Barriers to Demand Response in the Commercial and Industrial Sectors – An Empirical Investigation

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Abstract

Demand response can be an effective mechanism to balance electricity demand and supply. While there is an increasing research interest in demand response for private households, its realistic potential in industrial and commercial sectors remains largely untapped, with limited research on the barriers hindering adoption. This study identifies and examines the barriers in industrial and commercial sectors, shedding light on their significance. We conducted 20 semi-structured interviews with experts from German industrial and commercial companies and national industry associations. The most frequently cited barriers encompass concerns about diminished product quality, disruptions to production processes, human resource management, and revenue uncertainty. Despite some recent industrial participation in demand response programs in Germany, our findings suggest that numerous barriers impede widespread participation, which can partly be explained by the heterogeneity of production processes and facilities. Overcoming these barriers entails bridging knowledge gaps and allocating sufficient resources within an organization. Moreover, adapting external incentives and policies may be necessary to encourage widespread demand response adoption. Recognizing these challenges, alongside the underlying motivations and apprehensions, can guide policy makers in devising strategies to support the adoption of demand response among industrial and commercial consumers.

Highlights

- Empirical study on demand response barriers in industrial and commercial sectors.
- Barriers include a lack of profitability and fear of reduced product quality.
- Barrier dimensions categorize and illustrate demand response barrier interrelations.

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- Resources and information are vital for fostering demand response within a company.
- More external incentives and adapted regulations needed to overcome barriers.

Keywords

Demand response, manufacturing industry, commercial sector, qualitative survey, barriers, enablers

Word count

8403

Abbreviations

DR	Demand response
C&I	Commercial and industrial
GWh	Gigawatt hours
T	Technological
I	Information
R	Regulatory
E	Economic
B	Behavioral
O	Organizational
C	Competences
NIMBY	Not in my backyard

1. Introduction

To alleviate the effects of climate change, the reduction of greenhouse gas emissions is of central importance [1]. This has led to ambitious targets of greenhouse gas neutrality in national and international agreements and obligations [2]. Emission reduction efforts include a transition to renewable electricity generation and the electrification of energy demand, for example, in the heat and mobility sectors. The ongoing transformation from centralized and predictable electricity generation to more distributed and volatile generation, which is highly dependent on weather conditions, introduces new challenges of balancing electricity demand and supply, especially on a local level [3]. To manage the growing fluctuations in energy supply and demand, demand response (DR) measures are becoming increasingly important. DR measures

aim to shift electricity consumption patterns in time or quantity in response to a signal (e.g., a monetary incentive) [4]. They can thus help to balance electricity supply and demand [4,5]. Participation in DR measures can take on different forms. Load shifting describes temporary decreases in electricity consumption by interrupting and rescheduling specific processes or appliances to shift demand in time [6]. Load shedding involves temporary decreases in electricity consumption, but without making up for consumption at a later point in time [7]. Another option is a temporary switch from electricity to other energy carriers, such as natural gas, to decrease power peaks while keeping production processes running [8]. In the following, we refer to the time interval in which a DR measure is applied as a DR event.

The industrial sector is with around 40 % of the total electricity consumption by far the largest consumer worldwide, while the commercial sector ranks third with a world average of around 20% in 2019 [9]. In Germany, the industry and commercial sector make up 44% and 27% of the electricity consumption in 2021, respectively [10]. The high shares in electricity consumption also suggest a high technical DR potential. DR programs in the German manufacturing industry are gaining momentum and, compared to other demand sectors, is already involved in demand response programs, especially to provide ancillary services such as frequency control reserve [11] and interruptible loads [11,12]. However, due to various entry barriers, the actual amount of DR participation is small and falls short of the technical potential suggested by modeling studies, e. g. identified by Gils 2014 [13]. Existing DR participation is mainly limited to energy-intensive industries such as paper manufacturing or aluminum electrolysis [14]. Other industrial or commercial sectors have received almost no attention so far [15], even though some studies find considerable DR potentials in this sector [13]. Kirkerud et al. [16] also found DR potentials for space heating and ventilation, and Tina et al. [17] further identified DR potentials for air conditioning in commercial buildings.

Harnessing the technical potential of DR in the commercial and industrial (C&I) sectors requires companies to actively participate in DR programs by adequately reacting to DR signals (e.g., monetary signals). Therefore, it is crucial to identify the drivers and barriers to DR program participation. Most research so far focuses on the residential sector, indicating a range of drivers and barriers affecting households' decisions beyond purely economic considerations [18,19]. For example, a recent review of DR enablers and barriers found that most empirical studies focused on residential DR and thus excluded the commercial sector from the

review [19]. While companies are assumed to assess the costs and benefits mainly from a financial perspective, it is unclear what (other) factors may play a role in their decision-making regarding DR participation. For example, these other factors could include cultural, regulatory or structural barriers [20,21], or participatory and awareness related barriers [21]. Yet, empirical research on DR barriers in the C&I sectors is scarce. Existing research either focuses on the commercial or the industry sectors, often including other stakeholders to form a market or regulatory perspective. Furthermore, previous present research has focused on discrete barrier dimensions to group the identified demand response barriers, without considering possible interrelations between barrier dimensions. Moreover, while private households share considerable homogeneity regarding their electric appliances, C&I consumers are highly heterogeneous regarding electric appliances, production processes, or regulations. This requires empirical research studying industrial DR barriers in different contexts. To the best of our knowledge, no research so far has conducted interviews with C&I consumers and associations all over Germany to identify new demand response barriers and furthermore accounts for interrelations between barrier dimensions.

This study contributes to the literature in two ways: (1) First, we propose a new taxonomy for demand response barriers in the C&I sector, derived from the recent literature that studied relevant barrier dimensions. On the basis of new empirical data, we assess the relevance of each of the derived barrier dimension. Furthermore, we assess the interrelations between the dimensions, meaning that a specific barrier can relate to multiple barrier dimensions. We thereby extend previous research that conceptualized these demand response dimensions as independent from each other. (2) Second, we extend the empirical basis of previous studies by conducting interviews with not only industry companies, but also commercial companies and C&I associations, some of which have so far not been examined, despite their technical potential. Due to the heterogeneity of C&I sectors, we analyze our data using a hybrid deductive-inductive approach. Specifically, we deduced four overarching barrier dimensions from the previous literature, which we used as a guiding framework for the inductive part of the data analysis. This allowed the flexible identification of new specific barriers present in our sample of 20 semi-structured expert interviews with German[1] C&I companies and associations, and at the same time allowed for a better comparability with the barriers identified in other

[1] By focusing on Germany, this study accounts for the regulatory framework of one specific country.

studies. These barriers are allocated to their respective barrier dimension in a new dimension taxonomy that accounts for interrelations regarding barriers that relate to more than one barrier dimension.

Specifically, we aim to answer the following two research questions (RQ).

(RQ1) *What are industrial and commercial companies' perceived barriers to participate in DR programs?*

(RQ2) *Which dimensions can the identified DR barriers be categorized into, and how are they interrelated?*

The remainder of this paper is structured as follows. Section 1.1 of this study provides an overview of the existing literature on DR barriers in a C&I context and outlines a framework for the assessment of barriers of DR participation, proposing four distinct barrier dimensions in Section 1.2. Section 2 presents our research methods, comprising the recruiting of interview participants, the interview structure, and data analysis. Section 3 comprises the results, specifically the barriers identified in the interviews. Section 4 then discusses these results in light of related studies. Section 5 concludes with a summary of the findings and suggestions for practitioners and policy makers to encourage future participation in DR programs.

1.1. A review of demand response participation and barriers in the commercial and industry sectors

A growing body of literature assesses the benefits and challenges regarding the uptake of DR in the C&I sectors. However, the vast majority of these studies adopt a technical or utility perspective [22]. For example, DR benefits and challenges are discussed from a systems perspective for the UK by Strbac [23] and for Finland by Annala et al. [24]. By contrast, Murthy Balijepalli et al. [25] perform a literature review from a smart grid perspective, while Good et al. [26], as well as Nolan and O'Malley [27] classify barriers and enablers regarding DR in this context. Other studies take on a technical perspective and identify industries with high potentials for DR [e.g., 28] or provide an overview of DR enabling technologies, DR types, and the present state of existing international DR programs [e.g., 29]. Gils [13] identifies a technical DR potential of 25 GW in industry and 31 GW in the tertiary sector in Europe. As Dranka and Ferreira [30] show in their review and assessment of DR potential categories, technical DR potential is only one part towards reaching the realistic potential. The latter considers the level of acceptance regarding DR interventions by consumers, which is necessary to realize a

successful implementation of DR programs in practice [30,31]. Nonetheless, studies that take on the DR consumer perspective are so far underrepresented. This is especially true for C&I consumers (as opposed to private consumers) [19].

Going beyond purely technical assessments of DR potential, some initial studies have investigated the barriers that C&I companies might face when it comes to DR participation. Most (though not all) of this work is qualitative and indicates a variety of potential barriers to participation that are described and categorized in different ways. Grein and Pehnt conduct personal and phone interviews with plant operators, research institutes, equipment manufacturers, industry associations, and the statistical offices and administrations in the German city of Mannheim to analyze the DR potential of refrigeration systems, as well as perceived barriers toward participation in DR [32]. Overall, they identify legal, informational, and organizational barriers in addition to technological and economic barriers. The first comprehensive approach regarding the manufacturing industry provide Olsthoorn et al. [33] who examine the industry's perspective by conducting a survey on DR barriers in Southern Germany. In their survey, Olsthoorn et al. distinguish technological, informational, regulatory, economic, behavioral, organizational, and competency barrier dimensions [34].
Cardoso et al. are the first to provide an overview of DR barriers in the commercial sector as a whole [31]. They conduct a literature review on DR barriers by taking on theoretical perspectives from orthodox economics, behavioral economics, organizational perspectives, and social practice theory as a categorization method. They find that a company's small electricity loads combined with a complex internal decision-making process can impede DR adoption and cite hidden costs of participation, issues of bounded rationality and the actual end-use of electricity within the company as identified DR barriers.

A further empirical study by Alcázar-Ortega et al. presents findings from comprehensive stakeholder interviews that adopt a market and regulatory perspective [35]. Based on their interviews, these authors identify and weigh 34 barriers to DR implementation, including regulatory and economic barriers as the most significant barriers. Lashmar et al. [36] present an empirical investigation explicitly focusing on the consumer perspective of C&I companies. Their interview study focuses on C&I companies in Australia that had already enrolled successfully in DR programs [36]. They find that financial benefits are a primary motivation for participation but few consumers associate DR participation with the benefits of providing

balancing services to the system and managing intermittent renewable energy generation. Lashmar et al. conclude that with a growing investor focus on the energy transition, communicating these non-financial benefits could be used as an opportunity to stimulate participation [36]. More recently, Leinauer et al. [37] conducted 16 interviews focused on obstacles to DR faced by industrial companies in Germany. They identify the risk of production process disruption, insufficient revenues and cost savings, legislative contradictions, as well as missing IT standardization and interoperability as the main barriers in their case study. Furthermore, Alasseri et al. [38] underline the factor of regionality in their review of implementation strategies for DR in Kuwait and highlight the need for a study on barriers for DR implementation on a national level.

Several observations can be made about the present literature on DR barriers. Some early studies on DR barriers consist of literature reviews [31] or surveys [33] and do not use interviews to get information about perceived barriers to DR adoption [36]. Surveys often ask for a rating of a given set of options (in this case, different DR barriers) [33] and therefore lack the ability to identify new barriers [36]. Furthermore, due to the lack of an established taxonomy on DR barriers, the early studies on DR barriers draw from the literature on energy efficiency (e.g., Cagno et al. [34] and Sorrel et al. [39]). Although DR and energy efficiency are both part of a company's energy management, there are inherent differences between the two concepts, suggesting that barriers on energy efficiency may not directly apply to DR adoption [36]. Studies that use an empirical approach did not specifically focus on consumers, but also interviewed other stakeholders, such as grid operators, aggregators, retailers, and others not directly belonging to the category of consumers [15,24,35,36]. Studies that conduct interviews focusing specifically on consumers find new barriers, e.g., in the household, industrial, or commercial sectors, thus helping to improve the understanding of DR barriers for consumers [36,37,40–42]. More recent studies, such as Lashmar et al. [36] or Leinauer et al. [37], provide a holistic approach for Australia and Southern Germany, and the C&I or industry sectors, respectively. As regulations and DR programs may differ significantly between countries, these are likely to considerably impact the perceived DR barriers of a study. Furthermore, focusing on companies already participating in DR neglects companies that are holding back on DR participation due to the barriers in question. In summary, barring a few initial studies, research on the barriers to DR in the C&I sectors is still scarce. We therefore build upon the findings of the studies cited in the preceding paragraph. Our study takes both the commercial and the

industrial (i.e., manufacturing) sectors into account by presenting interview findings from 20 representatives from companies and national industry associations in Germany. Based on these interviews, 16 barriers to DR participation were identified, thus broadening the so far scarce literature on factors that impede DR program participation from the perspective of C&I consumers.

1.2. Towards a common framework of demand response barrier dimensions

This study proposes a framework comprising four DR barrier dimensions based on the existing literature with its different attempts to identify and classify barriers to DR participation, as presented in Table 1. The work of Lashmar et al. [36] distinguishes between economic (and market/regulatory), technical, social, and behavioral barriers derived from Good et al., who provide a review and classification of DR barriers from a smart grid perspective [26]. Similarly, Olsthoorn et al. [33] organize their identified barriers into seven dimensions (see Table 1). Leinauer et al. [37] use the same barrier dimensions as Olsthoorn et al. [33] and Cagno et al. [34]. The elaborate barrier dimensions presented by Olsthoorn provide a good overview of different barrier categories. This study proposes similar barrier dimensions, yet group the behavioral and competence barriers into the organizational barrier dimension, since these barriers are inherent to the commercial organization that consists of individuals working together [26]. Informational barriers are also mostly inherent to the organizational dimensions, as individuals make decisions within an organization based on the information that they possess at a certain point in time. This leads to a more parsimonious taxonomy of barrier dimensions comprising (i) economy, (ii) technology, (iii) policy, and (iv) organization. These dimensions are used to identify and categorize the barriers mentioned by our interview participants and briefly describe each dimension.

Table 1. Existing DR barrier dimensions used in literature

Barrier Dimension/ Study		**T**	**I**	**R**	**E**	**B**	**O**	**C**
Olsthoorn et al.	[33]	x	x	x	x	x	x	x
Leinauer et al.	[37]	x	x	x	x	x	x	x
Lashmar et al.	[36]	x		(x)	x	x		
Good et al.	[26]	x		x[a]	x	(x)	(x)	
Cardoso et al.	[31]				x[b]	x[b]	x[b]	
This study		x	(x)	x	x	(x)	x	(x)

T: Technological I: Information R: Regulatory E: Economic

B: Behavioral O: Organizational C: Competences

x: Barrier dimension applied in study

(x): Barrier dimension applied as sub-dimension of another barrier dimension

[a] not belonging to the fundamental barriers, but the secondary barriers, presented in their study (these further include: market structures, physical, and understanding barriers) [26]

[b] Cardoso et al. do not specify the dimensions above in their study, but draw their conclusions from different theoretical lenses [31]. We assigned the perspectives and conceptual barriers of Cardoso et al. to the above dimensions: O:"organizational perspectives", E:"cost related barriers", B:"behavioral economics"

The first dimension *Economy* comprises costs, such as transaction costs or hidden costs and (uncertain) revenues of DR participation [26]. Lashmar et al. find DR barriers such as additional cost, comprising, among others, idle labor, wear and tear on equipment, and updating control systems [36]. Furthermore, both Cardoso et al. and Olsthoorn et al. emphasize the critical role that predictable cost play and that these costs can vary significantly between companies [31,33]. The *Technology* dimension captures risks considering the safe and functioning operation of (production) processes. Olsthoorn et al., as well as Leinauer et al., identify in their study that technical risk is a barrier to DR adoption [33]. Other DR barriers in this dimension comprise the risk of lower product quality, high effort, and complexity within IT systems, lack of computational capacity, or technical infeasibility of peak load reduction according to findings of Leinauer et al. [37]. The *Policy* dimension represents barriers identified on the regulatory level, which are barriers emerging from government policies, usually implemented via regulation [26].[2] Leinauer et al. specify regulatory DR barriers from literature, as well as their

[2] Since this study focuses on German companies and associations, the barriers in the policy dimension have to be interpreted in the context of German legislation.

case study in Germany, highlighting the existence of complex, restrictive or contradictive regulatory frameworks and further identifying barriers such as prioritization of energy efficiency measures, high costs and effort for prequalification or globally heterogeneous legislation [37]. Barriers relating to internal organizational processes that need to be managed are accounted for in the *Organization* dimension. In addition to behavioral, competence-related, and informational barriers, following Sorell's identification, two main organizational barriers can be allocated to this dimension [26]: culture and power [43]. Lack of power relates to a person's inability to implement a DR program in their organization, e.g., by training staff or providing the necessary technology [26]. Linked to power is the culture barrier, meaning the prevailing company culture [26], that may hinder the adoption of DR if the company's values do not align with seeing participation in DR as important. Similar to Leinauer et al. [37], we account for the interdependencies and relations of barriers between dimensions so that one barrier may be categorized into more than one dimension.

2. Method

This study examines the role of drivers and barriers of DR participation. The empirical analysis is based on 20 semi-structured interviews with representatives of C&I companies and associations in Germany. Section 2.1 provides information on the sample characteristics, followed by Section 2.2 detailing the interview structure. Section 2.3 outlines the data analysis .

2.1. Sample characteristics

Participants were recruited in two stages. First, 23 German industry and commercial sector associations were contacted, asking whether experts from their association were willing to participate in an interview. Second, the associations were asked to forward our interview request to companies that were members of the respective association. Overall, 20 interviews were conducted, including eleven interviews with representatives of C&I companies and nine with interviewees from C&I associations. The interviews can be categorized into the following eight C&I sections from the German federal statistical office [44] (see Figure 1).

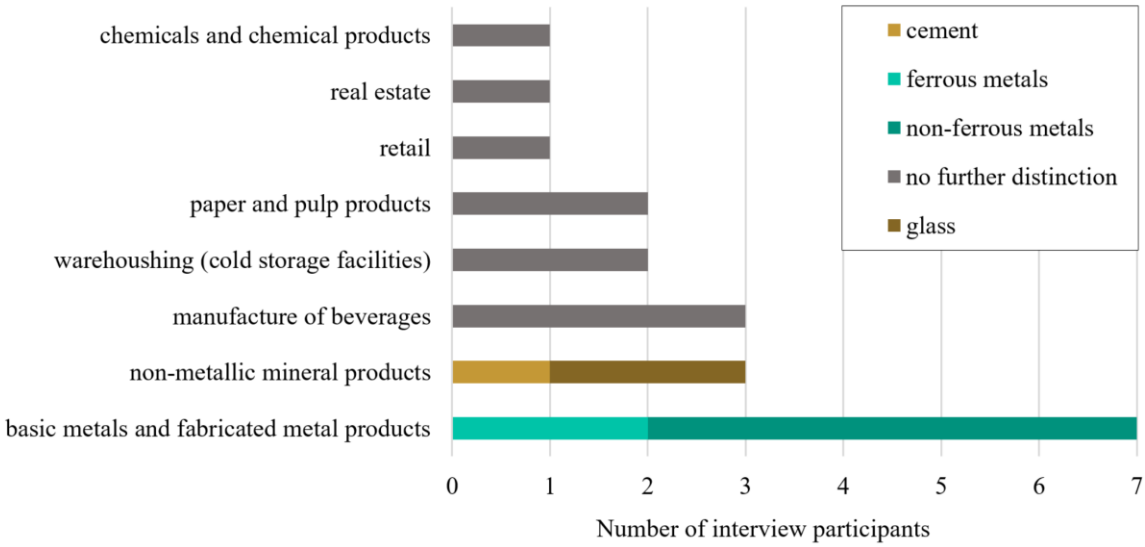

Figure 1. Number of interview participants sorted by industry branch and distinctive products

Since experts from the respective C&I sectors were contacted, most participants were division managers of either energy procurement, climate protection, resources or circular economy. In six cases, the managing directors of the respective company or association participated in the interviews (see Figure 2).

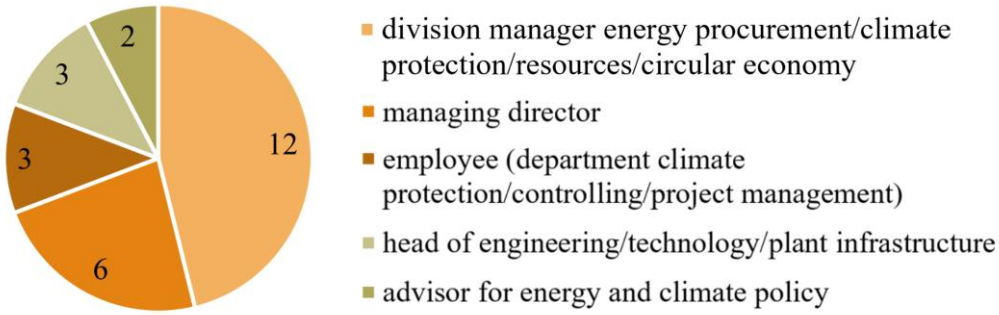

Figure 2. Classification of interview participants by job description

In contrast to Lashmar et al. [36], more than half of the companies in this study already provided flexibility at the time of the interviews, one company had been providing flexibility in the past, and three companies did not provide flexibility, with one having examined the option and decided against it afterwards (Figure 3).

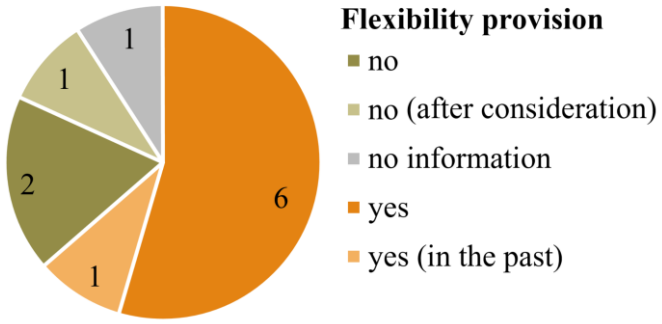

Figure 3. Number of interview participants representing a company that already partake in demand response programs

Regarding the companies that partake (or had partaken in one case) in flexibility provision, six companies provided balancing power for the secondary control reserve and one company for the tertiary control reserve, as shown in Figure 4.

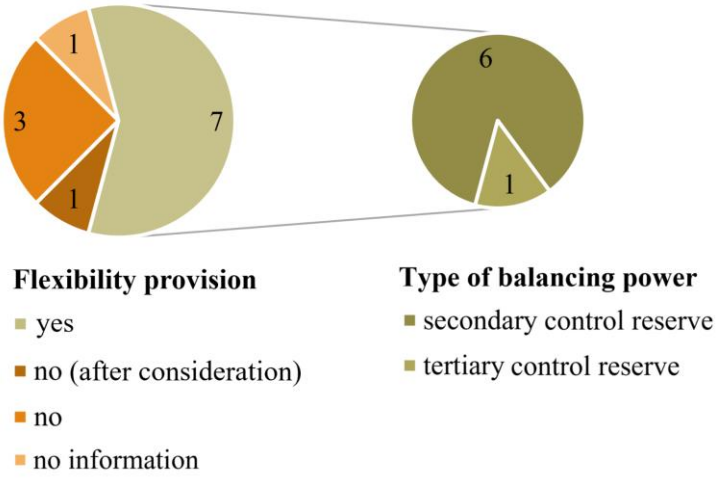

Figure 4. Number of interview participants representing a company that participates in demand response by providing balancing power in the secondary or tertiary control reserve

In addition to participation in the balancing power market, Figure 5 visualizes that one company provided interruptible load, a second had been pre-qualified and about to participate, while seven companies did not participate in this flexibility option [12].

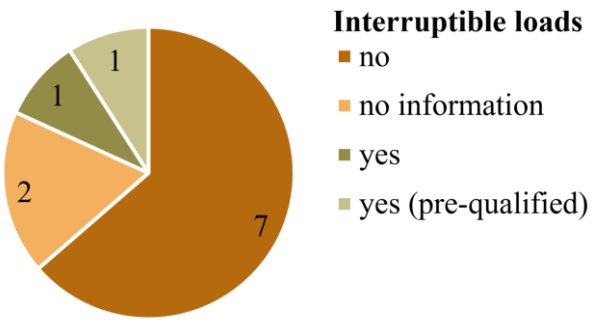

Figure 5. Number of interview participants providing interruptible loads

2.2. Interview structure

The interviews took between 30 and 60 minutes and were conducted via video calls due to COVID-19 travel and contact restrictions during that time. The interviews' audio was recorded after written consent was obtained from the participants. We used a semi-structured interview method in order to both cover relevant aspects of DR participation but also to allow participants to express their own ideas and views regarding specific DR potentials and barriers [45]. The interview guideline was structured into three sections: In the first section, the interviewees were asked to introduce themselves, identify their field of work, and provide some general information about their companies' energy use and whether they were already participating in DR programs. The second section focused on questions about processes and technologies that could potentially provide flexibility, accounting for the technological and, if applicable, economic barrier dimensions. The third section assessed potential difficulties regarding participation in the DR program by assessing economic, political, and organizational barriers in more detail. The interviews closed with open questions about further barriers.

2.3. Data analysis

The audio recordings of the interviews were transcribed using the software *f4transkript* [46]. Subsequently, the transcribed interviews were coded by using a hybrid inductive-deductive approach to identify the different DR barriers [47]. The hybrid inductive-deductive approach is a method used in qualitative content analysis. Relevant aspects (e.g., mentioned barriers to DR) are denoted as categories of a content analytic category system and text passages are allocated to this category system [47].

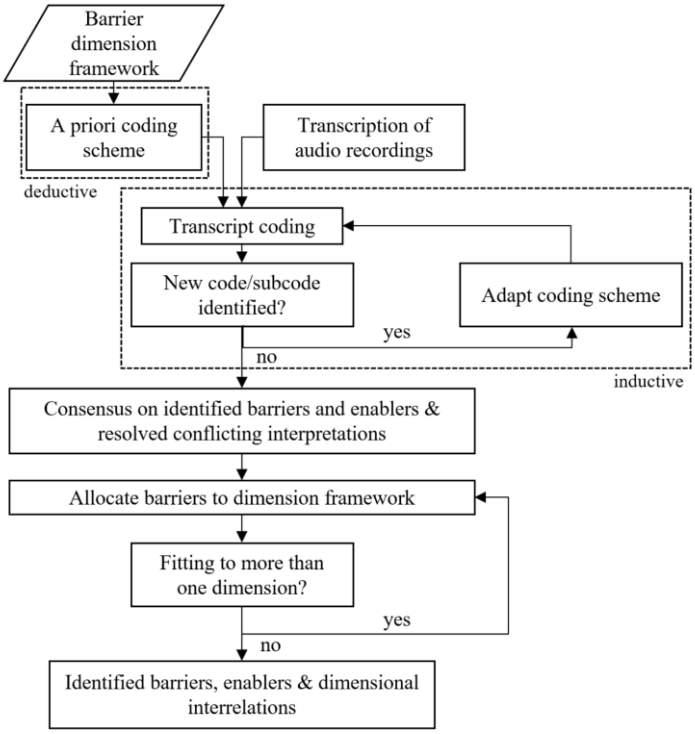

Figure 6. Hybrid inductive-deductive approach (adapted from [48])

Figure 6 details the process of the inductive-deductive approach. The deductive part of the analysis consisted of a pre-defined category system that was derived theoretically, in this case the barrier dimension framework. The specific barriers mentioned by the interview participants were then formed inductively and allocated to one or more dimensions [47]. In other words, the theoretically derived barrier dimensions from the literature (organizational, political, economic, and technological) were used as an a priori coding structure. The coding process consisted of analyzing the transcript regarding these barrier dimensions, subsequently identifying and defining specific barriers that could be connected to them. During this process, all text passages were coded. More specific sub-codes for individual barriers were inductively derived during the coding process to precisely differentiate between the barriers mentioned by the interviewees [49]. In the last step of the analysis, the identified barriers were analyzed and interdependencies between barrier dimensions were documented. Specifically, we examined what barriers were identified across C&I companies and associations and how they related to their respective barrier dimension.

3. Results

In this section, the barriers identified by the interviewees are presented and assigned to the barrier dimensions derived from the literature, taking into account interdependencies and

relations to other dimensions. This is followed by the assessment of the most frequently identified barriers across C&I associations and companies.

3.1. Demand response barriers: identification and categorization

Overall, our analysis identified 16 barriers to DR participation. Table 2 presents the barriers and provides a short definition in which context the barrier was mentioned by the interviewees. Furthermore, this study organizes the identified barriers according to the overarching barrier dimensions policy, technology, economy, and organization (see Figure 7). As some DR barriers are related to more than one overarching dimension, we use a Venn diagram instead of discrete categories to visualize the interrelations between the dimensions.

Table 2. Inductively identified barriers to demand response participation

ID	Barrier	Description
1	Advance-notice-time	• Time and staff needed to check and/or adapt production and or personnel schedules
2	Core business	• DR is not or will not become a core business, so that developments in this area are not prioritized
3	Energy efficiency	• May decrease at the cost of providing DR
4	Equipment wear	• Fear of equipment wear: more frequent and/or more extensive up/down ramping of production processes with potentially negative effects on machinery
5	Overall missing acceptance	• Obstacles within the organization (individual employees/supervisors that need to be convinced of the changes/need for DR)
6	Personnel planning	• Personnel planning may need to be re-scheduled spontaneously • Economic implications for re-scheduling and increased hourly wages for night-shifts, weekends or holidays • Regulative specifications need to be accounted for
7	Production capacity	• May need to be increased to make up for the time lost during the DR event since existing capacity runs near 100%
8	Product quality	• Fear of decreased product quality due to (spontaneous) DR events (power band limits are exceeded or undercut)
9	Profitability	• Value of DR unclear or too small to actually profit • Hidden (unforeseen) costs may be too high
10	Regulatory complexity	• Organizational effort to allocate human resources to regulation questions regarding DR implementation
11	Regulatory restrictiveness	• Existing regulations interfering with participating in DR • Economic disadvantages when dealing with regulatory requirements • Technological conditions (e.g., size of plant, technical DR potential) may not fit to program requirements
12	Storage capacities	• Need to increase storage capacity to produce more in stock prior to DR event (physical and electricity storage)
13	Space requirements	• Space limitations in case production or storage capacities need to be increased
14	Supply contracts	• May be breached or needed to be re-negotiated in case DR event leads to production delays
15	Third party control	• Unwillingness or fear of dependence on external signals that may directly interfere with the production process (e.g., automatized control from grid operator) • Fear of equipment wear, external signals may harm the equipment if they come at the wrong time or give a wrong target value forcing the process to ramp up/down
16	Up-/Downstream processes	• Linked processes may hinder DR due to technical requirements (storage, continued production)

Some of the specific barriers could be uniquely allocated to one overarching barrier dimension. The barriers equipment wear and up-/downstream processes are distinct technical barriers, directly linked to the risks regarding the safe and functioning operation of production processes during a DR event. The barriers concerning profitability and supply contracts were allocated to the economy dimension, which represents underlying cost and revenue uncertainties. The organizational dimension comprises barriers that need to be overcome within a company in order to participate in a DR program. Both a reluctance to accept third-party control and a general lack of acceptance are barriers mentioned by several interviewees that are uniquely connected to the organizational dimension. The first involves an aversion to giving up autonomy over production processes in case of a DR event that requires production to be ramped up or down for a certain period. A general lack of acceptance can have a multitude of reasons, which are described in more detail in Section 3.2. No barriers were identified that solely belong to the policy dimension, regarding the barriers regulatory complexity and regulatory restrictiveness. This can be explained by the fact that a multitude of barriers is related to more than one barrier dimension.

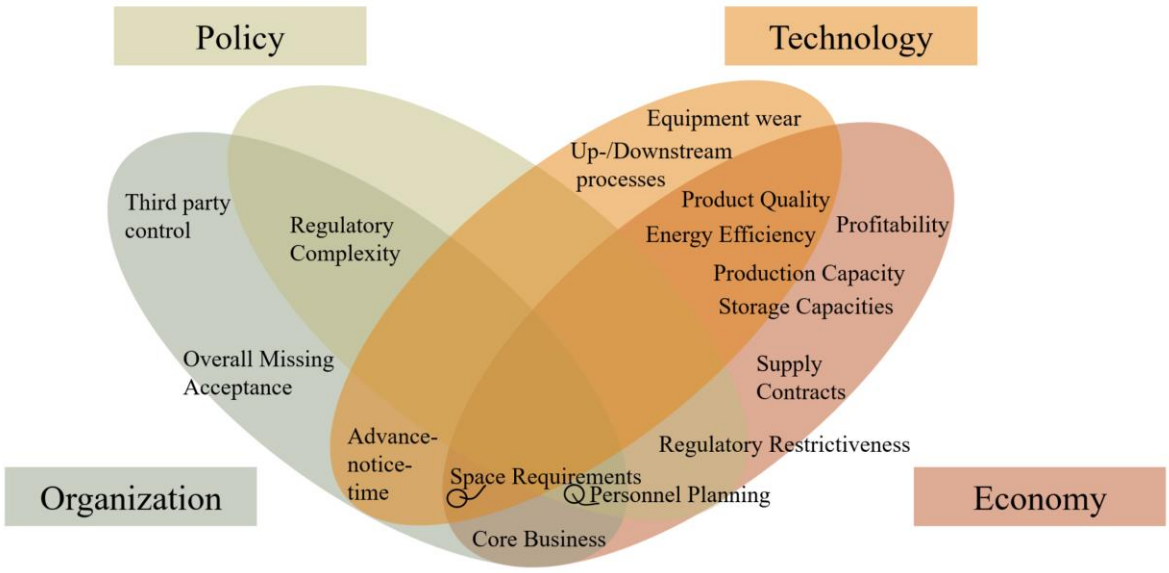

Figure 7. Assignment of DR barriers identified by C&I companies and associations to the four superordinate dimensions

While we did not find barriers solely related to the policy dimension, regulatory complexity emerged as one barrier in the shared space between organization and policy. This barrier refers to the organizational cost of allocating human resources to questions regarding the regulatory

framework for DR implementation. The overlap between the two dimensions indicates that the issue is not about a general lack of clear regulations or policies allowing the participation in DR, but about these regulations often being complex and thus requiring a significant amount of organizational capacity to manage them. A similar issue arises for regulatory restrictiveness that refers to conflicting or contradicting regulations which may result in financial disadvantages if a company decides to participate in DR. The German regulatory framework, for example, stipulates that energy-intensive companies (i.e., those with more than 10 GWh of electricity consumption per year) only receive a reduced grid fee if their electricity consumption is constant (i.e., 7000 full-load hours per year). Several interview partners remarked that their eligibility for the reduced grid fee might be contradictory with participation in DR events, as the latter would require greater fluctuations in consumption to react to DR events. Similarly, in the case of atypical grid usage, a company's peak consumption may not fall within a time window specified a-priori by the local grid operator [50]. However, participating in DR programs may entail short-term load shifting or load shedding, possibly breaching the legal threshold for individual grid fees.

Some barriers were related to both the technological and economic dimensions. This included, for example, the interviewees' concerns about product quality, which could arise from non-optimal temperatures at certain production steps, resulting in deviations from specified standards. Product quality is also related to economic concerns, as a deviation from specified standards can result in products unsuitable for selling or breaching supply contract specifications, which can again result in monetary penalties. Furthermore, the risk of a loss in production was mentioned, as machinery may not be fully utilized. In addition, deviating from optimal technical configurations in production during a DR event can lead to a loss of energy efficiency, thereby increasing the overall energy input, which, in turn, leads to an increase in costs. Several interviewees cited production and storage capacity limits in the context of the need for pre- and post-production of goods. More specifically, as production decreases or stops during a DR event, it is necessary to increase production before or after to meet the production targets. In both cases, a direct relation to the technology (the production process) as well as to the economy (the entailed cost of investment, running cost, etc.) dimension exists.

In two cases, three dimensions related to an identified barrier. The barrier concerning space requirements refers to the technological aspect of providing the space, e.g., for an expansion of

production capacity (technology dimension), where space requirements not only incur costs for the space itself (economy dimension), but also for space management (organization dimension), which was mentioned by several interviewees. Finally, personnel planning entails the required staff schedule planning to prepare for DR events (organizational dimension) and the related costs for additional staffing and weekend and holiday bonuses (economic dimension). Furthermore, interviewees emphasized the expenses for organizational and legal matters to be considered as well, e.g., negotiations with trade unions or juridical questions regarding labor law (organizational dimension). As in the case of the policy dimension, there also exist dimension interrelations that no barrier could be allocated to, such as policy-technology (see Figure 7). This does not necessarily mean that no barriers exist that could be allocated to these dimensional interrelations, but the interviewees in this study did not identify barriers corresponding to these kinds of interrelations.

3.2. Demand response barriers: perception

Following the categorization of barriers and their respective relations and interdependencies between dimensions, we analyzed the specific barriers in more detail, in particular regarding the frequency with which they were mentioned.

The most frequent barriers are those that were identified by at least ten interview participants and are ranked in Table 3. By far the most often mentioned barrier was profitability, or the lack thereof, with 17 interview partners citing this barrier. More specifically, revenue uncertainty was mentioned regarding uncertainty about the number of DR events and the compensation from participating in DR programs potentially being too little to cover the related costs and risks. The interview partners described the additional costs as the costs of human resources due to changes in work schedules, e.g., overtime or holidays, and the human resources needed for planning and rearranging shifts. These costs further entailed running costs, such as idle labor, costs of lost production, costs of intermediate products to decouple interlinked processes, the risk of equipment wear and tear or an increase in energy carrier costs due to an overall increase in energy consumption, and additional costs such as investments in additional production capacities. Regarding the latter, our respondents generally planned with short payback periods (e.g., of two years) to make investments worthwhile. Lastly, some interview partners also pointed out a substantial degree of international competition, which means that the additional costs of DR participation must be covered to not jeopardize competitiveness.

The most cited barrier in relation to the technology dimension was product quality. Fourteen interview partners made statements on this barrier dimension, and this barrier was described in different ways. Some processes were described as technically non-interruptible (at least not without serious harm to equipment or products). Some interviewees went into more detail about technical restrictions to ensure product quality and cited, for example, narrow temperature bands in manufacturing or product waste due to quality deficiencies. In this regard, one interview partner said:

> *"[…] the product quality and the achievement of an appropriate product quality must be the absolute priority." #interview5 (translated from German)*

Another interviewee remarked that manufacturing costs in Germany are already among the highest relative to other countries, and superior product quality is often a central aspect of maintaining competitiveness in the international market. Companies in the manufacturing sector would therefore be reluctant to jeopardize product quality. Interdependent processes, described here as up-/downstream processes were mentioned by half of the interviewees, who stated that some (production) processes are too closely linked and either do not possess or do not allow buffers (e.g., such as product storages) to operate the processes independently of each other for a certain time interval, as stated by one interviewee:

> *"For all things in the foundry it's like this: When I melt, I also have to form. And when I form, I also have to be able to cast, and then I need the cores for that. […] I need everything. The whole chain." #interview12 (translated from German)*

Idle labor was mentioned in terms of personnel planning by 11 interviewees, further accounting for the challenge of rearranging shifts in accordance with employees on short notice. In addition, in some cases an inflexible shift planning was stated, as well as the possibility of non-acceptance of a change in shifts, e.g., from workdays to the weekend or holidays. As one interview ironically remarked:

"Then you have to tell your employees to make up for the production loss on Saturday or Sunday. Everyone will be extremely pleased. (ironic undertone)" #interview16 (translated from German)

However, this point of view varied greatly between industrial companies, with some interviewees pointing out a high prospective motivation of employees to work on weekends or holidays due to extra compensation (holiday and weekend premiums).[3] Interviewees from the retail sector indicated that flexibility measures targeting office temperatures might cause aversion from employees with a potential increase in sick days. In most cases, the identified barriers to personnel planning also led to concerns about confrontations with trade unions and German labor law.

Eleven interview partners discussed the issue of a general acceptance of DR participation. This included a general aversion to changing the status quo, identifying established structures and expectations with regard to work processes and work environments within the organization, as well as the effort to convince supervisors and staff of the necessary changes and the necessity of DR participation. Interestingly, concerns about changing the status quo were often not discussed as a barrier for the interviewees but as a concern towards other people in the organization.

[3] In Germany, companies are not required by law to pay weekend and holiday premiums. However, this is common practice in many industries, even though the premiums differ considerably between industries.

Table 3. Most frequent mentioned demand response barriers, ranked by number of nominations

Rank	Counts	Barrier	Reasons
1	17	Profitability	• Revenue uncertainty • Too little compensation to cover costs/risks • Cost of human resources • Transaction cost • Not enough capacity to offer to become profitable • International competition
2	14	Product quality	• Non-interruptible processes • Restrictive product quality specifications • Fear of product waste
3	11	Personnel planning	• Idle labor • Employees' aversion to room temperature adaption • Staff availability in DR event • Inflexible shift planning • Non-acceptance of work schedule change • Consolidation with union and labor law
	11	Overall missing acceptance	• Aversion to changing the status quo • Obstacles within the organization • Heterogeneity within certain industrial sectors impedes systematic DR planning • Lack of knowledge within the organization • Not enough potential; therefore too little economic incentive to participate
4	10	Up-/Downstream processes	• Processes too closely linked, no buffers

For example, interviewees that worked as energy managers in their company often expressed a positive attitude towards participating in DR but voiced the concern that participation would be less accepted among employees responsible for manufacturing processes or product quality, as shows the following remark:

> *"The next problem is that the person in charge of food safety in the store yells out and says, 'You guys are nuts! What are you doing to the food?' Because if the network operator then leaves the electricity switched off for too long in ten minutes and then the*

cold chain is interrupted, then I can throw the whole batch away" #interview14 (translated from German)

Moreover, participants from industrial associations pointed out the great heterogeneity within certain industrial sectors, impeding a systematic DR planning and implementation. Some interviewees that were potentially open towards DR participation had already assessed its potential. However, due to market barriers such as minimum capacities (e.g., minimum bid sizes in the balancing power market) or too little technical potential in the company, these interview partners concluded that participation would be economically unattractive, particularly in conjunction with current regulatory restrictions. Multiple interviewees agreed with the importance of participating in DR programs, but pointed to other technologies, industry sectors, or even to the residential sector with the expectation of exploiting their respective DR potential first. In other cases, a lack of knowledge within the organization about DR programs or the organization's technical DR potential was expressed, making it difficult to assess whether participating in DR would be feasible or not.

Some barriers were not mentioned as frequently as the previously presented ones, which does not, however, lessen their importance for the respective interviewee. Supply contracts (mentioned by eight interviewees) describe the fulfilment of services, for example obligations to companies or private customers in the retail sector. In this context, interviewees especially mentioned supply contracts as the binding priority over DR program participation. One interviewee stated the importance of upholding delivery times, as well as the risk of reputational damage if contracts cannot be fulfilled.

"The customer is king and wants his products delivered at the agreed time. That is a completely different way of thinking." #interview12 (translated from German)

Restricting regulatory frameworks (stated by eight interviewees) were mentioned by interviewees with regard to conflicting and contradicting regulations. In Germany, for example, the grid charges for metered consumers (usually industrial and large commercial consumers) are calculated based on a capacity price component and an energy price component. Therefore, DR participation could result in additional costs, as DR events could push peak power consumption to make up for the lost production. Additionally, the fear was expressed that if

energy intensive consumers would reduce their energy consumption as a result of DR adoption, they could fall out of the individual grid fee option leading to higher electricity costs, as one interview remarks:

> *"And if you then somehow reduce the power too often and use too little power, you then lose the individual grid fee, which then accordingly, yes, would not be made up for by other compensation that currently exists." #interview13 (translated from German)*

Regulatory complexity (mentioned by seven interviewees) was cited in terms of unclear and fast changing frameworks interfering with planning security, as well as the immense bureaucracy involved in managing regulatory interdependencies. The aversion to cease control over production processes and appliances to a third party (mentioned by five interviewees) varied among interviewees. Some interviewees consider handing over control at predefined time intervals to be acceptable, while others see no possibility of allowing direct or automated access to internal processes at all. Even though third party control was in some cases completely rejected, some interviewees agreed to prior notification and (indirect) automatized third party control, partially with override control or in pre-defined time intervals, as expressed by one interviewee:

> *"If we can specify time windows where we can say that you are free to dispose of it […]. Then something like that would definitely be externally solvable. Definitely. But there must be the possibility for us to prevent this external shut down for a short time in special situations." #interview8 (translated from German)*

3.3. Analysis of barrier count by sector, interviewee and flexibility provision

We next considered the prevalence of the specific barriers in light of the companies' engagement in flexibility provision. Figure 8 shows the barriers encountered by companies participating in flexibility programs with those that do not. As the majority of companies (seven) has experience with flexibility provision, the barrier count is correspondingly higher. Furthermore, it can be seen that companies that provide flexibility also identified slightly more unique barriers than companies that do not. In particular, only the companies already partaking in flexibility programs mentioned barriers such as regulatory restrictiveness and regulatory complexity. Identifying these barriers indicates that the concern for companies that already have

experience with DR have encountered the challenges around regulatory restrictiveness and complexity in the qualification process of flexibility provision.

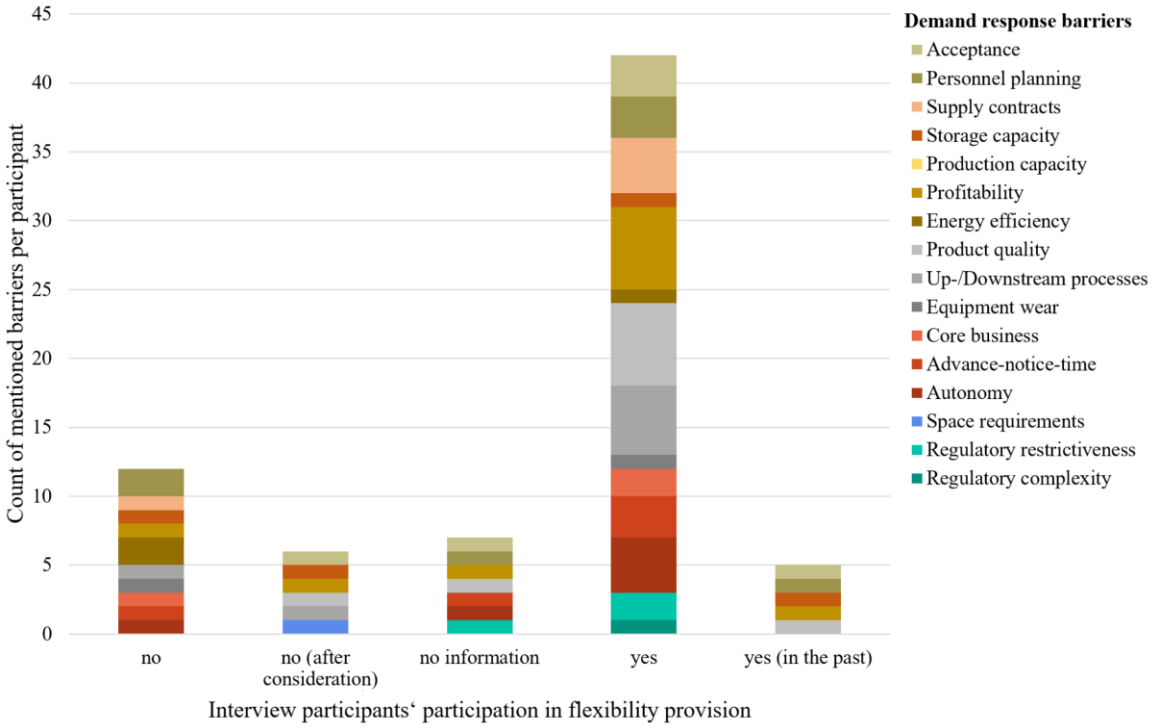

Figure 8. Counts of identified barriers by interview participants (companies), distinguished by their respective participation in flexibility programs

Regarding the variety of barriers, the interviewed associations and companies did not vary significantly, as presented by Figure 9. Regulatory concerns about complexity and restrictiveness were mainly identified by associations. The lack of profitability presented in both categories the most important barrier, while companies also prioritized up- and downstream processes, product quality and personnel planning. This also accounts for autonomy and the advance-notice-time, which might be due to their closeness to their respective production processes and equipment, resulting in protectiveness.

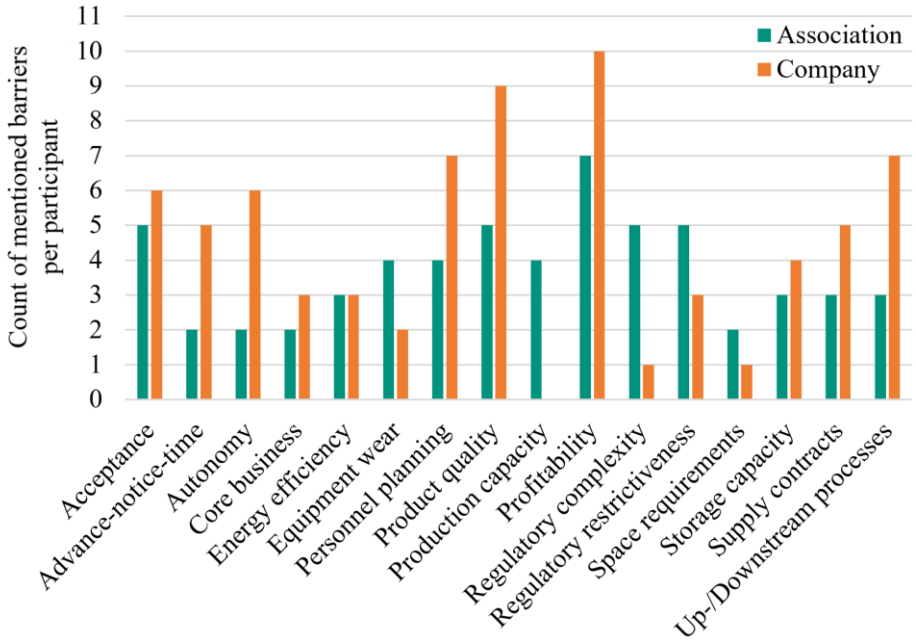

Figure 9. Counts of identified barriers distinguished by company and association

The investigation of DR barriers by industry branch in Figure 10 shows that no barrier was exclusively applicable to one industry. Regulatory complexity and restrictiveness were identified across almost all sectors, as well as the lack of profitability. Autonomy was identified in half of the industry branches comprising glass, manufacture of beverages, non-ferrous metals, paper and pulp products and warehousing. The non-ferrous metals industry had the highest number of interview participants (and thus the best representativeness) and also the highest amount of barrier counts and variety. In this industry, product quality, up-/downstream processes, and lack of profitability were the most prominent barriers. In real estate, the most important and only barrier identified was personnel planning, which mainly concerned employee satisfaction regarding possible temperature changes when tapping into the heating or cooling flexibility of office buildings.

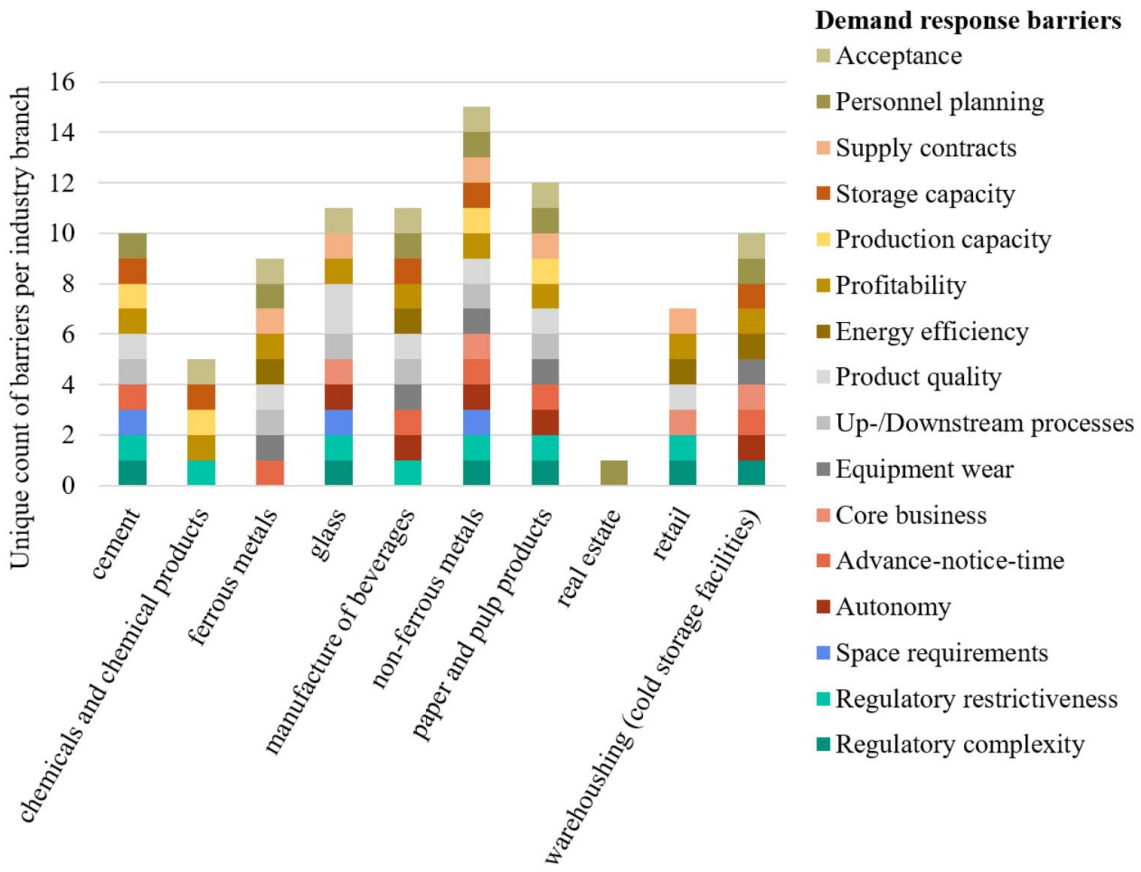

Figure 10. Industry specific demand response barriers

3.4. Enabling activities

In addition to identifying DR barriers, interview participants also mentioned activities that could enable them to overcome these barriers. Following the example of Lashmar et al. (2022), we further analyzed the interview transcripts for enabling activities to overcome the mentioned DR barriers and found 13 enabling activities that are presented in Table 4.

Table 4. Enabling activities the interviewees identified to overcome the mentioned barriers

Enabling activities	**Count**
Demand response program type	11
Sufficient advance-notice time	9
Managing expectations within the company	5
Overcoming space requirements and storage on site	3
Third party access acceptance	3
Existing excess storage capacity	3
Voluntary participation	2
Existing excess production capacity	2
Automation	2
Third party access acceptance	1
Enhance knowledge on processes and their up-/downstream linkages	1
Mitigate additional running costs (e.g., flexible workforce)	1
Voluntary participation	1

In accordance with Lashmar et al., the most often discussed enabling activity concerned the selection of the demand DR type. This comprised the company accounting for technological restrictions, safeguarding the production process equipment, and upholding standards (e.g., narrow temperature bands), but also included ensuring client or employee temperature comfort. Thus, barriers such as product quality reduction, energy efficiency, personnel planning and lack of profitability could be addressed. In addition, the incentive design of the demand response program could play a major role in the program's selection. One participant identified a fixed payment regardless of the amount of DR events per year that required load shifting or shedding as one way to counter revenue uncertainty. Almost half of the interview participants mentioned a sufficient advance-notice-time as an enabler to foster DR participation. While six participants stated that at least a day or two prior notice would be needed to prepare for the DR event (e.g., adapting production and personnel schedules), two participants agreed to at least 15 minutes and one participant to one week prior notice. This variation likely reflects the heterogeneity in production processes or services across different sectors.

As Table 5 shows, an enabling activity can address multiple barriers and vice versa. Due to the multifaceted nature of the barriers despite an identified enabling activity, the activity might not be sufficient or applicable to account for all the facets of the respective barrier. However, the identified enablers build directly on the participant's perceptions and requirements, suggesting that a company can overcome some barriers internally [36]. For some enabling activities, the

pre-requisites do not only depend on the consumers. To choose a suitable demand response program type, fitting demand response programs need to be implemented in the first place.

Table 5. Enabling activities, their impact on specific barrier and barriers without enablers

Enabling activity	**Addressed barriers**	**Barriers without enablers**
Demand response program type	Product quality; energy efficiency; profitability; personnel planning	Regulatory restrictiveness
Sufficient advance-notice time	Advance-notice-time; personnel planning; product quality	Regulatory complexity
Managing expectations within the company	Personnel planning, overall missing acceptance	Equipment wear
Space requirements and storage onsite	Space requirements, storage capacities	
Third party access acceptance	Autonomy	
Existing excess storage capacity	Storage capacity	
Voluntary participation	Profitability; product quality	
Existing excess production capacity	Production capacity	
Automation	Autonomy	
Delegation of DR management to third party	Autonomy; personnel planning; core business	
Enhance knowledge on processes and their up-/downstream linkages	Up-/downstream processes	
Mitigate additional running costs (e.g., flexible workforce)	Profitability	
Voluntary participation	Product quality; supply contracts	

4. Discussion

Commercial and industrial organizations can participate in DR measures through load shifting or load shedding. This research aimed to examine the barriers to DR adoption in the C&I sectors by conducting 20 semi-structured interviews with experts from C&I companies and associations. The DR barriers identified by the interviewees have been analyzed and categorized into four barrier dimensions (i) economy, (ii) technology, (iii) organization, and (iv) policy, by accounting for interrelations between dimensions. This section discusses the critical barriers in the context of the present state of research in Section 4.1 and details the limitations of the empirical investigation in Section 4.2.

4.1. Critical barriers

From the 16 distinct barriers identified in our analysis, five barriers emerged as the most frequently discussed barriers by our interviewees from the C&I companies and associations. These critical barriers comprise (i) the lack of profitability, (ii) the fear of reduced product quality, (iii) multiple aspects regarding personnel planning ranging from additional expenditures to consolidation with the labor union, (iv) an overall missing acceptance and (v) the technical interdependencies with upstream and downstream processes.

Profitability is discussed as the main driver for DR participation. In turn, a lack of profitability (i.e., revenue uncertainty and insufficient financial incentives) was described as the main barrier for participation, which corresponds to the findings by Leinauer et al. and Lashmar et al. [36,37]. Our interviewees further identified the risk of a decrease in delivery reliability, possibly resulting in the loss of additional business opportunities due to supply shortages, which matches the findings from Leinauer et al. [37]. Uncertainties about profitability could be addressed with simplified regulations and incentive structures, as well as by providing adequate and tailored information about the consequences of participation. The interviewees highlighted the risk of *reduced product quality*, which is consistent with Leinauer et al. and Lashmar et al. [36,37]. However, this kind of barrier can be overcome by precisely setting the specifications for participation in a DR program that, in any case, is entailed in the prequalification process. Such a prequalification process ensures safe load shifting, shedding, or energy carrier switch during a DR event while maintaining the technical specifications to not damage the production equipment and maintain product quality. Fears like a decrease in product quality further point out a certain lack in knowledge or an aversion to thinking about DR participation in general, since the prequalification process for the adoption of DR programs could solve these concerns.

A critical barrier identified in our study is *personnel planning*. Our participants mention multiple essential aspects in this regard. They express their concern about employee satisfaction when having to work very flexible shifts. Furthermore, the change in shifts would possibly lead to conflicts with labor unions and juridical questions regarding labor law. The occurrence of a DR event on short notice could possibly lead to idle labor and hence, to additional personnel expenditures. The risk of higher personnel expenditures is consistent with Leinauer et al. [37], while Lashmar et al. [36] categorizes additional work for personnel as a social barrier. However,

the findings about employee satisfaction or the implications to the need of consolidation with the labor union and labor law have not been described in previous literature and are hence newly identified. Announcing a DR event multiple days in advance, as opposed to short-notice events, could possibly help overcome this barrier. Barriers such as competing *business resources and additional work* were identified by the interviewees in our study and support the findings of Lashmar et al. [36], who declared these two barriers as newly identified by their interviewees compared to the existing literature.

The fact that DR programs or energy management are often *not part of the core business* is a critical barrier in our study and is consistent with Leinauer et al. [37]. Even though this barrier is not identified by Lashmar et al. [36], a relation to the *aversion of changing the status quo*, identified in this study as part of an *overall missing acceptance* as well as by Lashmar et al. [36] may exist, since this inertia may come from DR and energy management not being a priority in organizations. In this study, the barrier was expressed by multiple interviewees and can be further related to the NIMBY (not in my backyard) problem. Most interviewees showed some interest in DR which they express both by their willingness to participate in the interviews and their statements during the interviews. However, when asked about their potential participation they often referred to other sectors stating that these had higher DR potentials, so that their own participation would not make much of a difference. The issue of technological interdependencies between production processes has also been identified by Lashmar et al. [22], which supports our assumption that also country independent, general barriers exist.

As the comparison to similar literature targeting the C&I sectors reveals in this section, the demand response barrier dimension framework deduced in this study can be extended to account for further barriers found in studies beyond the interviews conducted here. Additionally, we suggest that the framework may be applicable to further demand response barrier research in other sectors, such as the transport sector (bi-directional charging) or the residential sector. The latter indicates promising applicability, as Alasseri et al. [51] formulate challenges in demand response implementation in the residential sector, such as governmental support, consumer awareness, policies/regulations, costs, and technical requirements, which can very well be allocated in the four dimensional framework considering policy, economy, organization and technology related demand response barriers.

4.2. Limitations of the empirical investigation

The generalizability of our results is subject to certain limitations. The limited number of interviews and variety of interview partners regarding industry branches and sectors, make it difficult to assess the comprehensibility of the results from this study. The interview partners varied concerning their position, ranging from energy managers and members of the management board of companies to association representatives. This may lead to different levels of knowledge about DR programs and potentials, leading to different motivations, opinions, and identified barriers. Of course, the variety of interview partners (associations, medium to large-scale companies, less and more energy-intensive industries/commercial companies) leads to very different perceptions of barriers. Hence, it is possible that further barriers exist and need to be identified, and that barriers that interviewees in this study did not mention often may be actually crucial in a different industry sector or company. In addition, the variety in industry sectors and interview partners did not allow for further significant conclusions considering the commonalities and differences between sectors. Focusing on this in follow-up studies would allow a considerable contribution to this research area. Nevertheless, we managed to interview experts from a variety of commercial and industrial sectors. We found a substantial degree of commonalities in the identified barriers as well as distinctions between sectors and companies. Our study thus continues to develop the still scarce body of literature on barriers in different C&I sectors, enabling more robust and generalizable conclusions about the importance of different barriers. In our study, we identified DR barriers relating to German legislation. Hence, differences in the regulatory frameworks across countries may result in more or different barriers for C&I companies.

Furthermore, since conducting the interviews, a lot has happened in the geopolitical context within Europe. With the start of the Russian invasion of Ukraine in 2022, a so-called energy crisis with gas shortages [52] and a rise in gas and electricity prices [53], among others, has led to substantial challenges for consumers from all sectors, especially energy-intensive industries [54–56]. These new circumstances would likely lead to very different results if we repeated the interviews in the present situation. In a situation with high uncertainty (regarding energy carrier supply and prices), companies may become more risk averse, which could lead to perceiving more barriers in the realm of DR adoption or the categorical non-acceptance of even considering DR adoption. Conversely, substantially higher energy prices may encourage innovative decision-making beyond the core business, including DR participation, which could

offset some of the higher energy costs. Generating new data from interviews or surveys specifically targeting this situation could shed more light on these recent developments.

5. Conclusion and future directions

In this empirical study, we investigated DR barriers by conducting 20 interviews with representatives from German commercial and industrial (C&I) companies and associations. Our analysis revealed 16 barriers, allocated to organizational, economic, policy, and technological dimensions, accounting for interdependencies among them. Notably, technology and economic barriers exhibited pronounced correlations, while many barriers exhibited multiple relations to different dimensions. Additionally, barriers within the policy dimension consistently exhibited links to at least one other dimension.

In-depth analysis and a comparison with recent literature identified five critical barriers: (i) lack of profitability, (ii) fear of reduced product quality, (iii) implications for personnel planning, (iv) overall missing acceptance, and (v) technical interdependencies with upstream and downstream processes. Other noteworthy, if less frequently mentioned, barriers included compliance with supply contracts, restrictive regulatory frameworks, and regulatory complexity, often linked to German regulatory frameworks. This study also identified 13 enabling activities for overcoming barriers in DR adoption, the most frequent mentioned ones comprising an adequate DR program type, an adequate advance notice time, and managing expectations within the company.

Identifying DR barriers and enablers supports the development of strategies to overcome these challenges. While some barriers may be addressed through internal resources and information dissemination, our findings emphasize the necessity of adapting external incentives and regulations to facilitate DR adoption. Raising awareness about DR programs and their associated barriers and benefits may encourage C&I companies to surmount these challenges. Focusing on reducing fears may lay the groundwork to overcome the barriers related to fears, such as a reduction in product quality that, e.g., could be resolved by raising awareness about the already existing extensive prequalification process that precedes participation in German DR programs. Furthermore, regulatory frameworks should be enhanced to reduce legislative contradictions and competition among financial incentives. By simplifying corporate decision-

making processes, DR participation can be promoted, aiding C&I consumers. Examining the barriers identified and the underlying motives and fears can help decision-makers devise strategies to support C&I consumers in participating in DR.

Further research could delve deeper into variations in barriers across different industrial sectors, enabling targeted strategies for specific segments. Expanding the study's scope internationally can enrich the understanding of barriers, especially in the context of divergent legislative frameworks and unexplored best practices. Shifting the research focus from barriers to enablers and measures for resolution can assist policy makers and market operators in improving regulatory frameworks and promoting the advantages of DR participation.

Author Contributions

Leandra Scharnhorst: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Validation; Visualization; Writing - original draft
Daniel Sloot: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Validation; Visualization; Writing - review & editing
Nico Lehmann: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Software; Supervision; Validation; Visualization; Writing - review & editing
Armin Ardone: Funding acquisition; Supervision; Writing - review & editing.
Wolf Fichtner: Funding acquisition; Supervision; Project administration; Writing - review & editing.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Grammarly and ChatGPT in order to mitigate grammatical errors and improve language. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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References

[1] IPCC. Climate Change 2021: The Physical Science Basis: Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2021.

[2] European Commission. European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions; 2021.

[3] Albadi MH, El-Saadany EF. A summary of demand response in electricity markets. Electr Power Systems Res 2008;78(11):1989–96. https://doi.org/10.1016/j.epsr.2008.04.002.

[4] U.S. Department of Energy. Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them. A report to the United States Congress Pursuant to Section 1252 of the Energy Policy Act of 2005 (February 2006). [March 09, 2022]; Available from: https://www.energy.gov/oe/downloads/benefits-demand-response-electricity-markets-and-recommendations-achieving-them-report.

[5] Sauer A, Abele E, Buhl HU. Energieflexibilität in der deutschen Industrie: Ergebnisse aus dem Kopernikus-Projekt – Synchronisierte und energieadaptive Produktionstechnik zur flexiblen Ausrichtung von Industrieprozessen auf eine fluktuierende Energieversorgung | SynErgie. Stuttgart; 2019.

[6] Fridgen G, Häfner L, König C, Sachs T. Providing Utility to Utilities: The Value of Information Systems Enabled Flexibility in Electricity Consumption. J Assoc Inf Syst 2016;17(8):537–63. https://doi.org/10.17705/1jais.00434.

[7] Fridgen G, Keller R, Thimmel M, Wederhake L. Shifting load through space–The economics of spatial demand side management using distributed data centers. Energy Policy 2017;109:400–13. https://doi.org/10.1016/j.enpol.2017.07.018.

[8] Haupt L, Körner M-F, Schöpf M, Schott P, Fridgen G. Strukturierte Analyse von Nachfrageflexibilität im Stromsystem und Ableitung eines generischen Geschäftsmodells für (stromintensive) Unternehmen. Z Energiewirtsch 2020;44:141–60. https://doi.org/10.1007/s12398-020-00279-5.

[9] International Energy Agency. Energy Statistics Data Browser – Data Tools - IEA. [September 22, 2022]; Available from: https://www.iea.org/data-and-statistics/data-

tools/energy-statistics-data-browser?country=WORLD&fuel=Energy%20consumption&indicator=ElecConsBySector.

[10] Statista. Anteil am Stromverbrauch nach Sektoren in Deutschland 2021 | Statista. [January 12, 2023]; Available from: https://de.statista.com/statistik/daten/studie/236757/umfrage/stromverbrauch-nach-sektoren-in-deutschland/.

[11] Bertoldi P, Zancanella P, Boza-Kiss B. Demand Response status in EU Member States: JRC Science for Policy Report 2016(EUR 27998 EN). https://doi.org/10.2790/962868.

[12] Bundesregierung. Verordnung über Vereinbarungen zu abschaltbaren Lasten (Verordnung zu abschaltbaren Lasten - AbLaV): AbLaV; 2016.

[13] Gils HC. Assessment of the theoretical demand response potential in Europe. Energy 2014;67:1–18. https://doi.org/10.1016/j.energy.2014.02.019.

[14] Gils HC. Economic potential for future demand response in Germany – Modeling approach and case study. Appl Energy 2016;162:401–15. https://doi.org/10.1016/j.apenergy.2015.10.083.

[15] Wohlfarth K, Klobasa M, Eßer A. Setting course for demand response in the service sector. Energy Efficiency 2019;12:327–41. https://doi.org/10.1007/s12053-018-9728-3.

[16] Kirkerud JG, Nagel NO, Bolkesjø TF. The role of demand response in the future renewable northern European energy system. Energy 2021;235. https://doi.org/10.1016/j.energy.2021.121336.

[17] Tina GM, Aneli S, Gagliano A. Technical and economic analysis of the provision of ancillary services through the flexibility of HVAC system in shopping centers. Energy 2022;258. https://doi.org/10.1016/j.energy.2022.124860.

[18] Sloot D, Lehmann N, Ardone A. Explaining and promoting participation in demand response programs: The role of rational and moral motivations among German energy consumers. Energy Res Soc Sci 2022;84. https://doi.org/10.1016/j.erss.2021.102431.

[19] Parrish B, Heptonstall P, Gross R, Sovacool BK. A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response. Energy Policy 2020;138. https://doi.org/10.1016/j.enpol.2019.111221.

[20] Ofgem. Making the electricity system more flexible and delivering the benefits for consumers: Position Paper; 2015.

[21] National Grid. Written evidence submitted by the nationalgrid REV0118. [September 22, 2022]; Available from:

http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/energy-and-climate-change-committee/energy-revolution/written/32989.html.

[22] Parrish B, Gross R, Heptonstall P. On demand: Can demand response live up to expectations in managing electricity systems? Energy Res Soc Sci 2019;51:107–18. https://doi.org/10.1016/j.erss.2018.11.018.

[23] Strbac G. Demand side management: Benefits and challenges. Energy Policy 2008;36:4419–26. https://doi.org/10.1016/j.enpol.2008.09.030.

[24] Annala S, Lukkarinen J, Primmer E, Honkapuro S, Ollikka K, Sunila K et al. Regulation as an enabler of demand response in electricity markets and power systems. J Clean Prod 2018;195:1139–48. https://doi.org/10.1016/j.jclepro.2018.05.276.

[25] Murthy Balijepalli VSK, Pradhan V, Khaparde SA, Shereef RM. Review of demand response under smart grid paradigm. In: IEEE (Hg.) 2011 – IEEE PES Innov Smart Grid Techn, p. 236–243.

[26] Good N, Ellis KA, Mancarella P. Review and classification of barriers and enablers of demand response in the smart grid. Renew Sustain Energy Rev 2017;72:57–72. https://doi.org/10.1016/j.rser.2017.01.043.

[27] Nolan S, O'Malley M. Challenges and barriers to demand response deployment and evaluation. Appl Energy 2015;152:1–10. https://doi.org/10.1016/j.apenergy.2015.04.083.

[28] Shoreh MH, Siano P, Shafie-khah M, Loia V, Catalão JP. A survey of industrial applications of Demand Response. Electr Power Systems Res 2016;141:31–49. https://doi.org/10.1016/j.epsr.2016.07.008.

[29] Paterakis NG, Erdinç O, Catalão JP. An overview of Demand Response: Key-elements and international experience. Renew Sustain Energy Rev 2017;69:871–91. https://doi.org/10.1016/j.rser.2016.11.167.

[30] Dranka GG, Ferreira P. Review and assessment of the different categories of demand response potentials. Energy 2019;179:280–94. https://doi.org/10.1016/j.energy.2019.05.009.

[31] Cardoso CA, Torriti J, Lorincz M. Making demand side response happen: A review of barriers in commercial and public organisations. Energy Res Soc Sci 2020;64. https://doi.org/10.1016/j.erss.2020.101443.

[32] Grein A, Pehnt M. Load management for refrigeration systems: Potentials and barriers. Energy Policy 2011;39(9):5598–608. https://doi.org/10.1016/j.enpol.2011.04.040.

[33] Olsthoorn M, Schleich J, Klobasa M. Barriers to electricity load shift in companies: A survey-based exploration of the end-user perspective. Energy Policy 2015;76:32–42. https://doi.org/10.1016/j.enpol.2014.11.015.

[34] Cagno E, Worrell E, Trianni A, Pugliese G. A novel approach for barriers to industrial energy efficiency. Renew Sustain Energy Rev 2013;19:290–308. https://doi.org/10.1016/j.rser.2012.11.007.

[35] Alcázar-Ortega M, Calpe C, Theisen T, Carbonell-Carretero JF. Methodology for the identification, evaluation and prioritization of market handicaps which prevent the implementation of Demand Response: Application to European electricity markets. Energy Policy 2015;86:529–43. https://doi.org/10.1016/j.enpol.2015.08.006.

[36] Lashmar N, Wade B, Molyneaux L, Ashworth P. Motivations, barriers, and enablers for demand response programs: A commercial and industrial consumer perspective. Energy Res Soc Sci 2022;90. https://doi.org/10.1016/j.erss.2022.102667.

[37] Leinauer C, Schott P, Fridgen G, Keller R, Ollig P, Weibelzahl M. Obstacles to demand response: Why industrial companies do not adapt their power consumption to volatile power generation. Energy Policy 2022;165. https://doi.org/10.1016/j.enpol.2022.112876.

[38] Alasseri R, Tripathi A, Joji Rao T, Sreekanth KJ. A review on implementation strategies for demand side management (DSM) in Kuwait through incentive-based demand response programs. Renewable and Sustainable Energy Reviews 2017;77:617–35. https://doi.org/10.1016/j.rser.2017.04.023.

[39] Sorrel S, O'Malley E, Schleich J, Scott S. The economics of energy efficiency: Book Review. Eur Env 2005;15(4):260–1. https://doi.org/10.1002/eet.383.

[40] Nicholls L, Strengers Y. Peak demand and the 'family peak' period in Australia: Understanding practice (in)flexibility in households with children. Energy Res Soc Sci 2015;9:116–24. https://doi.org/10.1016/j.erss.2015.08.018.

[41] Strengers Y. Air-conditioning Australian households: The impact of dynamic peak pricing. Energy Policy 2010;38(11):7312–22. https://doi.org/10.1016/j.enpol.2010.08.006.

[42] Scharnhorst L, Sandmeier T, Ardone A, Fichtner W. The Impact of Economic and Non-Economic Incentives to Induce Residential Demand Response Findings from a Living Lab Experiment. energies 2021(14):2036. https://doi.org/10.5445/IR/1000131273.

[43] Sorrell S, O'Malley E. The Economics of Energy Efficiency: Barriers to Cost-Effective Investment. Edward Elgar Publishing; 2004.

[44] Federal Statistical Office Germany. Classification of Economic Activities, issue 2008 (WZ 2008). [October 19, 2022]; Available from: https://www.klassifikationsserver.de/klassService/jsp/variant/variantInfo.jsf.

[45] Myers MD, Newman M. The qualitative interview in IS research: Examining the craft. Inf Organ 2007;17(1):2–26. https://doi.org/10.1016/j.infoandorg.2006.11.001.

[46] audiotranskription. f4transkript: Time-saving transcription. [October 19, 2022]; Available from: https://www.audiotranskription.de/en/f4transkript/.

[47] Margrit Schreier. Varianten qualitativer Inhaltsanalyse: Ein Wegweiser im Dickicht der Begrifflichkeiten. Forum: Qualitative Sozialforschung (FQS) 2014;15(1).

[48] Mayring P. Qualitative Content Analysis. Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, Vol 1, No 2 (2000): Qualitative Methods in Various Disciplines I: Psychology 2000. https://doi.org/10.17169/fqs-1.2.1089.

[49] Kuckartz U. Qualitative Inhaltsanalyse. Methoden, Praxis, Computerunterstützung. 4th ed. Weinheim: Beltz Verlagsgruppe; 2018.

[50] Verordnung über die Entgelte für den Zugang zu Elektrizitätsversorgungsnetzen (Stromnetzentgeltverordnung - StromNEV) § 19 Sonderformen der Netznutzung: § 19 Abs. 2 StromNEV; 2022.

[51] Alasseri R, Rao TJ, Sreekanth KJ. Conceptual framework for introducing incentive-based demand response programs for retail electricity markets. Energy Strategy Reviews 2018;19:44–62. https://doi.org/10.1016/j.esr.2017.12.001.

[52] Bundesnetzagentur. Aktuelle Lage Gasversorgung. [December 30, 2022]; Available from: https://www.bundesnetzagentur.de/DE/Gasversorgung/aktuelle_gasversorgung/start.html.

[53] Bundesnetzagentur. Aktuelle Lage Gasversorgung - Gaspreise Großhandel in EUR/MWh. [December 30, 2022]; Available from: https://www.bundesnetzagentur.de/DE/Gasversorgung/aktuelle_gasversorgung/_svg/Gaspreise/Gaspreise.html.

[54] Sprothen V, dpa. Energiekrise: Deutsche Industrie warnt vor Produktionstopps. Die Zeit 2022, 22 October 2022; Available from: https://www.zeit.de/wirtschaft/2022-10/dihk-industrie-energiekrise-produktionsstopps. [December 30, 2022].

[55] Olk J. Konjunktur: Energiekrise schafft Zweiteilung deutscher Industrie. Handelsblatt 2022, 9 December 2022; Available from: https://www.handelsblatt.com/politik/konjunktur/nachrichten/konjunktur-energiekrise-schafft-zweiteilung-deutscher-industrie/28853252.html. [December 30, 2022].

[56] tagesschau. Wettbewerbsfähigkeit: Energiekrise bedroht Industrie. tagesschau.de 2022, 28 November 2022; Available from: https://www.tagesschau.de/wirtschaft/weltwirtschaft/energiekrise-industriestandort-europa-101.html. [December 30, 2022].