Demand Response in the service sector – theoretical, technical and practical potentials

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Abstract

Flexible energy demand (demand response, DR) is seen as one solution to integrate intermittent renewable energy sources into future energy systems.

We provide a comprehensive analysis of the DR potential of the service sector, using a transparent bottom-up approach, along with quantitative survey data from a large sample size of over 1500 German companies. This allows us to estimate the theoretical and technical potentials and to representatively quantify the willingness of the companies to participate in DR, determining the practical potential. We identified food retail as well as restaurants as most promising subsectors, based on the availability of flexible appliances and control technologies and their willingness to conduct automated DR. Taking cross-cutting flexible appliances in the subsectors offices, trade and hotels/restaurants into account, our estimations result in approximately 22 TWh of theoretical potential (~ 35% of total electricity consumption of the subsectors), 4 TWh of technical potential and 1 TWh of practical potential. Relevant barriers to DR are its perceived low priority and inadequate financial incentives due to a small share of energy costs within firms, whereas customer image of DR is perceived as an important driver. Knowledge of barriers and drivers is valuable for designing policies, which incorporate the needs of applicants and enable companies to participate in DR. Across European countries, the structure and share of electricity demand of the service sector is fairly comparable (with differences arising from climatic context); hence the insights derived here are in its main conclusions also relevant for the entirety of Europe.

Keywords: demand response, service sector, flexibility potential, flexible appliances, survey data

1. Introduction

Over the course of the energy transition, it will be necessary to integrate increasing amounts of intermittent renewable energy. This prompts the discussion about the flexible use of energy. When energy consumption is adjusted temporarily to avoid grid problems and achieve a more efficient energy system, the term demand response is usually used [1,2]. DR (demand response) is an option to avoid/complement other flexibility enablers such as conventional balancing power plants, enhancement of interconnector lines between countries and transmission lines as well as energy storage. In the Energy Efficiency Directive [3], the European Network Codes [4] and the Commission's Energy Union Communication [5], DR is referred to as an important enabler of renewable integration, security of energy supply and improved market competition [6]. If the energy system is changed, it is necessary to explore opportunities for DR and find out how different sectors can be integrated. As mentioned, e.g. in the "winter package" of the European Commission in 2016, consumers will play a more active role and access to electricity markets will be facilitated [6]. These changes could support the implementation of DR. However, regarding companies, energy-intensive processes in industry are predominantly used for DR measures like congestion management and on the balancing power markets. According to Agora [7] almost 50% of German industrial enterprises already have experience with load shedding and industrial production processes overall have the largest DR potential. It is essential to exploit these potentials more extensively to meet the future need for flexibility, but the main barriers are directly associated with those processes: Industrial companies fear the risk of disruptions in production processes, the risk of lower product quality and the disruption of operations [8]. Therefore, less problematic cross-sectoral processes could be a supplement for flexible demand. Cross-sectoral processes that are relevant for DR include ventilation and air conditioning (VAC) as well as various heating and cooling process. This means that less energy-intensive sectors like the service sector come into play. Due to the rather homogeneous distribution of service companies across the country, their potential could complement the regionally more focused DR potentials of the industry sector. Additionally, as the service sector accounts for 29% of the German electricity demand, it could play an important role regarding DR [9] and might even gain more importance regarding the tertiarisation of the economy. However, the economic barriers to DR could be higher here, because the individual loads are smaller than in the industrial sector. At the European level, the structure and the share of the electricity demand of the service sector is fairly comparable across countries (with differences arising from different climatic context); hence the insights derived for the German context are in its main conclusions also relevant for the entirety of Europe and its service-based societies. While the present regulatory context differs among European countries, conclusions on possible future changes in the energy system still are largely valid elsewhere in Europe. This is especially true, since European energy markets are expected to work together more closely to be able to distribute flexible demand in the future [10].

When estimating flexibility potentials, usually theoretical, technical, economic and practical potentials are distinguished [11,12]. While the theoretical potential can be seen as an upper limit, representing the accumulated consumption of all the appliances eligible for DR, only a small share of this can actually be used due to technical, economic and practical considerations. The technical potential therefore takes technical restrictions into account (e.g. load profiles, ramping times, restrictions due to partial loads or security aspects) which is influenced by framework conditions like the climatic context. The economic potential deals with aspects concerning the financial viability of DR measures, e.g. evaluating investments, profits, energy costs, discount rates and operating expenses. This can be interpreted as the economically feasible potential. The practical potential describes what can actually be implemented, referring to the willingness to do so, taking existing barriers into account. Thus, the practical potential is usually smaller than the technical or economic potential, if no funding or subsidies exist [13]. The willingness is again dependent on "soft factors" like decision-making processes, knowledge, attitudes and perceived barriers. As conditions for DR are unfavourable today and are likely to improve in the future this also has implications for the practical potential and how it can be expected to change.

The estimations of DR potentials in the service sector vary strongly depending on the underlying assumptions or methods used (cp. Table 1). Table 1 shows technical or economical potentials, although sometimes these cannot be clearly categorised because the specific assumptions and parameters differ. The exemplary studies show that the potentials for the service sector are significant, even when compared to those of the industry sector.

Table 1: Estimated flexibility potentials in industry and the service sector

Study	Peak power (GW)	Flexible energy (TWh)	Base year of estimation/ proj. year	Energy uses	Sector
Dena [14]	3.5	12.2	2020	Energy-intensive industries	Industry
Klobasa [15]	2.8	1.3	2005	Industrial sectors and cross-sectoral appliances (esp. VAC)	Industry
VDE [16]	4.5	0.077	2010-2030	Production processes in energy-intensive industries (aluminium, steel, glass, paper, cement, chemical …)	Industry
Dena [14]	1.4	5.7	2020	Especially cross-sectoral appliances (air conditioning, ventilation, cooling, water/ room heating), financially incentivized	Service & Trade
Klobasa [15]	10.3	6.3	2004	VAC, cooling, night-storage and water heating, server	Service & Trade
VDE [16]	1.4 - 1.8	5-9.7	2010-2030	Based on standard load profiles and a model city with 500,000 inhabitants	Service & Trade

VAC = ventilation, air-conditioning

At present, the potential in the service sector is largely untapped, in contrast to the industrial sector. In the existing flexible markets in Germany, 2500 MW of consumer loads are prequalified for the balancing market [10]. So far, companies from the service sector are not represented in these markets [17]. Accordingly, the share of companies that have not yet addressed DR issues is distinctly higher than in the industrial sector (see Table 4: 42% in the service sector, vs. 26% in industry; [7]). Currently, there is no focus on the service sector's smaller and more distributed potential and companies willing to participate in DR face unfavourable regulatory conditions. There are still discrepancies in most EU member states between policy plans and actual regulation. When rating energy markets in terms of their degree of consumer participation, programme requirements, standardised verification and measurement as well as payment and risk structures, Germany is only ranked as "partially open", while other European countries (e.g. Belgium, France, Great Britain and Switzerland) already count as "commercially active" [6]. The share of companies from the service sector participating in load management schemes is higher in countries with a more favourable regulatory environment [18]. Considering market conditions in neighbouring countries, France and Switzerland have standardised processes for trading flexible loads on the spot and balancing markets and capacity charges are higher [10]. Usually, trading flexible loads requires a prequalification of loads to guarantee the technical requirements. The same applies for the balancing market or under the interruptible loads act [19] in Germany. This prequalification includes minimum loads and thus favours predictable constant loads that are easy to schedule. In the service sector, appliances that meet these requirements are rare, unless several appliances are pooled. Pooling is possible, but complex. Pooling via a third party aggregator might be the more ingenious solution, but the processes and contracts for aggregation are not yet standardised and imply transaction costs [20]. Adjustments and improvements of regulations are under discussion and already partially implemented (e.g. lower minimum bids in the balancing markets), but the German market still seems unprepared to integrate potentials from demand-side sectors other than the energy-intensive industry. While the current state of DR therefore is likely to change significantly in the future when flexible demand is needed to ensure grid stability, to shape this transition in the best possible way it is crucial to assess the current conditions for DR and to strongly consider the viewpoint of the applicants, to be able to incentivise participation. An important starting point is to investigate the availability and the potential for flexible demand that can be provided by different subsectors and branches.

While empirical research on DR in the service sector currently is scarce altogether, an assessment of the willingness to participate in DR and an estimation of the practical potential of German companies using empirical data from a sufficiently large sample and a high resolution regarding company-types has not yet been provided at all. While in the context of the USA more data is available and studies exist, that aim to evaluate DR potentials in different sectors and in high resolution (cp. Lawrence Berkley National Laboratory [21]) neither the grid situation nor the requirements of flexibility or regulatory situation is comparable to Germany or other European countries; usually also definitions of flexible loads differ [22]. Since most studies use simulation models to achieve detailed estimations and load availability on a high resolution, comparability between studies is problematic in general, because the origin of deviation is rarely transparent. While modelling approaches are certainly valuable for detailed analysis and optimization, for identifying DR potentials in a largely unexperienced field like the German service sector, a strong empirical foundation seems to be more valuable. Again in the context of the US efforts to estimate DR potentials using a bottom-up approach by calculating the sums of flexible shares of appliances while also considering aspects of acceptability were made [23,24], but the studies refer to the industrial sectors and project or assume the levels of controllability and acceptability based on technical parameters (load profiles/ average consumptions) rather than assessing them empirically, which discards the immediate needs and opinion of the end-users.

To evaluate options to support the energy transition, in this study we therefore provide a comprehensive analysis of the flexible demand potentials in the German service sector while also assessing the willingness to participate in DR measures, taking the direct perspective of applicants into account. In previous work, we already identified promising subsectors of the tertiary sector and their available technologies and appliances using qualitative methods [20]. The three subsectors trade, offices and hotels/ restaurants together account for more than 50 % of the total electric energy consumption of the tertiary sector in Germany [25]. Additionally, they have large shares of flexible cross-sectoral appliances (esp. thermal appliances, like VAC, electric water heating or refrigeration and cooling). The flexible appliances were selected based on previous work by Klobasa [15], VDE [16] and Gils [26]. In particular, the food retail subsector and companies operating restaurants seem to be suitable. The former especially due to regular refurbishments where appliances are replaced and/or could be made DR-ready and the large share of cooling devices that can be used as energy storage. The latter category of companies already has experience with load shedding and the necessary control technologies installed. Detailed information about the selection of promising subsectors and qualitative results about the applicability of DR in the subsectors can be found in Wohlfarth et al. [20].

In this study, we are especially interested in the quantitative assessment of technical, structural and motivational factors influencing the DR potentials of the service sector from the viewpoint of the end-users. We estimate the theoretical and technical potential based on our survey data of available flexible appliances. The measurement of the willingness to conduct DR measures within the survey also provide us with indications of the practical potential. The integration of the companies' perspective and assessment of empirical data to estimate the potentials distinguish this study from most of the modelling approaches on DR potentials. Especially the practical potential is of crucial interest, because of its practical relevance for implementation. Moreover it is important to find influencing factors on this practical potential to increase it. So far, only a few enterprises are participating in DR due to unclear regulatory conditions and companies' lack of knowledge. To motivate companies to participate in DR measures, we already know that financial incentives alone will not be sufficient. Yet, obstacles and restraints have not yet been clearly identified. We therefore aim to find out how to support a rollout of DR measures and which barriers need to be tackled. To this end, we complement previous qualitative data on stakeholders [20] by statistically analysing quantitative company survey data, focusing on the following main research questions:

- What are the conditions and the status quo of DR measures in the service sector to date?
- How large are the theoretical, technical and practical potentials?

- Which companies are best prepared for DR under the current conditions?
- What are the drivers and barriers from the viewpoint of enterprises interested in conducting DR measures?
- How do barriers and organisational circumstances influence the willingness to conduct DR measures?
- What incentives could help making DR a management priority?

In the remainder of the paper, we first give an overview to what extend the service sector is already using DR measures and on the current technical and attitudinal conditions. After that, the estimation of theoretical, technical and practical potentials and the analyses of drivers, barriers and influencing factors within the companies are described. The paper closes with recommendations and conclusions on how the service sector can best be supported to enable DR potentials.

2. Data and Methods

For the estimation of DR potentials in the service sector we use empirical survey data on the availability of appliances within the companies and combine these with benchmarks taken from the literature to estimate the average consumption and shiftable demand per year for each subsector and company size. By assessing the willingness of the companies to participate in DR we also provide an estimation of the practical potential. For identifying the most promising target groups and to give recommendations on how to enable the potentials of companies we also analyse the most important barriers to and drivers of DR measures and how these influence the willingness to participate in DR and the prioritisation of DR on manager level.

We conducted a standardised survey of the most relevant service sub-sectors in Germany (offices, trade and hotels/restaurants). Table 2 shows structural data regarding the number of enterprises and the electricity consumption of the subsectors. Table 2 reveals that food retail and wholesale, as well as hotels have the highest electricity consumption per enterprise, while offices have a high share of electricity consumption in total, but the smallest consumption per enterprise compared to the other subsectors.

Table 2: Structural data for the service sector – electricity consumption and number of enterprises in Germany

Sector	Subsector	Electricity consumption TWh/a, 2013	Share of consumption of selected sectors	No. of enterprises [1000]	Share of companies in selected sectors	Average MWh/ enterprise
Offices	Offices	28.8	46.0%	1135.7	60.3%	25.4
Trade	Retail food	6.8	10.9%	67.1	3.6%	101.3
	Retail non-food	9.8	15.7%	323.2	17.2%	30.3
	Wholesale food	1.0	1.6%	21.1	1.1%	47.4
	Wholesale non-food	4.0	6.4%	90.8	4.8%	44.1
Hotels and Restaurants	Hotels	4.1	6.5%	49.5	2.6%	82.8
	Restaurants	8.1	12.9%	194.7	10.3%	41.6
Total		**62.6**	**100%**	**1882.1**	**100%**	**53.3**

Source: data from Schlomann et al. [25] & DeStatis [27].

Our data was collected in each enterprise via a telephone interview (CATI, computer-assisted telephone interview) with the person in charge of energy issues. The interviews were conducted between May and July 2017 with the help of a market research institute (GfK Germany). We could utilise the experiences from a preceding qualitative study based on interviews with stakeholders like aggregators, energy suppliers and associations of the selected subsectors about DR potentials in the service sector (cp. Wohlfarth et al. [20]) to design the interviews in this study. We did not yet know much about the status quo of DR actions from the perspective of the enterprises, how prepared they were for DR and their level of information. Thus, we chose low entry points within the survey, starting with questions on the awareness of DR in general and going deeper into the conditions facilitating DR, specific options to conduct measures, and experiences with DR. Before asking about the willingness to conduct DR measures, a short scenario was described in which those measures were explained briefly (cp. Appendix). Since manual control of single cross-sectoral appliances within companies was considered unrealistic to tap into potentials in the future, the scenario specifically explained automated, externally controlled DR measures: The appliances would automatically adjust their consumption to meet the requirements of supply, load and grid stability. The appliances would therefore be upgraded to be externally controllable, and the costs of the control technologies would be covered (e.g. by a service provider), if these did not already exist. In case of emergency the company could always interfere and return to manual control.

In the basic population of the service sector, small enterprises with fewer than ten employees make up the largest share of companies in each sector [27]. Following this quoting criterion, we categorized the companies based on the number of employees into small, medium and large enterprises and tried to ensure a sufficient subsample for each subsector to allow evaluations within each category. This means that we intentionally decided to assess a quoted sample instead of a random or representative sample regarding the shares of companies of different sizes. To be able to also draw conclusions for the whole sectors, we extrapolate the numbers to the actual shares of companies by weighting them to fit the disproportional structure of the data to the distribution of the population [27]. The weighting procedure we therefore applied was developed by the GfK Germany based on the linear weighting approach of Cassel et al. [28] to optimize the distribution for number of employees and subsector. We assumed that medium and large enterprises would be the companies most interested in and most suited for conducting DR.

Before processing the survey results, we cleaned the data on the parameters of available appliances for erroneous values using the outlier labelling method [29]. This procedure is able to detect highly unlikely values in normally distributed data. As is typical for energy related parameters [25] our data showed an asymmetric distribution. We therefore analysed each subsector separately to minimize heterogeneity. To account for individual company size, we divided the parameters through the number of employees in each company. We then normalized the data using log-transformation and excluded the answers that were detected as outliers. Some companies reported the availability of certain flexible appliances but could not answer the questions on their parameters (like size of the appliance or concerned size of area). We therefore used the median of other answers within the same subsector and size to substitute missing values for each appliance (the percentage of substituted values ranged from 12-28%). Three cases were deleted completely from the dataset because of multiple missing or highly implausible values. Table 3 shows the structure of our final sample containing 1584 complete datasets:

Table 3: Sample of companies from the service sector

Subsector	**Size**	**Small (1-9)**	**Medium (10-49)**	**Large (50 and more)**	**Total**
Offices	Offices	147	266	262	**675**
Retail/ trade	Retail food	32	71	30	**133**
	Retail non-food	71	72	30	**173**
	Wholesale food	35	45	21	**101**
	Wholesale non-food	42	57	47	**146**
Hotel, restaurants	Hotel with restaurant	30	75	22	**127**
	Hotel	31	12	2	**45**
	Restaurant	68	93	23	**184**
Total		**456**	**691**	**437**	**1584**

Categories of company size based on number of employees

Hotels of a certain size usually also have a restaurant, thus the category of large hotels without a restaurant is very small. We therefore only present indicative results and no statistically reliable data for this category.

2.1. Evaluation of demand response potentials

As the first part of the study we estimate the potentials for each subgroup, using data on the availability of flexible appliances to estimate their electricity consumption. Following Wohlfarth et al. [20] on their classification of appliances that allow flexible consumption, we included ventilation, air conditioning, cooling and freezing besides electric water heating, night storage heaters and heat pumps in our estimations.

As described above, we distinguish theoretical, technical and practical DR potentials. The theoretical potential refers to the extrapolation of the estimated energy consumption caused by the flexible appliances (cp. Table A.1, appendix, for the parameters of consumption data per appliance). The technical potential depends on assumptions about the load, frequency and duration of use of a certain appliance for DR purposes, based on Klobasa [15]. Table A.2 shows the assumptions on technically applicable duration and frequency of usage for the considered appliances and the resulting flexible shares of appliance-specific consumption. Weather conditions are taken into account reflected by the duration and frequency of shifts. To take uncertainty of assumptions and variation into account a sensitivity analysis was conducted, which reports magnitude of changes (cp. Table A.3). In addition to the technical potential, we estimate the practical potential referring to the share of companies willing to conduct such measures (cp. Table 5). The calculation of these potentials is transferrable to other sectors or countries to estimate the flexibility potential of cross-cutting appliances, as long as data on their availability and parameters of dimension are available. This bottom-up approach allows the estimation of potentials on the resolution of appliances and sectors and is different from methods estimating the DR potential based on load profiles, electricity usage records or building energy modelling (cp. Curtis et al. [30]). The practical potential additionally requires data on the willingness to use the appliances for DR purposes. Both (availability of flexible appliances and the willingness) varies between sectors and countries [18] and requires a respective assessment.

The following equations for each potential present the comprehensible bottom-up approach using empirical data on available appliances. It avoids complex and sophisticated modelling, but still provides detailed results on the potentials of specific flexible appliances, subsectors and company sizes directly incorporating the viewpoint of the end-users.

Theoretical potential

The theoretical potential corresponds to the total demand of all flexible appliances considered. It is calculated by adding up the consumption of all the available flexible appliances in the companies, based on data from the questionnaire and the respective average consumption parameters shown in Table A.1. The theoretical potential is the upper limit of the flexible potential and equals the total consumption of all the flexible appliances.

$$P_{theo} = \sum_{1}^{i,n} a_{i,n} * m_{i,n} * p_i \qquad \text{(Equation 1)}$$

Technical potential

The technical potential refers to the share of the theoretical potential that can be used flexibly without omitting the actual function of the appliance. Besides technical restrictions to not damage the application, this means weather conditions or staff comfort further limits the usage of the appliances. All of this is reflected by the assumptions about frequency, duration and ratio of shiftable consumption and maximum load, taken from Klobasa [15]. The flexible shares are calculated for each of the flexible appliances (cp. Table A.2), assuming only one or two hours of flexible consumption per day for most of the appliances. The technical potential is strongly dependent on these assumptions, e.g. calculating two hours of availability instead of one doubles the potential. Our estimations can therefore be considered conservative. A sensitivity analysis for our results using higher flexible shares is provided in the appendix (cp. Table A.3, for adjustment of assumptions cp. Table A.2).

$$P_{tech} = \sum_{1}^{i,n} P_{theo,i,n} * l_i \qquad \text{(Equation 2)}$$

Practical potential

The practical potential is the sum of the technical potentials of those companies willing to conduct DR. In contrast to the technical potential, the practical potential is not just a share of the technical or theoretical potential, but the total technical potential of a share of the companies. As this share differs between the subgroups of companies, we sum the potential over these subgroups using the average willingness in each subgroup. The "willingness share" is thus used on each subsector and size cluster so the sample weighting is still valid.

$$P_{pract} = \sum_{1}^{s} P_{tech,s} * w_s \qquad \text{(Equation 3)}$$

n = company of the sub-/sample [1; N]
i = kind of appliance (ventilation, air-conditioning, ...)
$m_{i,n}$ = indicator of magnitude measurement of appliances (e.g. space of cooling room or air-conditioned area)
p_i = specific average electricity demand parameter of appliance i per indicator of magnitude (cp. Table 11)
a_i = availability of appliance i [0; 1]
l_i = specific load management share of appliance i (cp. Table 12)
w_s = specific average of willingness for DR within a subsector/ size cluster s
s = cluster of subsector and size

In the cases of electric water heating, night storage heaters and heat pumps, our survey data did not contain enough viable cases for extrapolation: night storage and heat pumps are rare, so data would not have been reliable. While a sufficient number of enterprises stated they would use electrical water heating, only a few were able to estimate their daily demand for warm water. The potentials for ventilation, air conditioning, cooling and freezing are therefore reported in detail, whereas the potentials for electric water heating, night storage and heat pumps are estimated with the help of other studies. The electricity consumption for water heating is taken from Schlomann et al. [25], applying the assumptions of flexibility shares from Klobasa [15] and the assumption of Stadler [31] that only 25% of the consumption can be used for DR, to estimate the technical potential. For night storages the consumption for the service sector in Germany is taken from Klobasa [15] and adjusted to the assumption that the selected subsectors account for 60% of the electricity consumption that is used for heat generation in the entire service sector [32]. Since heat pumps are not included in the study by Klobasa [15], their consumption for the sector is taken from Kleeberger et al. [33] and again adjusted to the share of our selected subsectors (60%) using the assumption from Wolf et al. [32]. The flexible share of heat pumps is estimated by transferring the parameters from Agora [7] to the respective data of our subsectors.

2.2. Factors influencing the willingness to conduct demand response

In the second part of the results, we investigate the relevance of factors influencing the probability of conducting or implementing DR measures, i.e. the willingness to conduct DR measures and the prioritisation of DR issues in the managerial department of enterprises. Most theories on motivation and decision-making are based on the confluence of different influencing factors, e.g. presumed probabilities, the valuation of results and the relevance of different motives. These approaches are comparable to a cost-benefit analysis in the broadest sense, which is not necessarily based on rational reasoning and they presume that the perceived benefit of effort and the valences of alternatives result in an intention of action (cp. the expectancy-value theory [34] and expectancy theory [35], theory of planned behaviour [36]). The latter describes intentions as the result of an interaction between different influencing factors like norms, attitudes and perceived control of the results. We relate to these theories for the compilation of barriers, driver and other “soft factors” that are explored regarding their influence on the target variables. The “soft factors” in our case include the responsibility for energy related decisions and prior experiences with energy issues, which complement the more technical factors in the first part of the results (cp. Table 5). The target variables are the intention to implement measures, i.e. the willingness to conduct DR, and the general interest in dealing with DR, i.e. making DR a priority for management. We conduct regression analyses (Eq. 4) to determine the relevance of each influencing factor.

$\hat{y}_i = a + \sum_j \beta_j \cdot x_{i,j}$ (for i = 1, …, N and j = number of predictor variables) (Equation 4)

Where $\hat{y}_i$ represents the estimated value of the outcome variable, $x_{i,j}$ the predictor variables, β_j are the weighted factors belonging to the predictor variables and a represents a constant.

Regression analyses are statistical methods to quantitatively estimate the relationship between a criterion variable and one or more predictor variables. They are used in particular when values of the criterion variable are to be predicted or to understand how the typical value of the criterion variable changes when any one of the predictor variables is varied. Since decades there is an ongoing controversial debate about the appropriate usage of regression procedures on Likert-type or ordinal data [37,38]. We opted for a parametric test procedure in the form of multiple linear regression. While we are assessing items that were measured on a 5-point Likert-type scale, which are not continuous from the viewpoint of measurement theory, parametric test procedures, especially for large sample sizes, have proven to be 'extremely' robust against this violation of prerequisites [39]. Even in the case of single Likert-type items [37,40]. In order to avoid artificial dichotomisation of variables that would be needed for non-parametric tests and can lead to distortion of the results [41], we chose a linear regression method, which also preserves loss of statistical power.

Our criterion variables are the willingness to conduct DR measures and the prioritisation of DR. The willingness describes a rating of the feasibility. The prioritisation indicates the general interest in the issue, i.e. if management is willing to pursue the issue by weighing up the pros and cons. Both these variables influence decision-making. The predictor variables comprise drivers and barriers, former experiences with energy issues such as audits, and whether the company itself is responsible for energy related decisions.

The set of items covering barriers to and drivers of DR are arranged based on the existing literature on barriers to energy efficiency and adjusted for our purpose. We especially refer to the work of Sorrell et al. [42,43] and Cagno et al. [44]. When selecting items, we use the common distinction between economic, behavioural, organisational and informational barriers and drivers. The mentioned authors express the categories of items in general terms, so it can be assumed, that they can be transferred from the energy efficiency context to DR, since DR measures are related to investments in energy issues, influence energy consumption patterns and are linked to energy-consuming appliances in the enterprises. We therefore assume that comparable decision criteria and persons in charge are involved. However, because DR is much less well established than energy efficiency, we added items on the general attitude towards DR. As we already knew about the unfavourable (external) regulatory conditions, we focus mainly on internal barriers in the enterprises, to incorporate the needs of the end-users. The final set of barriers and drivers is shown in Figure 1, the respective questions from the survey can be found in the appendix.

3. Results

3.1. Conditions and status quo of demand response options

Besides the political framework described in the introduction, internal issues in the enterprises come into play when evaluating the options to conduct DR. The following sections deal with aspects that describe and influence the current conditions under which the DR potential is to be tapped into. These include the level of information about, and adoption of DR, i.e. to what degree the enterprises have already dealt with DR. They further include technical options, i.e. the availability of flexible appliances and control systems. Other important aspects outlined in the following are the general willingness to conduct DR, estimates of the potentials, the preferred appliances to be used for DR, and the perceived barriers and drivers preventing and promoting DR within the companies.

3.1.1. Status quo of demand response, knowledge and openness

Given the existing restrictive regulatory conditions and the fact that the service sector has barely been addressed on DR so far, it was to be expected that companies might not have dealt with DR yet. Table 4 shows that indeed over 90% of small companies have not heard about DR or have not (yet) taken action. In contrast, however, over 30% of large companies are already conducting DR or have examined options to do so. If a company is categorised as already conducting DR, this includes: optimized energy purchasing, time variable tariffs, load shedding, participation in balancing markets, or agreements on load cut-offs. Most of the companies conducting DR stated they do load shedding (about 60%), followed by optimized purchasing and time variable tariffs (each with about 30%, multiple answers possible).

Table 4: Experiences in demand response in the service sector

size of enterprises (n)	Never heard of DR	Heard about, but no action	Checked DR options	Conduct DR
small (456)	42%	49%	6%	3%
medium (691)	40%	41%	13%	6%
large (473)	26%	39%	20%	14%
Weighted total	42%	48%	6%	4%

We also found differences between subsectors (see Table A.4 appendix): Restaurants and hotels with restaurants conduct DR most often with 18 and 11%, respectively. In hotels without restaurants, DR is less common. Over 10% of food retail companies and 17% of hotels with restaurants have already checked DR options. The share of the other subsectors that conduct DR is about 4%; the share of those that checked DR options varies between 5 and 8%. Generally, larger companies and those operating restaurants or trading with food seem to be the most involved in DR so far. The numbers of companies for the whole sector that deal with DR tend to be low because of the large share of small companies within the subsectors.

3.1.2. Evaluation of demand response potentials and target groups

Since the service sector is not yet integrated in the usage of DR, our interest lies in its future potentials and in identifying the most promising companies to approach for an intensified rollout of DR in the sector. Our evaluation of the potentials for possible target groups (companies from different subsectors and of different sizes) integrates multiple aspects: the technical potential given the available flexible appliances, facilitating factors like control technologies (e.g. building management system BMS) and the willingness to participate in DR. The willingness to participate is of particular interest, because it distinguishes the technically available potential from the realistically usable potential (practical potential). The column "willingness" in Table 5 includes those companies that already conduct DR and those who stated they are generally willing to participate in the future. Due to the currently low incentives and level of information, the willingness could improve in the future, especially once DR is more established and profitable. The controllability indicates the share of companies that are particularly easy to integrate in automated DR measures due to preinstalled control-systems. For the calculation of the practical potential we do not include the controllability however, since an available BMS facilitates the use of appliances for DR today, but could also be acquired in the future if the respective companies are willing to participate.

Table 5 lists the results of our survey data on available appliances, average technical potential, readiness and controllability for companies of each subsector and size category. Overall, enterprises with restaurants and the subsectors food retail/wholesale seem to be the most eligible for future automated DR taking the willingness, control technologies and availability of flexible appliances into account. As mentioned earlier, these are also the type of companies most likely to be currently involved in other DR options.

Across all sectors larger companies proof to exhibit higher theoretical potentials, are more likely to possess control-technology and usually demonstrate higher willingness for automated DR. For small companies the average potential per company is comparatively small; due to their large number, however, their accumulated potential should not be neglected.

Table 5: Evaluation of target groups for demand response – appliances, theoretical potential, readiness and controllability

Sector (n)	size	**Share of companies with flexible appliances**						**Theoretical Potential (MWh)**	**Readiness**	**Controllability**
		ventilation	AC	fridges	freezer	Cooling room	Freezing room	Average per company	Willingness automated DR	BMS available

Offices (675)	S	7%	18%	0%	0%	0%	0%	0.77	12%	5%
	M	19%	39%	29%	14%	14%	0%	6.42	19%	11%
	L	25%	59%	24%	24%	28%	24%	59.20	29%	33%
Retail food (133)	S	25%	25%	41%	30%	44%	15%	18.98	13%	14%
	M	56%	45%	54%	42%	71%	58%	139.99	39%	32%
	L	53%	57%	67%	71%	81%	62%	1246.20	62%	65%
Retail non-food (173)	S	9%	17%	6%	0%	4%	0%	7.86	19%	5%
	M	17%	42%	7%	4%	4%	4%	10.03	18%	4%
	L	43%	70%	4%	0%	4%	0%	104.00	31%	39%
Wholesale food (101)	S	11%	6%	17%	17%	24%	21%	59.64	9%	6%
	M	20%	24%	23%	10%	54%	26%	115.17	23%	28%
	L	33%	48%	29%	12%	71%	29%	672.75	48%	25%
Wholesale non-food (146)	S	2 %	17%	3%	0%	3%	0%	3.15	12%	5%
	M	18%	42%	7%	0%	7%	0%	14.15	18%	8%
	L	43%	81%	11%	3%	8%	3%	376.36	37%	25%
Hotel with restaurant (127)	S	57%	13%	43%	30%	33%	13%	12.60	43%	4%
	M	71%	29%	65%	62%	76%	53%	105.83	47%	16%
	L	68%	68%	36%	32%	73%	64%	257.93	73%	35%
Hotel (45)	S	10%	0%	3%	7%	0%	0%	0.83	6%	0%
	M	42%	67%	33%	42%	33%	0%	25.55	42%	18%
	L*									
Restaurants (184)	S	62%	15%	43%	31%	50%	24%	16.21	31%	9%
	M	71%	29%	67%	56%	70%	53%	54.88	35%	15%
	L	74%	52%	87%	78%	87%	66%	148.60	73%	48%

Abbreviations: S = small (up to 9 employees), M = medium (10 – 49 employees), L = large (50 employees and more); BMS = building management system; AC = air-conditioning; * = few data available

Table 6 summarises the weighted estimated theoretical, technical and practical flexible demand potentials of the subsectors and appliances. As already described, the practical potential is calculated via the willingness to conduct DR under the current technological and market conditions. This could be much closer to the technical potential if incentives were given and DR became more common and widespread. Again, restaurants and retailers (food) seem to be the most promising subsectors. The differences between the theoretical and technical potentials for each appliance reflect the assumptions behind the definitions: While the large number of ACs consume more electricity in sum than cooling rooms, their technical potential is smaller due to their technical restrictions (i.e. a smaller share of flexible load). Taking these restrictions into account, cooling rooms, followed by fridges and ACs have the highest technical potentials (more than 1 TWh in sum).

Table 6: Theoretical, technical and practical flexibility potentials per subsector and appliance in GWh

Theoretical potential Technical potential	ventilation	AC	fridges	freezer	cooling room	freezing room	**Total theoretical potential**	**Total technical potential**	**Total practical potential**
Offices	650.2 26.37	1551.79 108.62	53.18 6.7	11.45 1.46	17.70 2.34	9.15 1.21	2293.55	146.7	32.06
Retail food	402.7 16.31	653.40 34.85	695.47 87.62	333.70 42.05	1006.82 133.63	207.26 27.56	3299.08	342.02	127.70
Retail non-food	547.03 22.19	2202.95 117.49	96.19 12.12	2.75 0.35	57.61 7.64	5.37 0.71	2911.90	160.5	31.82
Wholesale food	70.22 2.85	95.32 5.09	264.28 33.29	180.72 22.76	1000.17 132.76	331.49 44.0	1942.20	240.75	55.24
Wholesale non-food	174.66 7.08	752.27 40.13	196.46 24.75	64.28 8.1	798.81 106.02	64.28 8.53	2050.76	194.61	64.56
Hotel with restaurant	73.40 2.97	98.40 16.53	315.99 39.82	240.60 30.31	116.93 15.53	74.71 9.92	920.03	115.08	59.77
Hotel *	30.88 1.25	15.07 2.53	4.84 0.56	11.84 1.49	3.67 0.49	0 0	65.93	6.32	2.23
Restaurants	324.32 13.16	190.77 25.95	1447.25 182.33	681.08 85.8	727.92 96.62	249.59 33.13	3620.94	436.99	145.95
Total	2272.77 92.18	5559.95 351.19	3073.31 387.19	1526.52 192.32	3729.63 495.03	942.22 125.06	17104.40	1642.97	519.34

Theoretical potential: sum of consumption of available flexible appliances (top digit in each cell); Technical potential: flexible share of the technical potential, considering frequency, duration and ratio max. load/ total consumption (bottom digit in each cell); Practical potential: technical potential, restricted to the companies that show willingness to conduct DR measures; * = few data available

As mentioned above, the potentials calculated through our survey data do not include the flexible appliances electric water heating, night storage heaters and heat pumps. Referring to data from other studies, we estimated the potentials for these appliances in our selected subsectors (see Table 7).

Table 7: Potentials for further flexible appliances (GWh)

Appliance	Subsectors	Availability of appliance	**Theoretical potential**	**Technical potential**	**Practical potential**
Electric water heating	Offices	34%	900	112.46	14.39
	Trade	42%	700	87.48	15.13
	Hotel/ restaurant	23%	1300	162.46	51.66
	Total (Offices, trade, hotel/ restaurant)	35%	2900	362.36	81.18
Heat pumps	Offices, trade, hotel/ restaurant	2%	298	18.35	3.02
Night storage	Offices, trade, hotel/ restaurant	1%	1785	1785	294.53
Total			4983	2165.71	378.73

Consumption of appliances/ technical potentials taken from Schlomann et al. (2015) - water; Kleeberger et al. (2016) and Wolf et al. (2016) – heat pumps; Klobasa (2007) and Wolf et al.(2016) – night storage

Klobasa [15] assumes that the theoretical potential of night storage heaters could (technically) be used to 100%, resulting in a technical potential of more than 1.7 TWh. However, this potential might be overestimated given that less than 1% of our sample uses night storage heating.

3.1.3. Preferred appliances

Besides the general statements on the willingness to use DR and the availability of technologies and appliances, we also asked questions about the acceptance of DR for specific appliances. We evaluated the appliances that are already integrated in DR and those that are potentially suitable for automated DR from the viewpoint of the companies. Thus, the results on preferred appliances refer to the subsample of companies that are willing to conduct DR and have suitable appliances.

For the flexible appliances listed above, ventilation, AC and refrigeration rooms account for more than 50% of all appliances currently used for DR. Cooling and refrigerating devices are also used, but to a slightly smaller extent. Heat pumps also seem suitable for DR, but are rarely available compared to the other appliances at present. Their relevance will probably increase in the next decades [45]. Regarding the appliances rated as utilisable for DR, the results are comparable to those for appliances already used for DR: more than 50% of the companies that are generally willing to conduct DR rate ventilation, AC and cooling devices as utilisable. With regard to cooling and refrigeration appliances, cooling is generally considered less problematic for DR than refrigeration, and cold and refrigeration rooms seem more feasible for DR than cooling or refrigeration devices. Only a few companies stated that none of their appliances could be made available for DR.

3.1.4. Barriers to and drivers of demand response

For the barriers and drivers towards DR the participating companies were asked to rank statements about DR on a 5-point Likert-scale (1: disagree strongly, 5: agree strongly). Figure 1 shows the weighted means over all company sizes and subsectors. The future importance of DR is the highest ranked driver, which supports the assumption that interest in DR is rising along with its future relevance. However, as today DR is still uncommon in the service sector and financial benefits are low, companies currently rate the low profitability of DR as the most important barrier, while rating the high priority of DR as an unimportant driver. The companies also disagree on perceiving positive image effects for participating in DR measures. This emphasises the importance of improving the attractiveness of measures to raise awareness. The risk of disruption to processes is ranked rather low in the service sector, which could positively influence the acceptance of DR measures.

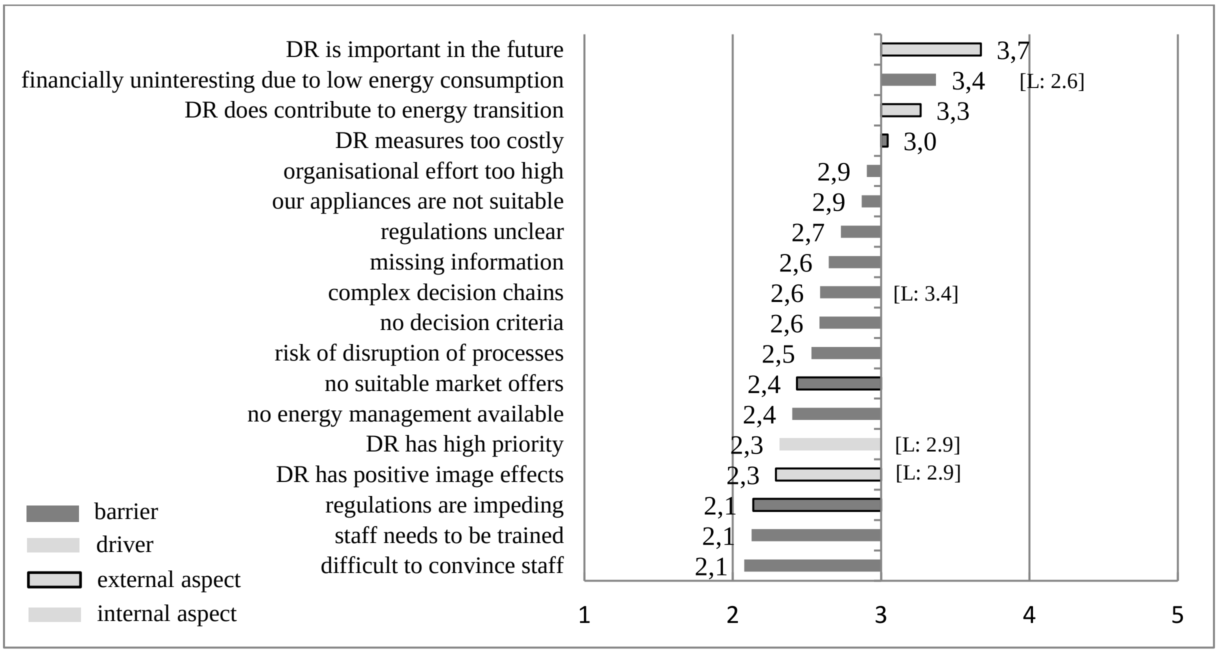

Fig. 1. Rating of barriers with respect to DR (weighted mean: 1 = disagree strongly, 5 = agree strongly)

We found differences between company sizes regarding the barriers. As a consequence of the weighted means (cp. section about data and methods), the figures are dominated by the larger share of small companies. For all significant differences between large (L) and smaller companies, the mean rating of the large enterprises is reported in brackets in Figure 1. It can be observed, that smaller companies (up to 10 employees) rate the barrier of low relevance due to low energy costs significantly higher and the priority of DR significantly lower than larger enterprises. This seems reasonable, since smaller companies consume less energy, which also implies a lower profitability of measures compared to large companies. In addition, smaller companies rate image effects as less relevant than large companies do. Their smaller potentials are probably less utilisable for advertising purposes. Lastly, larger enterprises rate the barrier of complex decision chains higher than small companies do. An explanation for this effect can be seen in the higher complexity of corporate structures of larger companies and the involvement of more people in decision-making processes compared to small companies.

Differences between subsectors are particularly apparent concerning low relevance/energy costs and prioritisation: Companies from the subsectors offices or wholesale seem to be more sceptical compared to those from the subsectors trade or restaurants. Offices and wholesale also state a lower willingness to conduct DR compared to hotels/restaurants. Companies with restaurants rate the aspect of image effects higher than companies of other subsectors, maybe due to their close relationship with customers as every guest is served individually and in person.

3.2. Factors influencing the willingness to conduct demand response and the priority of demand response

While the general existence and ranking of barriers and drivers is an important starting point to understand what aspects are prevalent in the perception of DR from the viewpoint of companies in the service-sector, it remains unclear what consequences this perception has. Thus, to take a more detailed look at the influence of such non-structural aspects (“soft factors”) like the barriers or drivers, it is necessary to relate them to a practical feasibility rating (i.e. the willingness to conduct DR) in order to discover more about the conditions needed to facilitate DR action. For being able to help raising awareness for DR and to address applicants, that are especially interested in DR, it is also important to know, how DR becomes a priority in the management department of companies, i.e. how soft factors influence the prioritisation of DR.

In order to identify influential soft factors on the willingness to conduct DR and the prioritisation of DR, we conducted linear regression models with a set of soft factors as predictor variables. These include the drivers and barriers (cp. Figure 1) as well as the question if companies conducted energy audits in the past and if decisions on energy related issues are of internal or external responsibility.

As the results in Table 8 show, the general perception that DR contributes to the energy transition and has future relevance, positively influences the willingness to conduct DR. Rating appliances not suitable for DR negatively influences the willingness to conduct DR measures. Low energy costs reduce the willingness if they make investments in DR uninteresting. The same is true for the perceived risk of disruption to working processes through DR. None of the other variables had significant influence on the willingness to conduct DR measures.

Table 8: influencing factors on the willingness to conduct demand response measures

Outcome variable	**Predictor variables with significant influence (ß)**		**Model quality**
Willingness to conduct DR	Important contribution to energy transition**	(0.133)	F(20)=5.95***
	Appliances not suitable**	(-0.132)	R^2=.15 (.13)
	Financially uninteresting due to small energy costs**	(-0.115)	
	Risk of disruption to processes*	(-0.089)	

Level of significance: * = p<.05; ** = p<.01; *** = p<.001; Model quality: R^2, coefficient of determination: the proportion of the variance in the criterion variable that is predictable from the predictor variables

As the rating of willingness as well as the perception of barriers and drivers vary between different company sizes (cp. Table 5 and Figure 1), it is to be assumed that the influencing factors differ within subgroups of company sizes. Table 9 therefore shows the results of the regression for small and medium-sized companies vs. large companies. The following differences are found: In large enterprises, the only factor that significantly influences the willingness to conduct DR measures is the perception of not having suitable appliances for DR. While this factor also negatively influences the willingness in smaller companies, in this group other factors also have influence: the perception of DR as financially uninteresting due to small energy costs negatively influences the willingness to conduct DR measures, whereas the perception of DR as an important contribution to energy transition improves the willingness to participate in DR measures. This could indicate that small companies follow their values or act with conviction when deciding whether to participate in DR measures. The differences between companies of different size in the perception of lacking financial benefits on the other hand, seem to reflect the unfavourable market conditions for small loads.

Table 9: Regression on willingness to conduct demand response - differences between company sizes

Small and medium-sized enterprises (<50 employees)		**Large enterprises (≥50 employees)**	
Outcome variables with significant influence (ß)	**Model quality**	**Predictor variables with significant influence (ß)**	**Model quality**
Appliances not suitable* (-0.118) Important contribution to energy transition* (0.127) Financially uninteresting due to small energy costs* (-0.123)	F(20)=4.07*** R^2=.15 (.11)	Appliances not suitable* (-0.178)	F(20)=2.24** R^2=.17 (.09)

All in all, the rating of barriers and drivers and the influences of soft factors on the willingness to conduct DR measures suggest, that to date especially technical (availability of suitable appliances/considerable energy consumption) and organisational feasibility, as well as existing market offers can be seen as preconditions to putting DR into practice.

Considering the large share of companies that have not even heard of DR, or assessed options for DR, it is of particular interest how to raise awareness for DR, i.e. which variables influence the prioritisation of DR issues at the management level ("DR has a high priority at the management level", rated on a 1-5 scale).

Table 10 shows the influencing variables on the prioritisation of DR, using the same method as applied to the willingness to conduct DR measures. The perception of positive image effects on customers has the strongest influence on this outcome, which means that greater visibility of DR for the customer could act as an additional way to raise awareness in companies of the service sector. Enterprises that already have experience and knowledge about energy consumption (i.e. have already conducted an energy audit in the past) tend to show more interest in DR than enterprises that have not. In addition, if decisions regarding DR are rated as complex, DR issues are prioritised on management level. This effect might occur because DR issues are no routine and therefore can not be decided on lower corporate levels. If DR is associated with high organisational effort on the other hand, the prioritisation of DR is less pronounced.

Table 10: Factors influencing the priority of demand response measures

Outcome variable	**Predictor variables with significant influence (ß)**		**Model quality**
Prioritisation of DR	Positive image effects on customers***	(0.283)	F(19)=9.70***
	Complex decision chains**	(0.128)	R^2=.21 (.19)
	Energy audit conducted**	(0.121)	
	Organisational effort too high*	(-0.094)	

The prioritisation of DR and the willingness to conduct DR measures describe two different decision-making stages. While the former can be seen as interest in possible options, the latter occurs before taking action and indicates the desire to carry out measures. The knowledge about factors that influence both of these stages are valuable for the facilitation of conditions that bring DR on the agenda and incentivise companies to actually take part in DR measures, by incorporating the needs and wishes of the applicants.

4. Discussion

Our results show that, so far, only few enterprises in the service sector are conducting DR. This goes in line with our preceding qualitative assessment, which points to poor incentives as well as unfavourable market and regulatory conditions for DR at present [20]. Companies best prepared, technically equipped and willing to conduct DR are enterprises in the subsector food retail as well as restaurants (with or without an affiliated hotel-business). Across all subsectors, larger companies seem more suitable for DR than smaller ones, regarding the willingness to implement measures, the amount of energy consumed as well as the facilitating conditions and the availability of flexible appliances. Again, these findings are in line with our previous qualitative study and refine the results.

An earlier modelling approach by VDE [16] estimated between 5/9.7 TWh of technical potential for the whole service sector depending on the year of projection (2010 or 2030). Bearing in mind, that the considered subsectors of this study account for more than 50% of electric consumption in the entire service sector while having a particular high proportion of the considered flexible appliances (compared to other service subsectors, cp. Wohlfarth et al. [20]), our results of approximately 3.8 TWh of technical potential seem comparably low. This could be due to our conservative assumptions based on Klobasa [15] of only 1-2 hours of load shift per appliance and day for most of the appliances considered. These cautious assumptions, however, seem appropriate in order to avoid conflicts with comfort aspects or work processes through flexibilisation, preventing overestimation of potentials. As can be seen in the provided sensitivity analysis (cp. Table A.3, appendix), the adjustment of assumptions lead to severe increases in the resulting technical potential. By assuming 2-4 hours of load shift for most appliances (Scenario A) estimations result in approximately 5.5 TWh (approximately 24.8% of theoretical potential) compared to the baseline of 3.8 TWh (17.2%). Additional adjustment of average shift frequency of AC throughout the year (60 days instead of 30, Scenario B) result in 6.2 TWh (27.9%). Our conservative assumptions also become apparent in the comparison to a modelling approach that uses the consumption data provided by our study, to estimate the technically deployable flexibility of the considered subsectors (Wohlfarth et al., under review). The model optimises the scheduling of flexible loads with the objective to smoothen the residual load. This approach is comparable to a real-time-pricing, taking the electricity consumption patterns of the appliances, technical restrictions regarding their flexibility and weather data (e.g. due to their influence on the use of AC) into account. The estimation in the model overall results in technical potentials as high as 7.74 TWh, which equals a share of 35.0% of the underlying theoretical potential in our considered subsectors. For AC in particular, the modelling approach yields higher potentials, even when compared to Scenario B of the sensitivity analysis in this study. This indicates a more extensive use of the technology than 2 hours per day, for 60 days per year on average. For automated DR, this kind of load control can be considered technically feasible, but restrictions in user-comfort are possible when using appliances more extensively.

Besides the quantitative and technical assessment of potentials we also considered influencing “soft factors” (e.g. drivers and barriers of DR) in order to provide insights that enable policy makers to incorporate the needs of the users on the one hand, and to make recommendations for addressing suitable enterprises on the other hand. The ranking of barriers and the differences between company sizes and subsectors generally confirm the observation of the technical preconditions. For example, small companies and technically less suitable subsectors rate the barrier towards DR “lacking financial incentives due to low energy consumption” higher than better suitable and larger companies. Missing image effects of DR as well as worries about high investment costs prove to be dominant barriers to DR in all considered subsectors. Compared to findings on barriers in industry, the positive image of DR on customers has a greater relevance for enterprises in the service sector, assumedly due to their closer relationship to the customers. While profitability of measures always plays an important role, in the service sector economic outcomes seems to be stronger linked to positive image effects on customers, whereas, in industry, preventing product quality losses mostly ensures profitability. In industry, possible interruption of processes due to DR therefore significantly lowers the willingness to implement DR measures [8]. This complicates the integration of energy-intensive core processes in DR measures. In the service sector, the risk of disruption of processes is ranked lower, which supports the assumption that cross-sectoral appliances in this sector are generally less problematic to integrate, as long as the integration is of financial interest for the companies. And while DR is barely used in the service sector today, the companies rate its importance in the future as the highest driver of DR.

Regarding the influencing factors (barriers, drivers and additional soft factors), it can be observed, that the ones ranked highest concerning DR in general are not the ones exhibiting the highest influence on the willingness to conduct DR and on its prioritisation in corporate management. Additionally, the ranking of the most relevant barriers and their influence on the outcomes vary between subsectors and companies of different sizes. These results confirm the findings of Trianni et al. [46], who assume that different barriers occur at different stages of the implementation process and therefore need to be related to the specific situation (e.g. stage of decision-making, company’s size, affected appliances). During the stage of generating interest (cp. regression on prioritisation), responsibility for and previous experience with energy issues as well as possible image effects on customers have significant influence. Technical, financial and organisational aspects (suitable appliances, profitability, undisturbed working processes) on the other hand, are relevant predictors in the case of practical implementation plans (i.e. willingness to conduct DR). This should be taken into account when designing appropriate conditions and policies that adequately meet the needs of the applicants in order to enable a successful rollout of DR measures in the service sector, since raising attention and incentivising early participation are considered crucial for the successful implementation of innovations [47]. Against this background the high importance of customer image for the prioritisation of DR is especially promising since enhancement of visibility seems to be an important aspect in the eyes of the applicants and attracts the initial interest of service companies.

In terms of methodical aspects, our results are based on primary quantitative data gathered using structured interviews with enterprises from the service sector. Compared to online or printed surveys, interviews give interviewees the chance to ask questions or to clarify answers. We therefore expect high data quality. Usually, enterprises with more than 250 employees are defined as large enterprises (cp. EU recommendation 2003/361 [48]). However, because the share of companies with more than 250 employees is rather small in the service sector (especially compared to other sectors, i.e. industry), we defined enterprises with more than 50 employees as large enterprises. This approach helped us to achieve samples within the groups of subsectors and enterprises' sizes that were large enough to allow detailed analyses, while at the same time differentiating adequately between size-categories. We achieved the desired sample size for all groups except the subgroup of large hotels without restaurants, which are generally rare above a certain company-size.

The large sample size in this study also allows drawing representative conclusions about the willingness to participate in DR and the practical potential for the considered subsectors for the current point in time. It should be noted however, that the assessment of the current willingness is an indicator for the intention to participate in DR in the near future, but not necessarily equivalent to the actual number of participants in DR. The factors influencing the willingness can be altered, e.g. the future profitability of DR depends on policy decisions and the future energy system design that determine the value of flexible demand. The high level of detail and the transparency of our calculations allows adjustments if single parameters change e.g. due to improved conditions. This is especially true for the practical potential and the quantitative acquisition of the willingness to participate in DR, which for the service sector, has not been determined before.

Apart from assumptions that framework conditions for DR might become more attractive due to the increasing share of volatile energy sources, predictions on the availability of flexible appliances assume that market penetration of e.g. AC and heat pumps will increase in the future [14,49]. This supposedly results in higher theoretical potentials, even in the face of energy efficiency improvements [16], which in turn has implications for the technical and practical potentials for DR. This emphasizes the need for survey based monitoring of the development in this area and better understanding of the underlying mechanics as well as influencing factors, for which this study provides first insights.

5. Conclusions and recommendations

Demand response (DR), i.e. the adjustment of energy usage on the demand side, is regarded as one promising solution to integrate volatile renewable energy sources into future energy systems. On the example of Germany, this study offers a comprehensive analysis of conditions and potentials for DR in the service sector by providing estimations of the theoretical and technical DR-potentials as well as analyzing drivers and barriers from the viewpoint of the companies and their willingness to engage in DR measures, determining the practical potential.

- Status quo and promising first-movers:
  Only few companies are so far involved in DR, but the results show that cross cutting appliances in the considered subsectors generally provide significant potentials. Potential pioneers that can help to establish DR in the considered sectors could be enterprises that are already willing and equipped and thus well qualified for DR. Especially larger restaurants as well as enterprises from the subsectors food retail/wholesale seem to be eligible for future automated DR while also having the most experiences with current DR options. The most promising appliances to start with are those with a high rate of acceptance for automated control, i.e. ventilation/ air-conditioning (VAC) and cooling/refrigeration.
- Supporting the willingness and prioritisation of demand response measures:
  The willingness to participate in DR-measures and consequently the practical potential is influenced by the perception of corporate operatives. We showed that organisational "soft factors" can influence the willingness for DR-measures and the prioritisation of DR-measures and that different factors are relevant between these two stages.
  - Prioritisation - Image effects and visibility:
    One central insight of this study is that in the service sector customer image acts as an important driver for the prioritisation of DR on management level. Emphasizing the role of DR for the integration of renewable energy sources on the one hand and enhancing the visibility of DR

measures on the other hand could attract more enterprises to engage in DR. One possible implementation of this could be the introduction of a certification label for enterprises that have carried out such measures. Similar to the energy efficiency standards for buildings, the European Commission introduced a "smart indicator" in its EPBD (Energy Performance of Buildings Directive [50]), which rates "the readiness of the building to adapt its operation to the needs of the occupant and of the grid, and to improve its performance". This could be the basis for such a label.

  - Willingness - Profitability and market access:
    While a large share of companies in the service sector have heard about DR options and agree on the future importance of DR, their potentials are often smaller and harder to tap into than those in industry. After all, the profitability of DR measures is considered the most important barrier by the companies but can be influenced by introducing more favourable policies and regulations that integrate and facilitate the marketing of smaller loads. Especially for the large number of small enterprises, which in sum demonstrate significant technical potentials, it is necessary to allow load aggregation with low organizational effort. In turn, improved conditions for load aggregation help to realize potentials, which would otherwise be unavailable.

- Transferability of method and results:
  Our study complements modelling approaches by provides a transparent bottom-up approach to estimate the theoretical, technical and practical potential in the most important service subsectors with a strong empirical foundation. While our study was exclusively carried out with companies from the German service sector, results are also relevant for the rest of Europe and other predominantly service-based societies, since the share of consumption in the sectors is largely comparable across countries. There may be differences regarding the availability of appliances however (e.g. availability of VAC is more dependent on the local climate). Additionally, the willingness to participate in DR and its prioritisation can differ with respect to the current regulatory conditions in the respective country, e.g. if DR is already more common as is the case in Switzerland or the U.S. Due to the transparent bottom-up approach in this study, our results and method can be used to evaluate and compare the potentials between countries. Further assessment of the user perspective and differences in the willingness to conduct DR depending on the regulatory conditions in different countries could additionally contribute to designing policies that optimally incentivise companies to participate in DR measures.

Apart from the magnitude of potentials and the assessment of soft-factors within the companies, further research is needed on the financial incentives required to engage enterprises in DR. Also practical field studies would be helpful in understanding how to integrate DR into working processes and how to dismantle perceived barriers.

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A Appendix

Table A.1: Parameters used to calculate demand

Subsectors	Appliance	Unit	Parameter	Source
All	Cooling room	kWh/m² pa	500	Evans [52]
All	Freezing room		750	Evans et al. [53]
All	Fridges	kWh/m pa	2000	Heinboke [54]
All	Freezer		2000	Steinmaßl [55]
Offices	AC	kWh/m² pa	40	Abela et al. [56]
Retail			110	Menezes et al. [57]
Hotels			35	
Restaurants			50	
Offices	Ventilation	kWh/m² pa	15	Benke & Leutgöb [58]
Retail			30	
Hotels			15	
Restaurants			30	

Table A.2: Flexibility parameters per appliance

appliance	duration of shift in h[a]	frequency of shift per year[b]	resulting flexible share[a,b]
Ventilation	1(2)	365	4.1 % (8.1%)
AC Offices	1(2)	30[60]	7.0 % (14.0%) [28.0%]
AC Retail	1(2)	30[60]	5.3 % (10.6%) [21.2%]
AC Hotel	1(2)	30[60]	16.8 % (33.6%) [67.2%]
AC Gastro	1(2)	30[60]	13.6 % (27.2%) [54.4%]
Fridges	2(4)	365	12.6 % (23.2%)
Freezer	2(4)	365	12.6 % (23.2%)
Cooling room	2(4)	365	13.3 % (26.6%)
Freezing room	2(4)	365	13.3 % (26.6%)
Heat pumps	1.5(3)	365	6.2 % (12.4%)
Electric water heating*	12	365	12.5 %
Night storage	16	90	100 %

Sensitivity analysis: a = preconditions for Scenario A with increased shift-duration (adjustment and resulting flexible share in parenthesis); b = preconditions for Scenario B with additional increase of shift-frequency for AC [adjustment and resulting flexible share in square brackets]. *According to Stadler ([31], p.63) only 25% of the electricity demand used for electrical water heating can be used for DR purposes. Thus, we reduced the calculated flexible share by 75%.

Table A.3: Sensitivity analysis for the technical potential

appliance	Theoretical potential	Technical potential (used data. baseline)	Scenario A (increased duration)	Scenario B (+increased frequency)
ventilation[a]	2272.8	92.2	*184.4*	184.4
AC[a.b]	5560.0	351.2	*702.4*	*1404.7*
fridges[a]	3073.3	387.2	*774.5*	774.5
freezer[a]	1526.5	192.3	*384.6*	384.6
cooling room[a]	3729.6	495.0	*990.0*	990.0
freezing room[a]	942.2	125.1	*250.0*	250.0
heatpumps[a]	298.0	18.3	*37.0*	37.0
WW & NS	4685.0	2147.4	2147.4	2147.4
Total	**22087.4**	**3808.7 (17.2%)**	**5470.2 (24.8%)**	**6172.6 (27.9%)**

WW & NS = Electric water heating and night storage. Scenario A = increased shift duration (doubled); Scneario B = additional increase of shift frequency (doubled, for AC only). The exact adjustments are shown in Table A.2. Percentages in brackets refer to the respective share of the total theoretical potential.

Table A.4: Experiences with DR in the subsectors

Weighted share of enterprises	Never heard of DR	Heard about, but no action	Checked DR options	Conduct DR
Offices	41.3%	51.2%	5.8%	1.6%
Retail food	53.6%	31.1%	10.6%	4.7%
Retail non-food	38.0%	51.8%	6.0%	4.3%
Wholesale food	47.4%	42.0%	5.5%	5.0%
Wholesale non-food	45.0%	44.2%	7.5%	3.3%
Hotel with Restaurant	34.3%	30.6%	16.8%	18.2%
Hotel	37.1%	56.2%	6.7%	0.0%
Restaurants	48.2%	35.0%	6.4%	10.5%

Excerpt from the questionnaire:

Questions about "Soft factors":

Introduction to load management:

The following questions deal with so-called "load management".

Load management refers to the possibility of controlling one's own electricity consumption in such a way that electricity costs can be reduced and consumption peaks avoided. This is possible because electricity is consumed primarily when it is cheap.

There are now technologies that can control devices and systems automatically. Appropriate tariffs or agreements can also be arranged with grid operators.

Have you ever heard of this?

- Yes
- No
- Not specified

Willingness:

Imagine the following scenario: Your devices or systems could be automatically adjusted in their power consumption. For this purpose, the devices would be equipped with a control technology so that, for example, your electricity network operator can reduce the performance of the devices in certain time windows. If electricity is expensive, devices such as air conditioning, cooling or ventilation systems or even electric heaters would not run at full power.

There are no additional costs for control technology. In an emergency, your company could return to internal control at any time.

Would this form of load management generally be an option for the devices or systems in your company?

If necessary: The systems are not damaged, operational exceptions/interventions are possible and legal concerns are sufficiently considered (e.g. legally prescribed temperature ranges are adhered to, product quality remains guaranteed, insurance protection exists etc.).

- definitely not
- rather not
- perchance
- rather yes
- definitely yes
- not specified

Drivers and Barriers

In the following I'm going to read out various statements. Please first tell me each time how strongly you think these statements apply to energy efficiency measures. Second, please tell me how much these statements apply to load management.

Please answer on a scale from 1 to 5, where 1 means "strongly disagree" and 5 means "strongly agree". With the values in between, you can gradate your opinion. (List was randomized and interviewer was instructed to specifically ask about energy efficiency measures or load management after the statements to avoid confusion)

- In general, it makes an important contribution to the energy transition.
- This topic will become more and more important in the future.
- Because of the low relevance of our energy costs, it is financially not interesting for us.
- It has a positive effect on our image towards our customers.
- We do not have sufficient information about concrete possibilities.
- Existing legal regulations limit our possibilities in implementation.
- For us, an implementation entails the risk of a disruption of operational processes.
- It is difficult to convince our employees of it.
- Implementation requires complex internal decision-making processes.
- Our equipment and systems are not suitable for this purpose.
- We lack an energy management system for implementation.
- Our employees would require extensive training on the subject.
- The implementation would be too expensive for us.
- We do not have any suitable evaluation criteria in our company that would make it easier for us to decide on such measures.
- We do not know or are not aware of the legal regulations and rules.
- There are no suitable market offers for us.
- The organisational effort for implementation is too high.
- The topic has high priority for the executives/the management.

Energy Audit conducted

Has your company conducted an energy consultation or an energy audit in the last 5 years?

- Yes
- No
- I don't know, no specification.

Responsibility for energy issues

And who at your location is responsible for decisions relating to energy and efficiency measures such as refurbishments or savings?

- we ourselves
- another company location
- the landlord/lessor
- a service provider on our behalf
- not specified

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