expansion measures and in maintenance work in relation to the moratorium. A lot of maintenance work can only be conducted when there is a very low load or no load at all within the systems, and as such the changes in load lead to delays in planned maintenance and servicing of the transmission system. For example, maintenance work at a key north-south hub, the Großkrotzenburg substation near Frankfurt, could not be carried out due to the affected power circuits being indispensable (Federal Network Agency, May 2011).

Relevance of load management in southern Germany

The Federal Network Agency's analysis of an array of simulated and actual, concrete situations within the transmission system in 2011/12 highlights the significance of establishing additional flexibility of load and generation management in southern Germany (see details

in the appendix): In certain cases, the available measures (such as redispatch, countertrading, and SIV) are fully exhausted. As a result, the complete elimination of all the power line overloads that occur and the provision of (N-1) security at all times in a critical situation cannot be guaranteed. Additional reserve power in southern Germany and further grid expansion are seen as a necessity.

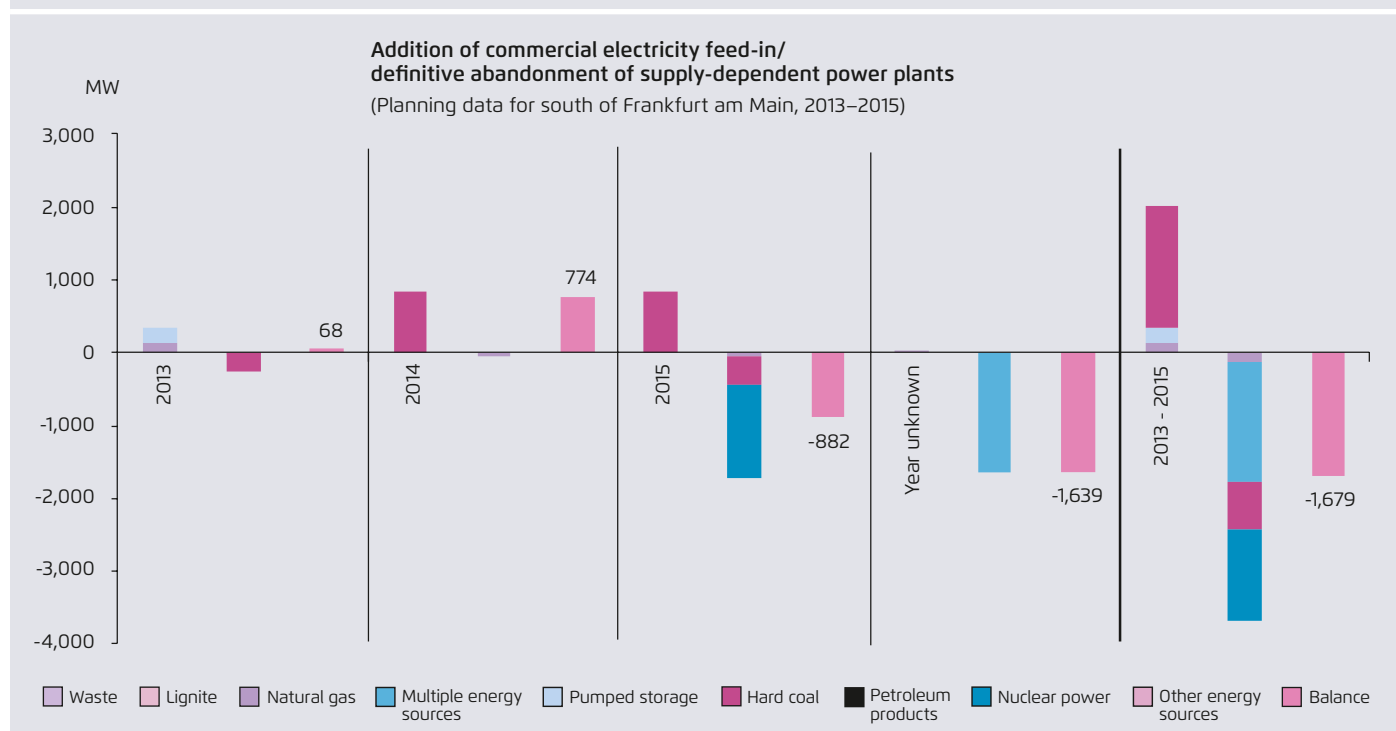
4.3 Development of generation capacity in southern Germany

Development of generation capacity

There is currently total generation capacity of approximately 172 GW linked up to the German grid, with renewable energies accounting for around 71 GW of this total. 2.7 GW of the total generation capacity is allocated to the cold reserve, albeit primarily at sites to the north of Frankfurt am Main. There can therefore be no expect-

Anticipated development in secured power plant capacities between 2013 and 2015 Frankfurt am Main and further south

Figure 7



Monitoring Report 2012, Federal Network Agency (February 2013)

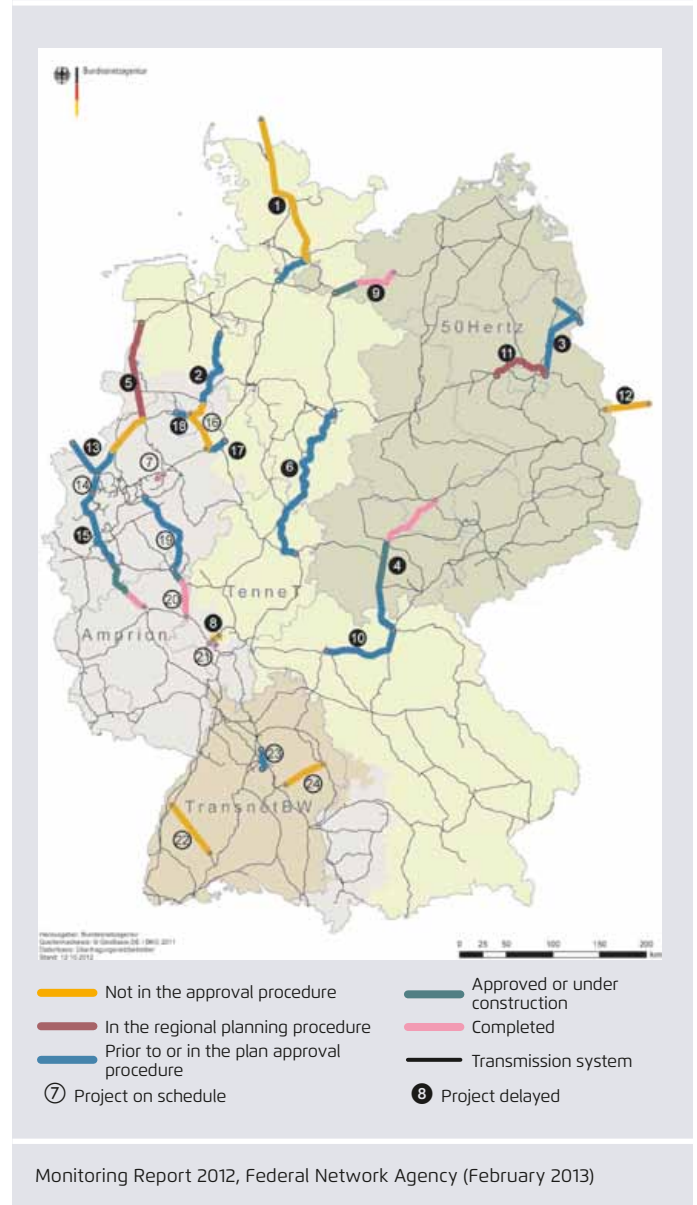
tations of this helping to mitigate the tight situation in southern Germany. According to the Federal Network Agency, the question as to whether there is sufficient generation capacity in the German control block in the existing grid structure with appropriate market, grid, and weather conditions is currently difficult to answer. For example, there was a maximum shortage of 6.2 GW on the generation side in Germany on February 13, 2012, which could not be fully offset by balancing energy reserves of 3.8 GW. The contracting of generation capacity from neighboring countries was therefore necessary. According to the Federal Network Agency, there is currently no way of determining whether the shortage could have been covered by the German control block. However, the inference is made that the current generation capacity is, at best, only just sufficient and that it would therefore be wise to safeguard and, if possible, also expand the current capacities. It is anticipated that there will be a slight surplus up to 2015, followed by a shortage in the capacity balance up to 2020.

In particular, the development of power plant capacities in southern Germany (increases and decreases) has a significant bearing on the stability of the transmission system (Federal Network Agency 2013). While there is, on balance, the expectation of an increase of 5.5 GW in the secured generation capacity according to the planning figures up to 2015, current estimates suggest that the secured generation capacity in southern Germany will drop by approximately 1.7 GW on balance up to 2015, among other things due to the inefficiency of the power plants (Figure 7). The planned regulation regarding reserve power plants in Germany will require that the system operators will likewise have to expand their capacities, if required.

Development of the grid situations

The majority of the most urgently required grid expansion projects throughout Germany have been delayed (Figure 8). The ‘Thuringian power bridge’ is a 380 kV connection between the 50Hertz system and the TenneT system, stretching from Halle to Schweinfurt. The lack of this productive transport connection is resulting

Most urgently required power lines in accordance with the German Power Grid Expansion Act (EnLAG) Figure 8



in a significantly increased load being placed on the other parts of the transmission system. A sizable proportion of the existing redispatch potential is used to overcome this bottleneck. Freeing up these capacities would go a long way to relaxing the situation in the whole of southern Germany. The Federal Network Agency is therefore calling on the TSO's responsible and the regional planning authorities involved to initiate and/or conclude the necessary planning procedures as quickly as possible.

4.4 Analysis of the use of secondary balancing energy

In addition to load management contributing to redispatch, it can also provide balancing energy. The use of secondary balancing energy will therefore now be looked at in greater detail, in order to more accurately ascertain the suitability of loads in terms of providing these system services. Secondary balancing energy balances the differences between power supplies and demand for periods of up to 15 minutes. Germany's balancing energy requirements within the so-called grid control cooperation are covered by the transmission system operators in a bidding process. Balancing energy is needed when there is a discrepancy between supply and demand due to demand forecast errors, the feed-in of renewable energies or, for example, power plant outages.

Balancing energy can be both positive and negative. In Germany, the maximum use of balancing energy at any one time is plus/minus two gigawatts. Load management potential is suitable for making a contribution to secondary balancing energy. There therefore follows an analysis of the times at which secondary balancing energy was used in 2012, with a view to determining

- the balancing energy requirements based on time and
- typical daily profiles of balancing energy use.

The requirement profiles are compared with the time-based availability of load shifting potential as calculated in this study (see Subsection 5.3).

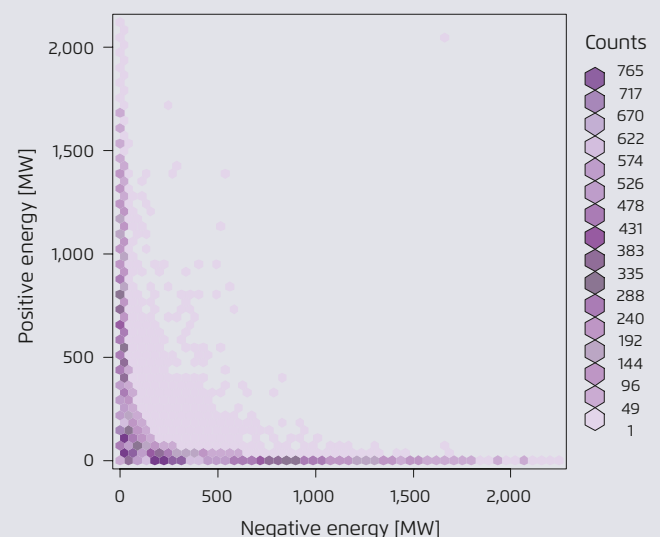
The analysis is based on day time series for positive and negative balancing energy, measured using quarter-hourly intervals. Analysis of the time correlation between uses of positive and negative balancing energy shows that there is a low probability of both positive and negative secondary balancing energy being used at the same time. If we put the cases of positive secondary balancing energy being used every quarter of an hour on the y-axis of a scatter plot, with the cases of negative secondary balancing energy being used on the x-axis, we see the

frequency of both positive and negative secondary balancing energy being used at the same time. The high accumulation of the pairs of dots (positive/negative energy) along the respective axes in the scatter plot in Figure 9 illustrates this. There are next to no instances of the simultaneous use of positive and negative balancing energy of more than 500 MW (the analysis is, however, only accurate to a quarter of an hour). Simultaneous positive and negative use may be necessitated by restrictions relating to grid operation (e.g. redispatch).

The day time series of the cases of balancing energy being used are highly heterogeneous throughout the day for both positive and negative energy (see figures in Subsection 12.2 in the appendix). A common characteristic of all the time series (both positive and negative) is the peaks in energy usage before and after the full hour, especially in the morning hours of 06:00 to 08:00 and in the afternoon

Scatter plot of the use of positive and negative secondary balancing energy within the German grid control cooperation in 2012

Figure 9



Time correlation between the use of positive and negative energy. According to the diagram, the simultaneous use of large volumes of positive and negative secondary balancing energy is rare.

Created by Fraunhofer ISI

and evening from 16:00 to 24:00 (positive before the hour and negative after the hour in the mornings, and vice versa in the evenings). This phenomenon can to some extent be ascribed to the market design and to the practice of putting the products traded in the energy markets into blocks of full hours.

The focus here is therefore on the time profile of the energy levels in order to analyze the contribution made by load management potential to the reserve. There are four diurnal variations (both positive and negative) that typically occur, differentiated on the basis of three periods of the day – the morning, midday, and the evening/overnight. The table below compiles the four versions for positive and negative secondary balancing energy and correlates them with the frequency with which they occur. The first version represents the typical course of a day with low secondary balancing energy usage throughout the day. This occurs on approximately 50 percent of the days in the year. In contrast, the fourth version represents a day which is characterized by high

secondary balancing energy usage. This occurs on approximately ten percent of the days in the year.

If we consider the quarter-hourly maximum in the course of the day, we see that the balancing energy needs can be very close to the traded maximum at any time of the day. However, as already explained, the frequency of occurrence is heavily dependent on the time of day.

4.5 Conclusion regarding application cases for load management

Based on the analyses discussed above, the following points can be concluded:

- There is a lack of flexibility in terms of load and generation management in southern Germany.
- High demand for secondary balancing energy can occur at any time of the day.
- The simultaneous use of positive and negative secondary balancing energy is rare.
- There is often low demand for (both positive and negative) secondary balancing energy (50 percent of the days).
- High demand for secondary balancing energy only occurs on a few days (ten percent of the days in the year).
- Additional grid expansion, in particular in a north-south direction, frees up capacities for system stabilization measures and has a mitigating effect on the problem. The duration of the grid expansion's realization is, however, an unknown quantity.
- Additional generation capacity in southern Germany likewise alleviates the situation. Here too, the realization duration is an unknown quantity, although initial steps have been taken with the planned regulation regarding reserve power plants.

The key conclusion is therefore that there is fundamentally a need for load management and that the time availability of balancing energy/redispach is adaptable. For this reason, there is the expectation that load management can make a contribution to achieving system stability.

The four basic diurnal variations
Secondary balancing energy use for both positive and negative energy
Table 5

Curve/ time phase	Morning	Midday	Evening/ overnight	Frequency during the year (approx.)
Positive 1 (black)	Low	Low	Low	50%
Positive 2 (green)	Low	High	Low	15%
Positive 3 (blue)	Higher	Low	Higher	25%
Positive 4 (red)	High	High	High	10%
Negative 1 (red)	Low	Low	Low	50%
Negative 2 (green)	Low	High	Higher	20%
Negative 3 (blue)	High	Low	Higher	20%
Negative 4 (black)	High	High	High	10%

Created by Fraunhofer ISI

5. Results of the Company Survey (ISI)

5.1 Approach and methodology

The aim of the company survey is to gather empirical evidence and data that corroborates estimation of the potential to shift electrical loads and the parameters and incentives needed in order to activate this potential. This was realized using a combination of broad-based and in-depth data logging. A survey specially developed for a broad study was placed online. Letters or emails were sent to more than 3,000 companies in Baden-Württemberg and Bavaria, bringing the survey to their attention and inviting them to complete it. A total of 297 companies completed the online survey, equating to a response rate of around ten percent of the companies contacted. The responses given indicate that the companies are sensing new challenges engendered by the energy transition and wish to rise to these challenges.

The survey was designed on the basis of individual production plants – a company with multiple production plants was at liberty to complete and submit multiple surveys.

To complement the online survey, interviews were arranged and conducted with ten companies. These interviews served to add detail to the results of the online survey, gather background information, and identify the motivation patterns of specific attitudes.

Assistance in the process of contacting the companies was given by the consultants for energy issues at the chambers of commerce and industry in Karlsruhe and Munich. They selected member companies, brought the ongoing survey to their attention, and recommended that they take part. All other company address and contacts were sourced from the ISI and FfE contact networks, and the Hoppenstedt company database.

5.2 Parameters for the evaluation of load management potential

There are other salient technical parameters in addition to the energy volume in kilowatts when it comes to determining the potential to shift electrical loads. These include:

- the time during which loads can be switched off or on;
- the time of the day when load shifting is available;
- the frequency with which load shifting may be employed in the course of the year without having a significant impact on value added;
- the time needed between notification of and the implementation of load shifting as requested by the grid (advance notice time); and
- the rate at which the load is modified.

These additional technical parameters need to be taken into account when the potential calculated for the individual production plants is aggregated. For example, loads that are only available during nighttime hours cannot be included if the grid loads are to be reduced during the day. This is the case in, for example, the cement industry, where the energy-intensive cement clinker mills tend to be run during the night in order to lower the electricity bill.

At this point, it is worth noting the definition of potential given at the beginning of this report. We can make a distinction between technical, economic, and realizable potential. In addition to technical and economic restrictions, there are also other restrictions that further reduce the potential, such as information deficits, HR shortages, financial restrictions, and other obstacles. Ultimately, it is the realizable potential that defines the influence that load management may possibly have on system operations and the system load.

It follows from the above that not only the technical parameters, but also economic parameters, necessary financial incentives and other implementation incentives, and also the obstacles to implementation need to be ascertained in order to estimate the realizable impact of company-based load management on the system load and security of supply. These are elements of the survey developed, which is structured as follows:

- A Company details
- B Details of the structure of electricity consumption
- C Questions about load management
- D Questions about technical potential
- E Questions about economic potential and financial incentives
- F Incentives for and obstacles to load management
- G Questions about power supply security within the company
- H Personal details (voluntary)

The information collated about the companies and their electricity consumption structure provides us with sector-specific characteristics which can be extrapolated from a sample of the surveys completed to tell us about the entire population of companies in Baden-Württemberg and Bavaria. Section C gives an insight into the extent to which the plants are already familiar with load management and the degree to which technical facilities and circuits that can be used for load management are already in place. Section G shows us what impact the companies think the energy transition has on security of supply. The more critical the assessment of the situation in the future, the greater the willingness to take preventive action by means of company-based load management.

The online surveys and company interviews were evaluated anonymously, to make sure that no inferences could be made regarding individual companies on the basis of the information provided.

5.3 Evaluation of the online survey

A total of 297 surveys were completed and returned. Answers to individual questions that were clearly given erroneously were identified by means of consistency checks and were not included in the evaluation process. In addition, the surveys were frequently not fully completed, with individual questions being left unanswered. The number of answers to the individual questions that could be appraised is therefore henceforth given as the sample size 'N = ...', with 'N' being the number of production plants evaluated.

Company details

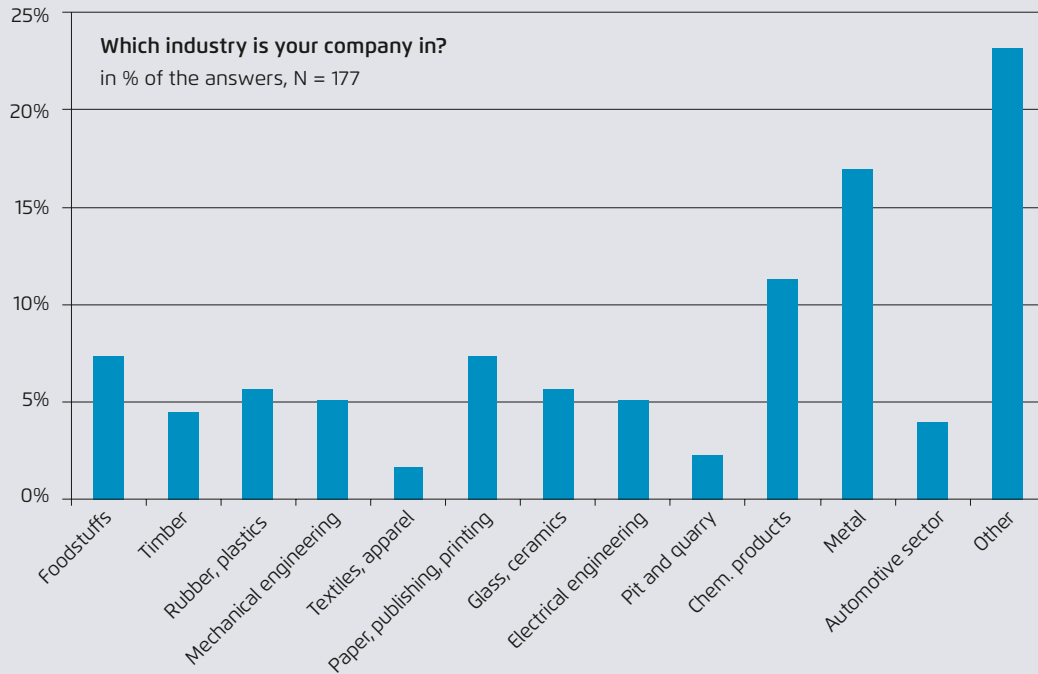
The key individual industries represented in the survey are metalworking, chemicals, paper, foodstuffs, and plastics (Figure 10). This reflects the industry structure in southern Germany, where the survey was conducted. Approximately half of the companies that responded have more than one production plant. A good quarter of the companies have sales of between €100 million and €10 billion (Figure 11).

For 68 percent of the surveyed production plants, electricity costs account for less than five percent of their sales. For 14 percent of the companies, the figure is between six and ten percent, and for 18 percent it is more than ten percent of sales (Figure 12). The arithmetic mean of all the answers is six percent of sales. This indicates that primarily energy-intensive plants participated in the survey. 40 percent of those surveyed stated that electricity costs were more or much more important than other overheads. This suggests a degree of strategic answering, because payroll figures and material costs place a substantially larger burden on production, at 20 percent and 40 percent of sales respectively.

20 percent of the sites surveyed operate on the basis of a single shift, 21 percent utilise a two-shift system, and 59 percent have a three-shift system. 54 percent always or frequently operate on weekends, with the remaining 46 percent stating that they rarely or never do

Proportion of individual industries among the surveys completed

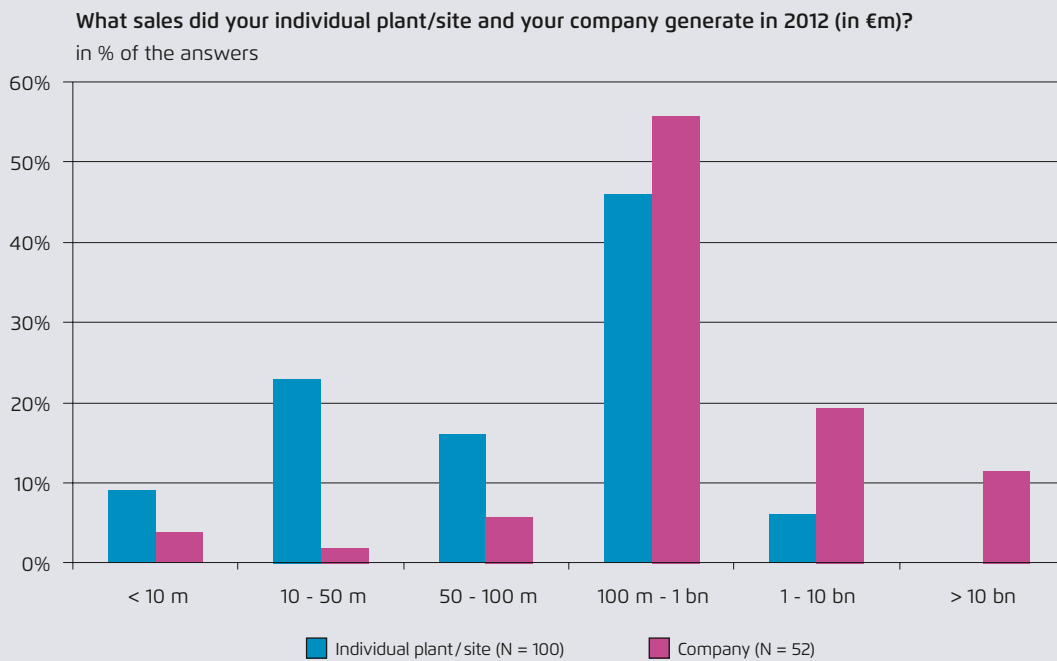
Figure 10



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Sales of the companies surveyed

Figure 11



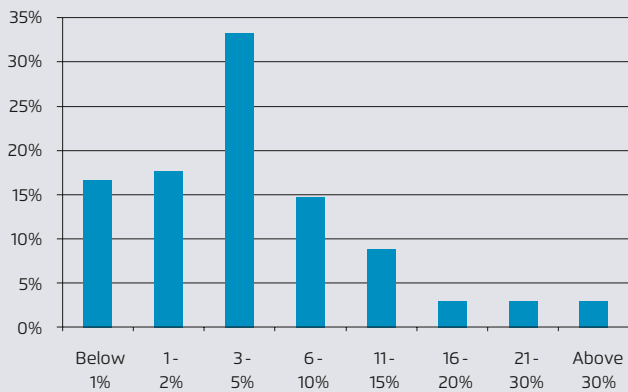
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Proportion of sales accounted for by electricity costs

Figure 12

What was the proportion of your individual plant's/site's electricity costs in relation to your sales last year?

in % of the answers, N = 102



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so. 16 percent of the sites run their production for up to 3,000 hours per annum, 42 percent for up to 6,000 hours per annum, and 41 percent for more than 6,000 hours per annum.

Electricity consumption

Two-thirds of the sites have annual electricity consumption of between 1 and 100 GWh (Figure 13). More than 40 percent of the sites reported electricity consumption of more than 10 GWh and up to 100 GWh. The proportion of companies with even higher electricity consumption (more than 100 GWh) was around ten percent.

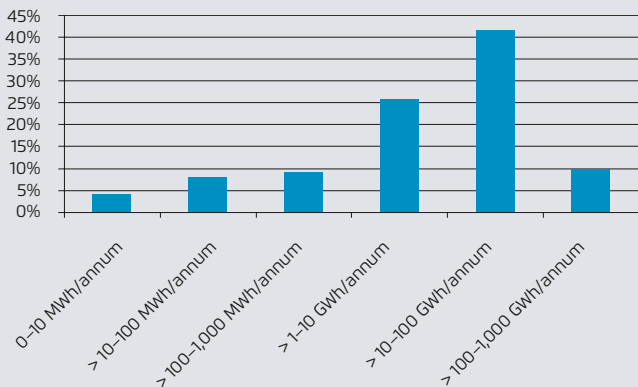
By far the most consumption is attributable to production, followed by compressed air generation, air-conditioning and ventilation, process cooling, process heating, and lighting (Figure 14). 53 percent of the sites have power requirements of between one and ten megawatts, 35 percent need less than a megawatt of electricity, and 12 percent need more than ten megawatts (Figure 15).

Annual electricity consumption of the sites

Figure 13

How high was your individual plant's/site's electricity consumption in 2012?

in % of the answers, N = 101



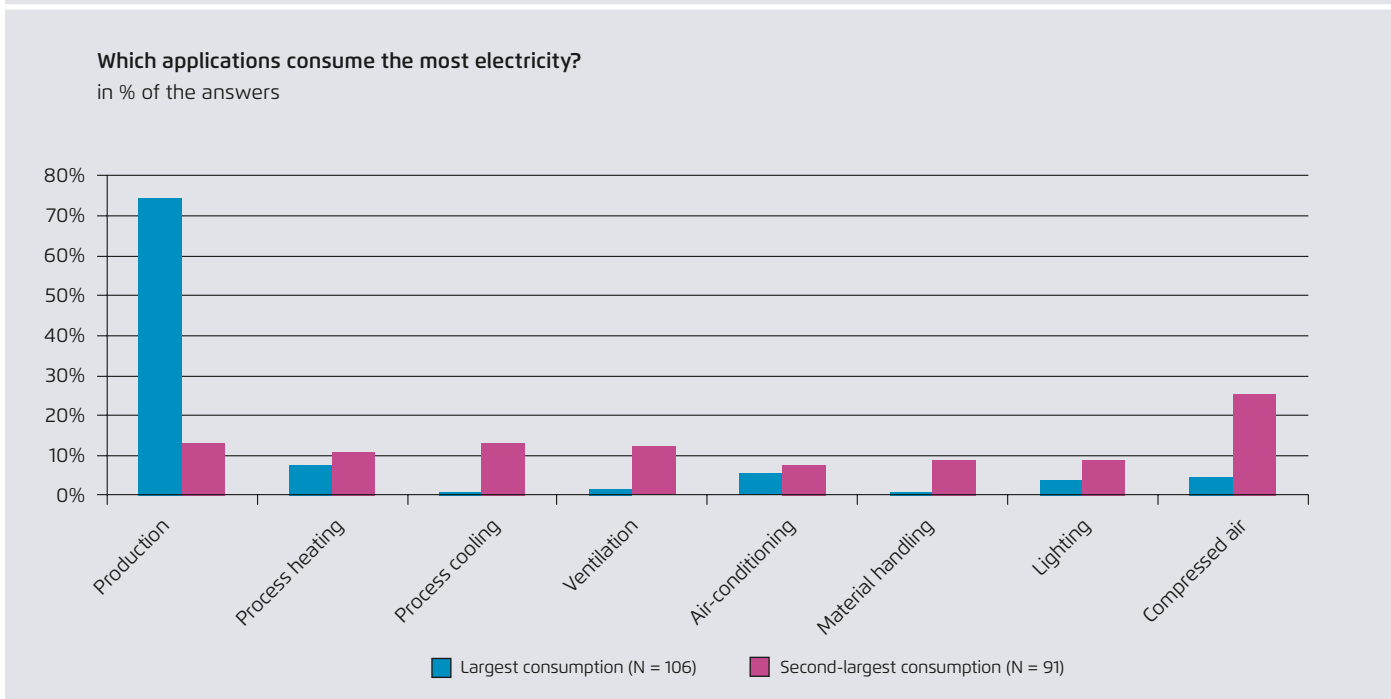
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Experience with load management

Just under half of the sites already employ load management as a way of avoiding load peaks, the motivation to do so being the reduction of their power-related costs. A small proportion of these companies also use load management to optimize their procurement. Even so, 26 percent of the companies have not yet looked into load management (Figure 16). There is also little experience among the companies in the area of grid-based load management. Two sites are active in the balancing energy market and another two have signed a bilateral agreement regarding load shifting with their system operator. In the past, system operators have been able to conclude bilateral agreements with their electricity customers which allow them to automatically engage in load shedding in the case of a dip in the frequency within the grid, in order to stabilize it. To a degree, these bilateral agreements are now replaced by the Interruptible Loads Ordinance (AbLaV), which sees the legislature now also regulating compensation and procurement.

Proportion of total electricity needs attributable to individual applications

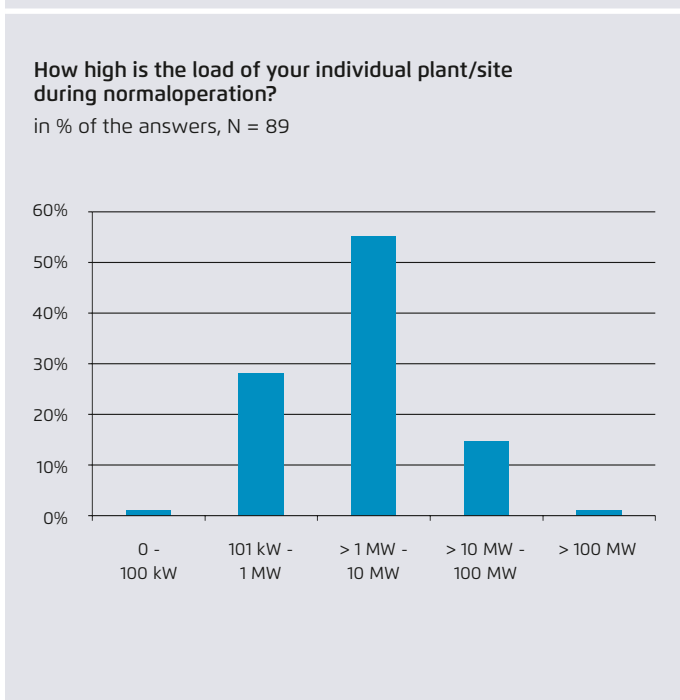
Figure 14



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Power requirements of the sites

Figure 15



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Approximately 30 percent of the companies are familiar with the newly introduced Interruptible Loads Ordinance (AbLaV) for supply voltage of 110 kV or more, although only a very small proportion of these companies, namely four, said that they were planning any kind of participation (see Figure 17). The majority of companies were not familiar with this regulation. Participation is only an option for companies with very high power requirements of 50 MW, however. A number of companies may be pooled in accordance with the regulation, and as such companies with power requirements of around ten megawatts may also participate, if they wish. Of the companies that stated in the online survey that they had an average load of at least ten megawatts, approximately half were not familiar with the Interruptible Loads Ordinance (AbLaV).

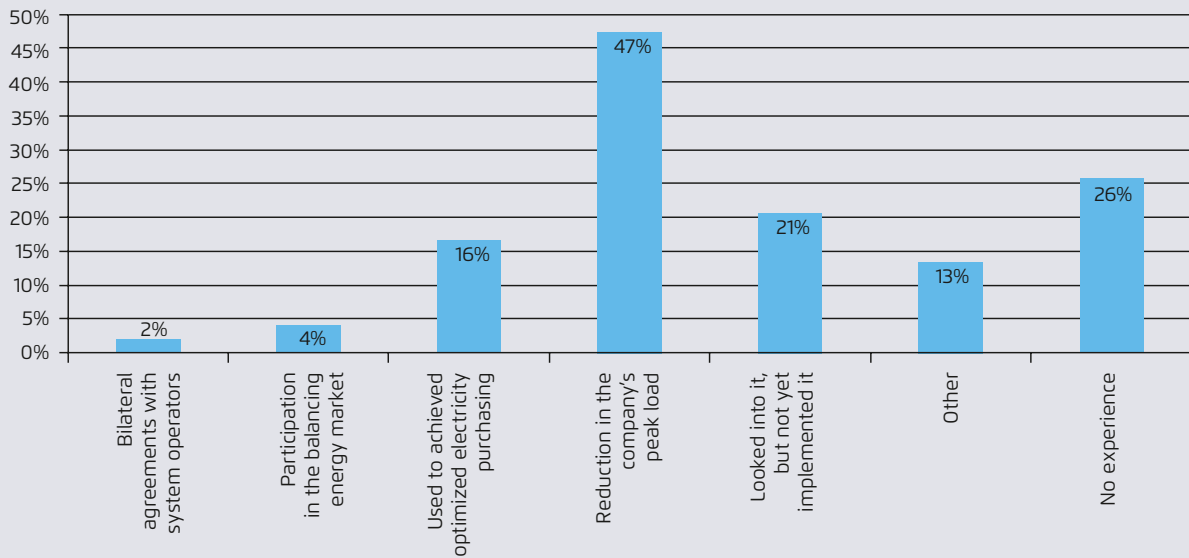
Information regarding load management that is already practiced is available for 33 sites. Of these, 19 sites reduce their electricity requirements by more than ten percent by means of such measures (Figure 18). In total, the com-

Companies' experience with load management

Figure 16

Please state the degree of experience that your individual plant/site has with the topic of load management.
in % of the answers, N = 97

N.B.: The percentage total is greater than 100% because multiple answers were permitted



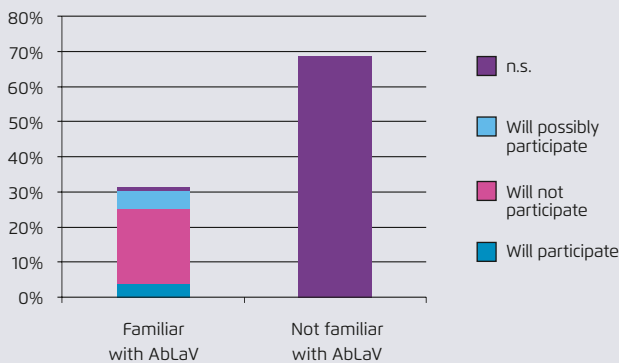
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Awareness of and participation in the Interruptible Loads Ordinance (AbLaV)

Figure 17

1) Are you familiar with AbLaV?
2) Do you intend to participate in it?

in % of the answers, N = 99



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panies that completed the survey have average power requirements of approximately 630 MW. Of this sum, they use up to 146 MW, or more than 20 percent of their average load, first and foremost for company-based load management.

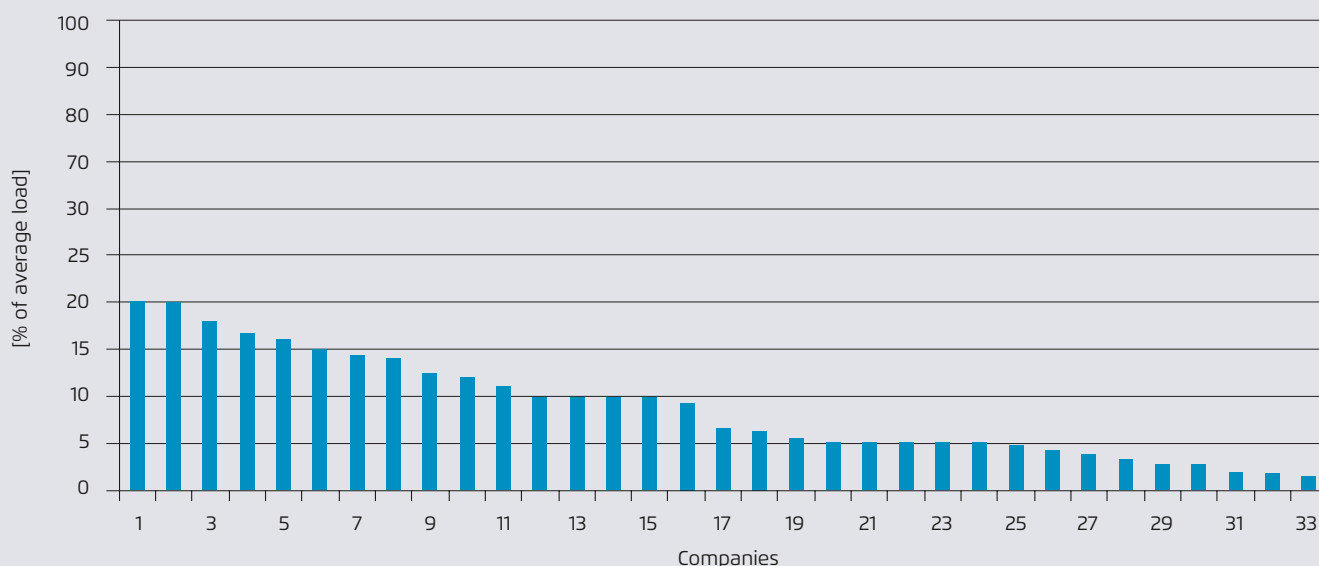
Slightly more than half of the company sites that responded have an automatic control mechanism in place to manage their loads. Those surveyed have a very critical view of management intervention carried out by the system operator, as provided for within the Interruptible Loads Ordinance (AbLaV). Only eleven percent of the companies that already have automated load management and three percent of the companies that have not yet implemented such load management can envisage external management intervention. The final decision regarding switch-offs therefore remains with the companies if their loads are used in the balancing energy market, as is offered by the service providers.

Current load management practices

Figure 18

What proportion of your normal load do you currently use for load management at your site?

in % of normal load, N = 33



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Survey results regarding load management potential

Only six sites, or eight percent of the evaluable sample, said that the technical potential for load reduction requested on the grid side was greater than 15 percent (Figure 19). 29 percent (25 sites) estimated the potential for load management to be less than two percent of the load during normal operation. The average for all 87 sites within the evaluable sample was load management potential of 5.5 percent. However, the interviews conducted failed to corroborate this already marginal potential. In fact, the broad-based survey highlights that there is still insufficient consideration among companies of the opportunities offered by company-based load management.

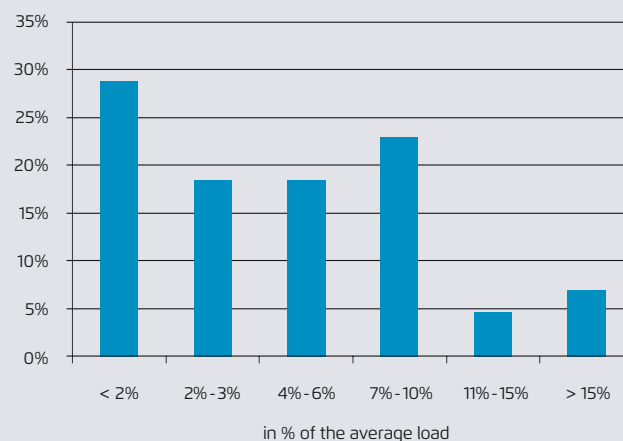
Figure 20 shows the load management potential as a percentage of the average load above a site's average load. There is no indication of any correlation between a company's power requirements and the potential for load reduction. There is, however, evidence of load management potential being dependent on a site's energy inten-

Technical load management potential for load switch-off

Figure 19

What is your estimate of the maximum technical load reduction potential at your site BY MEANS OF A SWITCH-OFF during normal operation?

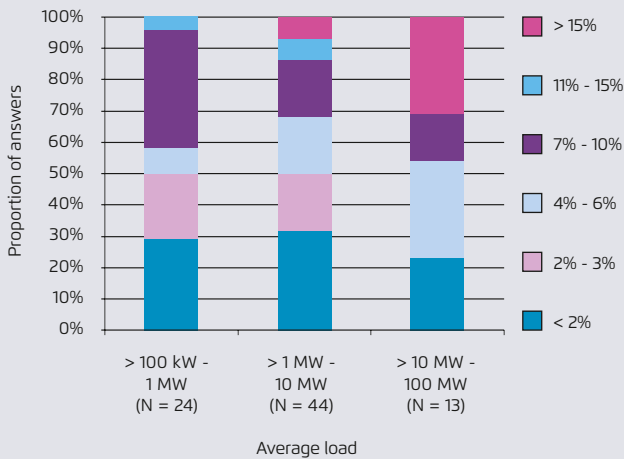
in % of the answers, N = 87



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Technical load management potential of load switch-off based on a site's average load Figure 20

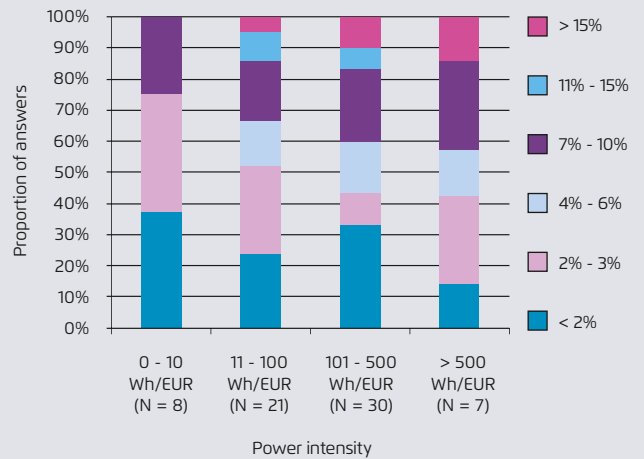
Technical potential for switch-off above average load (in % during normal operation)
in % of the answers per load category



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Technical load management potential of load switch-off based on a site's energy intensity Figure 21

Load management potential and power intensity
in % of the answers per power intensity category

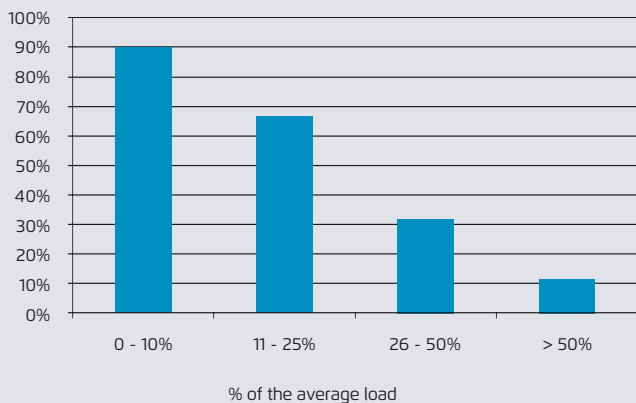


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Economic potential for load shifting Figure 22

How much load could your site reduce for approximately two hours on around ten days a year during normal operation?

Notice of at least 24 hours, sufficient financial incentives
in % of the answers, N = 69



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sity, with Figure 21 demonstrating a clear increase in load management potential as the energy intensity increases. Energy intensity is a site's electricity consumption in relation to its sales.

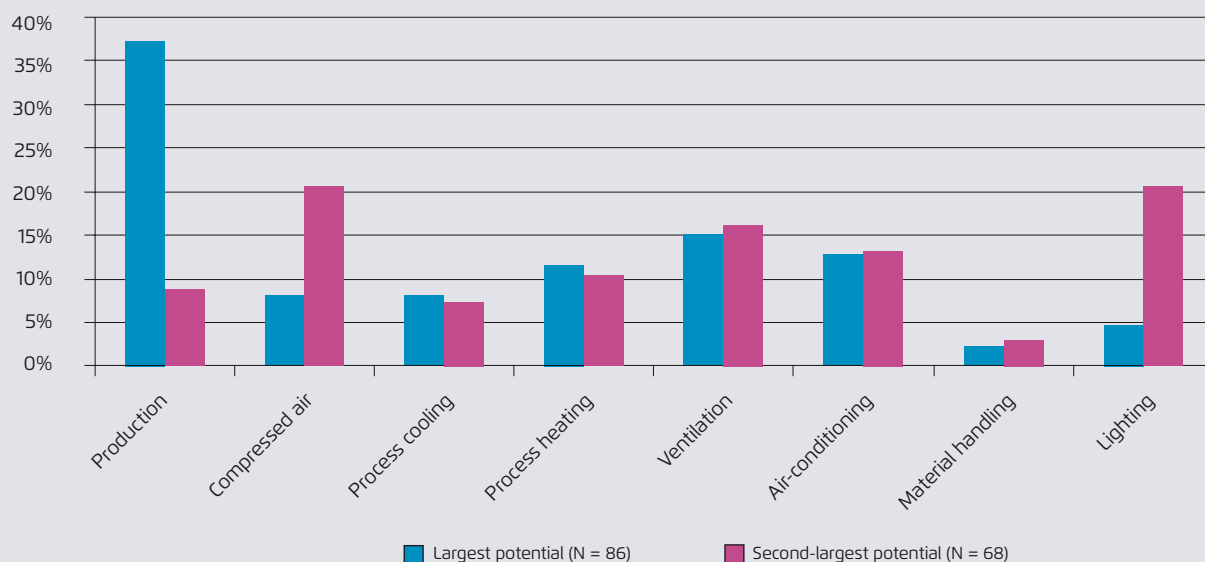
Surprisingly, the economic potential for load reduction is estimated to be higher than the technical potential. In response to the question "How much load could your site reduce for approximately two hours on around ten days a year during normal operation if you were given at least 24 hours' notice and if there were sufficient financial incentives?", the 69 sites evaluated offered potential of 19 percent of the average load (normal load) (Figure 22). The question regarding technical potential was either misunderstood or it was answered strategically in order to emphasize the importance of financial incentives.

No less than 38 percent of the sites believe the greatest potential for load shifting to be in the area of production, without a significant impact being had on value added

Electricity consumption applications suitable for load shifting/switch-offs

Figure 23

Which of your site's applications are suited to load shifting/switch-offs? Largest and second-largest potential in % of the answers



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(Figure 23). The second-largest potential is considered to be in the areas of lighting, compressed air generation, ventilation, and air-conditioning.

Potential for load increases

27 sites can envisage increasing their electrical load by five percent or more, if necessitated by the grid situation. Of these, seven sites said an increase of ten percent was feasible, and eight sites stated that an increase of 20 percent or more was possible.

Switch-off duration, advance notice, and frequency of load management

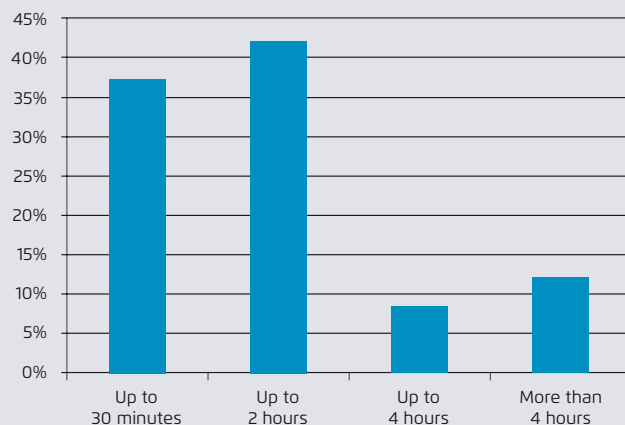
The interruptible loads of a good third of the sites are available for up to 30 minutes. For 43 percent of the sites, they are available for up to two hours and for 20 percent they are available for four hours or more (Figure 24).

Few sites are able to modify their loads at short notice, for example in order to offer balancing energy. 81 per-

Possible duration of load shifting with no significant impact on value added

Figure 24

For how long is the switch-off potential available? in % of the answers, N = 83



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cent need advance notice of more than 15 minutes, with 36 percent even needing notice of eight hours or more (Figure 25).

66 percent of the sites are able to effect up to 50 load shifts a year to reduce the electrical load, without this impacting on their value added. 26 percent can only permit up to ten instances of load shifting, with a further 26 percent being able to handle up to 20 load shifts (Figure 26). More than 100 switch-offs a year are feasible for 15 percent of the companies.

Availability at different times of the day

The majority of load management potential is available around the clock, according to 40 percent of the companies surveyed (see Figure 27). However, some potential is only available during off-peak times (18:00 to 08:00). In addition, there are companies that only operate with one shift, meaning they only have availability during peak hours (08:00 to 18:00). This category also includes a

number of companies that have increasingly moved their production into off-peak hours, thus giving them additional flexibility during peak hours.

Financial incentives

The companies demand financial incentives for them to modify their electrical loads in critical system situations without there being a significant impact on their value added. These incentives compensate the companies for the risk of production downtimes, declines in comfort, and any additional financial expenses incurred for human resources and investments. The expected financial incentives are, on average, twelve percent of a site's total electricity costs for a ten percent load reduction and 15 percent of these costs for a load reduction of 20 percent (Figure 28).

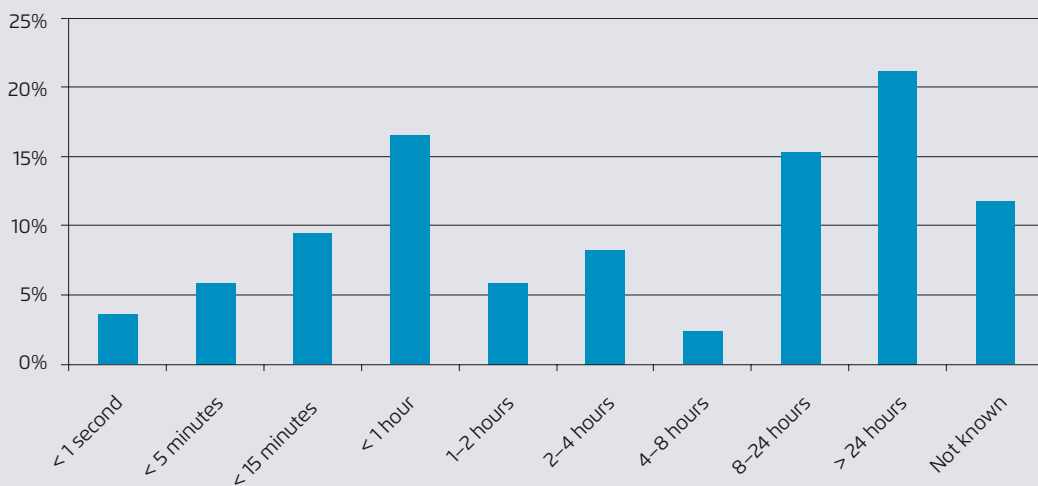
In response to the question regarding the investments needed in order to engage in load management, close to 50 percent of the evaluable sample of 69 companies said

Advance notice needed for load reduction

Figure 25

How much advance notice do you need in order to reduce the stipulated loads upon request?

in % of the answers, N = 85



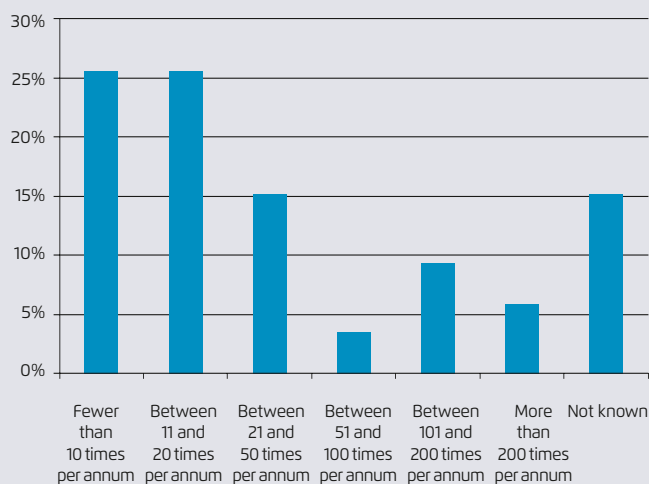
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Permissible frequency of load shifting in the course of a year

Figure 26

How often could you reduce the stipulated loads without this significantly interrupting your production?

in % of the answers, N = 86



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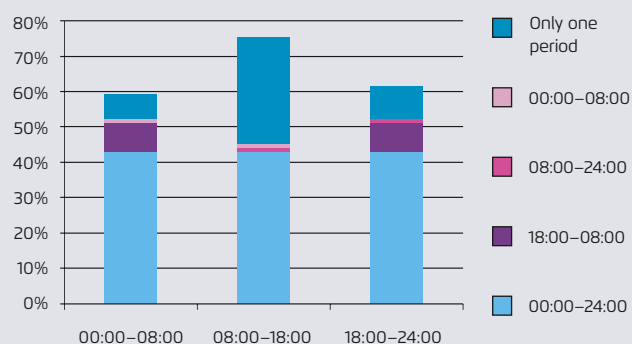
Availability of load management potential at different times of the day

Figure 27

At what time of the day is the aforementioned switch-off potential available?

in % of the answers, N = 86

N.B.: The percentage total is greater than 100% because multiple answers were permitted



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that the investment needs were considerable, just under 40 percent said that only a small degree of investment was needed, and a good 10 percent said that no additional investments at all were needed.

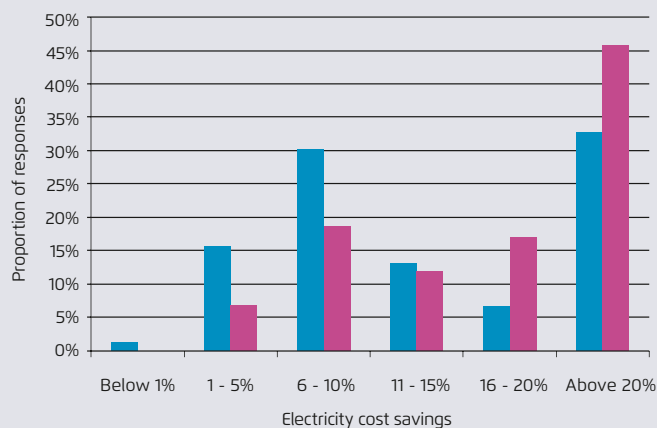
Motivation and obstacles

The primary motivation for employing or expanding load management within a company is business-related reasons. Lower electricity costs were stated as the main incentive, closely followed by improved security of supply (Figure 29). In the case of the latter, this is of interest both to individual companies and to the industry as a whole. The policy introduced with the energy transition in Germany sustainably changes the energy system not only at the national, but also at the European level. There are risks involved in this technological change, and the specific challenges of these risks can only be fully understood once the new system is in place. In this context, it makes sense for each individual company to play its part in managing grid-critical situations and in averting

Required financial incentives for load shifting in critical system situations

Figure 28

At least how high would the electricity cost savings at your site have to be per annum in order for you to reduce your power requirements for two hours on approximately 40 days a year? in % of the answers



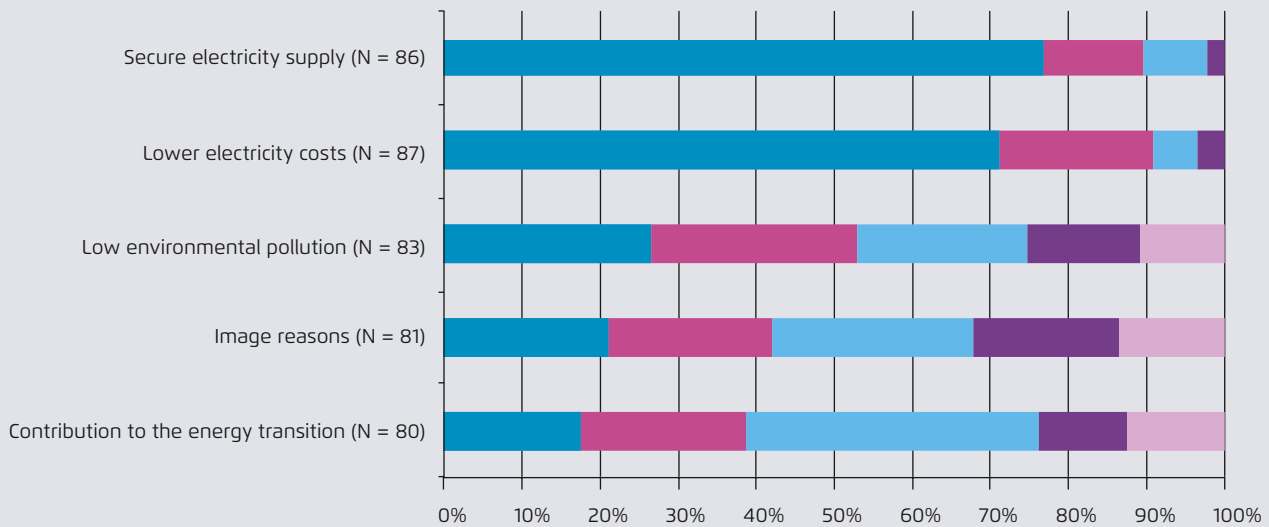
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Motivation pattern for employing grid-oriented load management at a production plant

Figure 29

How important are the following reasons/would the following reasons be in relation to your company employing load management?
in % of the answers

Very important Important Neutral Not important Not at all important



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an unplanned breakdown in the supply of electricity and in value added. One aspect of the challenges is to exploit load management as much as possible without having a significant impact on a site's value added.

The main obstacles to employing load management in order to manage critical system situations are concerns regarding production downtimes and the concomitant losses incurred. Indeed, close to 70 percent of the sites said that an hour-long power interruption would result in high to very high losses.

The cost savings that can be achieved by means of load management are not considered to be sufficient to offset the risks involved (Figure 30). From a historical perspective, this attitude is understandable. The process has not yet been completed of making people aware that, with the energy system changing, it is precisely the act of not acting that can result in electricity supply interruptions and consequently also production losses and problems with quality. This is in spite of the fact that more than 60 per-

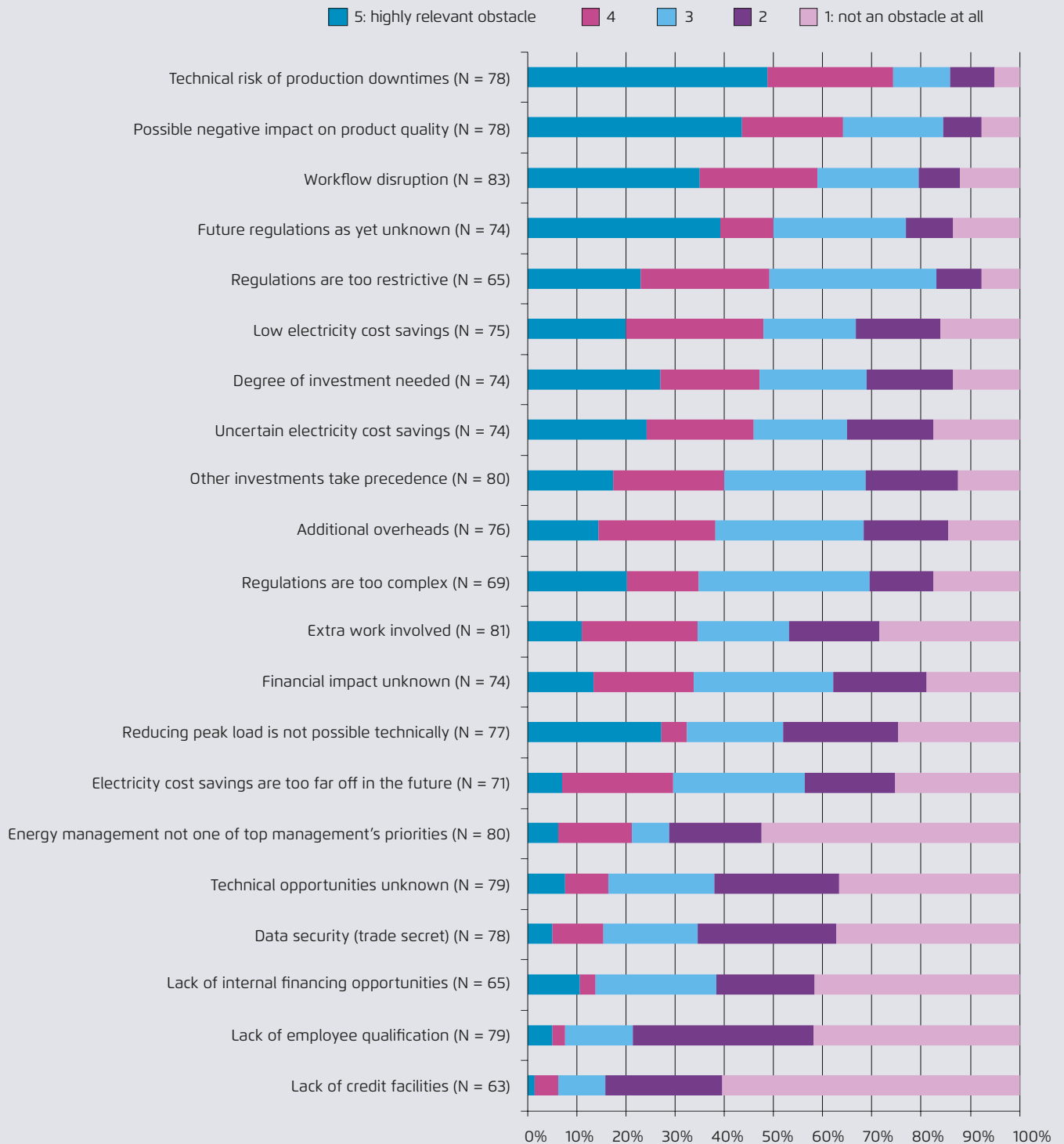
cent of the sites assume that a power outage in the years after 2018 is likely or highly likely, resulting in significant economic losses.

The pattern of obstacles indicates that there is a degree of dissatisfaction with the existing load management regulations. They are perceived as being too restrictive, incomplete, and to some extent also complex.

Pattern of obstacles to employing grid-oriented load management at a production plant

Figure 30

What are the reasons that prevent your company from employing load management to a larger degree or indeed at all?
in % of the answers



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6. Evaluation of the Available Load Management Potential in Energy-Intensive Industry (ISI)

The load management potential in energy-intensive industrial processes was analyzed in detail as part of the study. First, sites were identified where these processes are used. The available technical potential was calculated on the basis of production and electricity consumption data and also other key technical figures, such as the ability to run on a partial load. At the company level, annual and environmental reports were also used in order to arrive at figures for the site-specific load situation. Talks were also held with companies in order to validate the calculated potential and to get an estimate of its economic feasibility. The applications described are already frequently used for the purposes of company-based load management. This includes the use of optimized energy procurement and also peak load reduction.

6.1 Cement

Suitable applications

With specific electricity requirements of around 100 kWh/t, cement production is a relatively energy-intensive production process. The primary energy consumers in this field are cement mills and raw meal mills. Specific electricity requirements in the range of 30 to 60 kWh/t are given for cement mills, with these requirements dependent in particular on the fineness of the cement (Apel 2012). A raw meal mill which is used to grind gravel to make furnace meal has slightly lower specific electricity requirements. For example, approximately 26 kWh/t is given as the requirements for a specific site (Gutschi/Stiegler 2006). Another key consumer is the rotary kiln, which has specific electricity requirements on a par with those of a raw meal mill.

Of these applications, it is in particular cement mills that lend themselves well to flexible operation and load management. The sites tend to have large clinker and cement

stockpiles, thereby giving them production flexibility. Cement mills are already increasingly used during night-time hours and on weekends, in order to benefit from the lower electricity prices at these times. Individual companies stated that their weekend load is 30 percent higher than their load during workday peak hours.

Raw meal mills are likewise suited to load management. However, these are, in many cases, more dependent on the rotary kilns, and as such, flexible operation of raw meal mills is only possible to a limited degree. There tends to be only limited storage capacity beyond the raw meal mills that then charge the rotary kiln.

A typical site has capacity utilization periods of 5,000 to 6,000 hours, such that flexible operations are possible, in particular in relation to cement mills. Cement and raw meal mills account for approximately 65 percent of electricity requirements and can technically be made available for flexible operations, if the necessary production planning is implemented.

Power requirements of flexible consumers

14 sites with cement plants were identified in Bavaria and Baden-Württemberg, twelve of which with integrated production (clinker and cement production) and two with cement production only. The maximum annual cement production capacity of Bavaria and Baden-Württemberg is estimated to be around 16,000 to 17,000 kilotons, with the cement plants' capacity utilization pegged at around 60 to 70 percent. In 2011, approximately 11,000 kilotons of cement were produced. The maximum power requirements of all the cement and raw meal mills is therefore approximately 130 MW, with the total requirements for cement production (including the power needed for the rotary kilns and other applications) at around 200 MW. The companies involved in the sur-

vey estimated that around 20 to 30 percent of the current load was suitable for use in load management. This therefore equates to a load of around 50 MW that can be contributed to load reduction by the cement plants – potential which is primarily available during nighttime hours and on weekends. The potential for a load increase was estimated to be around 20 percent of the current load by the companies surveyed, with this potential primarily existing on workdays.

Technical characteristics

Additional technical characteristics were identified in the course of the online survey and the company interviews. The companies stated a maximum load shifting duration of four hours. During the daytime, this could be as short as 30 minutes when the raw meal mills are switched off. Within one to two hours, the cooling of the system results in efficiency downturns.

The companies estimated that it was feasible to achieve two activations a day or up to 50 activations a year. The advance notice period needed is at least 30 minutes. Notice of two to four hours was rated as being easily realizable. The control speeds are around 15 minutes to switch off the cement mills and approximately 30 minutes to switch them on.

Storage capacity

Estimation of the potential stated in this report is based on the condition that no major constraints are placed on a production process's value added. A substantial time shift in the production method has therefore not been taken into consideration here. To date, cement production has been interrupted for a number of weeks in the winter when construction work dwindles considerably due to the low outdoor temperatures. The cement stores are filled in advance, to make it possible to still produce cement during this period, if needed. It is estimated that the cement stores in Germany have storage capacity for between two and five days of production, depending on the type of cement and the site (Apel 2012). Germany is

estimated to have storage volume of 29 GWh in cement stores and 25 GWh in clinker stores. The storage volume in raw meal silos is much lower, at four gigawatt-hours, and the estimate for gravel bed silos is just two gigawatt-hours.

If these storage capacities are allocated to the federal states on the basis of cement production, Baden-Württemberg and Bavaria account for approximately 38 percent of Germany's total cement production. There is therefore storage volume of around eleven gigawatt-hours in cement silos and 1.5 GWh in raw meal silos.

Exploited potential

The identified applications are already used for the purposes of optimized procurement and for reducing a company's peak load. The cement plants tend to conclude individual grid charge agreements with their respective system operators for what is called atypical grid usage (Section 19 [2] [1] of Germany's Electricity Network Charges Ordinance [StromNEV]). The majority of the existing potential is therefore already used at the company level.

To date, the potential is barely used as balancing energy or as part of bilateral agreements with a system operator. For example, no loads in Baden-Württemberg currently already qualify for the balancing energy market. The operators are often familiar with the existing opportunities (balancing energy market, Interruptible Loads Ordinance [AbLaV]), but it would appear that using the potential for the purposes of power procurement and for grid charges is currently more attractive to them than participating in the balancing energy market. The companies do not usually meet the technical requirements for participation in the Interruptible Loads Ordinance (AbLaV), because they fail to meet the minimum volume requirement of 50 MW.

Financial incentives

The upfront investments tend to be minimal, because load management is frequently already being used to re-

duce the company's peak load. If this potential to reduce a company's peak load is activated or if a transmission system operator requests the provision of system services, costs may be incurred due to additional material expenses or due to a drop in process efficiency, in particular due to heat losses. With the incentive of around €30,000/MW per annum, as provided for by the Interruptible Loads Ordinance (AbLaV), it is anticipated that the majority of the cement plants will be able to provide system services when requested to do so by their system operator, in addition to employing load management to reduce the company's peak load. The online survey illustrated that a load reduction of ten percent was possible up to 40 times a year with electricity cost and grid charge savings of up to five percent. When the cost savings are greater than ten percent, a load reduction of 20 percent is also possible. If we take these figures as our basis, this equates to load compensation that exceeds the compensation offered by the Interruptible Loads Ordinance (AbLaV).

6.2 Paper

A large number of processes and applications used in the paper industry lend themselves well to flexible electricity consumption and load management. The most important of these is the wood grinders used in the manufacture of mechanical pulp. Other applications are in the area of paper recycling and pulp production.

The specific electricity requirements of wood grinders was given in the survey as approximately 2,000 kWh/t. At 80 to 85 percent, wood grinders have a relatively high level of capacity utilization. Wood grinders are used to break down logs into mechanical pulp. This is used as the basis for paper production and is generally kept in interim storage in order that the paper machines can continue to run, even if production in the grinding department is interrupted. This interim storage means the wood grinders can be operated flexibly.

The grinders are typically operated relatively continuously, but their power consumption is often higher on

weekends than on weekdays, according to the information provided by a number of companies. These companies are then benefiting from the reduced grid charges that apply to atypical grid usage. In accordance with a request lodged with the Federal Network Agency by a company, a transmission system operator can be obliged to offer tailored grid charges to a customer whose peak load will foreseeably deviate from the simultaneous annual peak load within the network or at the substation in question. The various system operators publish their peak load windows. However, this does not automatically make operation of these facilities compliant with the system as a whole, because the peak load windows are defined locally by the individual system operators (both at the distribution system and transmission system levels), meaning they do not necessarily coincide.

Power requirements

The twelve largest paper production sites in Bavaria and Baden-Württemberg were analyzed and their mechanical pulp production levels were ascertained. In all, these companies produced approximately 340 kilotons of mechanical pulp in 2011. Based on this, we can derive maximum power requirements of around 90 MW that is available for load management. The companies in the online survey reported that more than 15 percent of the current load could be used for load management. Setting aside wood grinding, the figure is four to six percent of the current load. There is greater potential available during nighttime hours and on weekends than is available on weekdays. The companies also stated that there was switch-on potential of five to ten percent of the current load. A statement more frequently made in the paper industry was that it is not yet possible to control the facilities automatically.

Technical characteristics

The companies in the online survey stated they could handle a switch-off lasting a maximum of around two hours, due to the further processing of the mechanical pulp produced and also the existing work time structures.

The companies estimated that up to 20 activations a year were feasible, which roughly equates to two activations a month. The advance notice times can be relatively short, with the companies estimating that notification periods of up to an hour were sufficient.

The control speeds are comparatively high: the wood grinders can be activated/deactivated within five minutes. They are also able to run on a partial load.

Storage capacity

The relevant interim storage comes after the wood grinders, where the fibrous material is made available for the paper machine. The storage capacity here is given as five to six hours (Apel 2012). With the grinders having power requirements of around 90 MW; the storage capacity is approximately 0.5 GWh.

Exploited potential

The applications described are to some extent already used for the purposes of company-based load management. This includes the use of optimized energy procurement and also peak load reduction. A number of companies pay discounted grid charges on the basis of their atypical grid usage. There are some initial cases of companies also having qualified their grinders for the balancing energy market. This form of load management is developing, although no applications have qualified for this thus far in Baden-Württemberg. Here, too, it can be assumed that a large proportion of the stipulated potential would still also be available for use in the balancing energy market and/or for redispatch.

Financial incentives

There are signs of the first applications here, too, being compliant with the current parameters in the balancing energy market. The financial incentives are well below the payments made in accordance with the Interruptible Loads Ordinance (AbLaV), for example. In the online survey, the companies stated electricity cost and grid charge

savings of between six and ten percent in relation to which they would be happy to reduce their loads by 10 to 20 percent.

Some of the systems cannot yet be controlled automatically, meaning a small degree of investment would be incurred in order for the applications to be used for the purposes of load management. In terms of activation, the companies above all mentioned additional material expenses and, for a number of companies, also extra staff costs.

6.3 Electric steel and metal industry

There is substantial potential for flexible electricity consumption in the area of electric steel production. This involves steel scrap being melted down in an electric arc furnace to be turned into new steel. There are two sites in southern Germany where this very energy-intensive process is used. The specific power requirements for electric steel production are between approximately 500 and 700 kWh/t.

Electric steel production is a batch process. In other words, it is not an ongoing process. Activation needs to be incorporated in production planning, because switching a furnace off mid-operation is difficult and can lead to significant efficiency losses. Overall, electric steel production is based on a process sequence which is as continuous as possible, above all to avoid heat losses and therefore also efficiency losses. Electric steel furnaces can, however, also be used for load shedding. The batch processing time ranges from 30 to 120 minutes, depending on the type of steel being produced.

Power requirements

The two sites in southern Germany have production capacity of approximately three million tons of finished steel per annum. Their specific electricity requirements are 540 and 730 kWh/t respectively, with the electric arc furnaces accounting for around two-thirds of this. Taking nothing but the average power requirements of the

electric arc furnaces into account, the power requirements are around 150 MW. The sites' total connected load/maximum power requirements are substantially higher.

Technical characteristics

The electric arc furnaces can be switched off in a matter of seconds for load shedding. A warm start can be implemented within approximately 15 seconds, while a cold start takes several minutes. Switch-off periods of up to two hours are possible, although the cooling down of the system can result in additional losses.

Exploited potential

Optimized procurement tends to already be in place, but there is nonetheless additional potential that can be used in the balancing energy market.

Financial incentives

There is no detailed information available on the topic of financial incentives, although the TSO in Baden-Württemberg states that no loads have qualified yet for the balancing energy market. The incentive to participate in the balancing energy market depends, on the one hand, on the revenue opportunities there and, on the other hand, on the development of steel prices and demand for steel. Based on the parameters of the Interruptible Loads Ordinance (AbLaV), which provides for load compensation of €30,000/MW per annum, the above-mentioned potential would likely be available for load management.

Other applications in the metal industry

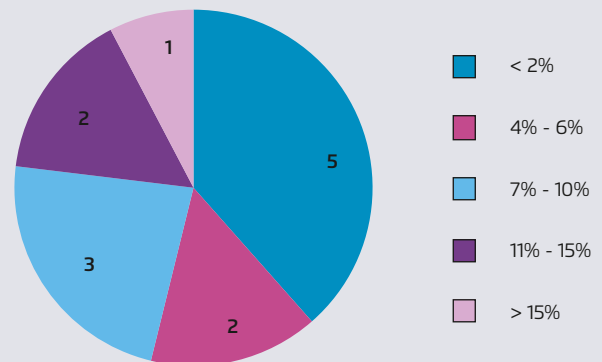
There are other applications in the metal industry that are well suited to load management, in addition to electric arc furnaces. In particular, these include applications for heat treatment, foundries (including in the automotive industry), hot forming, and the manufacture of forging parts. The companies in the online survey

stated load management potential of 10 to 20 percent of the current load. This typically relates to holding furnaces and smelting furnaces, which can be used for the purposes of load management. Estimates regarding load management potential were provided by 13 companies within the metal industry in Baden-Württemberg and Bavaria. In total, these companies had average power requirements of around 120 MW, approximately 28 MW of which could be used for load management. These companies already use roughly 14 MW, primarily for company-based load management to reduce their peak loads. Structured procurement is less widespread among these companies than it is in the other energy-intensive industries discussed above. The power requirements are also typically lower on weekends than during the week, in spite of production generally continuing at the week-end. Seven of the 13 companies surveyed estimate that they could make more than four percent of their average load available for additional load management (see Figure 31). One of the companies even considers more than 15 percent to be feasible.

Responses of the companies in the metal industry regarding the potential for load switch-offs

Figure 31

Technical potential for load switch-offs in % of the average load (based on the companies that responded, N = 13)



Created by Fraunhofer ISI

Evaluation of the online survey of the metal industry indicates that this is a very interesting area in terms of the availability of additional load management. As so few companies responded to the survey in this area, it is not possible to extrapolate the figures to the whole of Baden-Württemberg and Bavaria. Nonetheless, the information provided by the companies does suggest that there is at least additional double-digit megawatt potential here.

In the area of heat treatment, the power requirements of the heat treatment furnaces at German hardening plants is estimated to be around 260 MW (Klobasa 2011). Based on this, the proportion attributable to southern Germany (Baden-Württemberg and Bavaria) is approximately 70 MW. The survey showed that up to a third of the current load could be used for load management. The companies estimate that they could offer around 10 to 20 percent of their load for additional load management. There is therefore potential of up to 15 MW here.

One particularly interesting application is the melting bath. In the field of secondary aluminum production, however, the drop in output caused by a load reduction would have to be compensated for in advance in order not to adversely affect the downstream processes. With load shifting of one megawatt for one hour, output would be expected to drop by around two tons. In order for the potential to be available all year, in other words to be able to shut down the aluminum smelting works and the presses, two tons of aluminum would have to be kept in storage at all times and the capital commitment costs involved would have to be evaluated. With fixed warehouse costs and a variable aluminum price, the annual costs would be in the range of €7,000 to €9,000. In the case of 208 activations a year, there would be costs in the region of €40/MWh. In the case of ten activations, this would increase to around €800/MWh.

6.4 Chemicals

Within the chemicals industry, the production of chlorine is very well suited to load management. In particular, the membrane method and the mercury method, both of which can be run on a partial load, are good candidates.

Power requirements

There are three sites that engage in chlorine production in Bavaria. Chlorine is not produced in Baden-Württemberg. A site right on the border with Baden-Württemberg was also incorporated in this study, as this can likewise contribute to increasing security of supply. Together, these sites produced a total of 660 kilotons of chlorine in 2011. Depending on the method used, there are specific electricity requirements of between 2,500 kWh/t (membrane method) and 3,200 kWh/t (mercury method). The average power requirements for these plants are therefore around 250 MW. With partial-load potential of 40 and 30 percent of the full load depending on the method, there is around 160 MW worth of load reduction potential. The systems are also suitable for load shedding, in which case the entire power requirements of 250 MW would be available.

Technical characteristics

In the case of partial-load operation, the systems can be deactivated within 15 minutes. Load shedding takes place within a matter of seconds. Subsequently reactivating a system then takes a little longer. The applications can be switched off for approximately two hours, with longer periods possible in some cases.

Exploited potential

The applications are usually already used for company-based load management, in particular for the purposes of optimized procurement. As yet, not all of the systems are used in the balancing energy market, although the companies are well aware of this option. The companies also benefit from individual grid charge arrangements.

Financial incentives

In the case of chlorine electrolysis, it is assumed that the €30,000/MW per annum incentives paid on the basis of the Interruptible Loads Ordinance (AbLaV) are sufficient in order for this potential to also be used for system-sup-

porting load management, in addition to company-based load management.

Other applications in the chemicals industry

Another suitable area of application in the chemicals industry is gas liquefaction. This highly energy-intensive process can be run on a partial load and can to some extent therefore be operated as a flexible power consumer. Gas liquefaction involves air being compressed

and then cooled. It has high specific electricity requirements estimated to be 0.5 to 1 kWh per cubic meter. According to the estimates of the companies involved in the survey, there are approximately 25 air separation plants throughout Germany, with power requirements of approximately 500 MW. Approximately a quarter of these are estimated to be in southern Germany. The plants can be operated on a partial load of 80 percent at little extra expense. The companies estimate that there would therefore be approximately 25 MW of interrupt-

Power requirements of energy-intensive processes in southern Germany

Table 6

Industry	Anwendung	Production in southern Germany	Specific electricity requirements	Electricity requirements	Utilization period	Max. power requirements
		in kt	in MWh/kt	in GWh	in h	in MW
Cement	Raw meal and cement mills	11,000	65	715	5,500	130
Paper	Wood grinders	340	2,000	680	7,500	90
Metal	Electric steel furnaces	3,100	400	1,240	6,100	200
Chemicals	Chlorine production	660	2,900	1,914	7,700	250
Total						670

Fraunhofer ISI estimates

Additional load management potential available for use in the balancing energy market and/or for *redispatch* measures

Table 7

Application	Max. power requirements in MW	Flexible proportion in %	Econ. potential based on AbLaV in MW	Shifting period in h	Frequency per annum
Cement (raw meal and cement mills)	130	40	Approx. 50	Up to 4, sometimes longer	20 to 50 times
Paper (wood grinders)	Min. 90	100	Approx. 90	2, sometimes longer	20 to 50 times
Chlorine (electrolysis)	250	65	Approx. 160	Approx. 2	20 to 50 times
Steel (electric steel furnaces)	200	75	Approx. 150	Approx. 2	20 to 50 times
Total			Approx. 450	Approx. 2	20 to 50 times
Already used in the balancing energy market			Approx. 76		
Already used for optimized procurement			Estimated at 300 to 400		

Fraunhofer ISI estimates

ible load in southern Germany. Advance notice times of less than an hour are realizable.

The financial incentives paid in accordance with the Interruptible Loads Ordinance (AbLaV) are considered to be sufficient for the companies to participate in load switch-offs.

6.5 Summary of energy-intensive industry

Based on the production volumes of the individual processes, we can derive the power requirements and the interruptible loads that can be used for the purposes of load management. The applications examined in detail have power requirements of approximately 670 MW (see Table 6).

The economic potential were compensation to be paid in accordance with the Interruptible Loads Ordinance (AbLaV) was estimated on the basis of the calculated power requirements and the company surveys and interviews (see Table 7). This equates to load compensation of approximately €2,500/MW a month and additional compensation per activation of €100 to €400/MWh. The potential is already used for company-based load management in the form of optimized procurement and a reduction in the company peak load. Atypical grid usage is found in the cement industry in particular, and also in the paper industry.

In relation to these applications, additional load management potential is in particular offered by increasing the level of participation in the balancing energy markets and in grid relief redispatch measures. According to the TSO's, approximately 76 MW of load in southern Germany already qualifies for the balancing energy market. The calculations therefore show that southern Germany has additional potential for system-supporting load management of 400 to 450 MW in the four applications examined in detail alone. There are also additional applications in the metal, chemicals, and paper industries that could boost this potential even further.

Only a limited proportion of the potential of 450 MW is available for reducing the system's peak load, as it is generally already used for the purposes of optimized procurement. In situations where there is a high electricity exchange price, the majority of the applications mentioned should therefore no longer be connected to the grid. However, as already demonstrated in the previous chapter regarding analysis of the critical grid situations, these situations do not always go hand in hand with high electricity exchange prices. The applications in the energy-intensive industries therefore offer additional potential, especially in terms of system-supporting load management.

7. Evaluation of the Available Load Management Potential in Cross-Section Technologies (FfE)

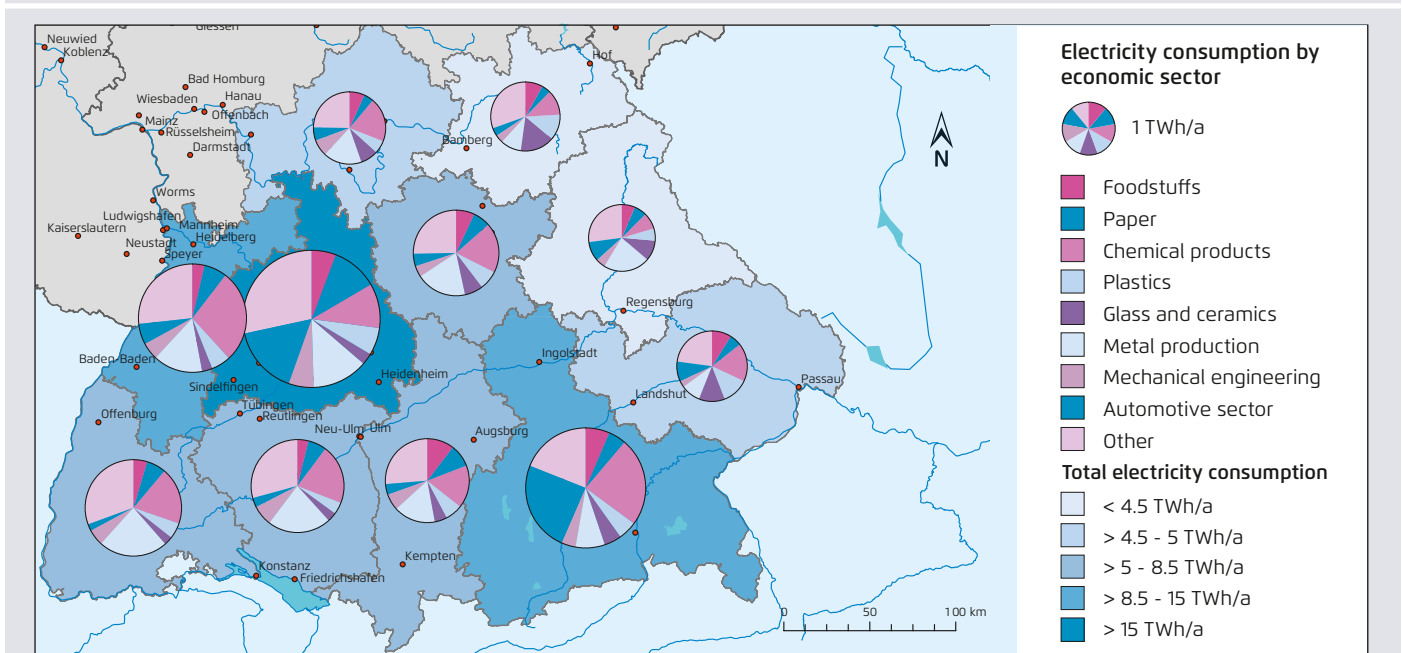
Figure 32 shows the spread of total electricity consumption by industry and governmental district in southern Germany. Of the economic sectors considered in this study, the majority of consumption is attributable to the chemical products industry in Bavaria (including the pharmaceutical sector) and to metal production, non-ferrous metal production, and metalworking in Baden-Württemberg. Other sectors that account for large proportions of the electricity consumption in the two federal states include mechanical engineering, the automotive sector, the paper and printing industry, and the foodstuffs industry (Schmid et al. 2010).

Based on its demand for electricity and the typical load profiles of the transmission/distribution systems in Bavaria and Baden-Württemberg, industry there has maximum power requirements of around 14 GW.

The load curves of electricity demand throughout the federal states were not available, and as such the power requirements were estimated on the basis of the electricity needs and the vertical grid loads in the transmission system and in the largest distribution systems. With the exception of sometimes slightly higher cooling generation loads in the summer, industry load profiles are characterized by relatively little seasonal fluctuation. In total, there is also very little fluctuation in production. The only noticeable load changes are caused by the reduction of production or the shutting down of production plants. These load changes can be derived on the basis of work shift models. For example, companies that operate their production on the basis of a two-shift system have much lower loads overnight than they do during the day, whereas companies with a three-shift system often have relatively stable consumption levels around the clock.

Electricity consumption by governmental district and industry (Schmid et al. 2010)

Figure 32



Created by FfE based on FfE's Regional Model of Power Consumption in 2006; economic sectors based on Destatis, 2003 (WZ 03)

Numerous studies have already demonstrated that industry can contribute to security of supply, based on the example of energy-intensive processes that can be used more flexibly. But in addition to energy-intensive processes, cross-section technologies are also well suited to load management. Examples of cross-section technologies are heat and cooling generation plants, air compressors, and ventilators, to name but a few. They are used interdisciplinarily and are characterized by high time availability and regional distribution (Gruber 2011).

Current knowledge regarding cross-section technologies

The potential for cross-section technologies to contribute to load management has previously been examined in the Klobasa thesis (Klobasa 2007) and in dena's Grid Study II (Agricola et al. 2010). Compressed air is discussed in a study conducted by the VDE (German Association for Electrical, Electronic & Information Technologies) (Apel 2012), but no potential is then reported in relation to it. Klobasa states that cooling and freezing processes and air-conditioning offer potential. Load management measures with air compressors are deemed not to be economical on

the basis of the defined criteria, as discussed in the Stadler habilitation thesis (Stadler 2005), in which the load management potential in the areas of ventilation, room cooling, and compressed air is determined on the basis of, among other things, simulations and models. A comparison of the potential reported by Stadler and the results of the other studies is difficult because the stated potential to some extent only applies to specific applications. These figures are therefore not taken into account in the comparison of studies, with the exception of those for compressed air.

In dena's Grid Study II, the cross-section technologies compressed air, ventilation, and process cooling (with a distinction made between the foodstuffs industry and the chemicals industry) are examined in terms of their load management potential.

The results of the study are laid out in Table 8. Both studies show the technical potential of the cross-section technologies examined.

The results of the two separate studies on food refrigeration and food freezing vary greatly. Among other things, this is likely due to the different levels of electric-

Load management potential of selected cross-section technologies

Table 8

Application	Instl. capacity	Av. pos. capacity (interruptible)	Realizable pos. capacity	Av. neg. capacity (introducible)	Realizable neg. capacity
	in MW	in MW	in MW	in MW	in MW
Compressed air [Agricola et al. 2010]	4,278	1,598	1,598	2,680	2,680
Compressed air [Stadler 2005]	n.a.	1,598	224	n.a.	91
Ventilation [Agricola et al. 2010]	1,215	1,075	1,075	141	141
Air-conditioning [Klobasa 2007]	n.a.	n.a.	320	n.a.	n.a.
Process cooling, chemicals industry [Agricola et al. 2010]	572	572	572	0	0
Process cooling, foodstuffs [Klobasa 2007]	n.a.	450 to 570	270	n.a.	n.a.
Process cooling, foodstuffs [Agricola et al. 2010]	2,180	1,478	1,478	703	703

Based on Agricola et al. (2010), Klobasa (2007), Stadler (2005)

ity consumption assumed in the studies (approximately 13 TWh/a according to dena, and a maximum of 5 TWh/a according to Klobasa).

7.1 Underlying data and methodology

In order to determine what contribution cross-section technologies can make to load shifting, a methodology was developed, which is illustrated in Figure 33.

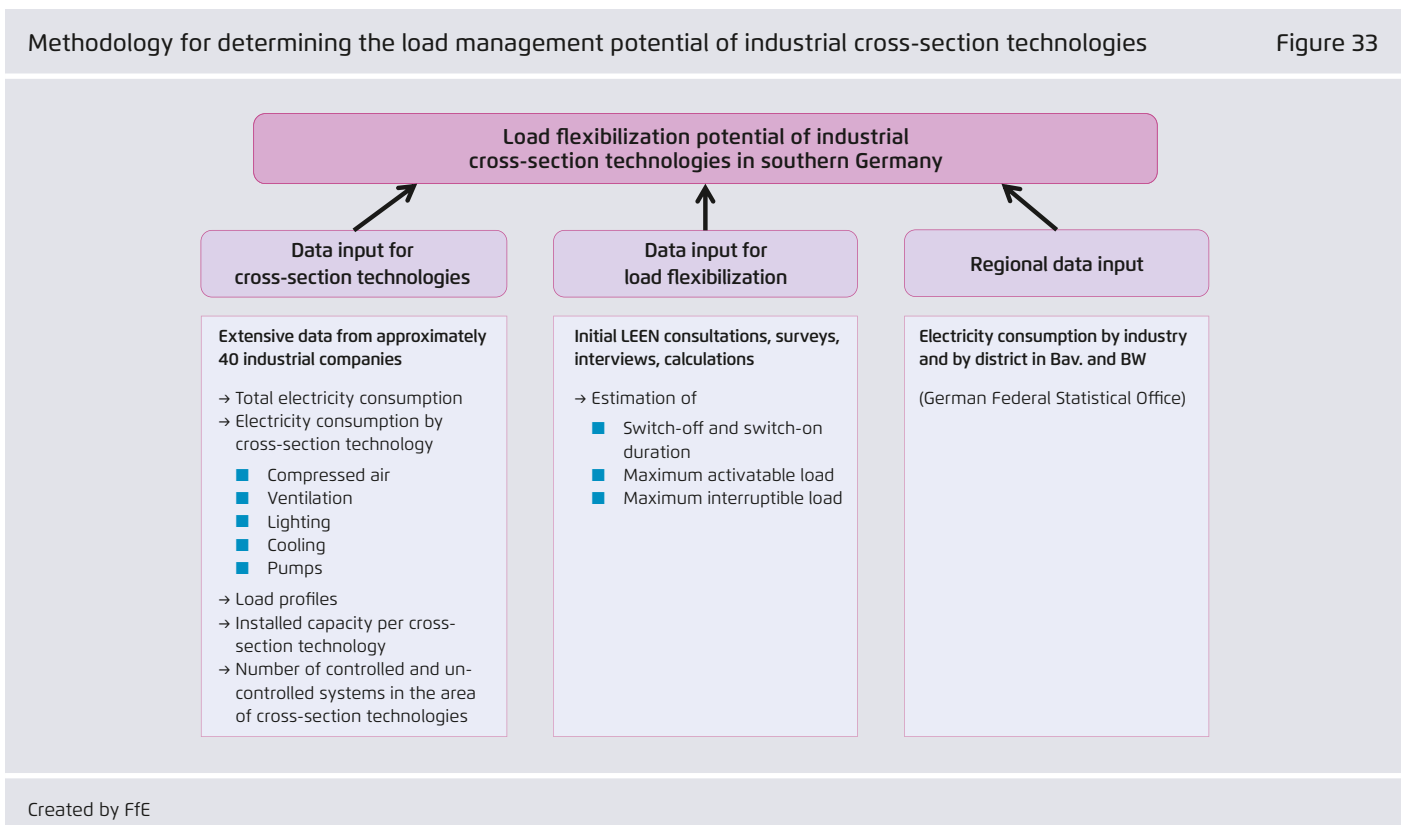
The underlying data used for the analysis was taken from detailed surveys carried out as part of FfE GmbH's Learning Energy Efficiency Networks (LEEN) (FfE GmbH 2012), which were then processed in order to ascertain load management potential for the purposes of this project. In all, the data provided by 40 companies was evaluated. Details of the total electricity consumption of these companies and also of the consumption of their individual cross-section technologies is available. The installed capacity of the individual systems is also known for each cross-section technology, and it is also known whether and how these

can be controlled (no control, in stages, or by speed). As a result, it was possible to calculate the total installed capacity of each cross-section technology. In addition, the load profiles in 15-minute intervals are available for each company. The operating times of each company could therefore be ascertained on the basis of the load profiles.

The following cross-section technologies were chosen to be examined in greater detail:

- Compressed air
- Ventilation
- Lighting
- Cooling (process cooling and room cooling)
- Pumps

The electrical drives of the various systems in the areas of compressed air, ventilation, air-conditioning, and pumps can be used for load management measures. In the case of lighting, dimming the illuminance does not generate a great deal of potential.



In addition, the results of the online survey (see Chapter 5) were used to determine the potential, and on-site interviews were also conducted with the individuals responsible for energy within the companies and with demand response providers.

Among the matters discussed in the detailed talks with the individuals responsible for energy at the companies within the energy efficiency networks overseen by FfE was the extent to which individual systems can be operated flexibly and which additional steps would have to be taken to make flexible operation possible. The realizable potential was derived on the basis of the technical potential, based on the assumption of economic operation without taking implementation costs into account. Among other things, the findings of the various surveys were used to determine the flexibilizable load for each cross-section technology. In addition, the on-site surveys were specifically used to find out about the duration and frequency of the load management of cross-section technologies. Other calculations regarding the maximum load management duration possible were also carried out.

The electricity consumption per industry and district in Bavaria and Baden-Württemberg was taken from FfE's Regional Model (Schmid et al. 2010), to then be able to determine the potential in southern Germany.

The following industries were examined in order to ascertain their potential:

- Foodstuffs and tobacco
- Paper
- Chemicals
- Glass, ceramics, pit and quarry
- Metal production, nonferrous metal production, metal-working
- Mechanical engineering, automotive sector
- Other economic sectors

Electricity consumption per cross-section technology and industry

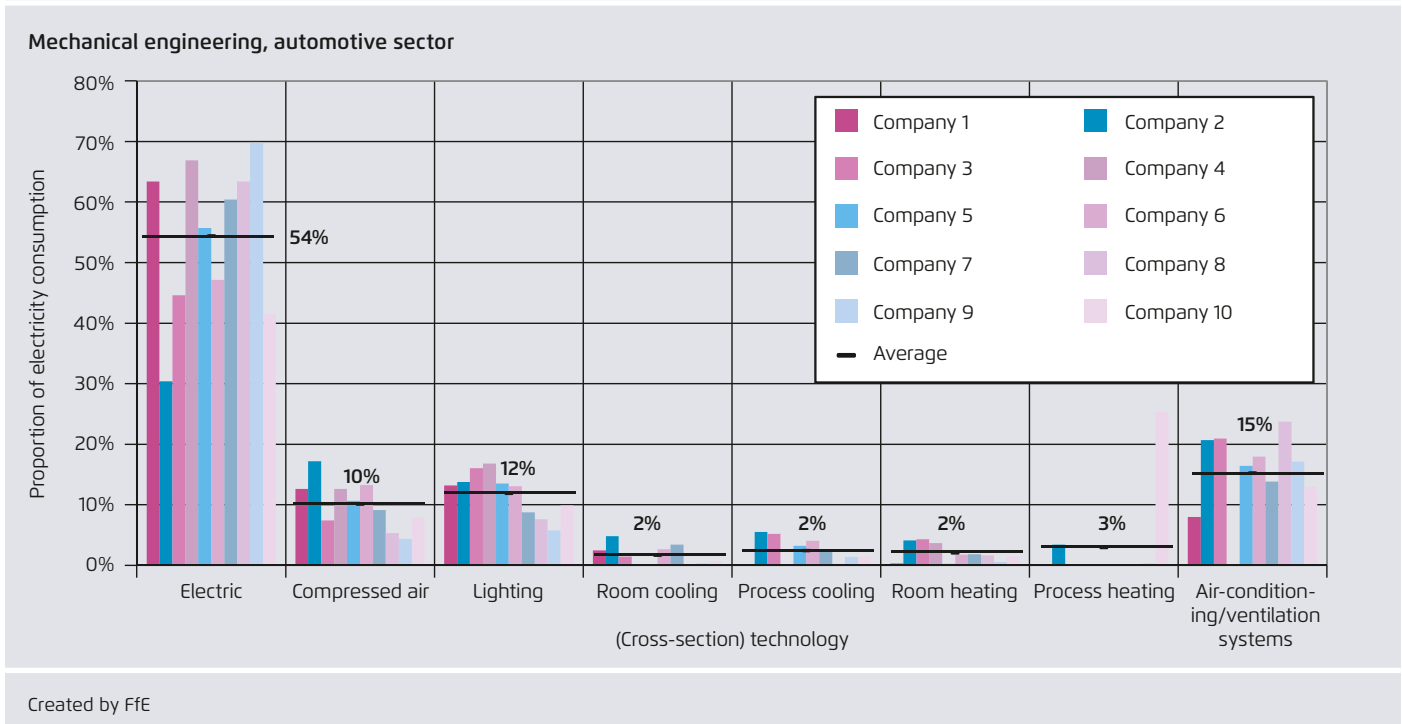
To begin with, the companies were divided up according to their respective industries. Due to the limited sample size, care was taken to group similar cross-section technologies. For example, companies from the mechanical engineering industry and the automotive sector were seen as one group, based on the fact that they make similar use of ventilation systems, air compressors, and cooling systems. The data available regarding the electricity consumption of the individual cross-section technologies and companies was averaged out for each industry, such that electricity consumption figures were available for these industries on the basis of the individual cross-section technologies and production plants. Figure 34 illustrates this spread, based on the example of the mechanical engineering industry and the automotive sector. The column entitled 'Electric' (52 percent of total electricity consumption) comprises the electricity consumption of the production facilities and of IT, although the latter is generally negligible. Other than the 'Electric' category, the other big consumers are compressed air, lighting, and ventilation, which account for between 10 and 15 percent of total electricity consumption. These pro rata electricity consumption levels per cross-section technology and industry were then subjected to a plausibility check by means of comparison with values cited in literature (Rohde 2011).

Arithmetic means were used as a basis for extrapolation. The extrapolation was also compared with a weighted average, which suggested slightly higher potential for load reduction within industry. The potential presented in this study should therefore be considered as a conservative estimate. The high degree of diversity from company to company as shown in Figure 34 clearly shows that individual cases of potential can diverge greatly from the average potential levels reported here.

Two benchmarks were then established per industry, in order to determine the load management potential. To present the regional potential, the electricity consumption per district and industry was multiplied by the factor a_i , which represents all the installed capacity of a

Distribution of electricity consumption by technology, based on the mechanical engineering and automotive sectors

Figure 34



cross-section technology, based on the total electricity consumption of the industry in question, i .

$$a_i = \frac{P_{inst,QST,i}}{E_{el,ges,i}}$$

i = industry

$P_{inst,QST}$ = installed capacity of the cross-section technology

$E_{el,ges}$ = total electricity consumption of the companies examined

Average load based on installed capacity per cross-section technology and industry

The realizable load management potential of the individual technologies is dependent on the average power consumption of the systems. The higher the average load based on the installed capacity of the cross-section technology, the higher the positive load management potential too, because more load can be reduced/switched off. The average loads of the three operational states 'normal operation,' 'reduced operation,' and 'baseload operation' are

therefore calculated. Figure 35 depicts a daily load profile. The average load is ascertained for three scenarios: normal operation (all of the departments are producing), reduced operation (only a proportion of the departments are producing, for example during the third shift), and baseload operation (times at which there is no production).

The factor $f_{i,b}$ then represents the average power consumption during normal operation ($b = 1$: all of the departments are producing), during reduced operation ($b = 2$: only a proportion of the departments are producing, for example during the third shift), or during baseload operation ($b = 3$: times at which there is no production).

$$f_{i,b,QST} = \frac{\emptyset P_{QST,i,b}}{P_{inst,QST,i}}$$

i = industry

b = operation type

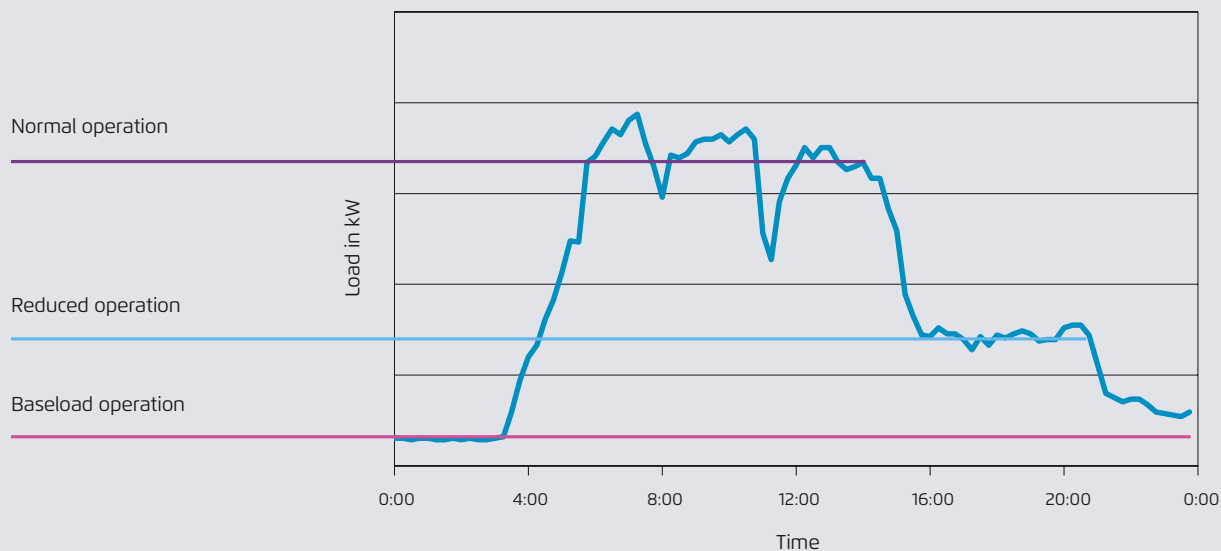
$\emptyset P_{QST,i,b}$ = average power consumption of the cross-section technology based on operation type b

$P_{inst,QST}$ = installed capacity of the cross-section technology

Average load dependent on the operation type, based on a daily load profile

Figure 35

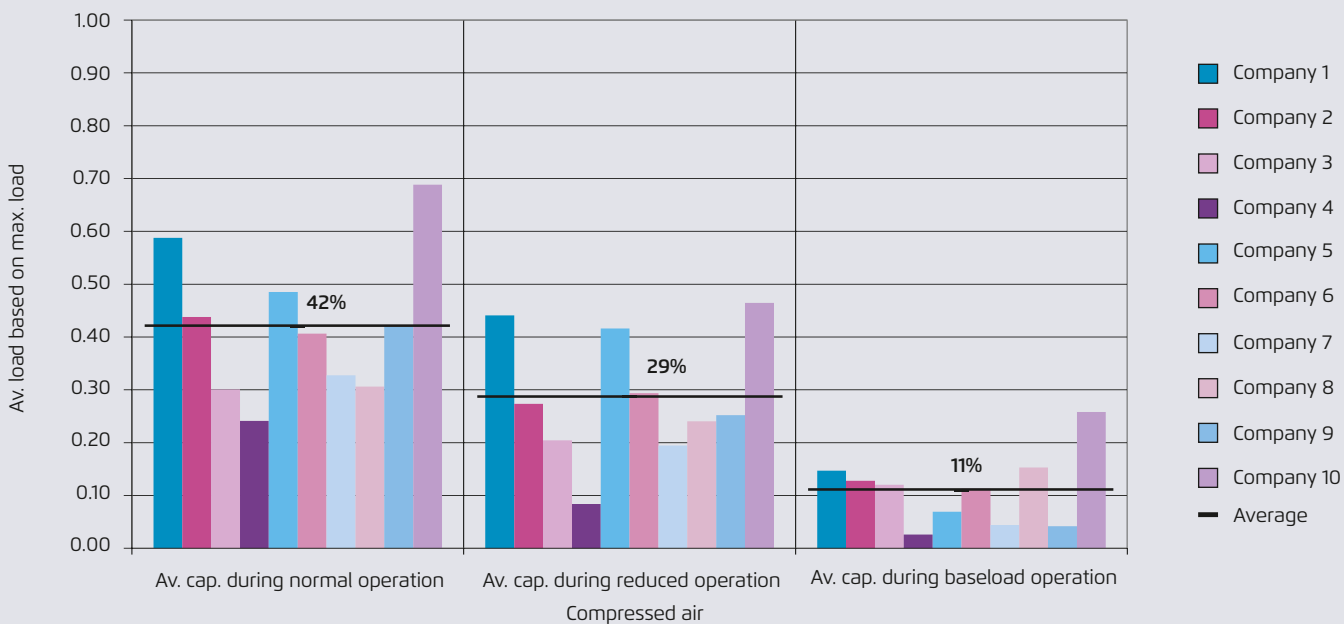
Daily load profile



Created by FfE

Average load based on the installed capacity and dependent on the operation type, based on the mechanical engineering and automotive sectors

Figure 36



Created by FfE

Figure 36 shows the average load of air compressors, based on the installed capacity of the compressors (factor f) and using the mechanical engineering and automotive sectors as an example.

It is evident that the average load of the compressors is around 42 percent of the installed capacity during normal operation, which means there is sufficient redundancy in the event that a compressor breaks down. In reduced operation, the average load drops to approximately 29 percent. And at times when there is no production, the pressure is maintained within the compressed air systems of most companies, as there are individual consumers that cannot be disconnected from the system. These consumers and also leaks result in an average load of around eleven percent of the installed capacity of the air compressors during times at which there is no production.

Influences on load management potential

The following limiting factors regarding load flexibilization were incorporated in the process of determining the potential:

- Nonavailability of systems: A few systems are not available for load management due to maintenance, repairs, or other servicing measures.
- Systems that cannot be switched off: There are legal requirements relating to some systems, such as ventilation systems in the area of pharmaceuticals. In certain areas in this field, a permanent air change rate of 30 times an hour has to be guaranteed, in which case it is not possible to operate such a system flexibly. In the case of extraction systems too, the volume flow can often not be reduced.
- Existence, size, and type of storage: Insofar as storage is available (e.g. compressed air tank, heat accumulator, or cold accumulator), production and consumption can be separated, and this works in favor of system flexibilization. Among other things, the size of the storage determines the load management duration.
- Switching on systems with no storage capacity is not taken into consideration: Surplus energy cannot be stored in areas such as lighting and ventilation; in-

creasing the volume flow or switching on ventilation systems and increasing the illuminance of lighting merely results in additional consumption. These systems do not therefore offer any negative potential.

- Minimum company size: Companies with electricity consumption of less than 5,000 MWh per annum are not taken into account in determining the load flexibilization potential, because these companies tend to only have systems with low installed capacity, and connection to an automated system would require excessive investments.
- Other economic sectors: As this group is highly heterogeneous, the potential determined was reduced slightly by an additional limiting factor.

Load management duration and frequency

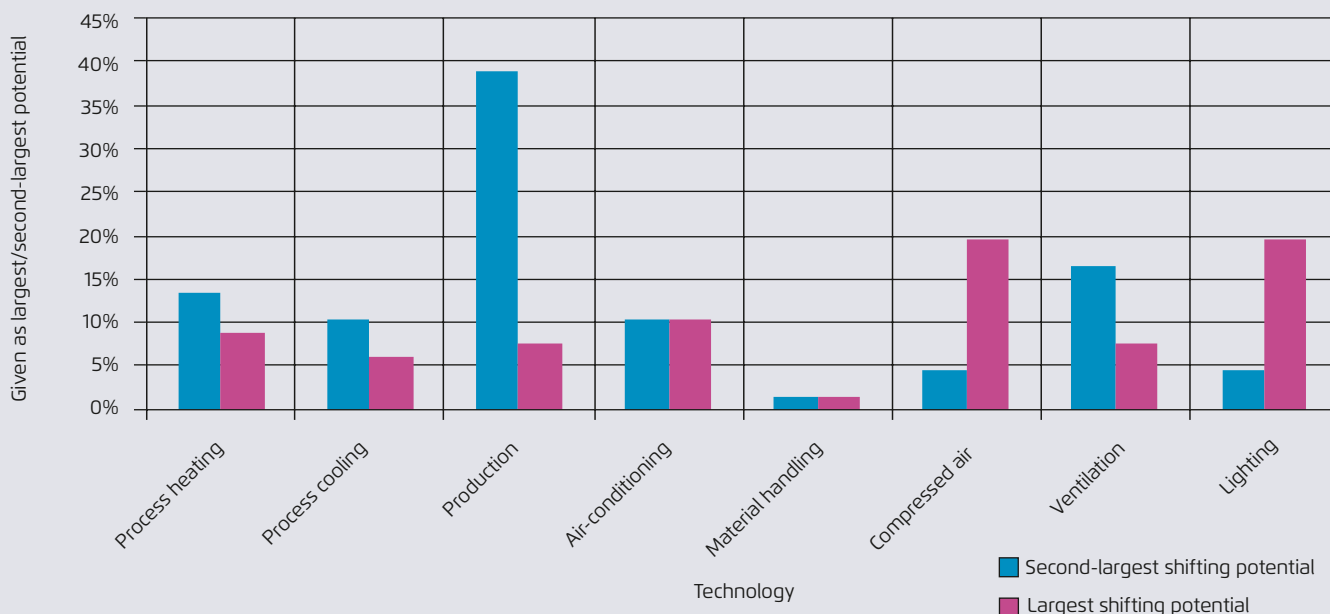
The duration and frequency of load management are important, in addition to determining the flexibilizable loads. Information provided by the companies in the online survey and in the on-site interviews was used to ascertain the energy volumes available per load management activation. In addition, we made our own calculations regarding storage capacities and used the findings of the initial LEEN consultations regarding flexibilizable cross-section technologies. Separate calculations were carried out for the three different operation types, in order to assess the availability at different times.

In the online survey, the companies were asked to state which technologies they believed offered the largest and the second-largest potential in terms of load management measures. Figure 37 illustrates the frequency with which each of the technologies was named relative to one another. The majority of the companies (approximately 39 percent) believed that production facilities offered the greatest load management potential. A great deal of potential was also ascribed to ventilation systems (16 percent). In terms of the second-largest potential, compressed air and lighting were mentioned most often (both around 19 percent).

The vast majority of the companies stated in the online survey that the flexibilizable load could be switched

Technologies offering the largest and second-largest potential in terms of load management measures according to the online survey responses

Figure 37



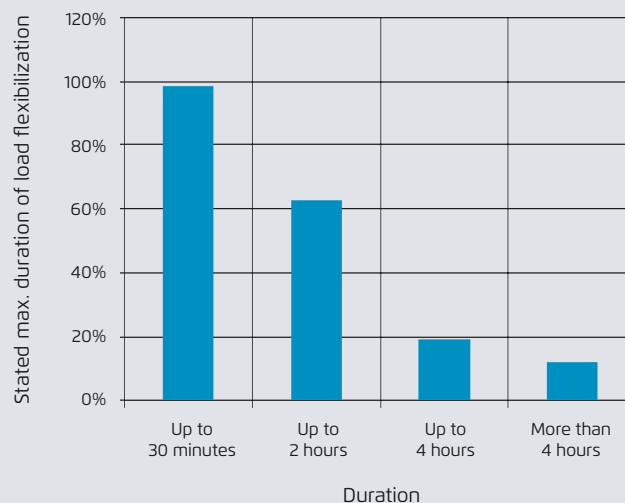
Created by FfE

off or reduced for up to 30 minutes (see Figure 38). Only 60 percent of the companies could switch the load off for as much as two hours, and few companies (around ten percent) said that they could switch off or reduce their loads for up to four hours.

The on-site interviews indicated that the majority of the companies believed that ventilation and cooling offered the greatest potential. Nearly all of the companies with which interviews were conducted stated that parts of their ventilation systems could be flexibilized for periods of 15 to 30 minutes, and in individual cases also for up to an hour. In some cases, the volume flow would be reduced, and in individual cases, the ventilation system could be briefly shut down, although this depends on the company and the season (the individuals responsible for energy are critical of switching off ventilation systems when the outdoor temperature is very low in the winter). In contrast, there are also areas in which the volume flows of ventilation systems cannot be reduced for one reason or another.

Maximum duration of load management measures according to the responses given in the online survey

Figure 38



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Cooling systems for process cooling and room cooling can likewise be flexibilized, although this tends to be dependent on there being storage available. Reducing or switching off cooling systems is usually noncritical in the area of air-conditioning. In the area of process cooling, the cooling of cooling chambers lends itself particularly well to flexibilization, although care must be taken to ensure that there is not a significant divergence either up or down from the set temperature values. In general, a difference in the room temperature of one to two kelvins in either direction does not have an impact on product quality. If storage is available, loads can also be shifted for longer periods of up to several hours. A number of the companies surveyed and examined already operate their cooling systems overnight, in order to benefit from the lower electricity tariffs or to reduce peaks in the daytime load profile.

The systems mentioned in the areas of ventilation and cooling are already integrated into load management at a number of companies. These systems are the first to be switched off if there is the risk of the maximum permissible load being exceeded. In individual cases, some of the lighting can even be reduced (dimmed) for the purposes of peak load management.

In contrast to the companies surveyed online, those that were interviewed on site did not believe that the area of compressed air generation offered any potential for load management. They are critical of switching off or reducing compressors, because this form of energy has to be available at all times for production purposes. An interruption in the supply of compressed air could impact on production. In addition, our own calculations indicated that a change in the load would only be possible for a matter of seconds for as long as the system pressure is increased by a maximum of two bar or for as long as the pressure is reduced by a maximum of 0.5 bar. The interval needed for the increase/decrease in the pressure is therefore very low. The calculations took into account the fact that the pressure level is increased/decreased both in the network and in the compressed air tank. The divergence in the responses

given online and in the on-site interviews may be due to compressed air being used for different purposes. For example, rather than controlling systems, the compressed air may only be used for cleaning purposes or for intermittent work.

The on-site interviewees also saw little to no potential in the area of lighting, which slightly contradicts the findings of the online survey. The following approach was therefore adopted in order to determine the potential: There can only be a brief reduction in the load for lighting if the illuminance as stated by the companies is above what is required by law for the workplace and if the lighting can be controlled according to the time of day with a dimming function. If a company is willing to briefly lower its lighting illuminance while still meeting the lighting level required for the workplace by law, it is able to make a contribution to load flexibilization. Additional load flexibilization is then only possible in conjunction with an increase in energy efficiency. If lighting is used for the purposes of flexibilization, there is, however, also the option of lowering the illuminance for a longer period of up to four hours, as this has less of an influence on the employees' comfort levels than if the lighting were to be repeatedly increased and decreased.

7.2 Potential

If we consider the suitable technologies in accordance with the aforementioned limiting factors, the largest power requirements that can be used for the purposes of load management are to be found in the cross-section technologies in the mechanical engineering industry, in the automotive sector, and in other economic sectors (see Figure 71 in the appendix).

Clearly, high load management potential is seen above all in the areas of cooling and ventilation. Approximately a quarter of the switch-off potential can be realized by reducing the degree of ventilation. Compressed air likewise has very high power requirements, but the loads in this area can only be shifted for a very short time.

The switch-off potential during reduced operation is lower than is the case during normal operation. In contrast, the potential that can be added increases, because the average load is lower in the case of reduced operation (see Figure 72 in the appendix).

In the case of baseload operation (see Figure 73), the positive potential is even smaller, while the negative potential is the highest available, because a large proportion of the systems can be added over a brief period.

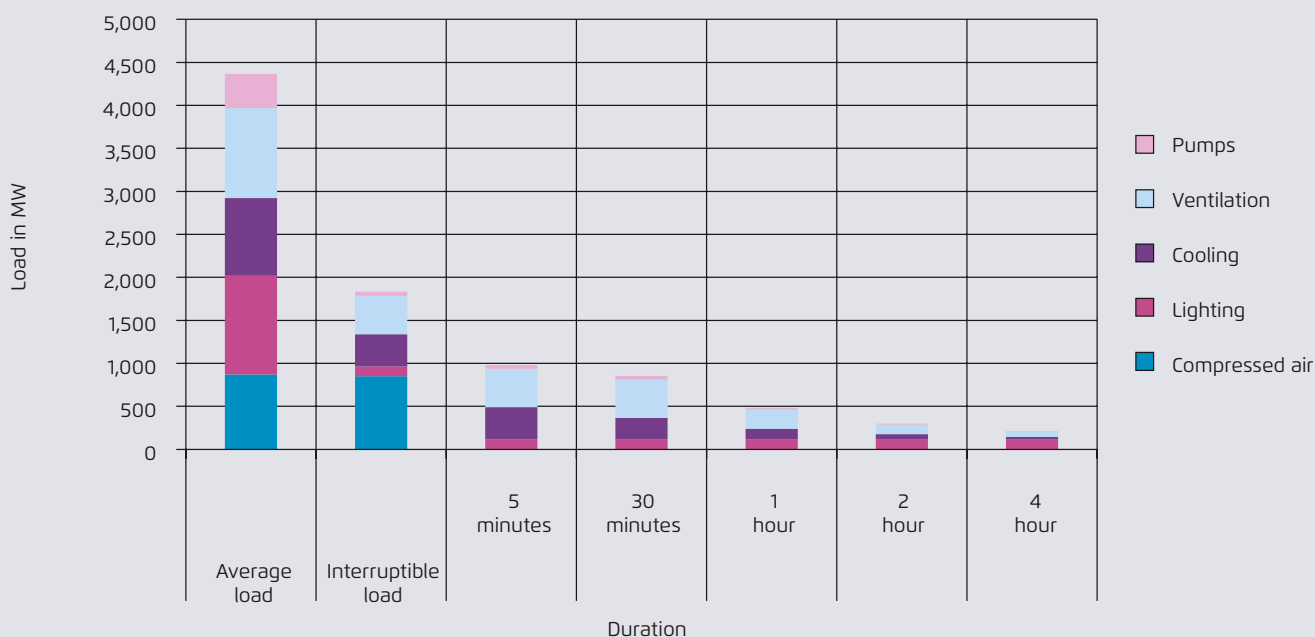
In terms of duration, a load of around 480 MW could be switched off for an hour during normal operation (see Figure 39). In comparison to the average load of the cross-section technologies considered, which is around 4.4 GW, the proportion that can be used flexibly is therefore approximately eleven percent. This proportion is just 3.4 percent in comparison to the total average consumption load of 14 GW for industry in southern Germany.

The relative contributions of the individual industries to the flexibilization of cross-section technologies over a period of an hour vary greatly. The average load during normal operation can be reduced in the range of 0.4 to, at the most, 4.6 percent, depending on the industry in question.

This information is corroborated by the online survey conducted among the companies. The companies' load-weighted information indicates load shifting of seven to eight percent of the average load, taking into account all of the industries. In the case of companies in the mechanical engineering, automotive, and electrical engineering sectors, which tend to consider cross-section technologies to be their biggest potential, there is load-weighted shifting potential of approximately six percent. Based on this, the estimate of potential conducted in this study should be regarded as being conservative.

Interruptible load achieved by flexibilizing cross-section technologies in southern Germany (normal operation) relative to duration – technical potential for suitable companies without consideration of the cost of implementation (staff and ICT)

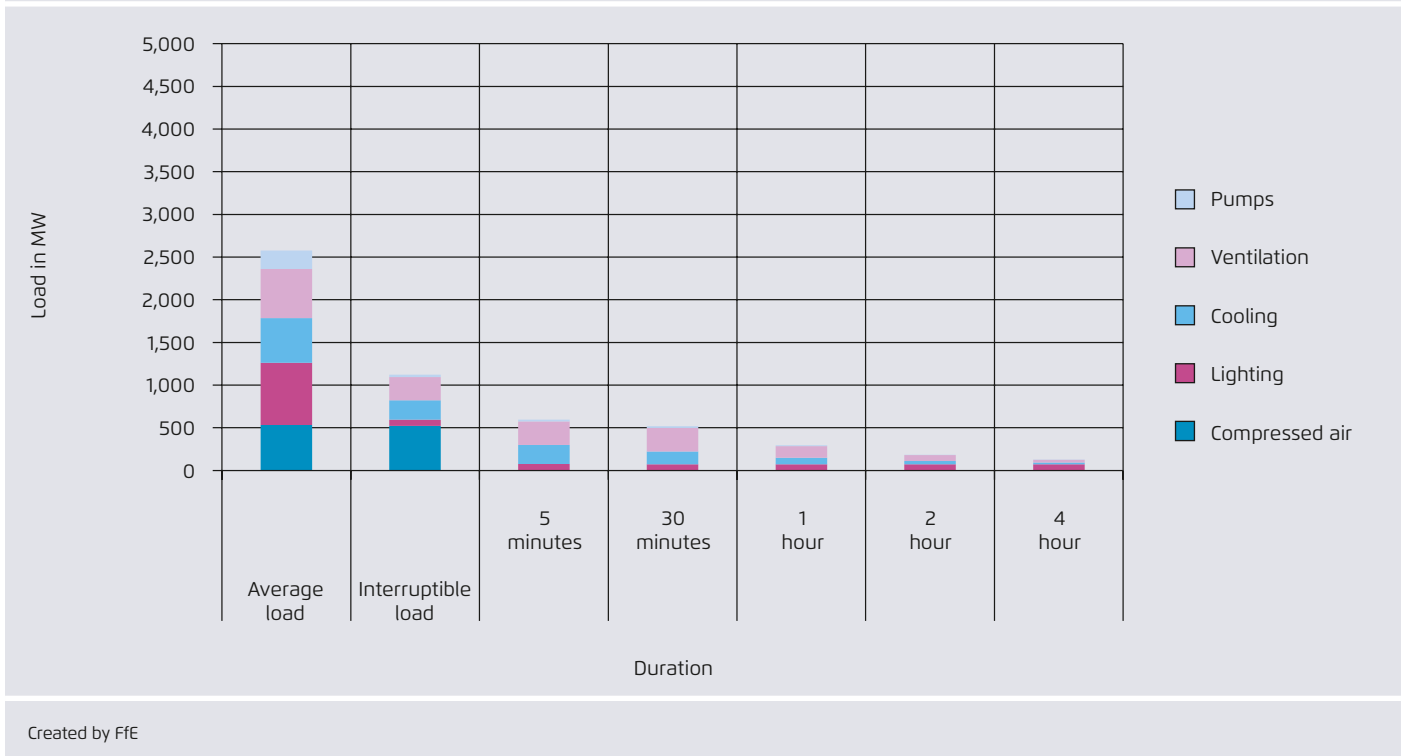
Figure 39



Created by FfE

Interruptible load achieved by flexibilizing cross-section technologies in southern Germany (reduced operation) relative to duration – technical potential for suitable companies without consideration of the cost of implementation (staff and ICT)

Figure 40



During reduced operation, an additional load of approximately 300 MW can be reduced or switched off over the same period (see Figure 40). The corresponding figure during baseload operation is approximately 120 MW.

In all, the greatest potential is anticipated in relation to ventilation systems and cooling systems, because a switch-off or reduction of these for periods ranging from 15 minutes to up to an hour often does not have any direct impact on production. However, in this area too, there are various systems that cannot be switched off for one reason or another.

It is striking that a lot of companies stated in the online survey that they saw load management potential in the area of compressed air. After closer consideration, however, this would appear to be rather optimistic. If compressed air is needed for production processes, a switch-off frequently results in production losses. The tanks tend to only be as big as is needed for the air compressors

to switch their loads on and off for a matter of seconds. Therefore, only compressed air applications not directly linked to the production process can be used for switch-offs, for example when compressed air is used for cleaning purposes.

Although lighting was also frequently mentioned as an option in the online survey, the potential it offers is limited because a reduction in illuminance is generally first and foremost attributed to an increase in energy efficiency. In exceptional cases, illuminance can be dimmed for an extended period (such as four hours) if it is above what is required by law for the workplace, although this can adversely affect the comfort levels and therefore also the productivity of the employees.

The potential could be increased by introducing additional storage capacity. Below, we examine the costs incurred by a company for expanding storage capacity in the areas of compressed air and cooling.

As approximately no variable costs are incurred in the case of the activation of the load flexibilization potential examined in the area of cross-section technologies, the costs incurred for increased storage flexibility could be allocated to the electrical energy used for peak load reduction. The investments in the following calculation examples are evaluated on the basis of the annuity method with an interest rate of ten percent and a term of 20 years. The calculations are also based on 208 activations of one hour each, in line with the maximum number stipulated in the Interruptible Loads Ordinance (AbLaV) (see Chapter 10).

It would take investments of around €2.8 million in order to provide shiftable load of one megawatt for an hour by expanding the storage capacity in the area of compressed air generation (reducing the pressure level of 13 bar to 7 bar). The price lists of various suppliers of compressed air tanks were used as the basis for calculating the average investments required. If maintenance and operating costs are also taken into account, an investment of around €2,000/MWh can be expected in the case of 208 activations per annum lasting one hour each. If there are just ten activations, the investment sum increases to just under €40,000/MWh. These results also include the costs relating to housing the compressed air tanks.

The investments needed to expand ice storage to shift a load of one megawatt are around €31,000. Taking into account storage housing expenses, fixed maintenance costs, and variable energy costs, the costs incurred for 208 activations per annum amount to around €160/MWh, with this sum increasing to approximately €680/MWh in the event of only ten activations.

8. Evaluation of the Available Load Management Potential in Electric Storage Heaters and Heat Pumps (FfE)

The annual electricity consumption of electric storage heaters in southern Germany is approximately 5.8 TWh. In the case of heat pumps, it is around 1.6 TWh. It was possible to extrapolate the consumption levels on the basis of information from distribution system operators and energy utilities. Both of these technologies include heat accumulators that are used to separate heat consumption from the time of electricity consumption. Based on these conditions, electric storage heaters and heat pumps lend themselves well to load management.

8.1 Technical parameters

Heat pumps

Heat pumps draw thermal energy from a source using electricity and then transfer it to the system to be heated. The ratio of extracted thermal energy to the electrical energy required is represented by a system's coefficient of performance, which, in the case of modern systems, is in the range of three to four. Heat pumps can be divided into three types depending on their heat source: brine pumps, groundwater pumps, and air source heat pumps (Viessmann 2007; Wagner et al. 2010).

Electric storage heaters

The increased use of electric storage heaters was originally based on the premise of increasing demand for electricity at times when the load was low, in order to make better capacity utilization of conventional power plants. As low loads tend to occur during nighttime hours, electric storage heaters are also sometimes called night storage heaters. Electric storage heaters turn the electrical energy they take when the load is low into thermal energy and store this energy in their core. Their

electricity consumption is charged at a special off-peak rate that includes a substantial grid charge reduction. Separate electricity meters are usually installed to this end (Stadler 2005).

Development in the numbers of electric storage heaters and heat pumps

It is difficult to predict the development in the number of electric storage heaters, as this is highly dependent on the regulatory framework and on the marketing models used. Paragraph 10a of the German Energy Conservation Ordinance (EnEV) 2009 originally prescribed a partial ban on the operation of electric storage heaters as of December 31, 2019. The prerequisites for this ban were that the storage heaters be in residential buildings comprising more than five residential units, that they be older than 30 years, and that the rooms be heated exclusively by means of storage heaters (EnEV 2009).

In the meeting of the Bundesrat on June 7, 2013, the fourth amendment to the Energy Conservation Act (EnEG) and a corresponding amendment to the Energy Conservation Ordinance (EnEV) were passed, thereby revoking the ban on electric storage heaters as of 2019. This was justified on the grounds that electric storage heater systems could contribute to the German energy transition by making use of surplus wind power and solar energy (EnEV 2009; EnEG 2013).

The number of heat pumps is likewise dependent on the regulatory parameters, which include grid charge discounts, and on the marketing models used. The German Heat Pump Association (BWP) outlines two different scenarios for the development of the heat pump market: Scenario one is a conservative estimate, while

scenario two is based on more optimistic assumptions. In scenario one, the number of installed heat pumps will increase from 0.45 million in 2011 to 1.1 million in 2020 (2030: 1.8 million). According to scenario two, the number of heat pumps will increase to 1.4 million by 2020 (2030: 3.4 million) (BWP 2012).

According to this study, the number of installed heat pumps is expected to increase by a factor of between two and three by 2020 (estimate as at 2011). In contrast, it is very difficult to estimate the number of electric storage heaters that will be installed in the future, as this is dependent, among other things, on future political decisions.

8.2 Underlying data

First of all, the current electricity consumption of heat pumps and electric storage heaters was calculated in order to determine their load management potential. To this end, data from distribution system operators and energy utilities was analyzed, including the consumption levels in their respective network areas, broken down by municipalities. As not all of the data records directly state the annual electricity consumption of heat pumps and electric storage heaters, some of the data was modified on the basis of comparative figures and calculations. Additional adjustments were made and the figures were verified on the basis of supply levels and information on installed capacity.

If the supply levels stated were above 30 percent, the consumption figures were ascertained on the basis of the data available at the municipality level. In the case of municipalities with a supply level below 30 percent, the values were extrapolated on the basis of the data for the whole of the supply area. If the only information available was whether there was full or only partial supply within an area, the consumption figures for the partially supplied municipalities were likewise extrapolated for the whole of the data.

In the case of the data pertaining to LEW Verteilnetz GmbH, a 100 percent supply level could be assumed for 84 percent of the municipalities. 8.5 percent of the municipalities had a supply level below 30 percent and a further 7.5 percent had a supply level of between 30 and 100 percent. The E.ON Bayern data records only make a distinction between partial- and full-supply municipalities. 20 percent of the E.ON Bayern municipalities are partially supplied, with the remaining 80 percent being fully supplied. The EnBW Vertrieb data does not differentiate between supply levels. This data was therefore used as it is.

It was possible to account for 67 percent of the municipalities in the area examined on the basis of the data. Adjustment of the data was followed by extrapolation for the areas for which there was insufficient data or no data at all. This extrapolation was based on the available 59 percent of the municipalities in the area examined. The following formula was used to calculate the consumption of electric storage heaters and heat pumps in the areas in relation to which no data was available on the basis of the electricity consumption figures for private households taken from FfE's Regional Model:

$$\begin{aligned} \text{Elec. consumption of elec. SH's/HP's}_{\text{Municipality}} &= \\ &= \frac{\text{Total elec. consumption}_{\text{Municipality}}}{\text{Total elec. consumption}_{\text{Data area}}} * \text{Elec. consumption of elec. SH's/HP's}_{\text{Data area}} \end{aligned}$$

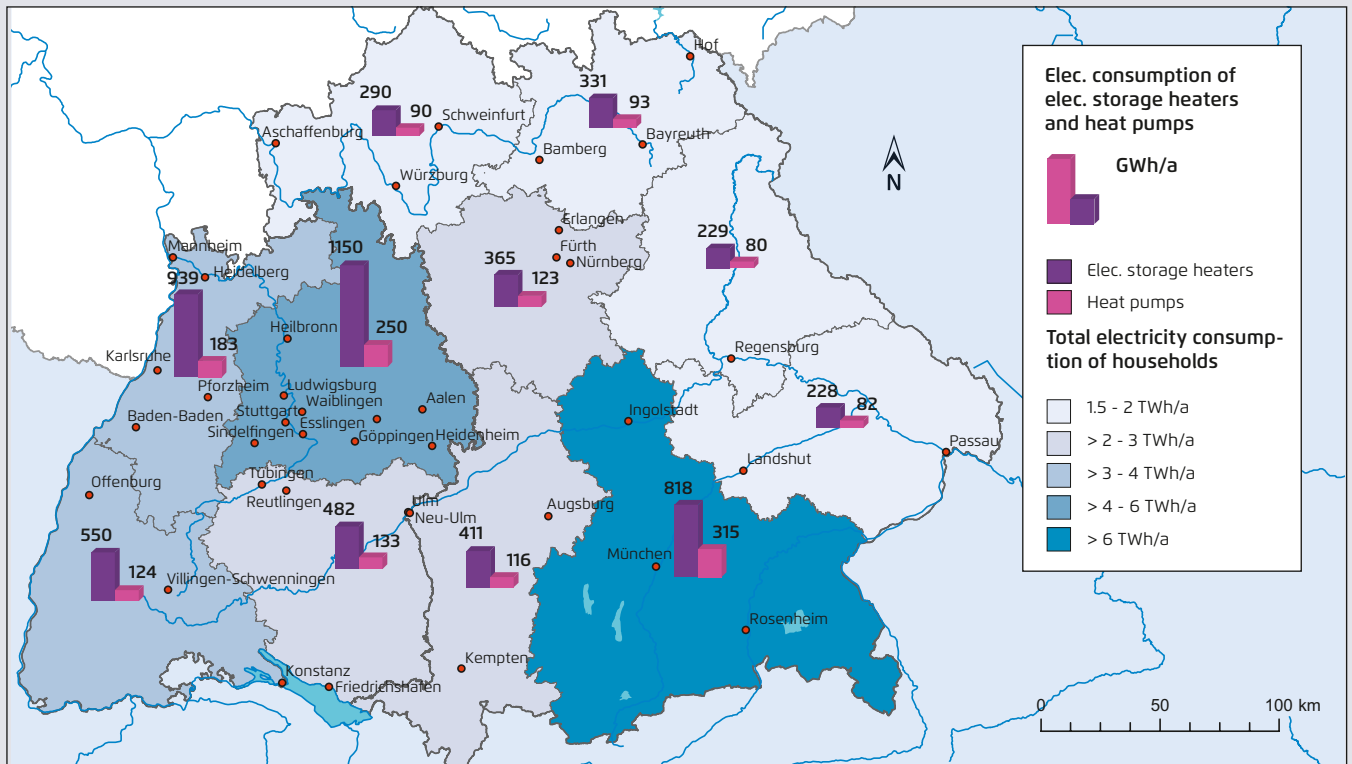
(Geographic spread of the underlying data presented in the appendix)

The calculations show that the annual electricity consumption of electric storage heaters in Bavaria and Baden-Württemberg amounts to around 5.8 TWh; the corresponding figure for heat pumps is approximately 1.6 TWh. The distribution of the annual electricity consumption by governmental district is shown in Figure 41.

Electric storage heaters and heat pumps are provided with power by means of temperature-dependent load profiles (see Figures 42 and 43) which are stipulated by

Annual electricity consumption of electric storage heaters and heat pumps in Bavaria and Baden-Württemberg

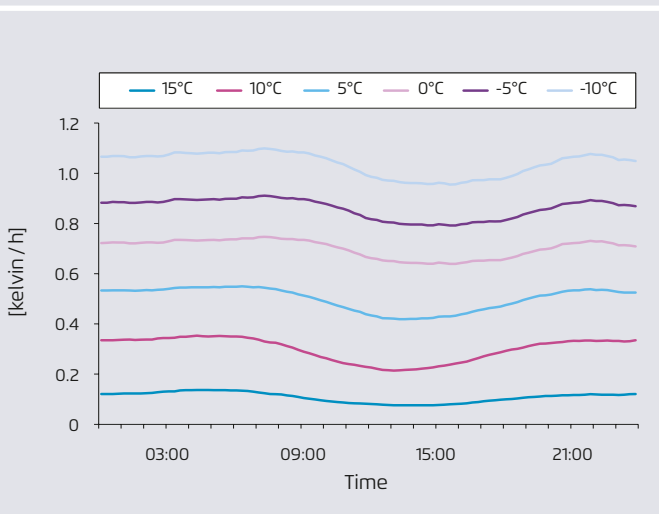
Figure 41



Created by FfE based on the FfE Regional Model 2012, Federal Statistical Office (Destatis); E.ON Bayern (DSO), LEW Verteilnetz GmbH (DSO), and EnBW Vertrieb (energy utility) 2010–2011

Temperature-dependent load profiles for heat pumps in the area overseen by LEW Verteilnetz GmbH

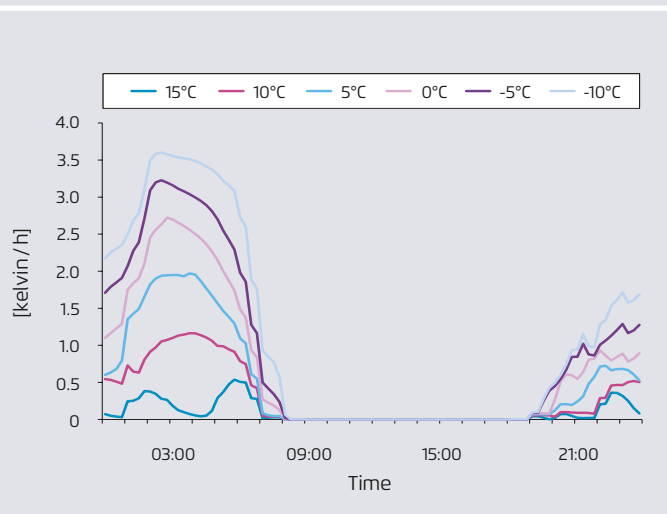
Figure 42



Created by FfE based on LEW data (2009)

Temperature-dependent load profiles for electric storage heaters in the area overseen by LEW Verteilnetz GmbH

Figure 43



Created by FfE based on LEW data (2013)

the distribution system operator in question. For reasons of clarity, only the load profiles for selected temperatures are shown.

The temperature-dependent load profiles represent all of the systems. The load profiles of heat pumps are relatively even throughout the day, and switch-offs for individual hours are sometimes evident. The maximum load for electric storage heaters is typically achieved during the night, with the minimum during the day. The load profiles are determined by the reference temperature upon which they are based.

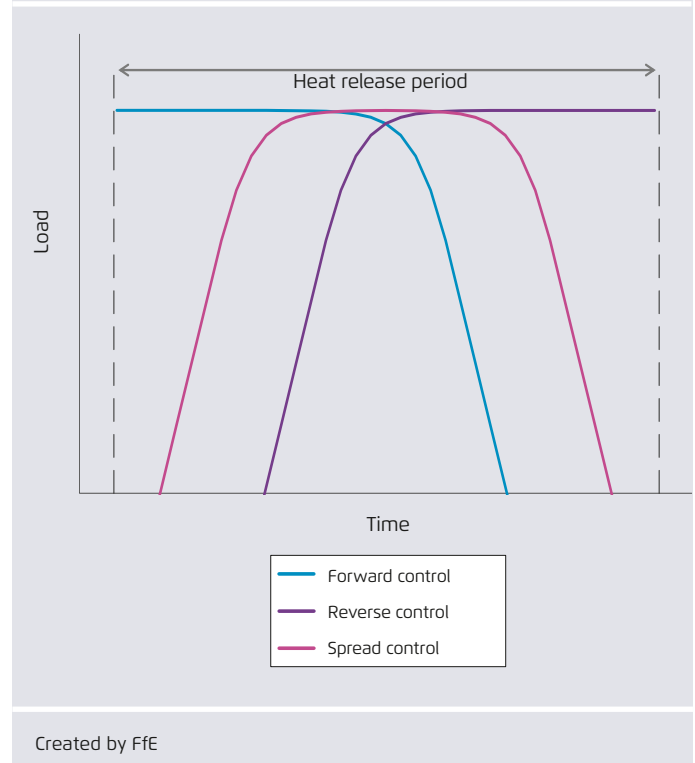
The load profile of electric storage heaters consists of various charging modes – forward control, reverse control, and spread control. All three modes use the outdoor temperature and the residual heat in the accumulator. The aim is to load only as much energy as will be used in the subsequent heat output phase. Before the energy is charged, the temperature curve is recorded using the load control's outdoor temperature sensor, in order to determine how much energy should be charged. The system operator then gives the signal to start charging, either remotely or on the basis of a schedule. To do so, the system operator sends out a ripple control signal transmitted either via the distribution system or via a long-wave radio channel. The system's control signal receiver then converts the signal into control information.

In the case of forward operation, the energy is charged at the start of the time frame; the heaters then switch off gradually depending on the load level and the outdoor temperature. In contrast, in the case of reverse operation, the heaters are switched on one after the other and do not reach their target temperature until the end of the heat release period. The spread mode of operation moves the load to the middle of the heat release period, or to the beginning and the end. These three different modes are presented in Figure 44.

The aggregate load profile of electric storage heaters and heat pumps can be calculated as follows, on the basis of the temperature-dependent load profiles and the calculated annual consumption levels:

Charging control modes of electric storage heaters

Figure 44



First of all, the equivalent daily average temperature is calculated as the weighted average of the daily average on the delivery day (T_m) and on the three previous days ($T_{m[d-1]}$, $T_{m[d-2]}$, $T_{m[d-3]}$), using the following formula:

$$T_{m,\ddot{a}} = 0,5 * T_{m(d)} + 0,3 * T_{m(d-1)} + 0,15 * T_{m(d-2)} + 0,05 * T_{m(d-3)}$$

The temperature measure (TMZ) for a given day can then be calculated on the basis of the equivalent daily average temperature:

$$TMZ(d) = \text{Maximum} \left((T_{\text{Bezug}} - T_{m,\ddot{a}}); K \right)$$

T_{Bezug} stands for the reference temperature, while K is the limitation constant (varies from DSO to DSO; in the case of E.ON Bayern AG: $T_{\text{Bezug}} = 17^\circ\text{C}$, $K = 1$).

The equivalent daily average temperatures and temperature measures that applied in the last few years are published on the distribution system operators' websites.

The specific electric energy (a_{-1}) for a system is then calculated on the basis of annual consumption (Z in kWh) and the sum of a year's temperature measures.

$$a_{-1} = \frac{Z}{\sum_{365} TMZ}$$

A system's load profile $P(t)$ for a given day is calculated by multiplying that day's temperature-dependent load profile $p(t)$ by the specific electric energy (a_{-1}).

$$P(t) = p(t) * a_{-1}$$

The total load profile for each temperature can then be calculated by adding up all of the systems.

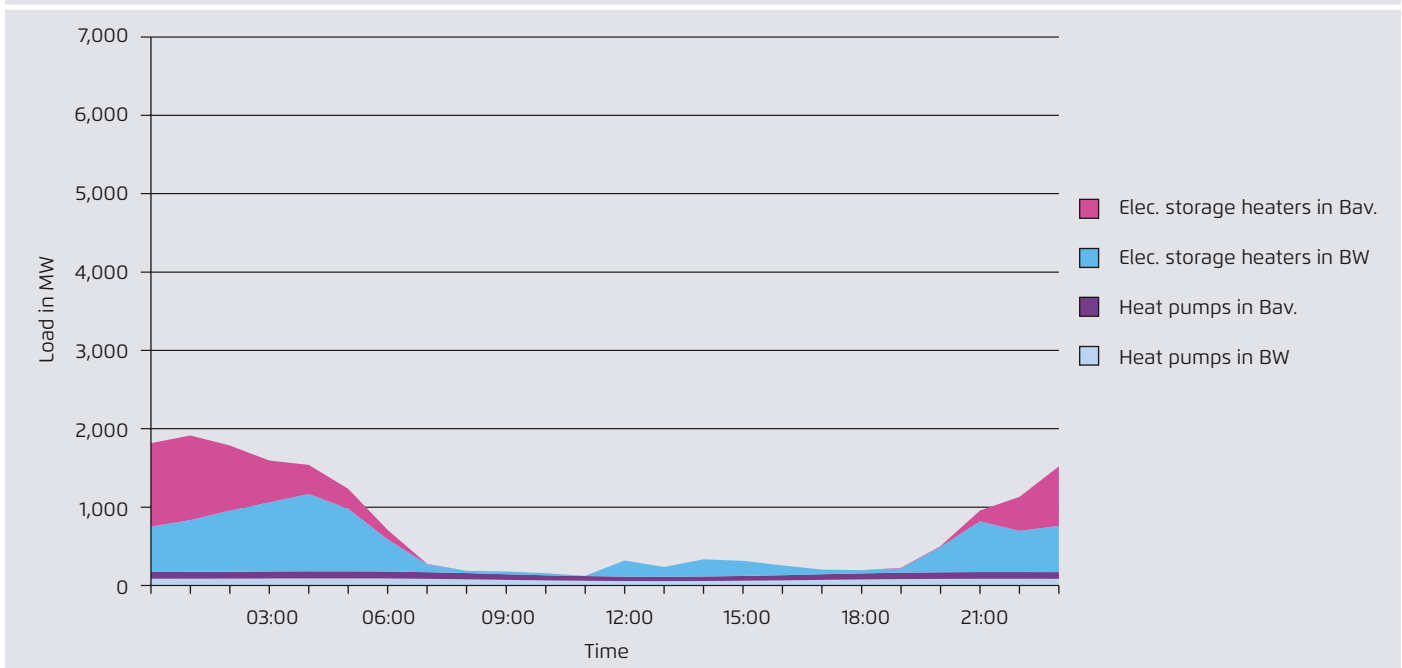
Figure 45 illustrates the total load profile of electric storage heaters and heat pumps in southern Germany for an equivalent daily average temperature of 10 °C. This clearly shows that the peak loads of electric storage heaters are typically overnight, while heat pumps

have a relatively constant load. Differences are evident between the load profiles of electric storage heaters in Bavaria and Baden-Württemberg, these being the result of the distribution system operators' different load profiles.

There is a peak load of 1,900 MW in southern Germany when the equivalent daily average temperature is 10 °C. The issue of temperature dependence is highlighted by a comparison with the load profiles in the case of a daily average temperature of 0 °C, as shown in Figure 46 (or in the case of -10 °C, as in Figure 47). At 0 °C, the peak load is just under 4,200 MW and never dips below 400 MW in the course of a day. At -10 °C, a peak load of up to 6,200 MW is achieved in the early hours of the morning.

Load profile of electric storage heaters and heat pumps in Baden-Württemberg and Bavaria (equivalent daily average temperature of 10 °C)

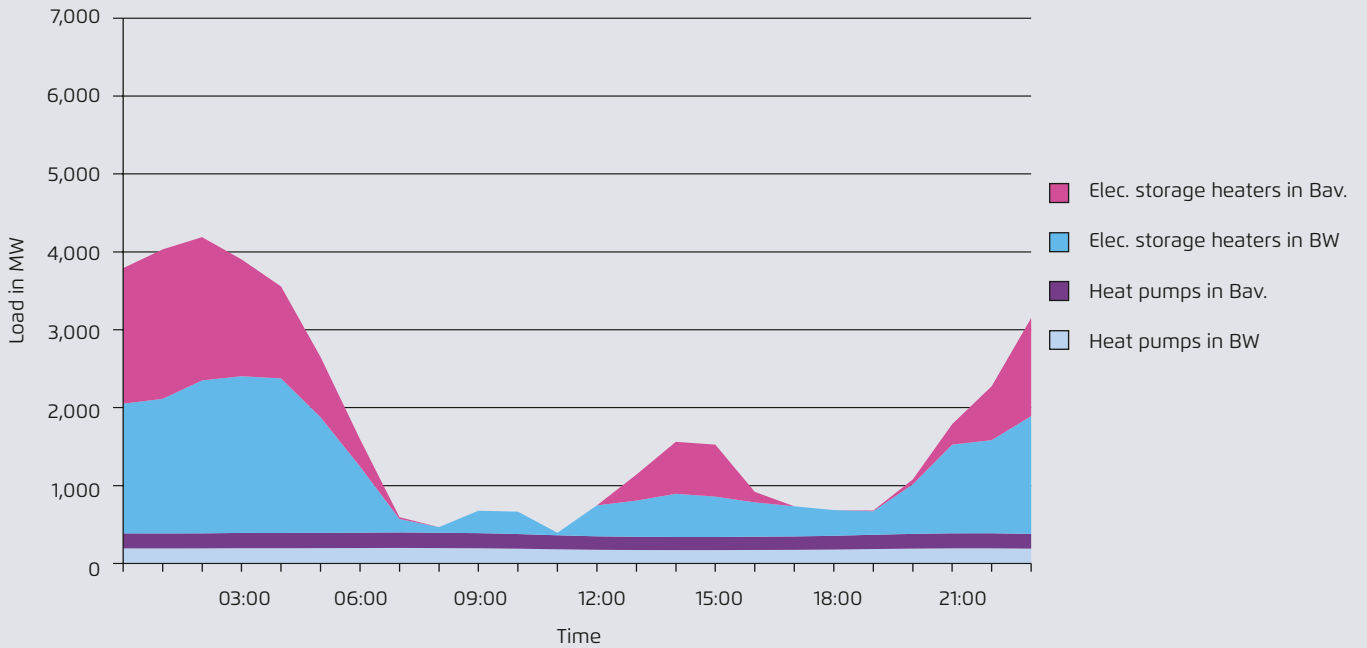
Figure 45



Created by FfE

Load profile of electric storage heaters and heat pumps in Baden-Württemberg and Bavaria (equivalent daily average temperature of 0 °C)

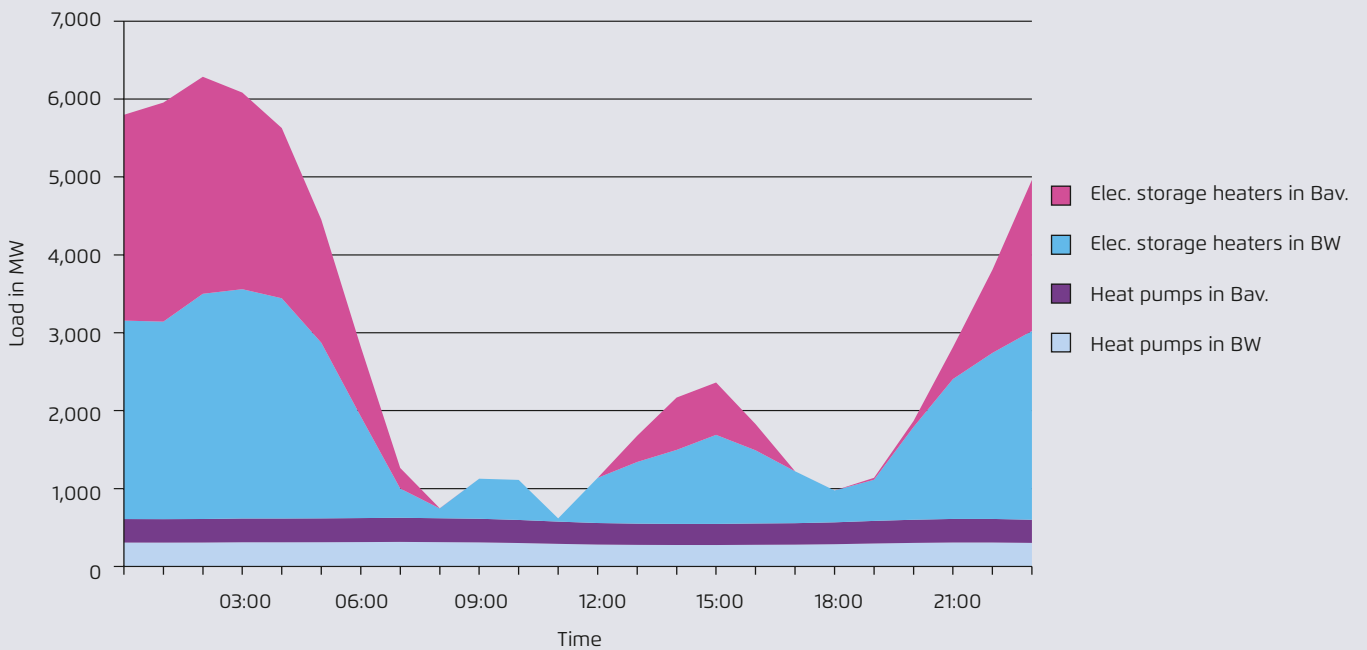
Figure 46



Created by FfE

Load profile of electric storage heaters and heat pumps in Baden-Württemberg and Bavaria (equivalent daily average temperature of -10 °C)

Figure 47



Created by FfE

8.3 Methodology for determining load management potential

The load profiles generated for electric heat supply in southern Germany serve as the basis for calculating load management potential. To understand the role of electric storage heaters and heat pumps, talks were held with representatives of E.ON Metering, E.ON Bayern, LEW Verteilnetz, and EnBW Vertrieb to discuss the technology, its current management, market mechanisms, and optimized application. Methods were developed to determine load shifting potential on the basis of various premises, taking into account not only methods requiring forward planning, but also approaches that can be used to respond to events at short notice without any prior planning.

Heat load profiles were generated on the basis of hourly intervals using an internal building simulation model and an energy consultancy program (FIB 2009), in order to estimate load shifting potential. Four different types of load shifting were developed for electric storage heaters,

as elucidated below. The load shifting potential calculated for heat pumps is based on just one method due to the relatively homogeneous spread of the load throughout the day and limited switch-off time.

Determining the potential of electric storage heaters

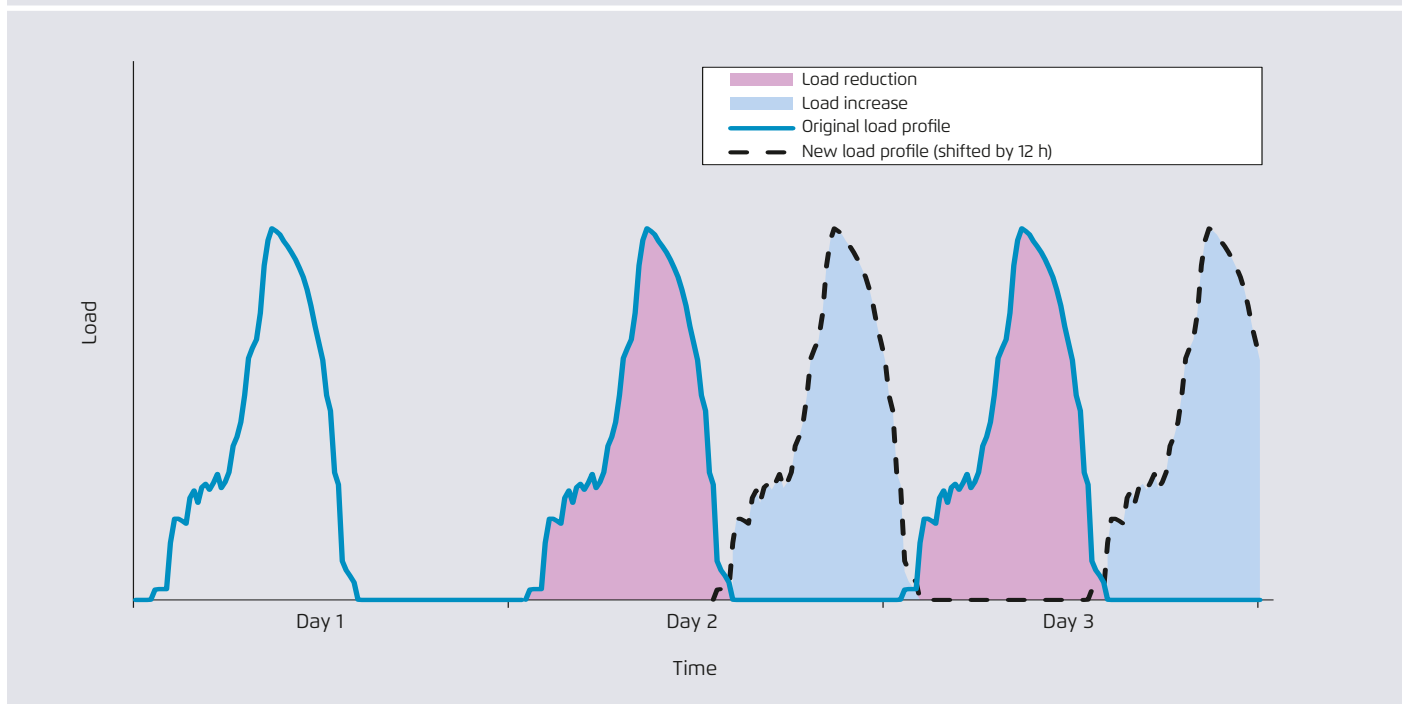
Version 1: Shifting the load profile

The following option of shifting the load window from the nighttime to during the day could present itself in the event of high photovoltaic power generation. This would allow the nighttime use of fossil fuel power plants to be reduced, while simultaneously also prudently integrating photovoltaic power generated sustainably.

The scale of electric storage heaters is such that it takes approximately eight hours to fully charge the accumulator, with a full accumulator being sufficient to cover the heat requirements for the remaining 16 hours of the day, even on the coldest day of the year (Stadler 2005).

Version 1: Load management potential of electric storage heaters when the load profile is shifted

Figure 48



Created by FfE

Because of this accumulator capacity, the charging process can be moved to any other period desired during the day. However, the current framework conditions do not allow for this shift being implemented spontaneously. Rather, a day is needed in order to make the shift. As the process of charging electric storage heaters is initiated by a ripple control signal or by a timer switch integrated into the heater, this version could be implemented without the need for any investment in control or communication technology. However, an on-site amendment would be needed, in order to adjust the timer switches or to guarantee that there is sufficient charging during the daytime window. Otherwise, the heater would be charged less when the outdoor temperature is higher during the daytime window than when there is a low outdoor temperature overnight.

Version 2: Earlier accumulator charging

If a supply shortfall can be foreseen, the heater charging process could be brought forward into the low-load

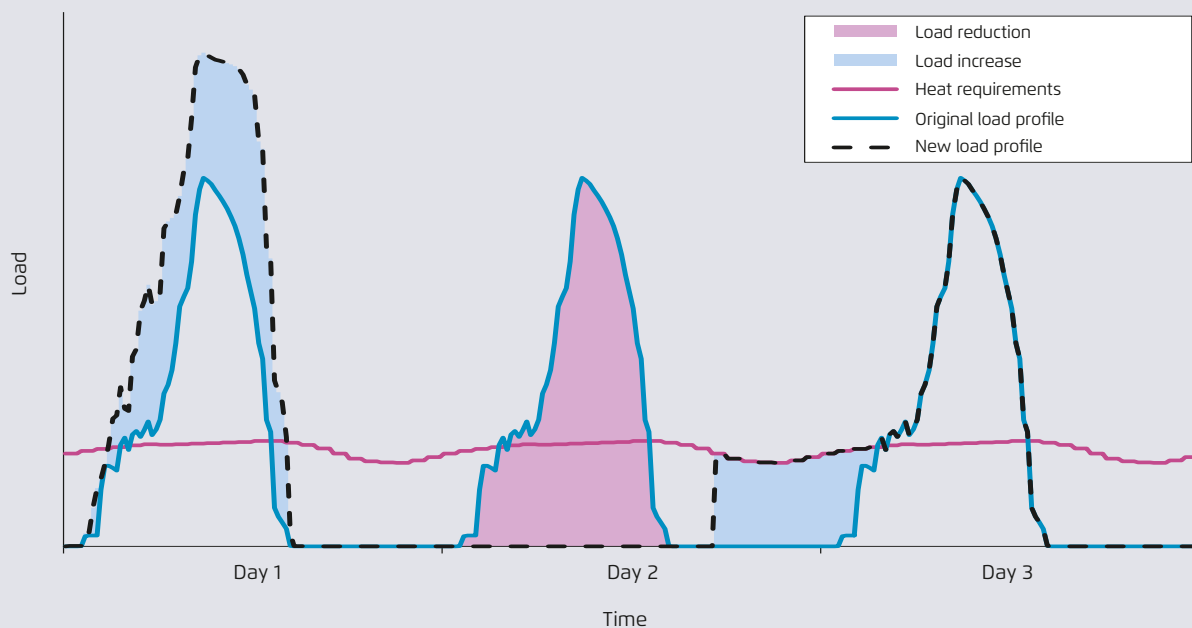
period, to take it out of the critical load window. The focus is then not on high power generation, but on covering the anticipated shortfall. If the load being brought forward cannot be covered using renewable energy sources, in this scenario it can also be provided by conventional power plants.

Alternatively, the occurrence of high generation capacity can also be the motivation behind bringing forward the heater charging process. For example, the heaters could be charged early if there is higher feed-in from renewable energy sources, thereby reducing future charging loads.

The accumulators in electric storage heaters are currently only charged enough for the heating requirements up to the next heat release period to be covered, based on the outdoor temperature. Accordingly, the heater is only fully charged on the coldest days of the year. The unused storage capacity can therefore be used for load shifting on all the remaining days. More heat

Version 2: Load management potential of electric storage heaters when charging is brought forward

Figure 49



Created by FfE

could also be stored during the heat release period than is actually required on the basis of the relevant temperature-dependent load profile. The heating requirements can then be covered by the heater for longer and the load of the following charging period can be reduced. However, it needs to be borne in mind that the heater cannot be fully charged when the outdoor temperature is higher due to the risk of room overheating. The maximum permissible load depending on the outdoor temperature is taken from the Stadler habilitation thesis (Stadler 2005).

Version 2 (see Figure 49) can serve to prevent a foreseeable supply shortfall (for example, due to a forecast lack of wind) by actively increasing the electricity requirements in advance (day one), so as to be able to reduce them again later (start of day two). As soon as the additional stored energy is used up, the load has to at least match the heating requirements (end of day two). Implementation of this would require investment in control and communication technology, because only the start-

ing time of a charging period can currently be controlled and not the volume of energy to be charged; this can only be influenced by a temperature sensor within the heater itself.

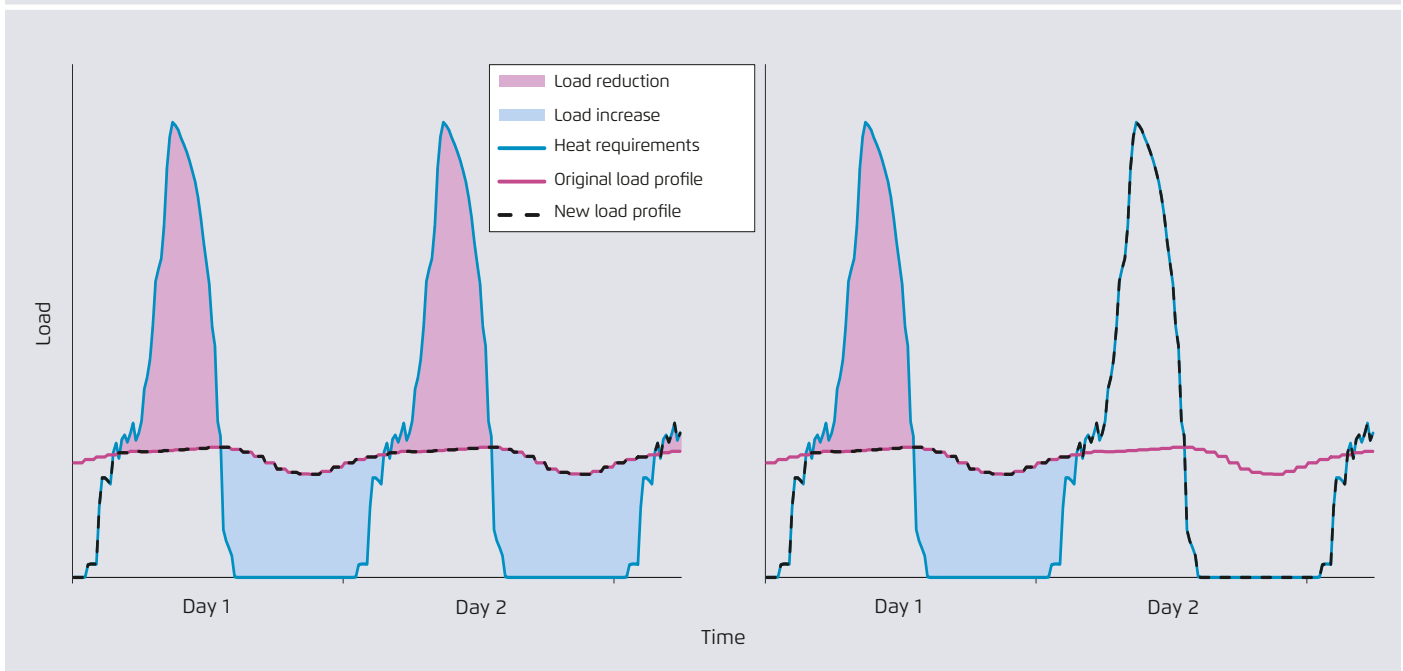
Version 3: Reduction of heat requirements

In the event of unforeseen shortfalls, for example when there is less power generation using renewable energy sources, the load profile can be reduced to nothing but the actual heat requirements and can be used as direct heating during the charging process, without any forward planning and regardless of the degree to which the accumulator is charged at that time.

It should be noted that load increases will subsequently occur, because the heating requirements can then not be covered by the accumulator up to the next heat release period. Consequently, the heating requirements can continue to be drawn on or can be switched back to the original load profile. The advantage of this version is that the

Version 3: Load management potential of electric storage heaters when the load is reduced to nothing but the heat requirements

Figure 50



Created by FfE

switch-off potential is available without any lead time and without needing to know how charged the accumulator is. However, here too, investments in control and communication technology would be needed.

Version 4: Load switch-off taking the accumulator charge level into account

In the event of unforeseen shortages, for example due to the outage of a power plant, the load profile can – depending on the accumulator charge level – be completely reduced for a limited period, in order to gain some time for the activation of additional generation capacity.

This can happen spontaneously, without any forward planning required. The switch-off duration is determined by the accumulator charge level. As soon as the heat requirements can no longer be covered by the accumulator after the switch-off, the load profile has to be made to at least match the heat requirements again. In addition, the accumulator has to subsequently be charged anew,

resulting in a load increase later on. Here too, investments in control and communication technology would be needed in order to implement this version.

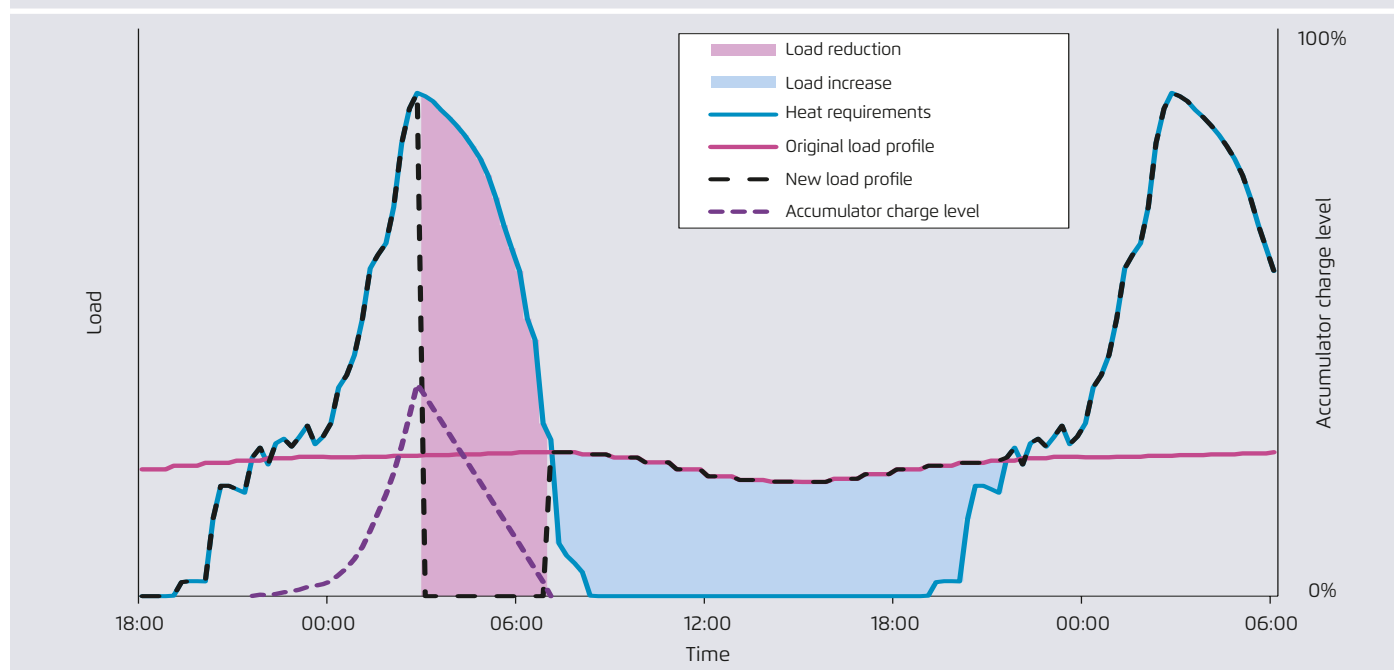
The four versions described above are compared in Table 9.

Determining the potential of heat pumps

Distribution system operators are given assurances of off-times for heat pumps, to give them flexibility in choosing their load profiles. In E.ON Bayern AG's network area, for example, the power supply to heat pumps can be interrupted for a maximum of four hours. An interruption may not, however, last for more than an hour at a time and the operation time between two switch-offs must be at least as long as the previous off-time. Similar regulations apply to the other system operators. The maximum daily interruption possible varies from three to six hours, with the maximum duration of an individual off-time ranging from one to two hours. In simplified terms, these

Version 4: Load management potential of electric storage heaters, taking into account the accumulator charge level

Figure 51



Created by FfE

Overview of the four versions of determining the potential of electric storage heaters

Table 9

	Version 1	Version 2	Version 3	Version 4
Realizable with the existing control and communication technology	X			
New control and communication technology required		X	X	X
Forward planning needed prior to the switch-off	X	X		
Spontaneous switch-off possible, without forward planning			X	X

Created by FfE

off-times can be classed as the load management potential of heat pumps. The electric power consumption of heat pumps can therefore be interrupted for one to two hours anytime, taking into account the boundary conditions described.

8.4 Potential

The load reduction potential is dependent both on the temperature and the time of day. The load shifting potential is therefore calculated for different temperature ranges based on the time of day. Figure 52 presents the average load of the temperature-dependent standard load profiles with the frequency of temperatures during a typical year (test reference year).

The progression during a year as shown in Figure 53 clearly demonstrates that the loads of electric storage heaters and heat pumps are typically at their highest in winter and are close to zero in summer. The maximum average daily load for electric storage heaters and heat pumps totaled 2,900 MW in the test reference year. The minimum average daily load was around 100 MW in the summer. In addition, the peak loads of electric storage heaters typically occur overnight, while heat pumps have a relatively constant load.

Electric storage heaters

We will now look at the load reduction potential of electric storage heaters with a load profile shift of twelve hours (version 1). The diagrams show the maximum and minimum average loads for various time frames. These values represent the average load over the period in question. As the loads of electric storage heaters are often around zero in the course of a day, the minimum values are likewise at or around zero. The maximum contribution to peak load reduction is not the same as the maximum load, due to the shifting of the load profile. If the profile progression is maintained, the maximum contribution is reduced by the original daytime recharging or a baseload, as these are shifted accordingly and then coincide with the maximum contribution window.

We can see that on a day with an equivalent daily average temperature of 10 °C, a maximum contribution of 1,600 MW of the average load can be made to reducing the peak load for an hour – albeit a specific hour, rather than any hour during the day. In the worst-case scenario, no contribution is made to reducing the peak load. With this method, a maximum contribution of 980 MW of the average load can be realized over a period of twelve hours. But this, too, is only possible during a specific twelve-hour switch-off block. Only limited potential can be realized in the case of the other 24 possible

Frequency of the temperature ranges in southern Germany based on valid test reference years and the corresponding load profile averages of electric storage heaters and heat pumps

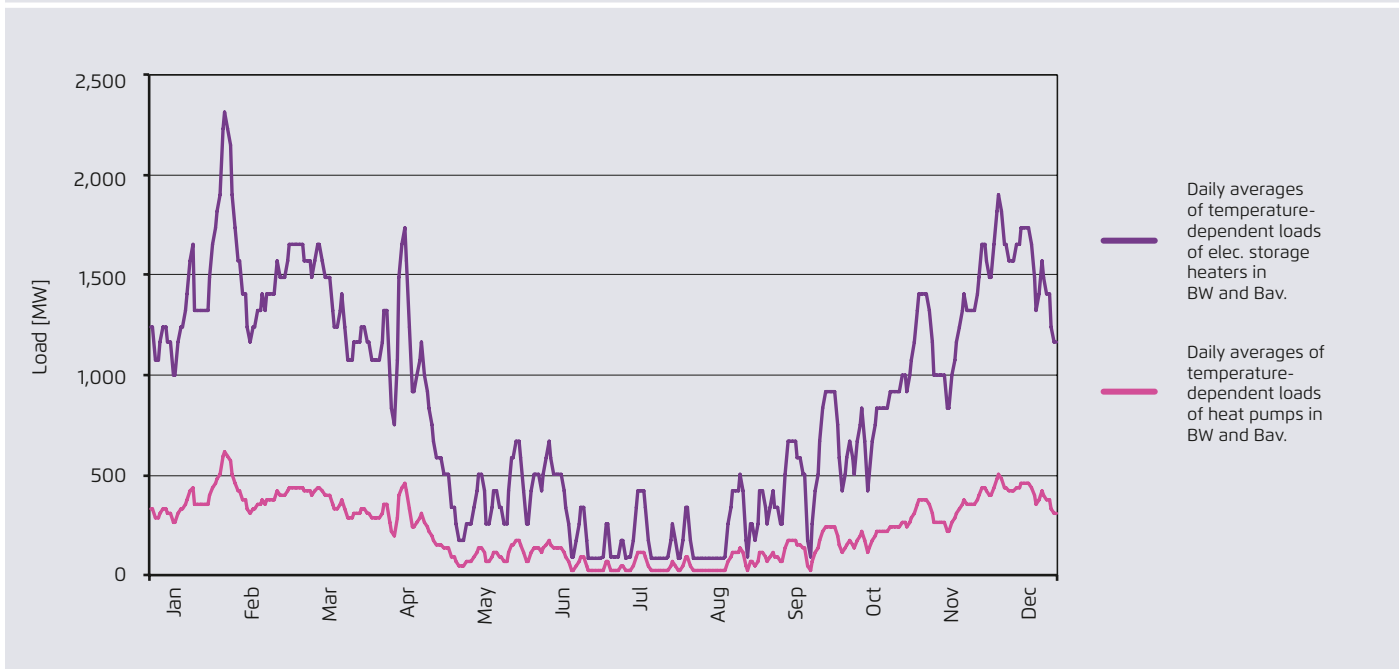
Figure 52



Created by FfE

Load of electric storage heaters and heat pumps in southern Germany based on the applicable test reference years

Figure 53



Created by FfE

starting points. With an equivalent daily average temperature of 0 °C, the maximum contribution increases to 3,000 MW for an hour; a maximum of 1,800 MW can be made available for a period of twelve hours. In the rare event of a daily average temperature of -10 °C – there were four days on which the daily average temperature was between -7.5 °C and -12.5 °C in the test reference year – the potential increases again. At a peak load of around 5,700 MW, the maximum contribution made to peak load reduction for an hour is 4,600 MW. At best over twelve hours, an average load reduction of 2,900 MW is possible. The results are presented in a graph in the appendix.

If the heater charging process is brought forward (version 2), storage heaters can be disconnected from the grid for longer, depending on the equivalent daily average temperature. Both the volume of energy with which the heater is charged overnight in addition to the actual requirements and the subsequent period in which a contribution can be made to peak load reduction by means of a prevented charging process are shown (see appendix). Both the duration of the actual load reduction (in comparison to usual charging) and the period during which there would have been no load on the grid in the event of normal charging are shown.

The switch-off period always starts in the morning, when the charging process is completed. For example, at an equivalent daily average temperature of 5 °C, storage heaters can be disconnected from the grid for a period of 19 hours subsequent to an additional overnight charge of twelve gigawatt-hours. In this case, the storage heaters would not go back onto the grid until the early hours of the following day. Based on the temperature-dependent load profiles that actually apply, the charging process would already begin in the early evening. In this way, an anticipated peak load in the evening could be reduced by the actual load of the electric storage heaters.

At an equivalent daily average temperature of -10 °C, an additional 600 MWh of electricity can be charged to

the heater, consequently resulting in a load-free period of approximately five hours (with the load only truly reduced in three of those hours, as there would not have been any charging in the remaining two hours anyway). At an equivalent daily average temperature of 10 °C, the storage heaters can be disconnected from the grid for 24 hours if there is an additional charge of around 13 GWh overnight. The fact that the accumulators may not be fully charged when the outdoor temperature increases in order to avoid room overheating is also taken into account.

The distribution system operators' temperature-dependent load profiles vary during the day in particular, as follows:

- LEW Verteilnetz GmbH: Load at zero throughout the day
- E.ON Bayern AG: Daytime recharging
- EnBW Regional AG: Permanently low baseload range throughout the day

There are some significant differences in the switch-off duration and in the additional load-free time depending on the network area. For example, as the total load of electric storage heaters in the EnBW area is almost always a baseload, the switch-off duration is longer than average – although only a very low load can be reduced (and there is zero additional load-free time).

A scaling factor was determined for each of the network areas, in order to be able to present a single switch-off duration for southern Germany, in spite of these differences. This factor is dependent on the volume of additional energy charged overnight by the various network areas and is used to calculate a weighted average based on the figures for the switch-off period and the additional load-free period.

If the load of electric storage heaters is reduced down to the heat requirements (version 3), next to no contribution can be made to peak load reduction at the times of the lowest loads. With a daily average temperature of

10 °C, the hour with the greatest potential can contribute 900 MW to peak load reduction. At most, 400 MW of average load can be provided over a period of twelve hours. In the case of a daily average temperature of 0 °C, the maximum contribution made by an hour is 2,300 MW, with 1,050 MW of average load available over a period of twelve hours.

The lower the temperature, the higher the potential. At -10 °C, the maximum contribution increases to 3,100 MW of average load (switch-off duration of one hour) and 1,500 MW of average load (switch-off duration of twelve hours). The results are presented in a graph in the appendix.

In the case of load switch-offs that take the accumulator charge level into account (version 4), it is not possible to state the total potential for southern Germany because the various distribution system operators' load profiles vary too greatly, as discussed above. For example, the EnBW Regional load profiles never drop to zero in the course of the day. As a result, very long switch-off periods are possible, although the interruptible load is then very low.

The maximum switch-off times on a day with an equivalent daily average temperature of 10 °C therefore vary from six to twelve hours depending on the

network area. In the case of an equivalent daily average temperature of -10 °C, the switch-off times range from five to ten hours in all of the network areas examined. At -10 °C, the maximum switch-off load is more than 5,000 MW, and at 10 °C it is just under 1,300 MW. However, these loads can only be achieved at a particular switch-off time and also only apply to the first hour of switch-off, rather than to the whole of the switch-off period. The average load that can be reduced at these switch-off times for the full switch-off duration can be significantly lower.

Heat pumps

Calculation of the switch-off potential of heat pumps in southern Germany is based on a flexible system switch-off period according to the off-times of the various distribution system operators. Recovery of the reduced load is effected before the heat pumps can be blocked again. The maximum and minimum average loads and the switch-off potential of the switch-off intervals for the various daily average temperatures are presented in the appendix. The total heat pump load can be reduced for an hour. With an equivalent daily average temperature of 10 °C, between 110 and 180 MW can therefore be switched off, depending on the time of day. It is evident that, due to the low storage capacity, the load reduction potential decreases as

Overview of the load management potential of electric storage heaters and heat pumps

Table 10

Equivalent daily average temperature	Elec. storage heaters Version 1		Elec. storage heaters Version 3		Heat pumps	
	Minimum in MW	Maximum in MW	Minimum in MW	Maximum in MW	Minimum in MW	Maximum in MW
	Switch-off 1 hour					
-10 °C	0	4,610	0	3,150	550	630
0 °C	0	3,010	0	2,300	340	400
10 °C	0	1,620	0	910	110	180

the switch-off duration increases. The average interruptible load over a period lasting twelve hours is approximately 14 MW.

At 0 °C, 340 to 400 MW can be switched off for one hour. The equivalent figure for twelve hours is around 40 MW. At -10 °C, the potential increases to 540 to 620 MW for one hour and to around 60 MW for twelve hours.

An overview of the load management potential of electric storage heaters and heat pumps is given in Table 10.

9. Realizable Load Management Potential in Industry and of Heat Pumps/Electric Storage Heaters

9.1 Potential in the area of energy-intensive industry and cross-section technologies

9.1.1 Contribution to security of supply

From the perspective of the system, load management potential can contribute to security of supply if it is available in critical situations. The Federal Network Agency's reports indicate that there were critical situations with cold reserve activation in the winter months of December 2011 and February 2012 (see also Chapter 4 and Section 12 in the appendix). On a number of occasions, the critical window was between 19:00 and 20:00, and was characterized by high demand for electricity coupled with no photovoltaic power. However, redispatch measures were also implemented during the day and in the early hours of the morning in order to stabilize the grid. There were instances of balancing energy being used throughout the day, with these instances being more frequent during daytime hours in 2012. There are few differences between the frequency of such instances in the summer and the winter. To some extent, this characteristic can be met by means of flexible loads. The surveys discussed in Subsection 5.3 showed that the companies estimated that between 20 and 50 load activations per annum were realizable. A proportion of the redispatch and balancing energy usages can therefore be implemented with loads. In terms of time availability, the usages are sometimes longer than can typically be realized by means of loads, which tend to be available for one to four hours.

The time of day has very little bearing on the contribution to security of supply made by energy-intensive processes, due to their continuous production mode. Instead, their contribution is available throughout the year. The potential of the processes in the paper or cement industries are even sometimes higher at the weekend than

they are during the week. In general, the potential can be activated within 15 minutes to an hour. The total potential for system-supporting load management is around 450 MW (see Table 11). These processes are often already used for internal peak load management or for optimized procurement. As a rule, this company-based management is only related to the current situation within the system to a limited degree. Situations in which redispatch is needed or which call for higher balancing energy usage do not necessarily go hand in hand with high electricity exchange prices. As a result, tying this demand in with the system situation offers the opportunity to increase security of supply.

The load flexibilization potential of cross-section technologies depends on the shift model by which a company operates. The potential is available at different times of the day to varying degrees and can be drawn upon at short notice for periods lasting from 15 minutes to several hours (in individual cases). The load and therefore also the switch-off potential are at their lowest on Sundays and on public holidays. As can be expected, the switch-off potential is therefore at its highest at the peak operating times on workdays. The maximum and minimum switch-off potential available for an hour is presented in

Load management potential of energy-intensive applications that is realizable and that is already used

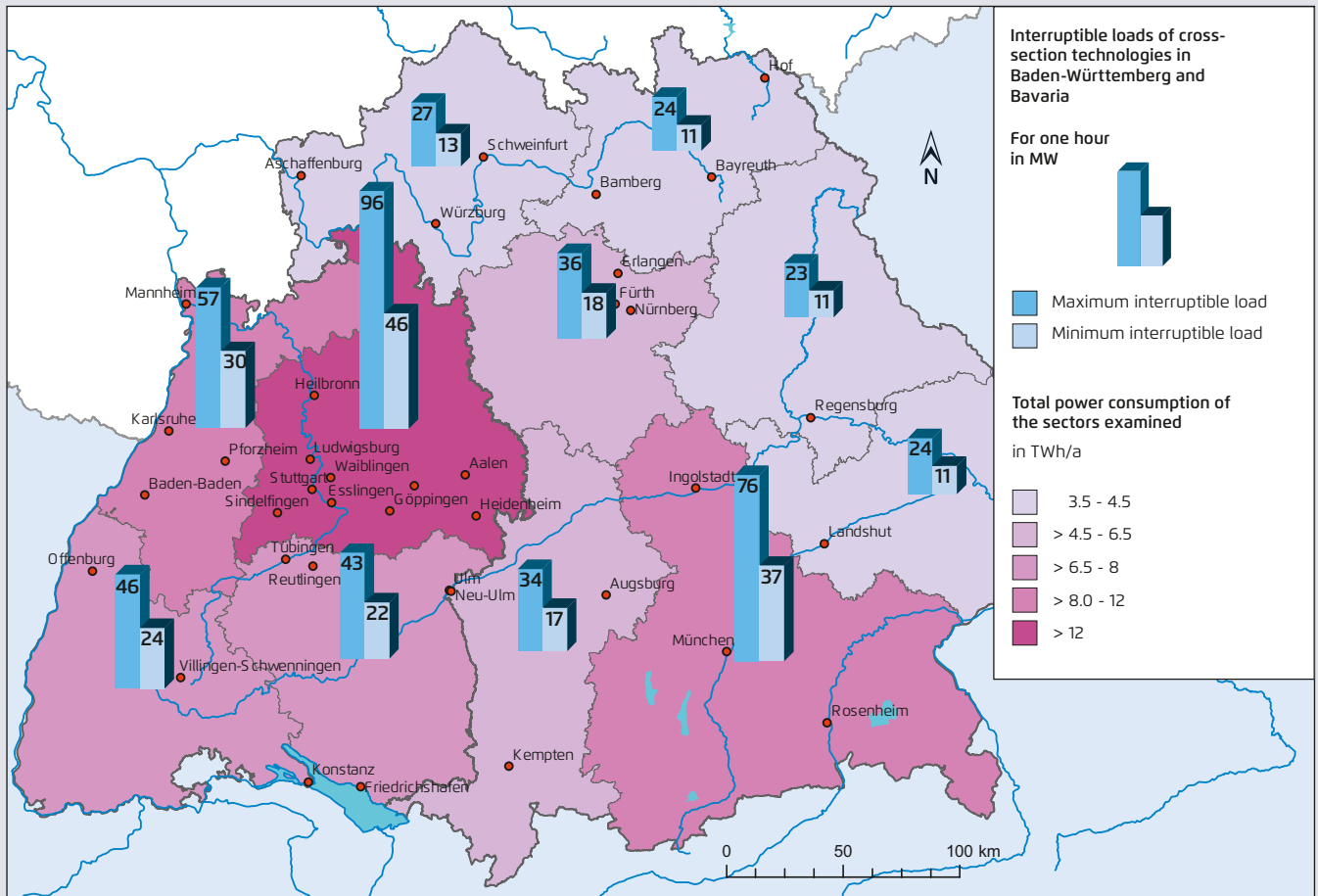
Table 11

Realizable load management potential	Approx. 450 MW
Already used for redispatch	-
Already used in the balancing energy market	Approx. 76 MW
Already used for optimized procurement	Estimated at 300 to 400 MW

Fraunhofer ISI estimates

Maximum and minimum interruptible loads of the cross-section technologies for one hour

Figure 54



Created by FfE based on data from the German Federal Statistical Office and data collected in-house

Figure 54. The maximum switch-off potential is just below 480 MW, and the minimum is around 270 MW. The minimum potential does not equate to the sum of all the potential calculated during baseload operation, because it cannot be assumed that all the companies operate at the baseload level on Sundays. Instead, estimates were made of the proportion of companies in each industry that operate at the three different operating levels (normal operation, reduced operation, baseload operation) on Sundays, as the basis for determining the minimum potential. Fluctuations depending on the season are negligible. The spread of the loads is relatively homogeneous to the industry loads in the grid and these loads can also be

used to remedy local shortage situations. For example, the loads of cooling systems could be increased earlier than scheduled in such situations.

9.1.2 Obstacles and approaches to realization

Obstacles

As part of the study, the most relevant obstacles to further realization of the load management potential of increasing grid stability were identified. A key prerequisite for companies is that load management potential can only be activated if it complies with the company requirements.

The design of the appropriate incentives, such as use of the balancing energy market or the Interruptible Loads Ordinance (AbLaV), determines which potential can be activated to what extent and at what cost. The companies surveyed stated that the primary obstacles to engaging in load management were production downtimes and the impact it had on product quality. To a degree, the companies are fearful of work process interruptions, were it possible to activate load management potential upon request. In addition, a lot of the companies believe that the current conditions are too restrictive for them to be able to engage in load management. Many companies stipulated longer notification periods that could be incorporated into production planning and also activation periods of a maximum of two hours as necessary framework conditions. Interruptible loads ranging from several hundred kilowatts to several megawatts are typically available, but these load levels are excluded by, for example, the Interruptible Loads Ordinance (AbLaV) due to minimum load requirements. Another important condition as stated by the companies was the ability to react at short notice to changes in the production requirements and then not be obliged to make load management potential available. And for a lot of companies, the existing financial incentives to engage in load management measures are currently too low.

Realization and costs

Some of the companies currently already engage in company-based load management. They use load management potential to lower their peak loads or to optimize their electricity procurement. These load management measures can, but do not necessarily have to, also serve the system. Only a very small proportion of the companies actively implement system-supporting load management, for example providing balancing energy at the request of a system operator. There are upfront investments needed in order to implement load management, and these have to be financed from the proceeds. The companies estimate that they incur several thousand euros of costs in order to integrate the necessary technology and to plan their load management. An investment

becomes interesting for companies if it allows them to reduce their electricity costs by more than five percent. Lower percentage savings can also be attractive to larger companies with high electricity costs.

Another point of criticism relates to the activation of negative load. When load management usage causes a peak in the load, the capacity charge to be paid for using the grid increases. These additional costs have to be offset against – and can even be higher than – the proceeds generated. The suppliers of negative load have to take this into account in their calculations and are possibly deterred from engaging in load management as a result. This leads to a drop in the supply of negative load or to an increase in the price at which negative load is offered, thereby potentially causing the costs incurred for procuring balancing energy to increase.

The requirements and obstacles described above illustrate that service providers are key to the realization of load management potential. They can offer the companies the necessary flexibility by pooling systems and can also provide the system operators with a guaranteed load. For these stakeholders, the biggest obstacle to load management implementation is the current division of the roles of the market participants. The unbundling of the energy market has led to just one role being attributed to each participant, thereby preventing management of the loads in a way that would benefit the system as a whole. Due to the number of market roles, it is difficult for demand response aggregators to become established in the market, as they are required to enter into separate agreements with each participant (see Figure 55).

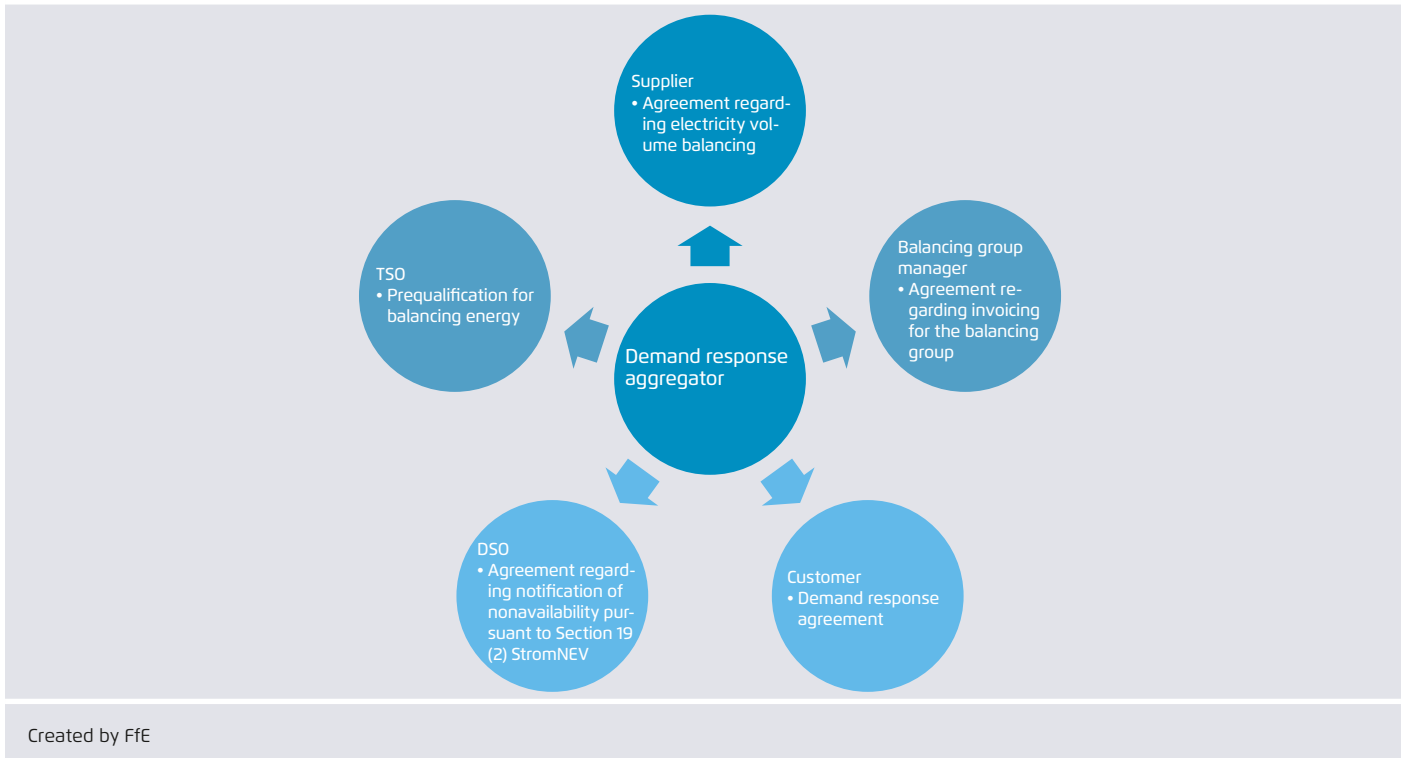
9.2 Potential in the area of heat pumps and electric storage heaters

9.2.1 Contribution to security of supply

The current load profiles of electric storage heaters and heat pumps are subject to very strong temperature-dependent fluctuations. There is therefore primarily

Bilateral agreement of a *demand response* aggregator

Figure 55



Created by FfE

switch-off potential overnight on cold days. There tends to be only limited potential during the winter peak load times (18:00 to 20:00). Heat pumps offer greater availability of load-reducing potential because of their relatively constant load profile over the course of a day, meaning that these loads can be reduced briefly any-time. In addition, the load of electric storage heaters can be increased, depending on the time of day and the temperature. It can be assumed that the potential offered by heat pumps will increase, as the number of heat pumps is expected to double or even triple between 2011 and 2020.

9.2.2 Obstacles and approaches to realization

Obstacles

For regulatory reasons, it is currently not possible to realize the load reduction potential of electric storage heaters and heat pumps in reaction to market signals, because the distribution system operators are responsible both for

forecasts (generating the load profiles) and for activation. The energy utilities have to incorporate the load profiles into their schedules.

Realization and costs

Load management measures require investments in technical upgrades that vary in volume depending on the load shifting method adopted. The technology is already in place to shift the loads from the nighttime to during the day; all that is needed is a one-time modification of the control unit settings. A technical upgrade and corresponding implementation costs would be needed in order to bring the loads forward to circumvent imminent shortages or to provide the systems' minimum requirements, with the costs varying depending on the intended load shifting methods. Once these investments have been made, no other costs would be incurred in the implementation of load shifting, with the exception of organizational costs. In the case of flexible operation, quarter-hourly reference

readings for typical systems could be used in order to calculate and charge for the load profiles.

The current regulations (Section 13 [1] [1] and [2] of the German Electricity Grid Access Ordinance [StromNZV]) stipulate that the distribution system operator shall produce the load forecasts for the standard load profile customers. Each supplier scales their supplies on the basis of their customers' standard load profiles (SLP's) and previous-year figures. The distribution system operator's primary objective is to achieve a low divergence from the forecast loads, as divergences can lead to balancing energy payments. The costs related to this can be offset using the grid charges, but this may lead to the Federal Network Agency giving the system operator a poorer rating, thereby reducing the compensation they receive. However, flexible alignment to the system or market situation or alignment at short notice does not offer any advantages. The electricity procurement costs and the generation of balancing energy are of secondary importance. The supplier responsible for procurement cannot align their supplies with the market or system prices and cannot implement any economic optimization.

A solution being discussed is that the supplier might generate and shape the supply profile, with the activation of the systems then also being transferred to them. The supplier would take greater account of price signals that reflect the generation and consumption situation in question and would manage their supplies flexibly. There is no expectation that the forecast would then become worse, because the supplier is obliged to provide a precise consumption schedule. The supplier can then make use of the shifting potential of electric storage heaters and heat pumps in particular, to shift electricity consumption into low-price periods flexibly and at short notice. As high-price periods are, on the other hand, generally a sign of generation shortages, greater grid stability could be achieved on the basis of this process. Also, additional revenues could be generated by participating in the balancing energy market and a contribution could be made to system security. A key prerequisite in this respect is that supplying and invoicing is no longer on the basis of

standardized load profiles. Additional investments would be required for the installation of control units to allow the supplier to control the systems.

However, alignment with the existing price signals only does not take into account the electricity grid's capacity limitations. A number of stakeholders therefore propose the establishment of so-called grid traffic lights within the distribution system in order to flexibly bring the loads into line with the grid situation. The role of the market alone diminishes as the situation changes from 'green' to 'yellow' to 'red,' while the ability of the system operator to make decisions increases (Lücking 2013; Wiechmann 2012).

In addition to the medium-term solutions described, use of the highlighted load management potential at short notice could also be realized. The power consumption of electric storage heaters and heat pumps is currently influenced by the distribution system operators' heat release and blocking periods. Based on generally applicable legal requirements (obligatory load profile, activation obligation in the instance of shortages) or incentives (balancing group balance) for the distribution system operators, the existing infrastructure could be used in order to activate electric storage heaters and heat pumps in line with grid stability and security of supply.

There are projects and work groups that are already discussing the flexible charging of electric storage heaters and the flexible operation of heat pumps or that are already testing this in practice. Below, we briefly present the most up-to-date projects and work groups, in order to give an idea of the activities in this area.

As an example, E.ON Metering GmbH is running a field trial to test the controlled charging of electric storage heaters in 45 households (E.ON 2013). And in a project entitled 'Windheizung' (Wind Heating), RWE AG cooperated with tekmar Regelsysteme GmbH and Siemens Energy to replace fixed charging times with flexible charging in 50 test households. The trial is currently being expanded to 30 electric storage heaters (Rummeni 2012). In a project entitled 'Das virtuelle Kraftwerk' (The Virtual

Power Plant), Vattenfall Europe Wärme AG is testing the flexible use of heat pumps and combined heat and power plants under the motto of 'Windstrom trifft Wärme' (Wind Power Meets Heat). 200,000 residential units are to be provided with heat as part of the project by the end of 2013 (Vattenfall 2011).

The heat requirements of these various projects are to be covered by means of the flexible management of the systems, taking the system situation into account. Among other things, they aim to make better use of renewable energies, and to provide system services, improvements in comfort, and cost reductions.

Germany's Federal Ministry of Economics and Technology (BMWi) formed a work group entitled 'Intelligente Netze und Zähler' (Smart Grids and Meters) with the aim of identifying technical, socioeconomic, legal, and political framework conditions, to then derive recommendations for action regarding the establishment of a smart grid (BMWi 2013). A work group of the Power Engineering Society within the German Association for Electrical, Electronic & Information Technologies (VDE) is looking at, among other things, the use of electric storage heaters and heat pumps under a heading of 'Heating and cooling supplies in flexible energy supply systems with a high proportion of renewable energies.' The aim of this work group is to illustrate the future role of power-led heating and cooling systems in an electricity system with a high degree of fluctuating power generation. The work group discusses technologies, potential, economic implementation, and political framework conditions.

10. Economic Assessment of Load Management

An interesting factor with respect to the implementation of possible incentive systems and/or compensation models is the degree of costs involved for the provision of flexible power generators or consumers and what revenues can be generated in the current markets. A supply shortfall in the electricity grid can be remedied either by increasing the generation capacity or by reducing the consumer load at the site in question.

Upfront investments in control and communication technology are generally necessary in order for a company to engage in load management. Only very few companies require next to no investments, for example companies that already participate in the balancing energy market, meaning that their systems are already qualified for it. The majority of the other companies that have so far only used load management for company-level optimization if at all would need to make some investments. The service providers surveyed estimated that investments worth several thousand euros per company would be needed in order to connect them to an external control unit. Other possible costs in the event of activation of the potential include higher payroll figures, additional material costs, and costs relating to production losses. These latter costs have a subordinate role to play in relation to the potential identified in this study because this potential was calculated on the premise that neither comfort levels nor value added would be significantly limited.

So far, the amendment has typically been made by increasing the generation capacity of conventionally operated power plants. Power plant usage figures suggest that pumped-storage power plants and gas-fired power stations were most frequently used to cover peak loads in recent years. As this function could also be performed by load management at the hour level, the costs of operating a typical gas turbine in order to cover few peak load hours will be illustrated below. A general presentation of the costs of load management is not possible due to the various load management options and their specific cir-

cumstances. Therefore, the gas turbine costs are compared with the costs incurred by a system operator for load management in accordance with the Interruptible Loads Ordinance (AbLaV). The revenues that can theoretically be generated in the balancing energy market are also highlighted.

A major advantage of gas turbines in comparison to load management measures is that their generation capacity is available almost entirely independent of the time of the day, the day of the week, and seasonal influences. With the exception of scheduled and unscheduled operation downtimes, the generation capacity can be varied from zero to the maximum rated output without having to take any other restrictions into account.

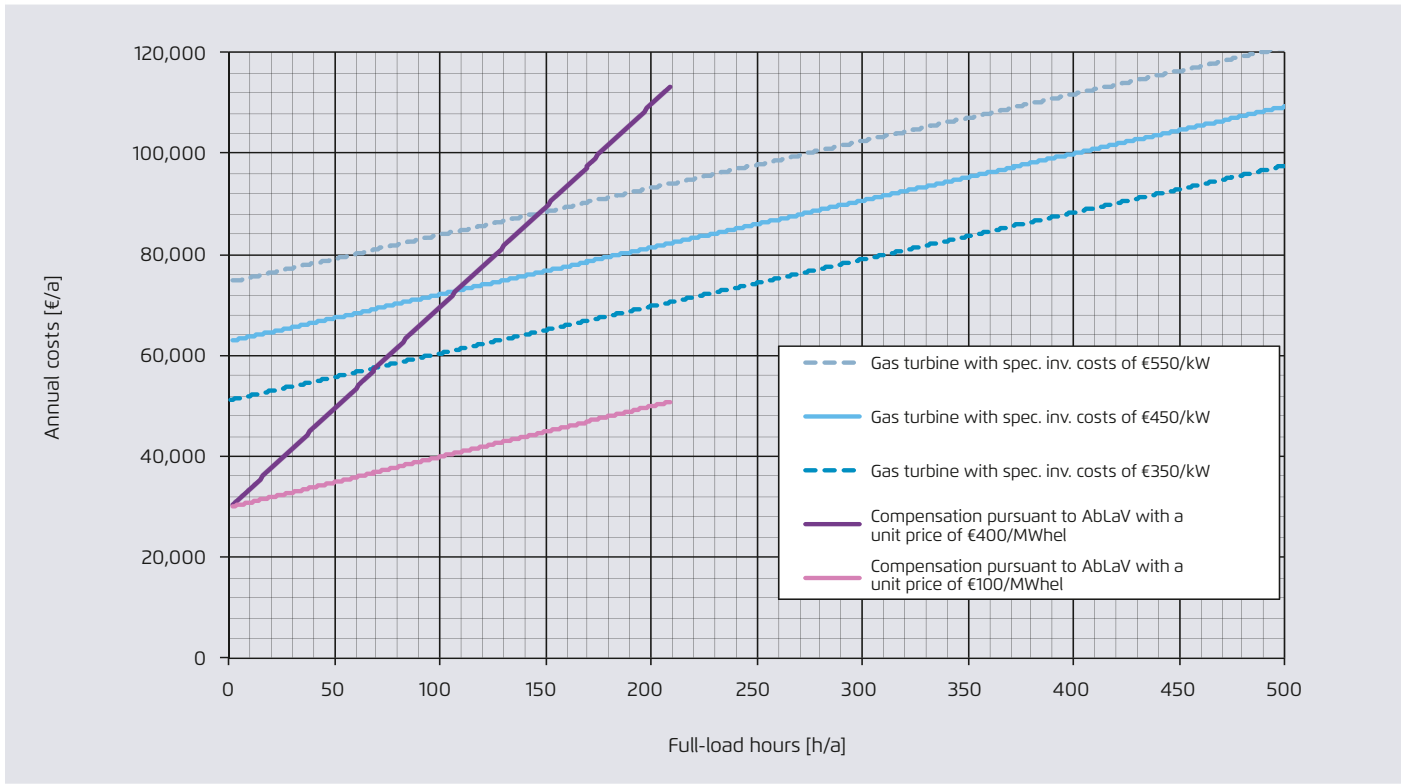
In contrast, one of the advantages of load management is that the demand can also be increased at certain times. This can be helpful, especially in the event of necessary grid interventions such as redispatch. In addition, past experience in the USA shows that the reliability and accuracy of the load management measures implemented can match those of conventional power plants if system requirements are followed. (Hurley et al. 2013).

Based on AbLaV, there is a maximum possible load management duration of 208 activation hours. The annual costs of a gas turbine are therefore calculated for 208 full-load hours in this study. The calculation assumptions for gas turbines can be found in the appendix. The actual activation period pursuant to AbLaV is provisionally likely to be a maximum of just a few hours. The costs relating to ten activation hours are therefore likewise provided, for comparison purposes. Figure 56 offers a comparison of compensation based on AbLaV and the costs of a gas turbine.

AbLaV offers compensation of €30,000/MW per annum and a unit price that varies between €100 and €400/MWh for the provision of one megawatt of interruptible load.

Comparison of a gas turbine’s annual costs per megawatt and compensation pursuant to AbLaV

Figure 56



Created by FfE

With a maximum activation period of 208 hours, the total compensation for a megawatt therefore ranges from €50,800 to €113,200. Based on an activation period of ten hours, the annual compensation would be in the range of €31,000 to €34,000.

For example, total costs per installed megawatt of just under €82,200 per annum would have to be assumed for a gas turbine with specific investments of €450/kW which is activated exclusively in order to cover the peak load for 208 hours of the year. With these activation times, the gas turbine costs lie within the range of the possible compensation pursuant to AbLaV. In the case of just ten full-load hours, the annual costs for the gas turbine examined amount to €63,800/MW. We can therefore see that the compensation pursuant to AbLaV for just a few activation hours per annum is much more favorable than the gas turbine costs (see also Table 15 in the appendix).

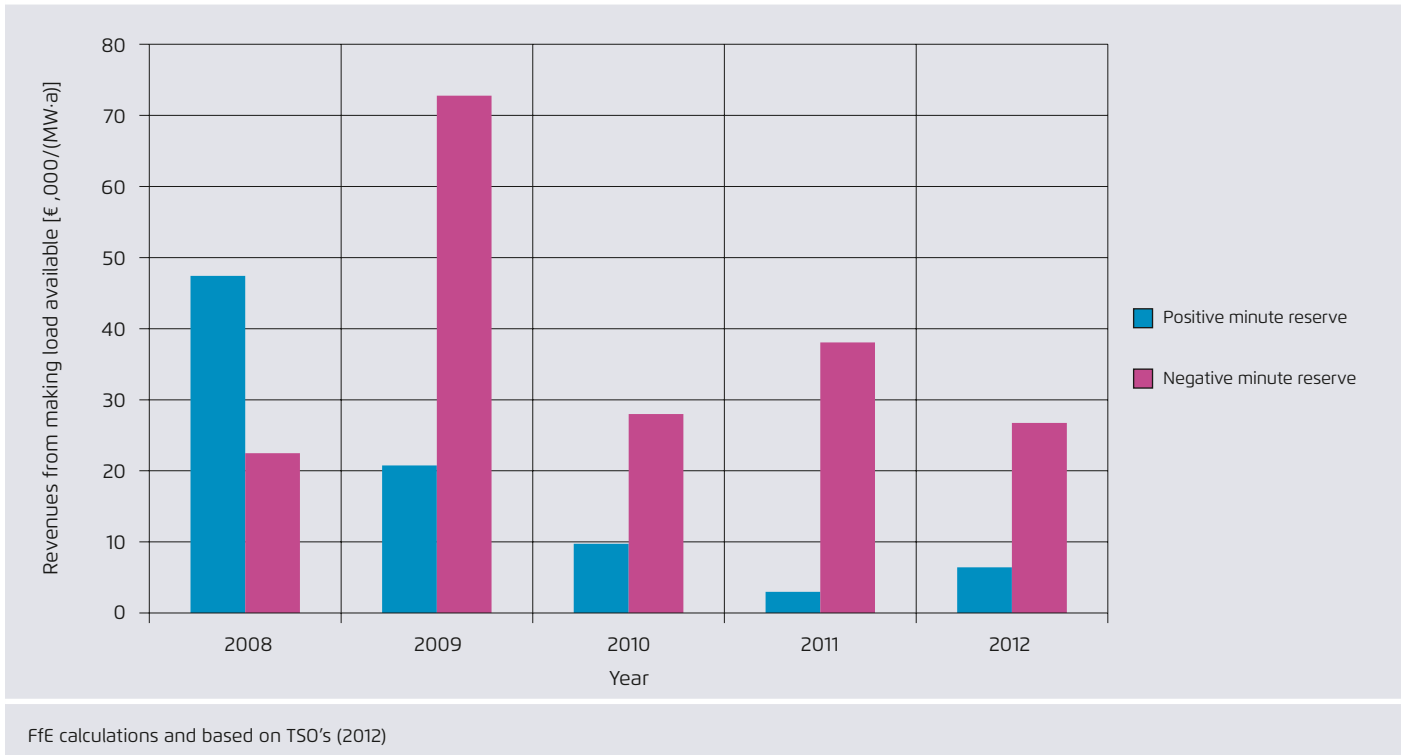
Revenues that can be achieved in the balancing energy market

Revenues can be achieved in the balancing energy market by providing flexible loads. According to TenneT TSO GmbH, two suppliers were already qualified for positive minute reserve in the TenneT control area at the time this study was produced. Balancing energy is tendered by the transmission system operators and is used if necessary, to balance the generation and consumption of electrical energy at short notice, as there would otherwise be major fluctuations in the frequency.

Depending on the fulfillment of access criteria, the switchable loads can be offered as minute reserve or secondary balancing energy, with the prerequisites for qualifying for secondary balancing energy being much tougher than those for minute reserve. Positive balancing energy can be provided by reducing the consumer

Theoretical revenues for the provision of minute reserve on the basis of the average capacity charges

Figure 57



load and negative balancing energy can be provided by switching on additional consumers. The revenues in the balancing energy market are based on the one hand on the capacity charge for providing flexibility and on the other hand on the unit price paid in the event of the activation of the load made available.

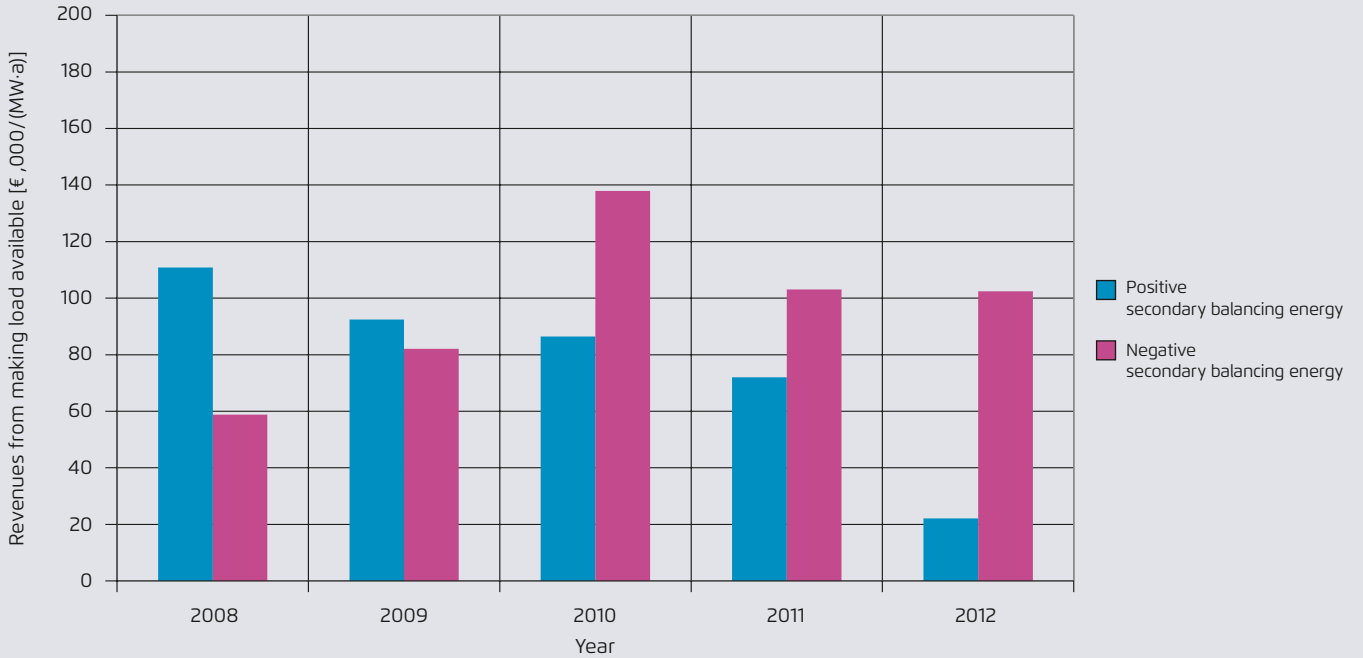
There has been a decline in the capacity charge for the provision of positive load in recent years. In terms of positive minute reserve, in 2008, around €45,000 could theoretically be generated for the continuous availability of one megawatt for the whole year (see Figure 57). There was next to no compensation for such availability in 2012, and revenues were therefore generated almost exclusively on the basis of the unit price.

Higher revenues are possible for positive secondary balancing energy (see Figure 58), but here too there is a downward trend. Compensation of €110,000/MW was achieved in 2008, but this had slumped to just €22,000/MW in 2012. The average unit prices for positive minute

reserve remain relatively constant at the €200/MWh mark (see Figure 59). For positive secondary balancing energy, they are around €100/MWh (see Figure 60).

The compensation for negative load in 2008 was approximately half of that for positive load, at around €22,000/MW for minute reserve and just under €60,000/MW for secondary balancing energy. In 2012, this compensation rose to around €25,000/MW for minute reserve and to approximately €100,000/MW for secondary balancing energy. The unit prices for negative minute reserve between 2008 and 2010 were just above €0/MWh. On average, the additional electricity consumption is now even compensated at just under €70/MWh in the event of activation. The average unit price revenues for negative secondary balancing energy were in the range of €3 to €9/MWh in the period examined (TSO's 2012).

Theoretical revenues for the provision of secondary balancing energy on the basis of the average capacity charges **Figure 58**



FfE calculations and based on TSO's (2012)

Average unit prices for minute reserve

Figure 59



FfE calculations and based on TSO's (2012)

Average unit prices for secondary balancing energy

Figure 60



FFe calculations and based on TSO's (2012)

11. Conclusions

The focus in the search for major application fields is, on the one hand, on energy-intensive processes which are already used for load management within companies, but which could also be used for grid- and market-compliant load management. There is also additional potential in the area of cross-section technologies, especially industrial ventilation and air-conditioning applications, which can include loads of several hundred kilowatts. And in the field of electric heat generation (heat pumps and electric storage heaters), the existing potential could be tailored more to the market and the grid.

There are varying degrees of dependency on the season, the day of the week, and the time of day in relation to the potential. Table 12 illustrates whether the influence that these factors have on the potential offered by the various areas is low (-), medium (0), or high (+). It shows that seasonal and time-of-day factors have little influence on industrial processes in contrast to electric storage heaters and heat pumps, and that these processes are available around the clock.

Factors influencing potential

Table 12

	Seasonal influences	Day-specific influences	Time-of-day influences
Energy-intensive processes	-	-	-
Industrial cross-section technologies	-	0	0
Heat pumps	+	-	0
Electric storage heaters	+	-	+

Created by FfE

Table 13 shows the realizable load switch-off potential of the areas examined, for a switch-off period of one hour. It is noteworthy that the maximum load management potential of electric storage heaters and heat pumps is only available on a handful of days and only at specific times of the day.

Overview of the realizable load management potential in Baden-Württemberg, including potential already exploited

Table 13

	Load reduction potential for one hour		Potential already exploited	
	Minimum in MW	Maximum in MW	Contribution to peak load reduction in MW	Balancing energy in MW
Energy-intensive processes	Almost anytime > 400		300 - 400	76
Industrial cross-section technologies	Basic operation, Sunday ≈ 240	Normal operation, workday, daytime ≈ 480	0	0
Heat pumps	Summer ≈ 30	Winter (-10 °C) ≈ 630	Minimal contribution	0
Electric storage heaters	Summer, daytime 0	Winter, nighttime (-10 °C) ≈ 4,610	No contribution, as systems not connected to grid	0

Created by Fraunhofer ISI and FfE

The above-mentioned realizable potential is available in particular for providing balancing energy and to cover redispatch needs. Peak loads, which tend to occur between the hours of 18:00 and 20:00 in the winter, are primarily covered by the load management potential of cross-section technologies. The energy-intensive processes tend to already have been reduced to a large extent when these peak loads occur, because based on experience, electricity prices are especially high at peak load times. The energy-intensive processes therefore offer next to no additional load management potential to reduce the system-wide peak load. Heat pumps have the potential to make a small contribution to load management. Electric storage heaters are likewise not really a peak load reduction option during this window, because they account for only a small proportion of the load. In addition, the degree of the contribution to load management that heat pumps and electric storage heaters can potentially make is dependent on the outdoor temperature and can be extremely low in summer.

Making use of load management potential in the balancing energy market is dependent on the time availability and on the required provision period. As energy-intensive processes are subject to the lowest fluctuations and represent high loads, they are especially suited to the balancing energy market. The expectations are lower with regard to cross-section technologies due to time-of-day

and day-specific influences. The potential of heat pumps and electric storage heaters to participate in this market is characterized by significant seasonal fluctuations. Time-of-day influences are an additional limiting factor in the case of storage heaters.

The results of the study also show that the load management potential of industrial cross-section technologies depends on the intended shifting periods. With a shifting period of just 30 minutes, cross-section technologies can offer approximately 850 MW for load management. Taking into account the energy-intensive processes too, there is total potential in this shifting period of more than one gigawatt in southern Germany, some of which is already used for company-based load management. The potential then falls to around 880 MW in the case of shifting periods of longer than an hour (see Table 14). Here, too, only a small proportion of the potential, in particular that of energy-intensive processes, is available for the reduction of the system-wide peak load. Above all, the potential can be used as balancing energy or for redispatch.

A distinction can be made between two groups in terms of the advance notice times. On the one hand, there are applications that can be activated at short notice within an hour, and on the other hand, there are applications that can be activated on the basis of production planning with

Realizable load management potential in the industrial field depending on the shifting period

Table 14

Field	Shifting period	
	30 minutes	1 hour
Industrial cross-section technologies		
Normal operation, workday	850 MW	480 MW
Basic operation, Sunday	420 MW	240 MW
Energy-intensive processes*	> 400 MW	> 400 MW
Total (Already used for balancing energy) (Already used for system-wide peak load reduction)	820 – 1,250 MW (76 MW) (300 – 400 MW)	640 – 880 MW (76 MW) (300 – 400 MW)

* Potential to reduce system-wide peak load already used to a large extent

longer lead times (8 to 24 hours). The typical company loads range from several hundred kilowatts to several megawatts. Very few companies are able to make potential of more than ten megawatts available.

The financial incentives for load management should initially be sufficient to cover the upfront investments (implementation and planning of load management along with the cost of the control technology required). Companies typically expect to have to spend several thousand euros up front before they can participate in a load management program. An investment becomes interesting for companies if it allows them to reduce their electricity costs by more than five percent. Lower incentives may also be sufficient for larger companies.

The characteristics of load management potential need to be taken into account when designing load management programs. The current starting points for load management (Interruptible Loads Ordinance [AbLaV] and the balancing energy market) are either too restrictive in terms of the regulations for participation to be an option or they offer only very limited financial incentives for participation.

Demonstration projects in, for example, the area of ventilation and air-conditioning are a good opportunity to remove further obstacles and also to include applications in load management that have previously not been involved. Such projects could demonstrate the effects that load management has on a company's operation and production, and how participation might be technically implemented. Recommendations for action could also be derived as an outlook on the energy market of the future.

Load peaks caused by externally activated load management measures such as the activation of negative balancing energy or the need to make up for previous load reductions should not lead to an increase in the capacity charge to be paid for grid usage, as this would deter potential suppliers of controllable load from making a competitive offer.

To some extent, the potential suppliers of balancing energy are unable to comply with the required activation or supply periods. The barriers to participating in the balancing energy market need to be reduced to a minimum, in order to increase the number of potential suppliers.

Regulatory modifications also need to be considered. On the one hand, the role of load management aggregators needs to be defined. At present, it is the suppliers who are the key stakeholders, implementing load management in the electricity market with the assistance of aggregators. Standardization of the role of aggregators could perhaps activate additional potential.

In the area of heat pumps and electric storage heaters, the requirements of which have up to now been covered by temperature-dependent load profiles, there needs to be both flexible alignment with the system requirements at short notice and alignment of consumption with the prevailing national and local supply situations, in order for the existing load management potential to be used.

12. Appendix

12.1 Specific grid-critical situations

This subsection takes a look at a series of critical system situations that are either based on scenarios simulated by the TSO's or which have already occurred. Looking at southern Germany in particular should tell us something about the potential for power reserve to be made available in this region by means of load management.

Simulation: bad-case scenario, May 18, 2011

To evaluate grid stability, the TSO's used simulative grid calculations to analyze specific risk-prone scenarios in terms of, among other things, grid load and (n-1) security (presented on May 20, 2011, see Federal Network Agency, May 2011). This (n-1) security is understood as the intended hedging against the failure of the main individual grid units. The calculations were based on the system situation at 12:00 on May 18, 2011, as a time representing a high-load situation combined with a high degree of wind power feed-in and low photovoltaics feed-in. On this day, 16 GW of power plant load was scheduled to be unavailable due to revisions. Three types of feed-in from renewable energy (RE) sources were examined: RE high, RE low, and only wind high. Manageable grid situations were forecast for each of these three feed-in types. For the simulated (n-1) case, overloads were forecast for the entire grid and also for the connection between Thuringia and Bavaria, and also in a north-south direction between the Ruhr and Baden-Württemberg. However, even after implementation of the measures (such as redispatch and SIV), there is a significant degree of overload in the connections in southern Germany.

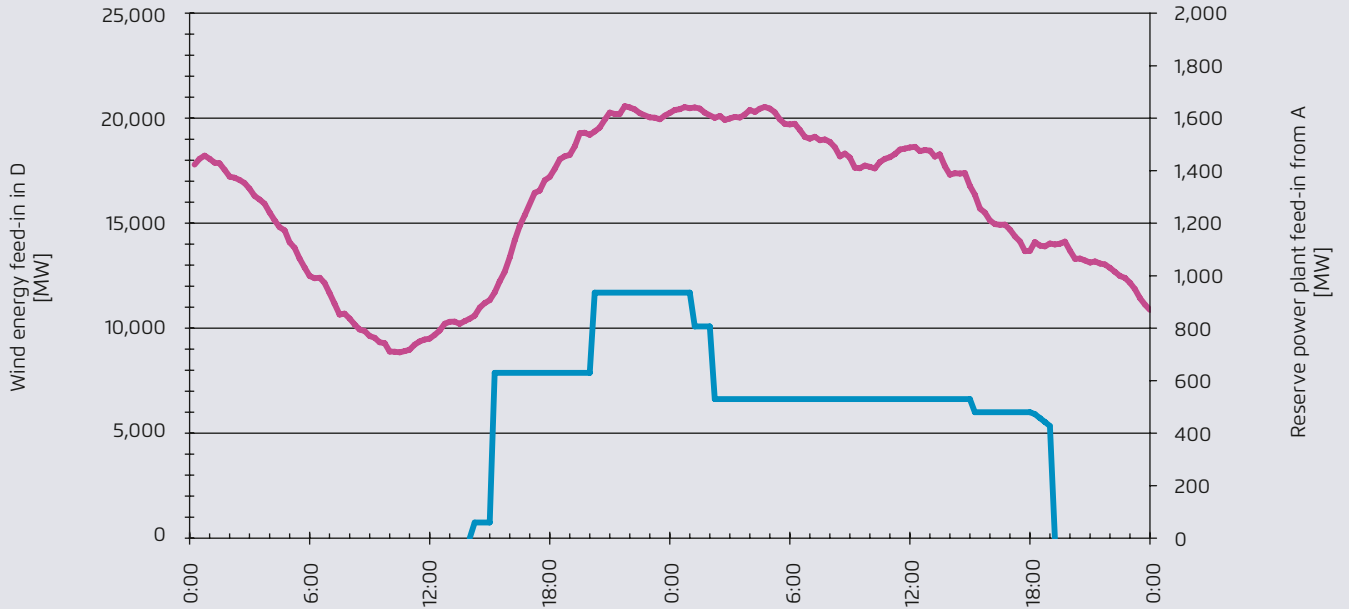
Real: first-time use of the Austrian reserve power plants on December 8 and 9, 2011

The Gundremmingen C nuclear power station, which is a major southern German power generator with a net load of 1.3 GW, was not available as of November 29, 2011. The existing redispatch potential for relieving overloaded power circuits was therefore limited. High north-south load flows were triggered by the high grid load (winter workday) relating to high wind feed-in of 19 GW in the night of December 8/9. Only with the aid of considerable redispatch between 50Hertz Transmission GmbH and TenneT TSO GmbH, and thanks to the relief offered by the Austrian reserve power plants, could a loss of (n-1) security in the power lines of the 380-kilovolt power circuits Vieselbach-Remptendorf, Röhrsdorf-Remptendorf (50Hertz), and Remptendorf-Redwitz (50Hertz/TenneT) be prevented.

While they were in use, the Austrian reserve power plants generated a total peak rated output of 935 MW. The time frame is illustrated in Figure 61, and shows that the reserve power plants were used for a period of 29 hours. The peak load was activated for approximately five hours. Figure 62 shows the impact of the Austrian feed-in on the overloaded power circuits in the TenneT system, thereby giving us an impression of the importance of reserve load in the southern German network area.

Wind energy feed-in in Germany (pink) and feed-in from reserve power plants in Austria (blue) on December 8 and 9, 2011

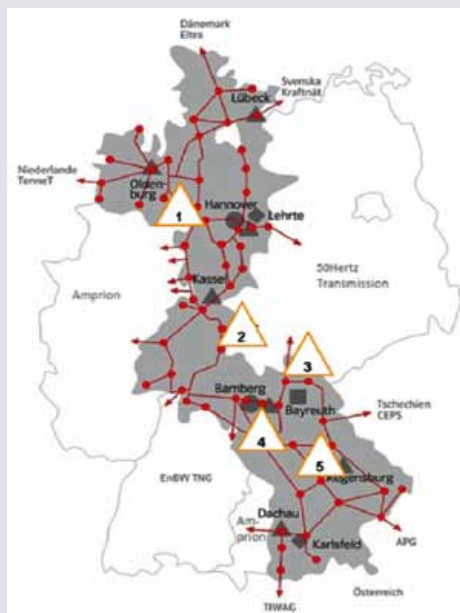
Figure 61



Grid report on the situation in winter 2011/12, Federal Network Agency (May 2012)

Impact of the Austrian reserve power plants on the power circuits in the TenneT system on December 8, 2011

Figure 62



Impact of the cold reserve on the shortages				
in [MW]		without	with	Δ
1	Landesbergen-Wechold (220 kV)	622	580	-7%
2	Diepperz-Mecklar (380 kV)	2,072	2,015	-3%
3	Remptendorf-Redwitz (380 kV)	3,000	2,914	-3%
4	Ludersheim-Raitersaich (220 kV)	266	230	-14%
5	Ludersheim-Sittling (220 kV)	254	224	-12%
Time:		23:30, Thur, 12/08/2011		
Wind in D (actual):		19,948 MW		
Cold reserve in A:		935 MW		
(Calculated using DACF data)				

Grid report on the situation in winter 2011/12, Federal Network Agency (May 2012)

Real: overloads from February 8 to 10, 2012

With Europe in the middle of a cold spell in early February, the Amprion system was placed under a heavy strain due to high transportation requirements from power plants in the northwest of Germany to the consumption hubs in the south and also because of a high volume of transit to Austria, France, and Switzerland. This resulted in planned redispatch measures along the Middle Rhine power line, with temporary feed-in of one gigawatt in the south. The high vertical load meant that the majority of the German power plants were activated. At the same time, gas-fired power stations in southern Germany were not available due to gas supply bottlenecks. The redispatch possibilities in Germany were therefore essentially exhausted, and the neighboring countries in the south were likewise unable to mobilize additional power generation at short notice. As a result, (n-1) security could not be guaranteed at all times, which meant that balancing would hardly have been possible had a major power plant/power unit gone out of action.

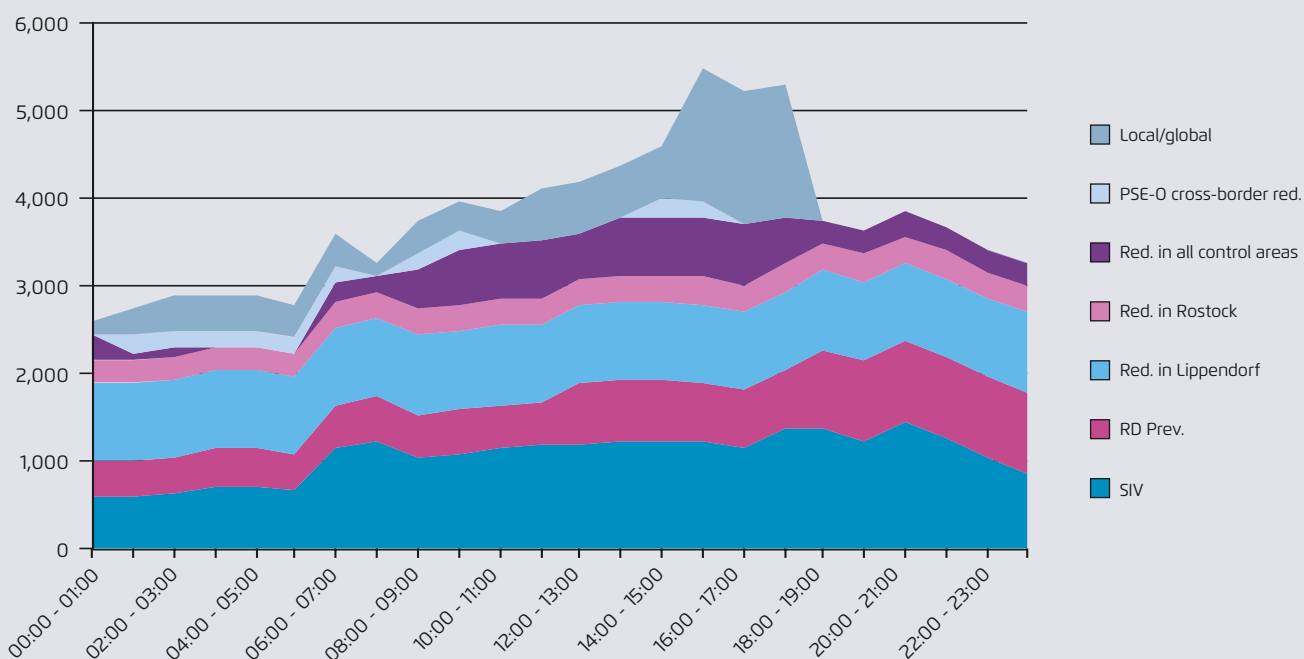
The Federal Network Agency concluded that it was important that the expansion of north-south transmission capacities and the increase in guaranteed power plant capacities be accelerated (Federal Network Agency, May 2012).

Real: overload of grid units on February 15, 2012

At around 02:15 on February 15, 2012, there was maximum wind power feed-in of 21.5 GW. 50Hertz implemented significant redispatch countertrading and SIV as a preventive measure, in order to avoid forecast (n-1) breaches. Figure 65 gives an overview of the agreed measures. An amendment of more than five gigawatts in the feed-in loads was needed in order to maintain operation, as was an energy volume of around 80 GWh in one day. Based on this, the Federal Network Agency decided it was necessary as a long-term measure to expand the grid, in particular in the 50Hertz control area and in the cross-border power lines to Poland.

Overview of the *redispatch* measures in the 50Hertz control area on February 15, 2012

Figure 63



Grid report on the situation in winter 2011/12, Federal Network Agency (May 2012)

Real: breach of (n-1) security on February 22 and 23, 2012

Multiple (n-1) breaches were forecast for the 50Hertz and TenneT control areas due to high wind power feed-in (peaking at 20 GW). Numerous preventive redispatch and feed-in management measures were implemented (up to one gigawatt) in order to relieve the 380 kV power circuits between the Remptendorf (50Hertz) and Redwitz (TenneT) substations in particular. In spite of these measures, (n-1) security could not be guaranteed for approximately 1.5 hours. In order to guarantee safe grid operation, almost four gigawatts of load had to be reduced and balanced out by means of redispatch or derated using wind turbines.

12.2 Detailed analysis of secondary balancing energy activation

Figures 64 and 65 are designed to illustrate the spectrum of the various time-of-day trends in typical curve

form. This involved the 2012 day time series for positive and negative loads being grouped according to similarity with the aid of a cluster method based on self-organizing maps. The resultant cluster structures are presented in Figure 66.

The diurnal variations have a clear structure of four clusters, with the figures for each cluster being aggregated to produce an average course. The resultant curves represent fundamentally different diurnal variations in secondary balancing energy activation. Averaging out the figures per cluster means that the peaks are not quite so pronounced, but the spectrum of figures is nonetheless presented in the form of error bars. For the purposes of comparison, the magenta curve represents the quarter-hour maximum for all the days of the year, which remains very constant throughout the day within the range of 1.5 GW and 2 GW both for negative and positive balancing energy.

Averaged typical time-of-day courses of positive secondary balancing energy activation within the German grid control cooperation in 2012

Figure 64

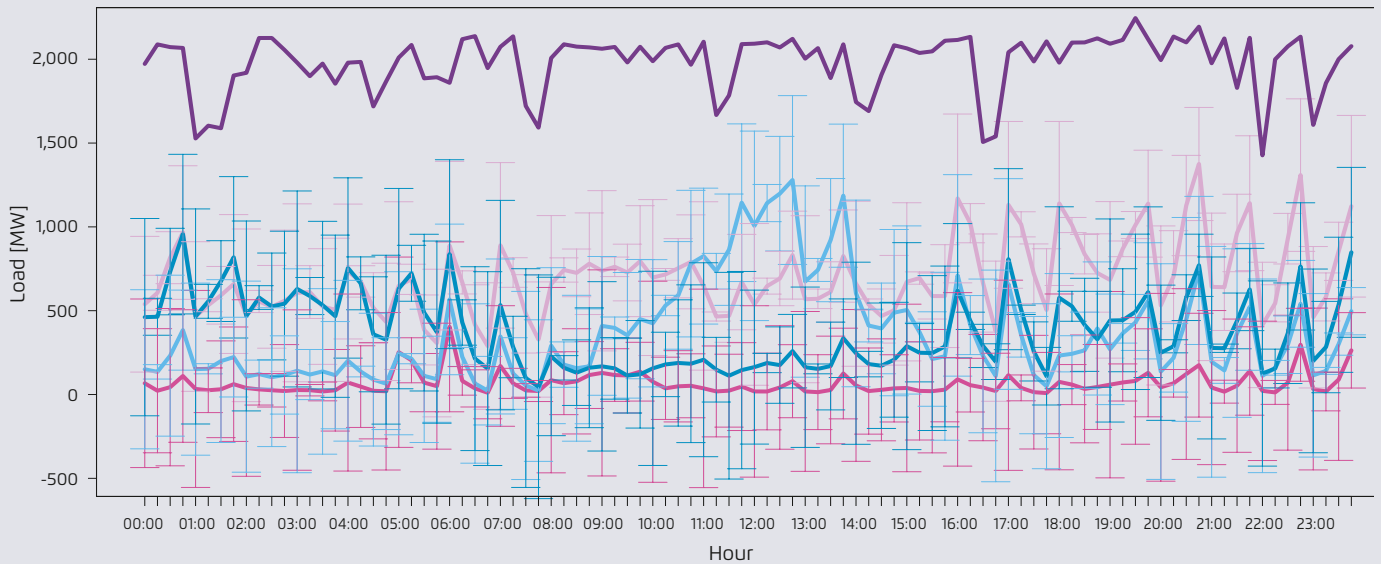


Cluster analysis of all of the year's diurnal variations (light pink, pink, blue, light blue) and quarter-hour balancing energy activation maximum throughout the year in magenta

Fraunhofer ISI calculations

Averaged typical time-of-day courses of negative secondary balancing energy activation within the German grid control cooperation in 2012

Figure 65

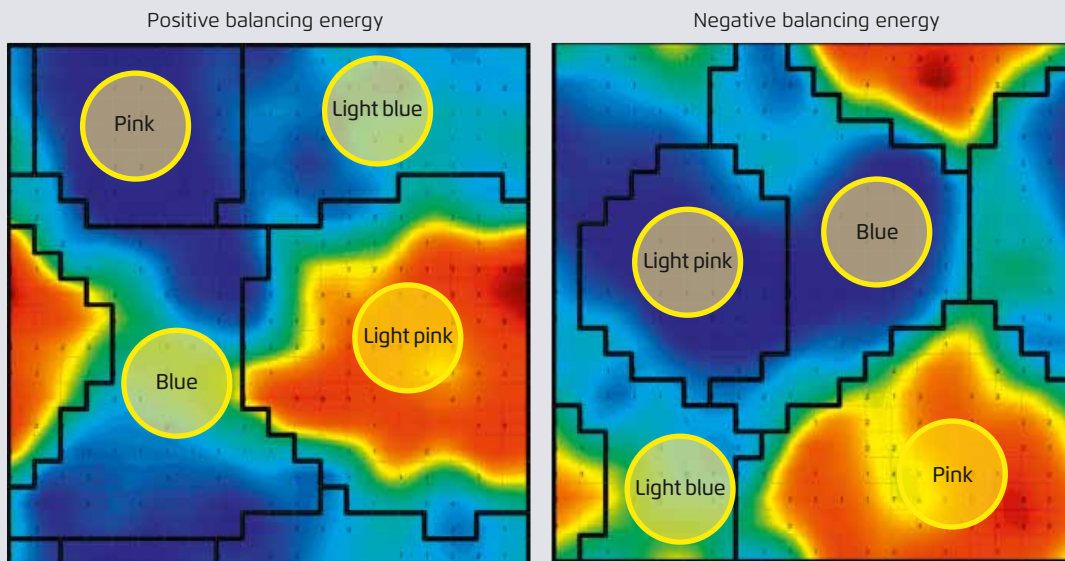


Cluster analysis of all of the year's diurnal variations (light pink, pink, blue, light blue) and quarter-hour balancing energy activation maximum throughout the year in magenta

Fraunhofer ISI calculations

Cluster structure of the diurnal variations of secondary balancing energy activation for positive and negative load on self-organizing maps

Figure 66



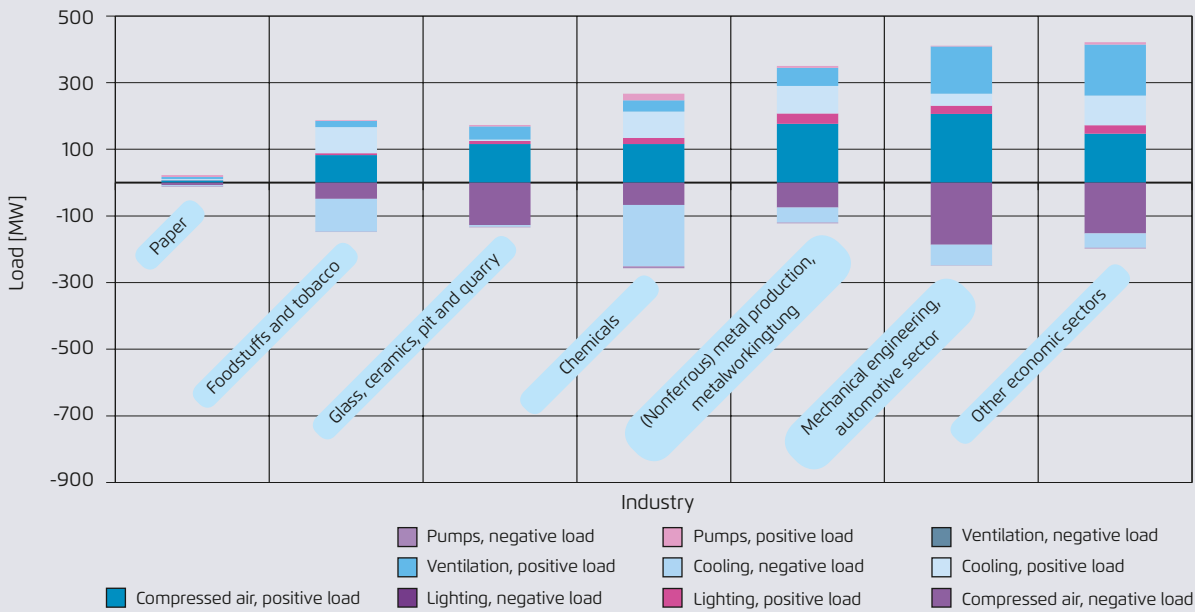
The yellow circles represent clusters within the map whose individual figures (diurnal variations) were aggregated for the curves shown in the graphs above.

Fraunhofer ISI calculations

12.3 Positive and negative loads achieved by flexibilizing cross-section technologies

Positive and negative loads achieved by flexibilizing cross-section technologies in southern Germany (normal operation) – realizable potential without consideration of the cost of implementation (staff and ICT)

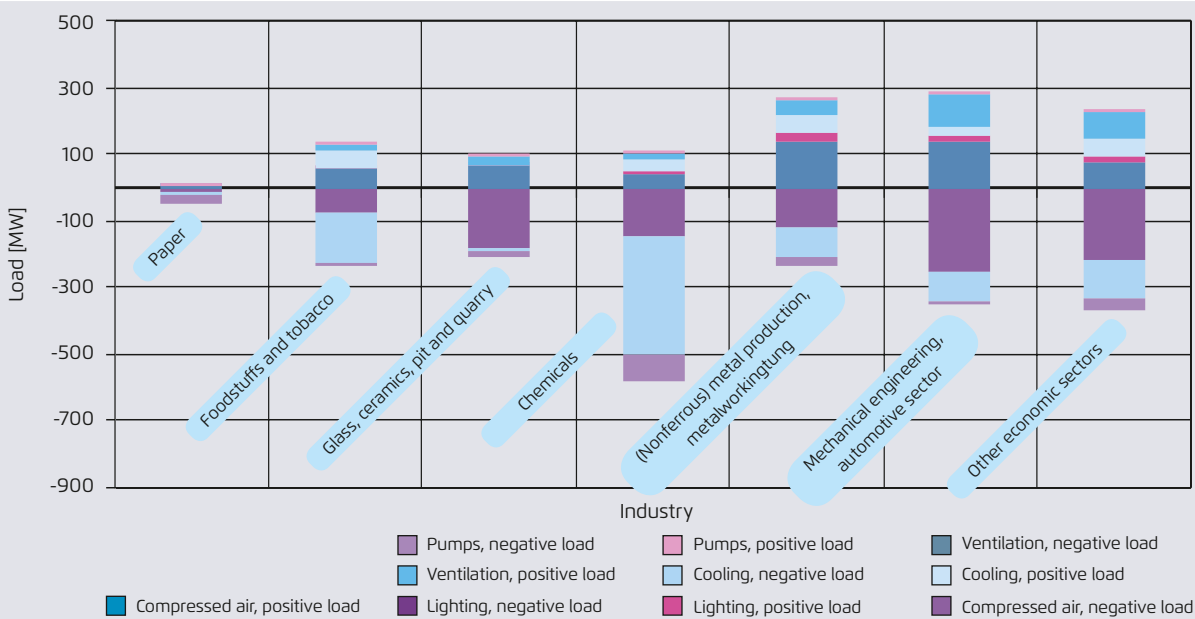
Figure 67



Created by FfE

Positive and negative loads achieved by flexibilizing cross-section technologies in southern Germany (reduced operation) – realizable potential without consideration of the cost of implementation (staff and ICT)

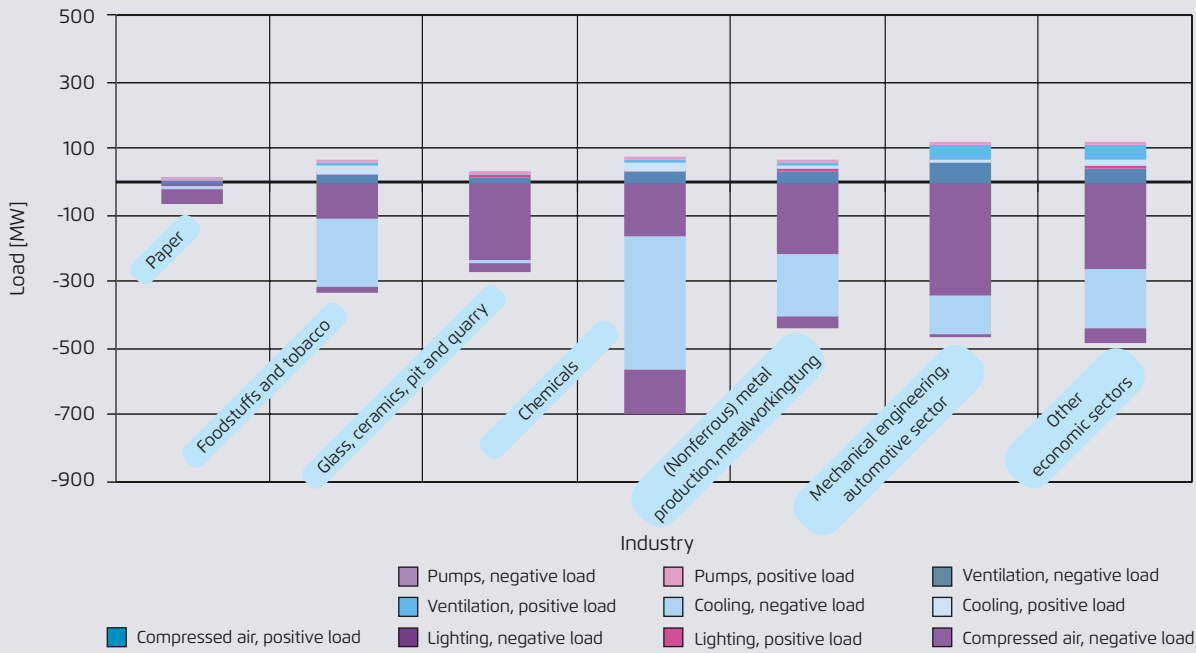
Figure 68



Created by FfE

Positive and negative loads achieved by flexibilizing cross-section technologies in southern Germany (baseload operation) – realizable potential without consideration of the cost of implementation (staff and ICT)

Figure 69

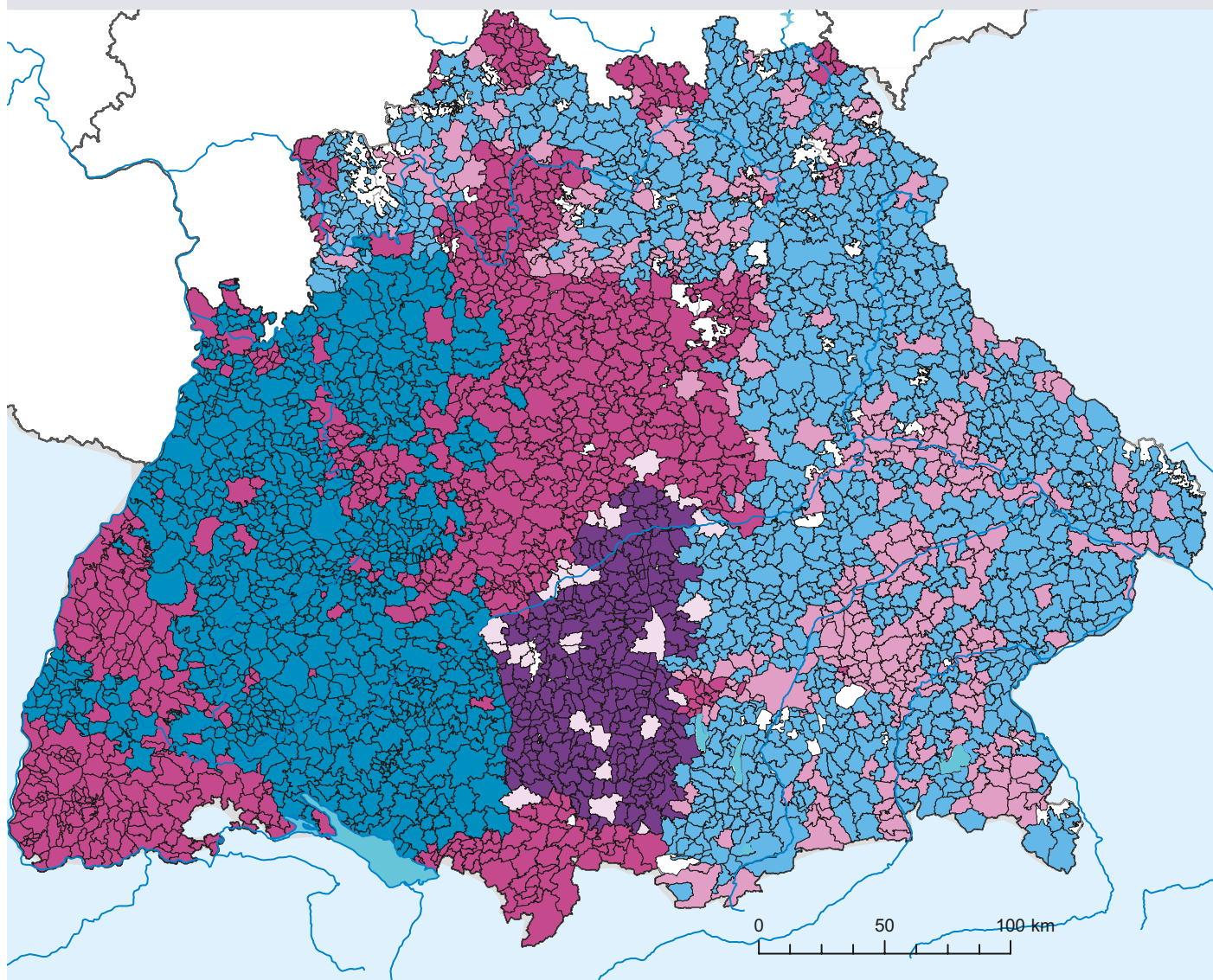


Created by FfE

12.4 Basis for calculating the load management potential of heat pumps and electric storage heaters

Geographic spread of the underlying data

Figure 70

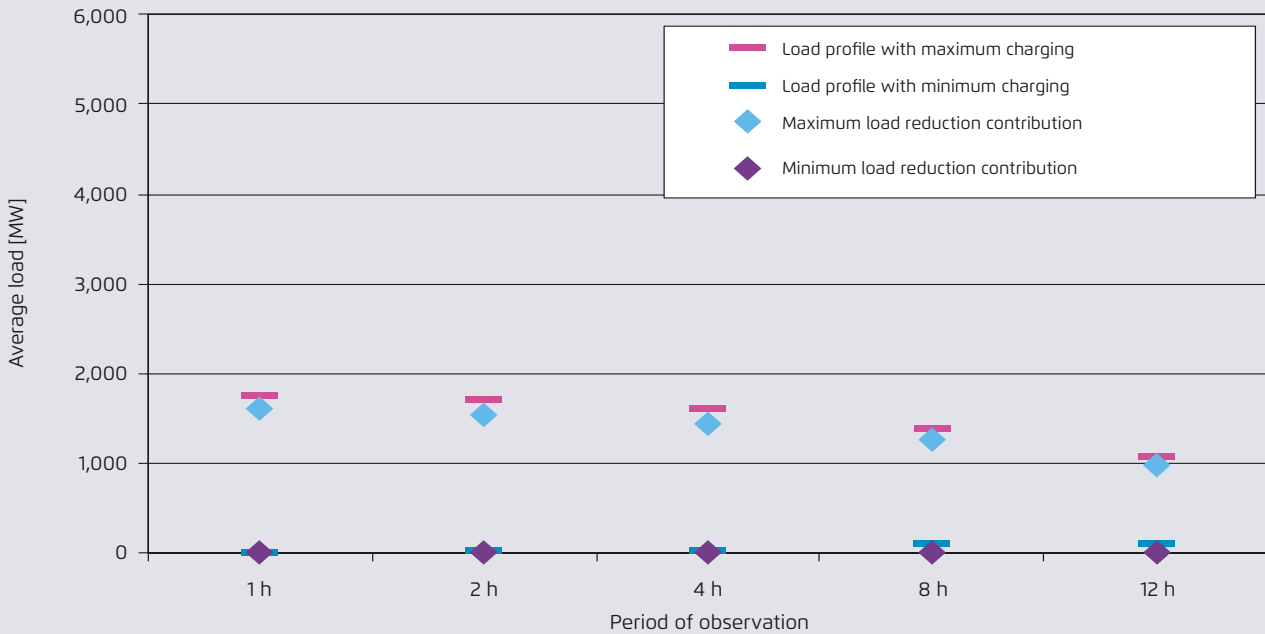


Underlying data	LEW	Calculated by LEW
	E.ON	Calculated by E.ON
	EnBW	Extrapolated municipalities

Created by FfE

Load reduction potential of electric storage heaters in Bavaria and Baden-Württemberg in the event of load shifting of twelve hours (equivalent daily average temperature 10 °C)

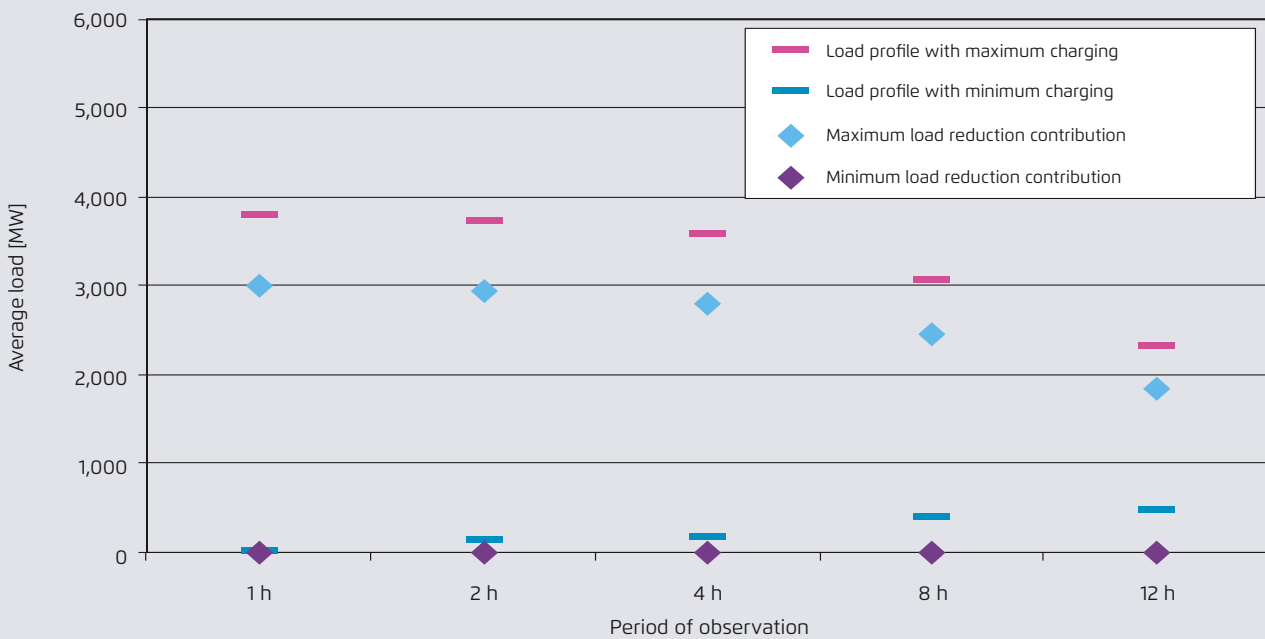
Figure 71



Created by FfE

Load reduction potential of electric storage heaters in Bavaria and Baden-Württemberg in the event of load shifting of twelve hours (equivalent daily average temperature 0 °C)

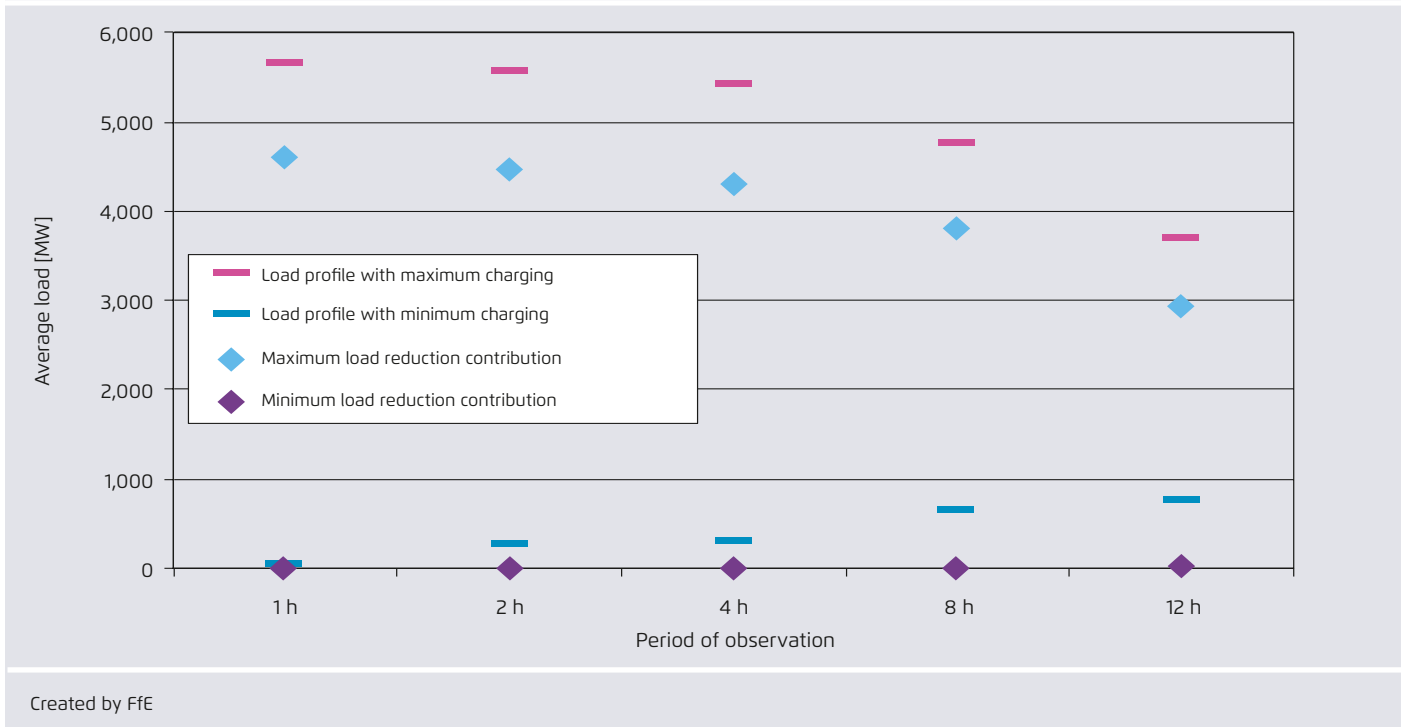
Figure 72



Created by FfE

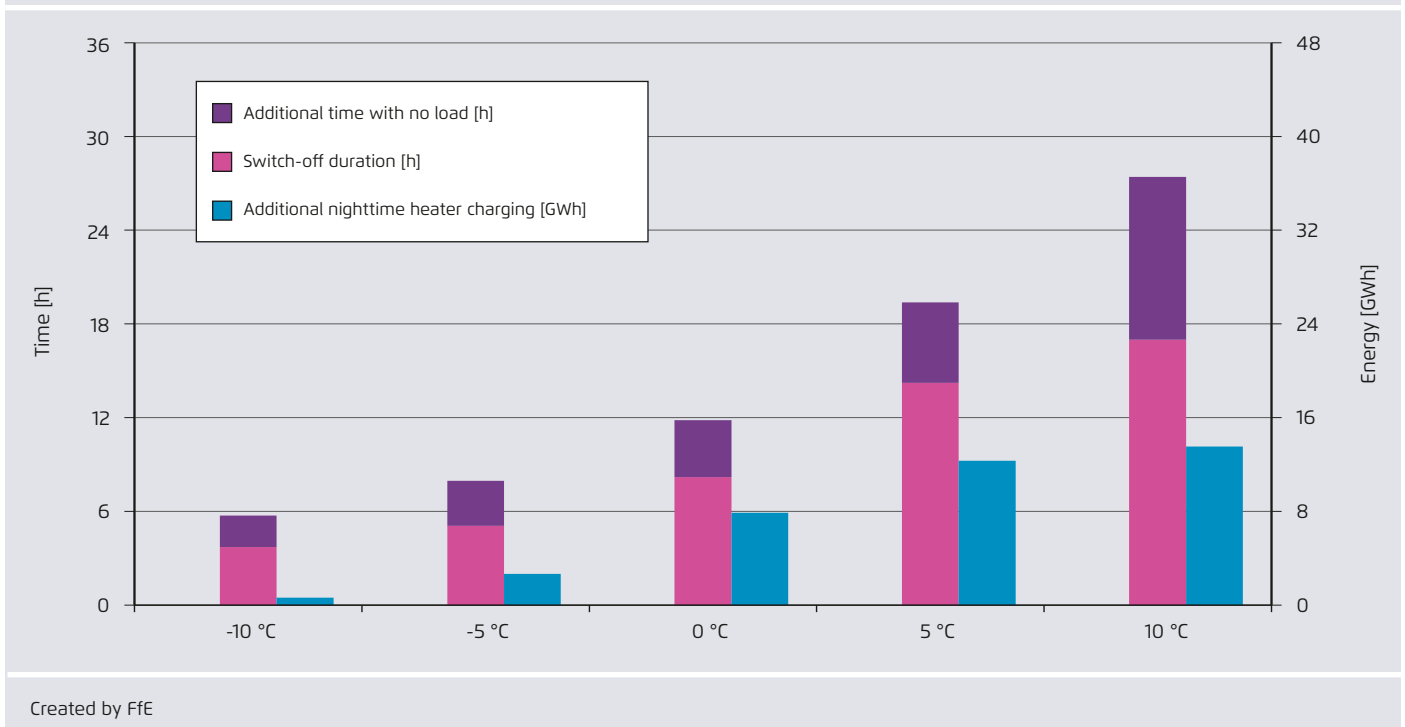
Load reduction potential of electric storage heaters in Bavaria and Baden-Württemberg in the event of load shifting of twelve hours (equivalent daily average temperature -10 °C)

Figure 73



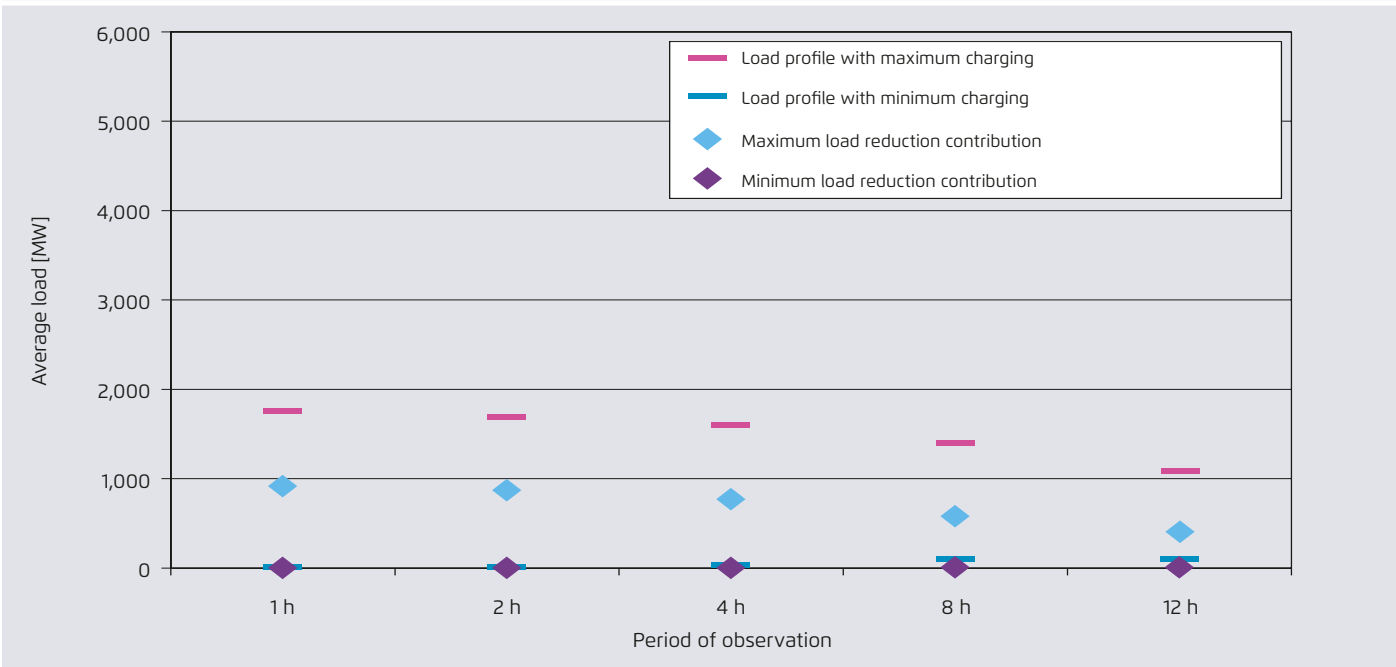
Load reduction potential of electric storage heaters in Baden-Württemberg and Bavaria in the event of the charging process being brought forward

Figure 74



Load reduction potential of electric storage heaters in Bavaria and Baden-Württemberg in the event of the load being reduced to heating requirements (equivalent daily average temperature 10 °C)

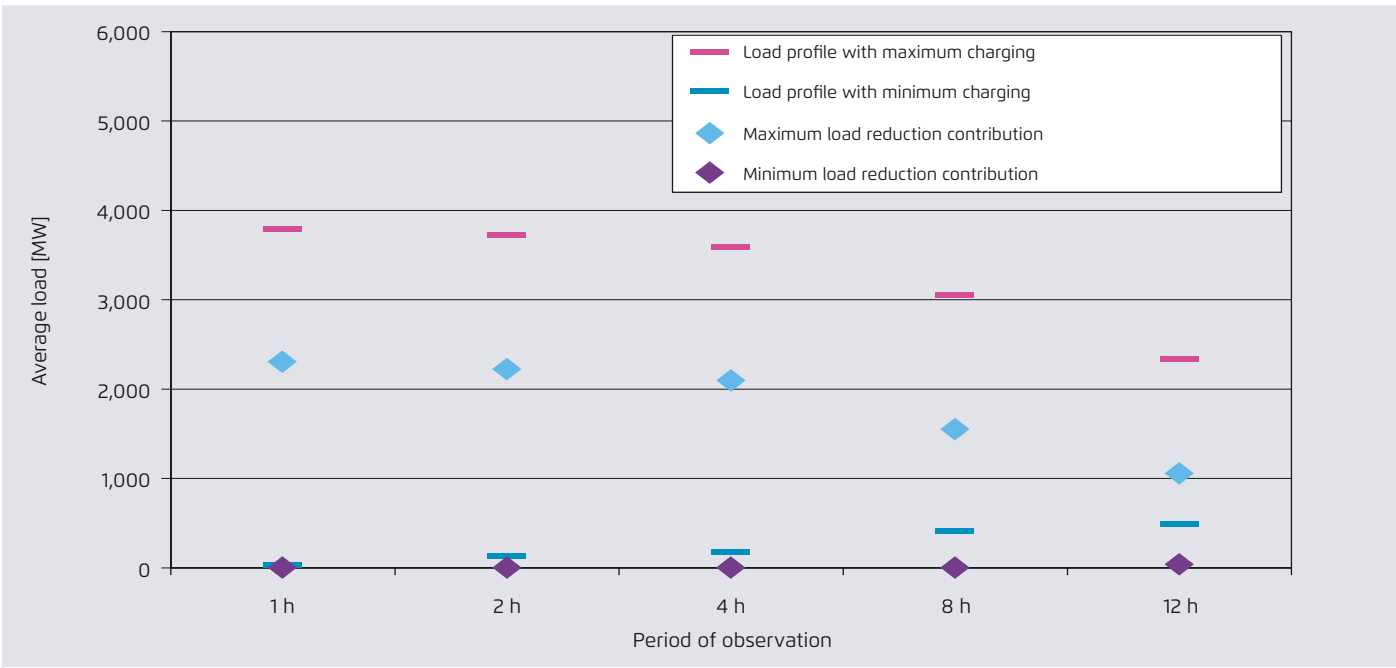
Figure 75



Created by FfE

Load reduction potential of electric storage heaters in Bavaria and Baden-Württemberg in the event of the load being reduced to heating requirements (equivalent daily average temperature 0 °C)

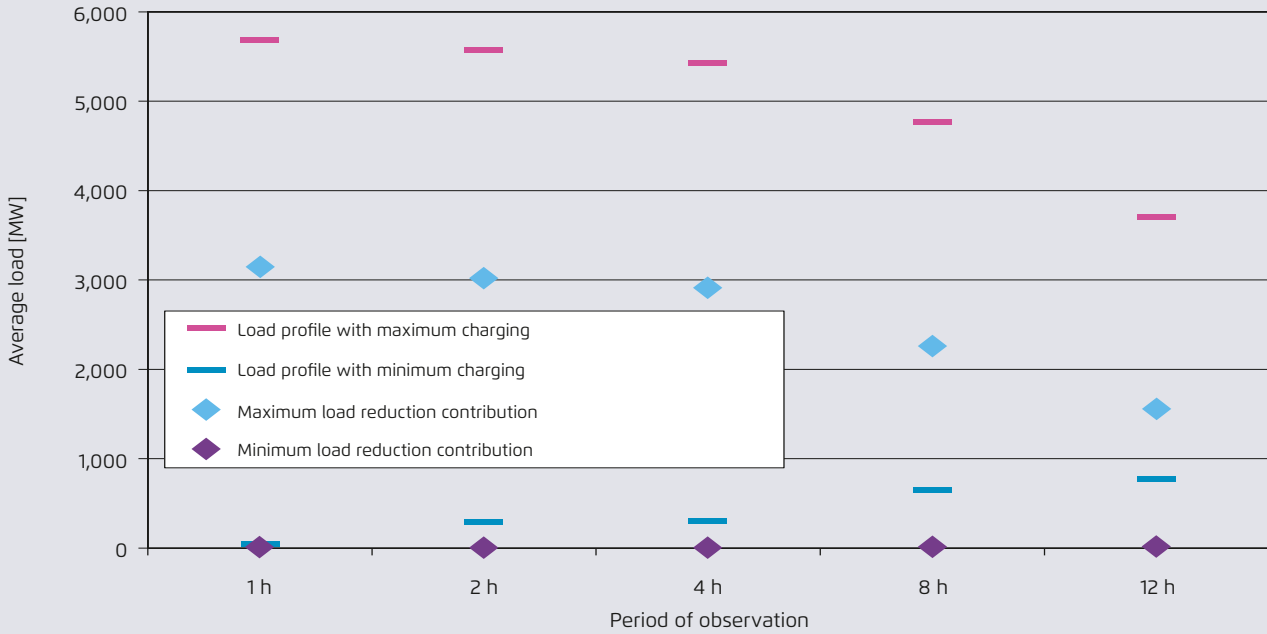
Figure 76



Created by FfE

Load reduction potential of electric storage heaters in Bavaria and Baden-Württemberg in the event of the load being reduced to heating requirements (equivalent daily average temperature -10 °C)

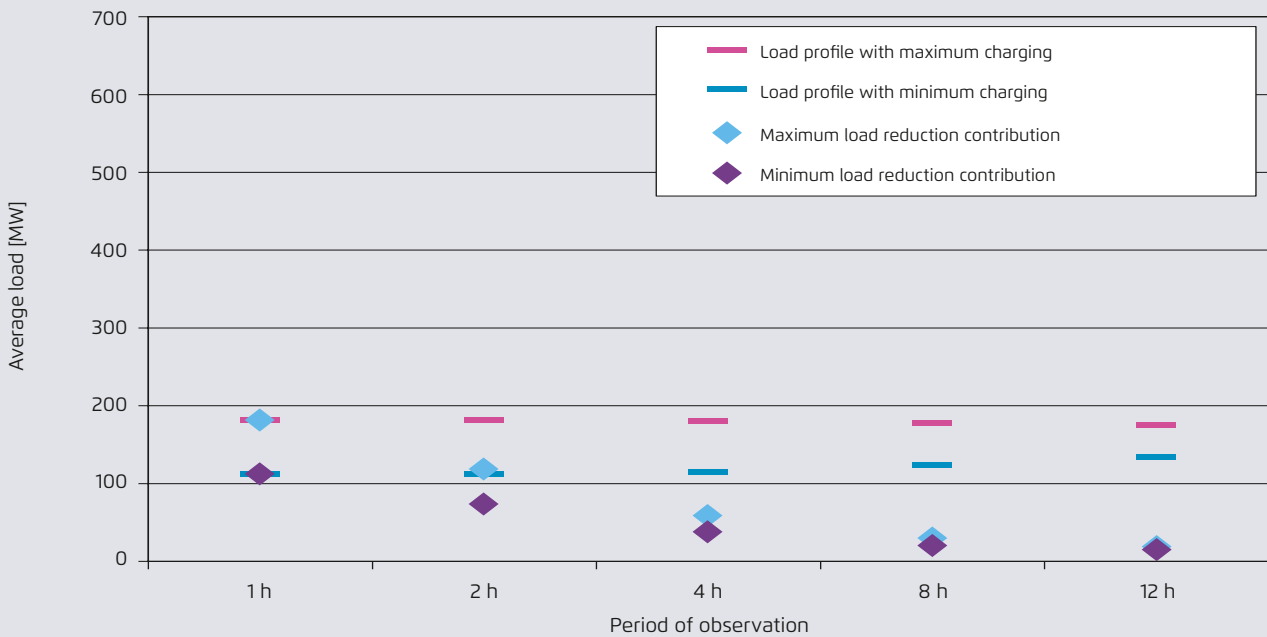
Figure 77



Created by FfE

Load reduction potential of heat pumps in Bavaria and Baden-Württemberg at a reference temperature of 10 °C

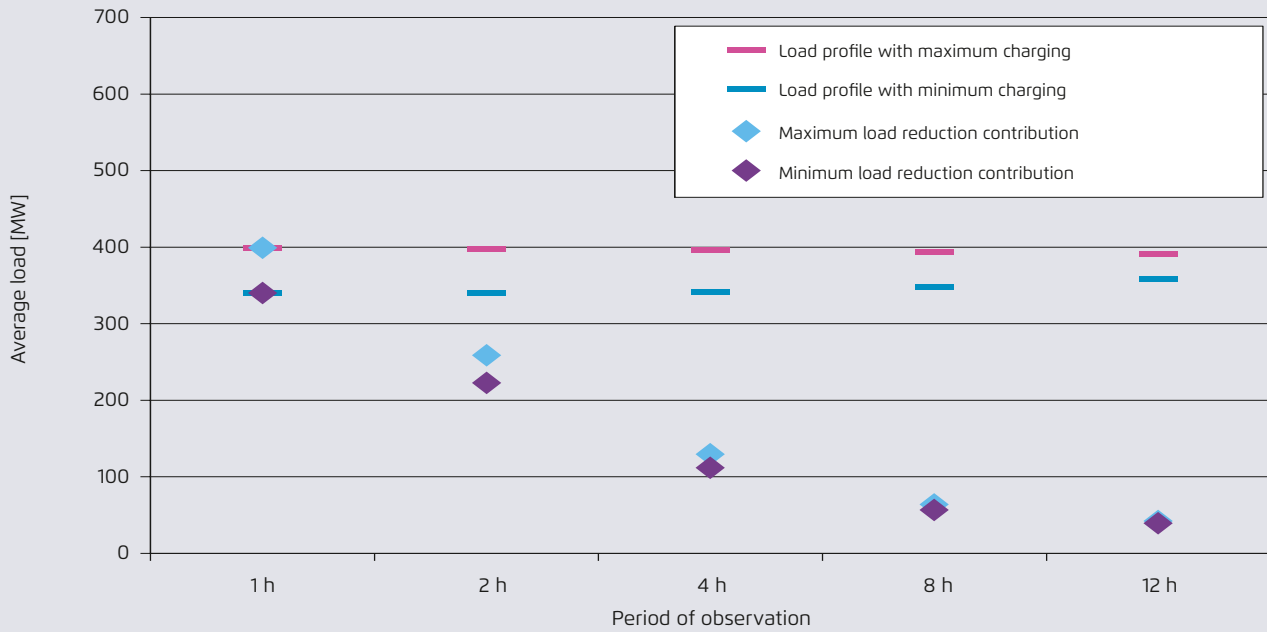
Figure 78



Created by FfE

Load reduction potential of heat pumps in Bavaria and Baden-Württemberg at a reference temperature of 0 °C

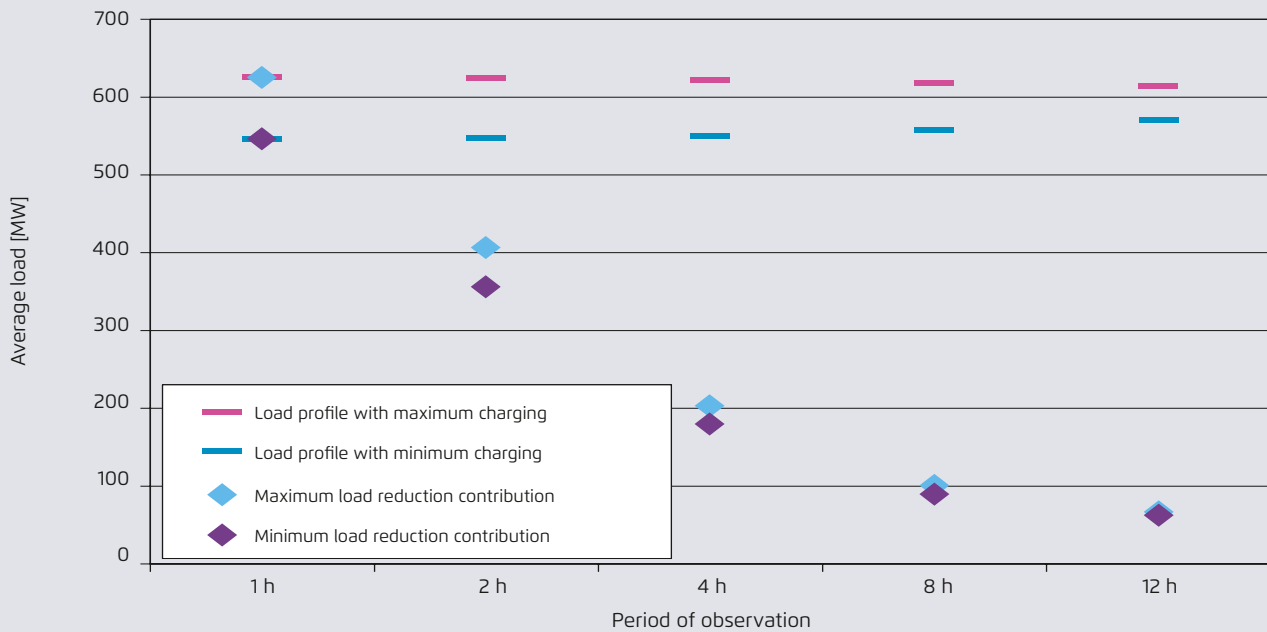
Figure 79



Created by FfE

Load reduction potential of heat pumps in Bavaria and Baden-Württemberg at a reference temperature of -10 °C

Figure 80



Created by FfE

12.5 Calculation assumptions for gas turbines

Calculation assumptions for gas turbines		Table 15
Energy conversion efficiency	40%	
Spec. investments	€ 450 / kW _{el}	
Annual fixed costs	€ 10,000 / (MW · a)	
Variable costs	€ 1 / MWh _{el}	
Financing term	20 years	
Rate of interest	10%	
CO ₂ costs	€ 10 / t	
Natural gas price	€ 35 / MWh _{th}	

Created by Agricola et al. (2010); Blesl et al. (2012); dena (2005); Hobohm et al. (2011)

Notes regarding the calculation assumptions:

The specific investment costs were assumed on the basis of Agricola et al. (2010) and were confirmed in talks with a Bavarian power plant operator. In particular, the figures stated for fixed and variable costs vary greatly in the literature sources (dena 2005; Hobohm et al. 2011; Blesl et al. 2012). It should nevertheless be borne in mind that the specific investment costs constitute the largest proportion of annual total costs by a large margin when the activation times are low, thereby putting the possible spread of fixed and variable costs into perspective.

The price of natural gas assumed in this study is based on the following considerations. The spot market price is currently 2.7 ct/kWh, which is why a supply contract can currently be found at a level of 2.9 ct/kWh. In addition, grid charges of between 0.2 and 0.6 ct/kWh are incurred. The upper estimate is therefore 3.5 ct/kWh. With regard to CO₂ certificates, the assumption was made that prices would rise again in the medium term, because the current price is considered to be clearly too low by many in the political arena.

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